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Oral Health Data Analysis in National Child Cohort Surveys

A thesis submitted to the University of Dublin, Trinity College for the
Degree of Doctor of Philosophy

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Volume I

Declaration

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Summary

Evidence based public health practice should use the best available peer-reviewed evidence for evaluating the success and impact of public health interventions. This research carried out with a systematic review of children's dental caries surveys at National, Regional, and County-levels conducted in the Republic of Ireland from 1950 to 2021 and summarised trends in dental caries. The effectiveness of Community Water Fluoridation (CWF) was explored by comparing dental caries experience in children living in areas with and without CWF. Over the last seventy years, at National, Regional and County levels, mean dmft/DMFT (decayed, missing, and filled teeth) scores decreased and the percentage of caries free children increased in 5, 8, 12, and 15-year-olds. The decline in dental caries indices observed throughout the country was greater in children living in areas with CWF than those without CWF. However, these results should be interpreted in the context of widespread use of fluoridated toothpaste in the RoI. Moreover, the variations in dental caries diagnostic criteria among the included surveys may also have impacted our findings. The last National Children's Oral Health Survey in the Republic of Ireland (RoI) was completed almost twenty-one years ago. In the absence of periodic national oral health surveys, self-reported oral health data from national birth and child cohort surveys provide an opportunity for estimating the distributions and prevalence of oral diseases in children over time. However, a major challenge for oral health research using national cohort surveys is the inconsistency in survey questionnaires within and across cohort surveys. In the second phase of this research, the quality and comparability of oral health-related questionnaire data from nationally representative birth and child cohort surveys was evaluated. Seven nationally representative birth and child cohort surveys were included and questionnaires examined from 50 survey waves. Questionnaires were classified into three domains and fifteen constructs and summarised by age groups. A DataSchema (a list of core variables representing the suitable version of the oral health outcomes and risk factors) was compiled comprising 42 variables. For each study wave, the potential (or not) to generate each DataSchema variable was evaluated. Of the 2100 harmonisation status assessments, 543 (26%) were complete (DataSchema variable could be generated). Approximately 50% of the DataSchema

variables can be generated across at least 4 cohort surveys while only 10% ($n = 4$) variables can be generated across all surveys. For each survey, the DataSchema variables that can be generated ranged between 26% and 76%. Data harmonisation can improve the comparability of variables both within and across surveys. For future cohort surveys, this research advocates more consistency and standardisation in survey questionnaires within and between surveys.

The third phase of this research included the development of an analytical interactive dashboard. Deploying multiple sources of population-level oral health data in an accessible dashboard could help monitor trends, explore risk factors and provide support for policy decisions. While data-driven dashboards are commonly used as an information exploration and communication tool in a wide range of domains this tool has not been similarly deployed in oral health epidemiology. The *flexdashboard* package was used within the R Studio framework to create the structural elements of the dashboard and interactivity was added with the *Shiny* package. Data were derived from three national Irish surveys, the Growing Up in Ireland infant and child cohort surveys and the second National Children's Food Survey. Variables for input were selected based on their known associations with oral health. The deployed dashboard is openly accessible at <https://dduh.shinyapps.io/dduh/>. As a research tool a dashboard is a rapid means of communicating exploratory descriptive results, an overall summary of variables or data-driven hypothesis generation.

The final phase of this research investigated oral health inequalities in Irish adolescents and the potential role of behavioural, material and psychosocial factors in explaining these disparities. There were socioeconomic disparities in Irish adolescents' self-rated oral health (SROH) and parent-reported oral health (number of teeth with dental fillings). Young persons with a lower socioeconomic background at 13 years of age had poorer self and parent-reported oral health at 17 years of age than their peers with a higher socioeconomic background. There were gender based differences, females reported better SROH and positive oral health behaviours. Behaviour, material and psychosocial factors were important factors contributing to socioeconomic disparities in young males' SROH. Material factors contributed most to the explanation of parental education and family income-related SROH inequalities.

Socioeconomic disparities in young persons' parent report oral health were partially explained by material factors, while behavioural and psychosocial factors played no role in accounting for these disparities.

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List of Abbreviations

AHA	American Heart Association
BASCD	British Association for the Study of Community Dentistry
BioSHare	Biobank Standardisation and Harmonisation for Research Excellence in European Union project
CLOSER	Cohort and Longitudinal Studies Enhancement Resources
CWF	Community Water Fluoridation; GUI
GUI	Growing Up in Ireland.
DALYs	Disability-Adjusted Life Years
DDUH	Dublin Dental University Hospital
DEDIPAC	European Determinants of Diet and Physical Activity
DFT/S	decayed and filled teeth/surfaces (permanent dentition)
dft/s	decayed, and filled teeth/surfaces (primary dentition)
DMFT/S	decayed, missing, and filled teeth/surfaces (permanent tooth)
dmft/s	decayed, missing, and filled teeth/surfaces (primary dentition)
dt/s	decayed tooth/surface (primary dentition)
DTS	decayed teeth/surfaces (permanent dentition)
ECC	Early Childhood Caries
EFSA	European Food Safety Authority (EFSA)
EHB	Eastern Health Board
ENRIECO	Environmental Health Risks In European Birth Cohorts
ESPGHAN	European Society for Paediatric and Gastroenterology, Hepatology and Nutrition
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reusable
FAO	Food and Agriculture Organisation
FBS	Food Balance Sheets
FDI	Federation Dentaire Internationale
FFQ	Food frequency Questionnaires
GNI	Gross National Income
GRADE	Grading of Recommendations, Assessment, Development, and Evaluations
GUI	Growing Up in Ireland
GUN	Growing Up in New Zealand
GUS	Growing Up in Scotland
HCES	Household Consumption and Expenditure Surveys
ICAD	International Children's Accelerometry database
ICDAS	International Caries Detection and Assessment System
IDE	Integrated Developmental Environment

JB1	Joanna Briggs Institute
LCHD	Life Course Health Development
LSAC B	Longitudinal Study of Australian Children Birth Cohort
LSAC K	Longitudinal Study of Australian Children Kindergarten Cohort
MCS	Millennium Cohort Study
MHB	Midland Health Board
MICYRN	Maternal, infant, Child and Youth Research Network
MS	Mutans Streptococci
MWHB	Mid-Western Health Board
NCD	Non-Communicable Diseases
NCFS	National Children's Food Survey
NDEP	National Dental Epidemiology Programme
NEHB	North-Eastern Health Board
NHANES	National Health and Nutrition Examination Survey
NHS	National Health Service
NPNS	National Pre-school Nutrition Survey
NWHB	North-Western Health Board
OECD	Organisation for Economic Co-operation and Development
PCG	Primary Care Giver
PHE	Public Health England
RDS	Rapidly Digestible Starch
ReACH	Research Advancement through Cohort Cataloguing and Harmonisation
RoI	Republic of Ireland
SCAN	Scientific Advisory Committee on Nutrition
SDOH	Social Determinants of Health
SEHB	South-Eastern Health Board
SES	Socio-Economic Status
SHB	Southern Health Board
SLLS	Society for Longitudinal and Life Course Studies
SQL	Structured Query Language
SROH	Self-Rated Oral Health
UK	United Kingdom
UN	United Nations
VCS	Version Control System
WHB	Western Health Board
WHO	World Health Organisation
YLDs	Years Lived with Disability

Publications

Presentations and proceedings

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CHAPTER 1

1. General Introduction

1.1 Oral Health

1.1.1 Overview

Oral health is integral to overall health and affects an individual's physical, social, and psychological well-being (Sheiham, 2005). Poor oral health causes pain and discomfort which can influence how an individual eats, speaks, smiles, looks, and socialises (Jackson *et al.*, 2011). The World Health Organisation (WHO) defines oral health as “a state of being free from mouth and facial pain, oral diseases and disorders that limit an individual's capacity in biting, chewing, smiling, speaking and psychosocial well-being (World Health Organisation, 2023). A more elaborative definition of oral health has been proposed by the Federation Dentaire Internationale (FDI) World Dental Federation, which states that “oral health is multi-faceted and includes the ability to speak, smile, smell, taste, touch, chew, swallow, and convey a range of emotions through facial expressions with confidence and without pain, discomfort and disease of the craniofacial complex” (Glick *et al.*, 2016). The FDI definition also suggests that oral health is greatly influenced by the values, attitudes, and physiological and psychological attributes of individuals and communities (Glick *et al.*, 2016). In addition, individual life experiences, perceptions, expectations and adaptability to new circumstances and opportunities play a key role in determining oral health (Glick *et al.*, 2016). The most frequent oral diseases are dental caries, periodontal disease, oral cancer, oral infectious diseases, trauma from injuries and hereditary disorders (Heilmann, Tsakos and Watt, 2015; World Health Organisation, 2023).

Oral diseases not only impact an individual in terms of pain, discomfort and deterioration of their general health and quality of life but also impact community and healthcare systems as a result of the increased economic and financial burden (Patel, 2012). Even though the level of oral health has improved in developed nations due to water fluoridation, fluoride dentifrices, improved sanitation and nutrition and access to dental care, dental caries still remains the most common chronic disease in children (Fisher-Owens *et al.*, 2007; Hugoson *et al.*, 2005; Kassebaum *et al.*, 2017).

1.1.2 Prevalence of Dental Diseases

According to the Global Burden of Disease Study, approximately 3.5 billion people worldwide suffer from oral health conditions, including an estimated 2.3 billion people with dental caries in permanent teeth and more than half a billion children suffering from caries in primary teeth (James *et al.*, 2018b; World Health Organisation, 2023). In a systematic review and meta-analysis of global dental caries levels, it was reported that approximately 46.2% of children suffered from dental caries in primary teeth (95% CI: 41.6-50.8%) and 53.8% (95% CI: 50-57.5%) in permanent teeth (Kazeminia *et al.*, 2020). In the United States alone, about 20% of children between the age range of 5 and 11 years and 13% of teens aged 12 to 19 years reported having at least one carious tooth (Dye, Thornton and Li, 2015). It has also been reported that children coming from low-income families were twice as likely to suffer from tooth decay compared to those from high-income households (Dye, Thornton and Li, 2015). The WHO regards oral diseases as a leading public health concern in the list of non-communicable diseases (Patel, 2012). The prevalence of tooth decay in 6-year-old children ranged from 20% to 90% among European Union (EU) countries (Patel, 2012). However, a decline of 60% in the number of decayed, missing and filled) teeth (DMFT) for 12-year-olds was reported in the European region from 1990 to 2015 (mean DMFT scores of 3 and 1.8 in 1990 and 2015, respectively) (Kassebaum *et al.*, 2017).

1.1.2.1 Oral Health in the United Kingdom and the Republic of Ireland

The second Public Health England (PHE) National Dental Epidemiology Programme (NDEP) survey of 3-year-old children conducted from 2019 to 2020 reported that among the children examined in the survey, about 10.7% suffered from dental caries with a mean dmft (number of decayed, missing and filled primary teeth) score of 3 (C.I 2.81 – 3.03) (Public Health England, 2021). These numbers represented an improvement in the oral health of 3-year-old children living in England from the first survey completed in 2013 by PHE, in which 12% had dental caries and had a mean dmft score of 3.08 (Public Health England, 2014). In contrast, for 5-year-old-children no apparent change was observed in oral health over the last two national surveys. Approximately, 23.4% of the 5-year-old children in England had dental caries with a

mean dmft of 3.4 in 2019 (Public Health England, 2020) and the respective numbers from the 2017 national survey were 23.3% and 3.04 (Public Health England, 2018). Oral health surveys for both age groups reported wide variations in the prevalence and severity of dental caries by geographical area, ethnic group and level of deprivation. In general, the level of dental caries was higher in the populations of children living in deprived areas in comparison to the children residing in more affluent areas (Public Health England, 2020; Public Health England, 2021).

In the Republic of Ireland, the oral health of young children has significantly improved over the last five decades. Despite continued improvements in oral health, dental caries is still a common oral health problem affecting at least one in every three children aged five years (Department of Health Ireland, 2019). A comparison of the prevalence of tooth decay in 5-year-olds versus 12-year-olds in Ireland from 1984 to 2014 is shown in Figure 1.1.

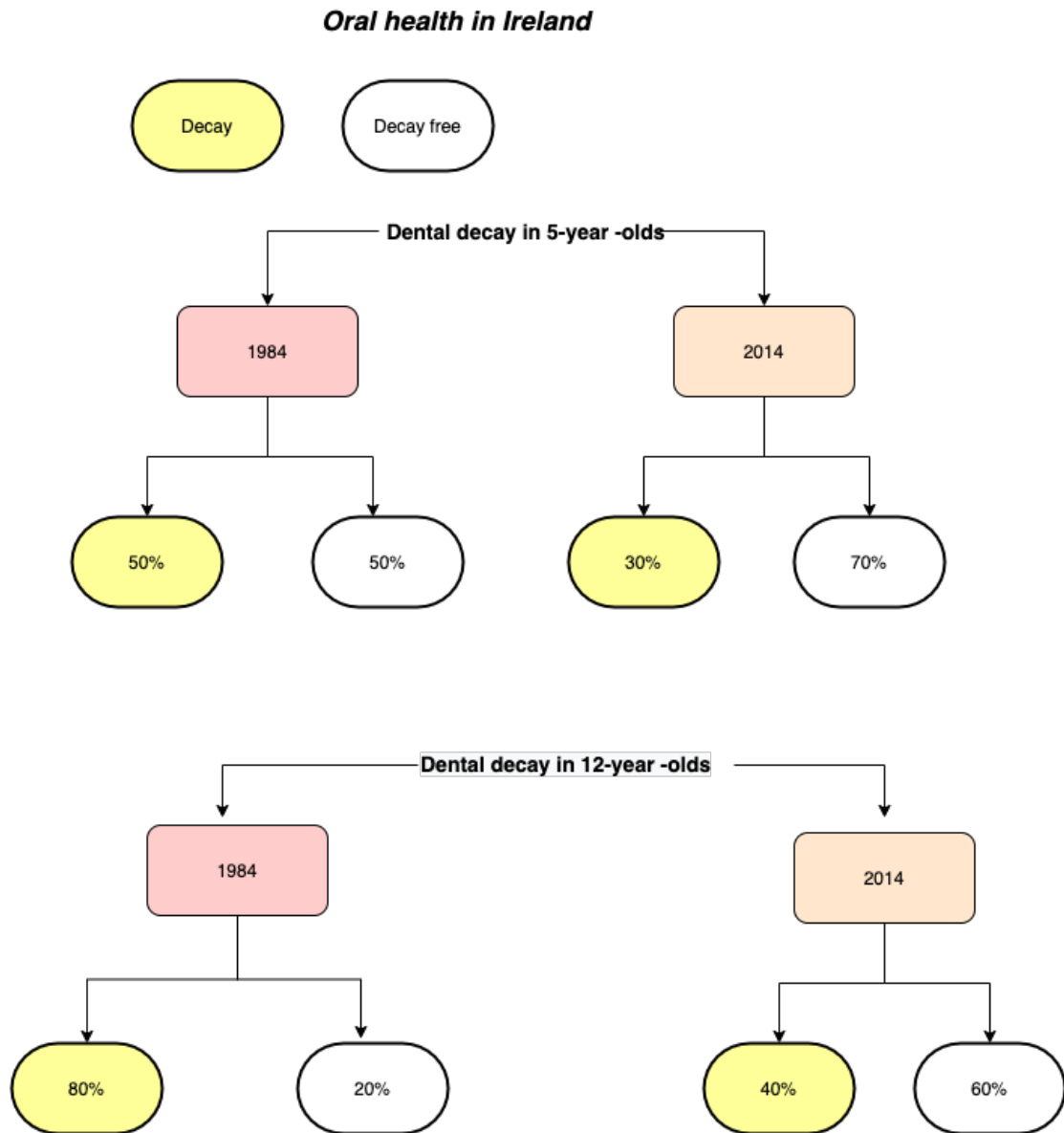


Figure 1.1 Dental decay in 5 and 12-year-olds in Ireland. Adapted from National Oral Health Policy, Ireland, Department of Health Ireland (2019).

1.1.3 Impact of Poor Oral Health on Children

Dental caries affects both the primary and permanent dentitions of children and influences general health and growth. Other oral health conditions in children such as periodontal or orthodontic problems and developmental defects of dental tissues are rarer but also have negative consequences in childrens' lives. A comprehensive list of possible consequences arising due to poor oral health in children is summarised in Figure 1.2.

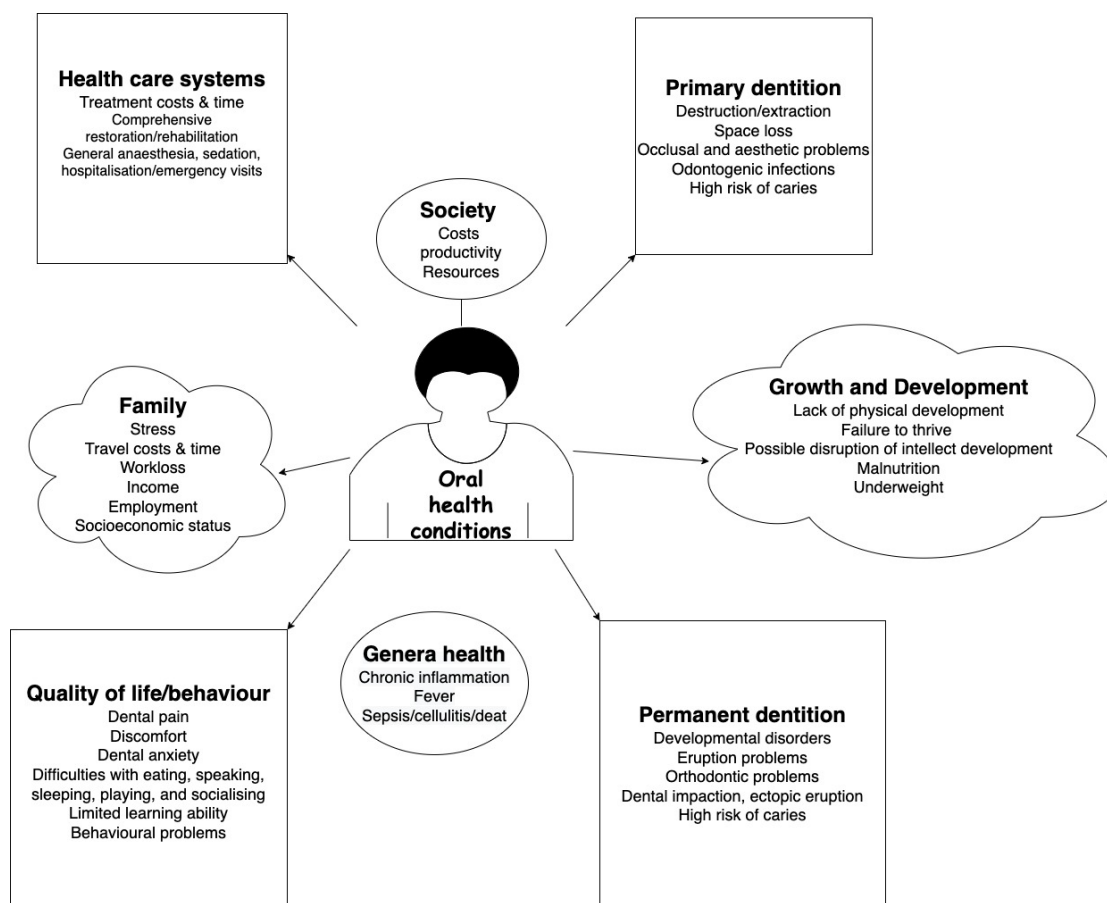


Figure 1.2 Impact of oral health diseases in children. Adapted from Wagner and Heinrich-Weltzien (2017).

Oral health problems may cause pain and discomfort and impact upon the quality of life of an individual. Dental diseases are also associated with non-communicable diseases (NCDs). For example, associations have been demonstrated between periodontal health and NCDs such as cognitive dysfunction (Nascimento *et al.*, 2019; Hu *et al.*, 2021), diabetes (Genco *et al.*, 2005; Baeza *et al.*, 2020), coronary heart diseases (Humphrey *et al.*, 2008; Dhadse, Gattani and Mishra, 2010; World Health Organisation, 2023) and also a relationship between dental caries and obesity in children (Hooley *et al.*, 2012a; Hayden *et al.*, 2013; Manohar *et al.*, 2021).

Industrialised countries experience financial and economic burdens as a result of significant spending on dental diseases. In 2012, approximately €79 billion was spent on dental treatments in the EU region and was predicted to be €93 billion in 2020 (Patel, 2012). The treatment of oral diseases was one of the most expensive

undertakings, exceeding the treatment costs for managing cancer, heart disease, stroke or dementia (Patel, 2012). Similarly, dental expenditure in 32 Organisation for Economic Co-operation and Development (OECD) countries was estimated to range between US\$485.12bn and US\$728.32bn in 2040 (Jevdjovic *et al.*, 2021).

In 2015, the global expenditure on dental diseases was \$356.8 billion and productivity losses due to oral diseases was \$187.61 billion (Righolt *et al.*, 2018). The Royal College of Surgeons in England issued a position statement in 2019 stating that dental caries was the single leading cause of unplanned/emergency hospital admissions of children aged between 5 and 9 years in England (approximately 78,000 admissions from 2015 to 2018) (Royal College of Surgeons of England. Faculty of Dental Surgery, 2019).

The Center for Disease Control and Prevention has also pointed out that school-going children suffering from poor oral health generally missed more school time and received lower grades than those with better oral health (Dye, Thornton and Li, 2015). Poor oral health in children can cause dental fear and anxiety as the first introduction to dental care may be on an emergency basis and can have life-long negative consequences (Gao *et al.*, 2013). The National Health Service (NHS) in 2014 estimated the cost of dental care spending to be £3.4 billion while an estimated additional cost of £2.3 billion was spent in private dental care settings (Godson, Csikar and White, 2018). Collectively, the oral health conditions in 2010 all over the world account for nearly 15 million Disability-Adjusted Life Years (DALYs) which represents 1.9% of all Years Lived with Disability (YLDs) and 0.6% of all DALYs. This amounts to an average health loss of 224 years per 100,000 people (Richards, 2013).

1.2 Dental Problems in Children

Parents tend to take their children to dentists for two main reasons. The first is to treat a dental problem experienced by the child or secondly for prevention of future dental problems. Common dental problems faced by children include dental pain, dental caries, gum problems, irregularly aligned teeth, and trauma (Cesarino Gomes *et al.*, 2015; Wagner and Heinrich-Weltzien, 2017). Dental caries is the most common cause

of dental pain followed by trauma and tooth exfoliation (Slade, 2001; Bastos *et al.*, 2008; Tickle, Blinkhorn and Milsom, 2008).

The association between dental pain and dental caries experience has repeatedly been found to be higher in lower socioeconomic groups than higher socioeconomic groups because of their limited access to dental care (Slade, 2001; Boeira *et al.*, 2012). A dentist can provide children with early detection of dental diseases and treatment services, anticipatory guidance, disease risk assessment and preventive care (Beil *et al.*, 2014). Children attending an emergency appointment are much more likely to have tooth extraction than if they visit for a regular dental examination (Luzzi, Chrisopoulos and Brennan, 2014). The impairment of oral function due to dental caries has been reported as the most common reason for a “problem visit” to a dentist (Leroy *et al.*, 2013; Luzzi, Chrisopoulos and Brennan, 2014; Mika *et al.*, 2018; John *et al.*, 2020). Along with symptoms of pain and swelling, one of the signs of odontogenic infections as a result of untreated carious teeth is a periapical abscess, which, if not managed properly can result in potentially life-threatening complications of cellulitis and sepsis in children (Wagner and Heinrich-Weltzien, 2017).

Periodontal problems in children include all inherited or acquired diseases of the periodontium (gingiva, cementum, periodontal ligament, and alveolar bone) that surround and support the teeth (Al-Ghutaimel *et al.*, 2014). Plaque induced gingival inflammation is the most common periodontal problem in children (Clerehugh, 2008). It has been observed that the same amount of plaque causes less inflammation in children than adults (Oh, Eber and Wang, 2002; Al-Ghutaimel *et al.*, 2014). Periodontal problems in children are predominantly reversible and result in less tissue damage than in adults (Oh, Eber and Wang, 2002; Clerehugh, 2008). Periodontal problems in children can be best managed by prevention, early detection, and treatment.

Children with developmental defects of enamel often present with problems of aesthetics and discolouration, tooth surface loss, increased susceptibility to caries and dental sensitivity. Malocclusion may compromise mastication and aesthetics. Angle’s Class II Div. 1 malocclusion increases the risk of trauma due to incisor prominence and

lack of lip coverage (Yaman Dosdogru *et al.*, 2017). Children often experience dental trauma due to a fall whilst playing for which they are brought to the dentist or the family physician. About 30% of the children experience injury to primary teeth, and about 20% of 12-year-old children have an injury to permanent teeth (Stephens, Wiedemer and Kushner, 2018). In children aged 0-6 years, dental trauma is the most common facial injury (Flores *et al.*, 2007).

1.2.1 Dental Caries

1.2.1.1 Introduction

Featherstone described dental caries as a multifactorial disease which is simple conceptually but complicated in detail (2004). The study of underlying mechanisms of dental caries is critical to develop and implement intervention and prevention strategies (Gussy *et al.*, 2006; Leong *et al.*, 2013). Caulfield defined dental caries as an infectious and transmissible disease caused by bacteria colonising tooth surfaces (2000). Gussy defined dental caries as an infectious disease modified by diet (2006). Others have contested their views and argued that the “pivotal role of sugars in causing caries differs markedly from the widely held view that caries is a multifactorial disease” (Sheiham and James, 2015a). The generally accepted model describes the carious process as an interaction between a susceptible tooth surface (host), fermentable carbohydrates (environment), cariogenic biofilm (agent) and time (Marsh, 2006; Gussy *et al.*, 2006; Usha and Sathyanarayanan, 2009) (Figure 1.3). These factors are influenced by modifiable and non-modifiable factors such as lifestyle choices, socio-economic status, education, ethnicity, culture, environmental conditions and genetics (Reisine and Psoter, 2001; Petersen, 2005; Opal *et al.*, 2015). Previous caries experience has been shown to be an important predictor of future caries risk in both primary and permanent dentitions in children (Declerck *et al.*, 2008). Evaluation of oral health and its determinants should start in the early stages of a child’s life.

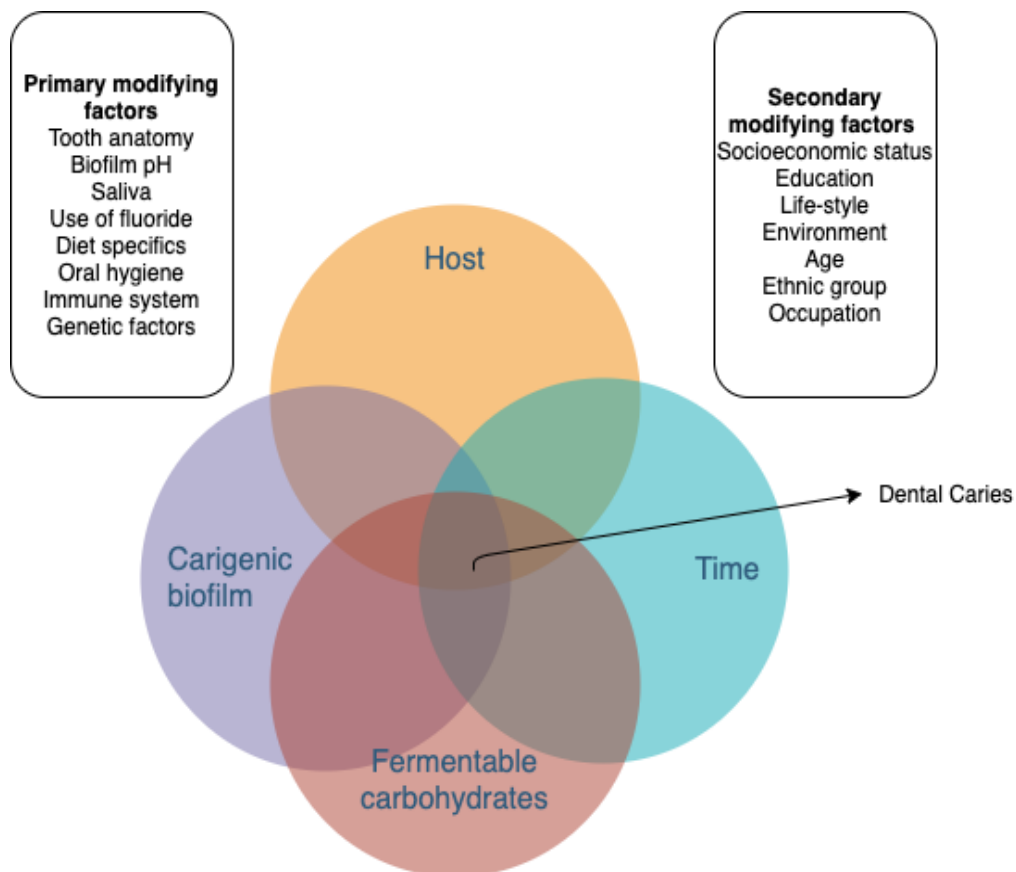


Figure 1.3 Modified Keyes-Jordan Diagram of dental caries development. Adapted from Hirleman (2018).

1.2.1.2 Pathogenesis of Dental Caries

Dental plaque is a microbial biofilm which produces acids upon metabolising fermentable carbohydrates (sugars) in food. These acids can diffuse through plaque and reach tooth enamel or dentine where they dissolve calcium and phosphate minerals. The loss of these tooth minerals is termed demineralisation. Saliva produced by the salivary glands helps to neutralise the acid by providing minerals that were dissolved during demineralisation. This process is termed remineralisation. The cumulative effect of these two processes (demineralisation and remineralisation) can sometimes lead to net loss of minerals from the tooth in which case there is a potential to develop dental caries in the tooth. The caries process is essentially the interplay between demineralisation and remineralisation processes and a balance between the promoters and inhibitors of the caries process (Featherstone, 2008; Gomez *et al.*, 2010) (Figure 1.4).

Critical pH

Stephan introduced the concept of critical pH. It states that the dissolution of enamel does not begin until the pH in plaque reaches 5.5 (Stephan, 1944). This critical pH of 5.5 was derived from the theoretical enamel solubility in saliva and not plaque fluid. Because of the low mineral content of dentin and cementum their critical pH may be higher than enamel. However, others suggested that the dissolution of enamel depends on many factors, such as the level of calcium, phosphorus and fluoride in plaque fluid (Bowen, 2013).

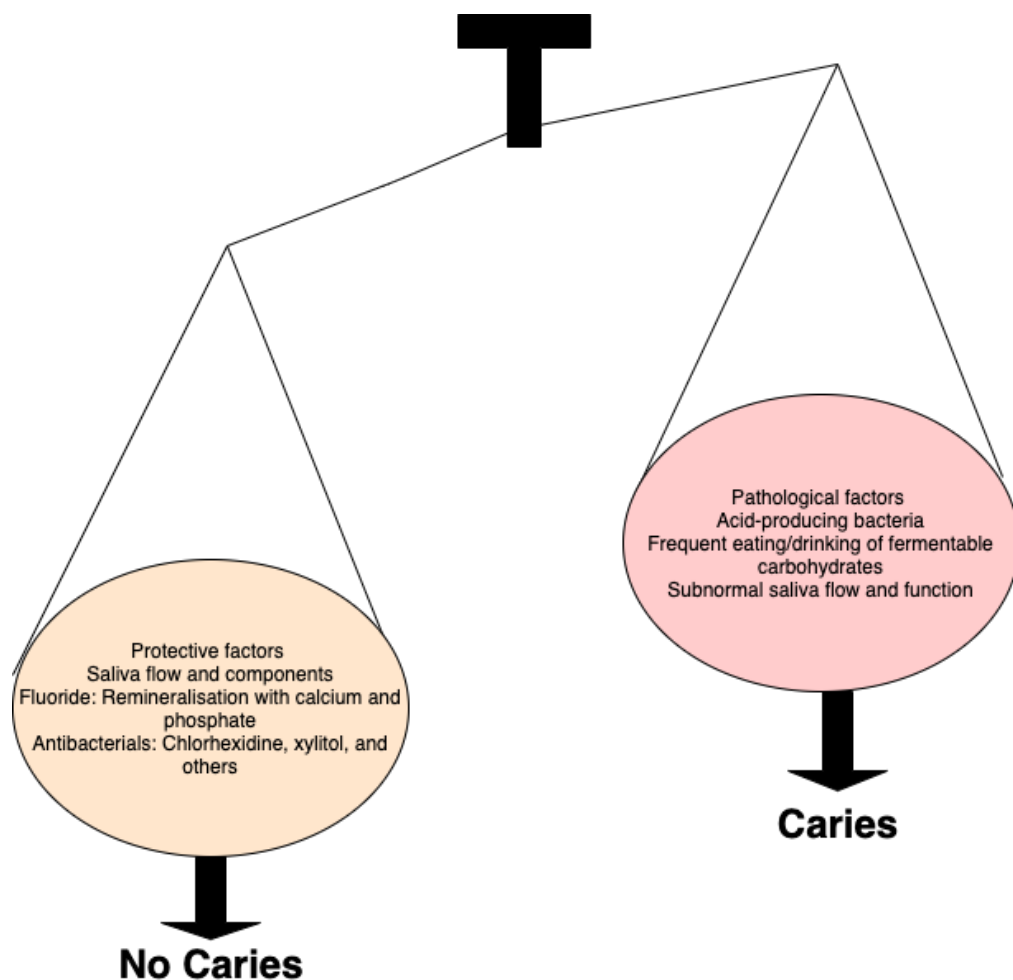


Figure 1.4 Caries balance. Adapted from Gomez *et al.* (2010).

1.2.1.3 Risk Factors and Indicators for Dental Caries

Risk factors are “environmental, behavioural or biological factors confirmed by temporal sequence, usually in longitudinal studies, which if present directly increase the probability of a disease occurring, and if absent or removed reduce the probability” (Beck, 1998). Prospective longitudinal cohort studies are required to establish the temporal relationship between a risk factor (exposure) and the condition (outcome) (Song and Chung, 2010; Mann, 2003). An exposure which is associated with an outcome established only in cross-sectional studies is called a risk indicator (Kirkevang and Wenzel, 2003). A risk indicator can be considered a putative risk factor with the caveat that cross-sectional relationships are deceptive as exposure and outcome data are collected at the same time (Burt, 2005).

The current understanding of the role of risk factors in caries development is incomplete. Traditionally, the main focus has been towards the biological risk factors such as consumption of sugars, bacterial counts, oral health and hygiene and fluoride exposure. Certainly, these factors have a role to play but caries cannot be predicted on the basis of a single risk factor because of its multifactorial aetiology (Burt, 2005; Fejerskov, 2004).

Harris and co-workers, in their systematic review, suggested that there were 106 risk factors associated with the prevalence of dental caries in young children (Harris *et al.*, 2004). They also grouped risk factors into different categories: demographic factors, dietary factors, factors related to breast/bottle feeding, oral hygiene-related factors, bacterial flora, and other factors, including parental oral hygiene and presence of enamel hypoplasia (Harris *et al.*, 2004). Leong and co-workers in their review focussed on the role of bacterial presence in the pre-dentate stage and early caries experience. Authors reported that pregnancy and neonatal periods are the most crucial times to identify children at risk, and advocated early maternal intervention to reduce the likelihood of early childhood caries (Leong *et al.*, 2013).

Risk factors for dental problems in children during infancy have been grouped in terms of host (including general health and oral health), parental and environmental factors (Wagner and Heinrich-Weltzien, 2017). Kirthiga and associates identified 123 risk factors associated with early childhood caries (2019). The majority of the included studies were from high income countries (50 out of a total of 89 studies). The important risk factors, as identified in the review, are summarised in Figure 1.5.

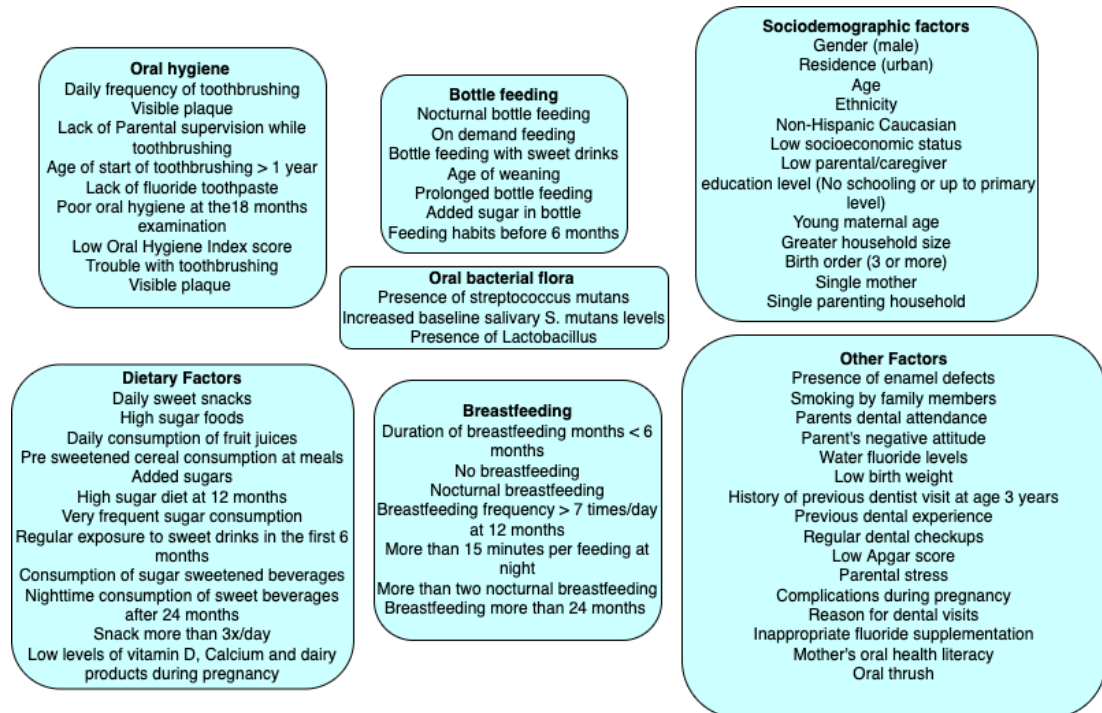


Figure 1.5 Risk factors for early childhood caries. Adapted from Kirthiga *et al.* (2019).

1.2.1.3.1 Sociodemographic Factors

Dental caries has been described as a “social disease” (Moimaz *et al.*, 2014). Amongst the socio-demographic factors found to be associated with dental caries, the most important is the socio-economic status of the individual (Schwendicke *et al.*, 2015; Kirthiga *et al.*, 2019). The socioeconomic status of an individual is a complex construct which defines the distribution of power and resources in a society, and is determined by indicators of human capital, including income, level of education and occupation (Brown, Guy and Broad, 2005). In addition, the social status of an individual can also be influenced by factors, such as place of residence and government schemes which may offer economic and psychosocial benefits to individuals and families (Costa *et al.*,

2012; Stormon *et al.*, 2019). An inverse relationship exists between dental caries levels and socioeconomic status in children aged 12 years and under (Reisine and Psoter, 2001). However, this relationship was unclear for older children (Reisine and Psoter, 2001). The prevalence of dental caries in disadvantaged Irish children was higher in comparison to those who were not disadvantaged (Whelton *et al.*, 2006).

Individuals from lower educational, income and occupational backgrounds had a higher prevalence of dental caries than individuals belonging to higher socioeconomic groups (Schwendicke *et al.*, 2015). The socioeconomic variation of dental caries was most pronounced in developed countries (Schwendicke *et al.*, 2015). Pathways mediating the relationship between dental caries and socio-economic status have been proposed. Household income and occupational class played crucial roles in controlling access to home or professional preventive means such as, access to fluoridated toothpastes, use of dental floss, dietary intake of fruits and vegetables, lower dietary intake of added sugars and self-funded dental procedures (Peres *et al.*, 2007b; Selwitz, Ismail and Pitts, 2007). The parental educational background influences health literacy, which in turn determines households' oral health behaviour (Lee and Divaris, 2014). In addition, social position affects social participation and community support, which in turn improves health behaviours and overall health (Russell, Ickovics and Yaffee, 2010; Lee and Divaris, 2014).

1.2.1.3.2 Bacterial Factors

Mutans streptococci (MS) has been identified as one of the major pathogens responsible for dental caries. The following reasons have been proposed linking MS with dental caries: a) frequent isolation of MS from cavitated carious lesions, b) initiation of dental caries in animal studies in the presence of MS and sucrose-rich diets, c) highly acidogenic and aciduric nature of MS, and d) adhesion of MS to tooth surface and other bacteria by the production of surface antigens I and II and glycans (Takahashi and Nyvad, 2008). An extension of the ecological plaque hypothesis was proposed (Takahashi and Nyvad, 2011). The proposed hypothesis highlighted the role of dental plaque as a key player in maintaining a natural pH cycle in the mouth. The

microbial acid-induced adaptation and subsequent selection of low pH non-Mutans bacteria shifted the remineralisation/demineralisation cycle from 'net mineral gain' towards 'net mineral loss' (Takahashi and Nyvad, 2011).

Another frequently studied bacterial pathogen in caries research is lactobacilli. Unlike MS, their role in caries initiation has not been found (Tanzer, Livingston and Thompson, 2001). However, Lactobacilli are opportunistic invaders of existing caries and important contributory bacteria in tooth decay (Caufield *et al.*, 2015).

1.2.1.3.3 Dietary Factors

Consumption of fermentable carbohydrates (sugars) is associated with a higher prevalence of dental caries (Touger-Decker and Van Loveren, 2003; Sheiham and James, 2014b; Moynihan and Kelly, 2014). Epidemiological studies on populations consuming low and high quantities of sugars (especially sucrose) have consistently shown that high dietary intakes of sugars are key dietary factors promoting the development and progression of dental caries (Sheiham and James, 2015b). The classic Vipeholm study in Sweden and the Hopewood House studies were among the earliest efforts to investigate the effects of high sugar consumption on the prevalence of dental caries in Swedish and Australian populations, respectively (Gustafsson *et al.*, 1954; Harris, 1963). The results of both studies indicated that the sugar consumption frequency, timing and consistency were related to increased caries activity.

The association between caries experience and sugar consumption provided consistent evidence that dietary free sugar intake of < 15 to 20 kg/person/year (<10% of total energy intake) resulted in an average DMFT score of less than 3 for 12-year-old children (Moynihan and Kelly, 2014). An in-depth systematic review by Moynihan on the relationship between dietary sugar intake and the development of dental caries across different age groups supported the evidence that limiting the dietary intake of free sugars to less than 10% of total daily energy intake was beneficial in limiting the formation of dental caries. The evidence for reducing the total dietary intake of sugar to less than 10% as assessed by the GRADE (Grading of Recommendations,

Assessment, Development, and Evaluations) process was found to be of ‘moderate’ quality (moderately confident in the effect estimate: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different), while that of reducing it below 5% was of ‘very low’ quality (very little information in the effect estimate: the true effect is likely to be substantially different from the estimate of effect) (Moynihan and Kelly, 2014).

1.2.1.3.4 Other Factors

Primary caregiver’s (PCG) health and well-being influence their child’s health; the PCG acts as a gatekeeper in providing and fostering general and oral health care for the growing child (DeWalt and Hink, 2009; Moimaz *et al.*, 2014). Higher parental stress levels negatively impact children’s health and are associated with poor oral health outcomes and dental caries (LaValle *et al.*, 2000; Hooley *et al.*, 2012b). It has been proposed that parents preoccupied with multiple issues have high stress levels and are unable to follow preventive oral health behaviours for themselves and their children (Menon *et al.*, 2013). Mothers with depression were unable to cope with the normal demands of child parenting, and their signs of depression were associated with nutritional and feeding problems in children (Seow, 2012). Authors in their review concluded that depression, anxiety and stress levels in parents were associated with early childhood caries (ECC) (Chouchene *et al.*, 2021). PCG depression scores and ethnicity were also found to be first-level predictors of dental problems in Irish preschool children (Crowe *et al.*, 2016).

Children’s ethnicity was found to be an independent predictor for dental caries (Harris *et al.*, 2004; Kirthiga *et al.*, 2019). However, recent literature has been more focused on evaluating ethnic disparities in dental caries among children. In a Dutch study, children belonging to Surinamese-Hindustani, Turkish, Moroccan, Surinamese-Creole and Cape Verdean backgrounds had a higher risk of dental caries compared to native Dutch children (van der Tas *et al.*, 2016). Socioeconomic indicators, the family household income and mother’s educational level explained up to 43% of the association between ethnicity and dental caries (van der Tas *et al.*, 2016). Similarly, during the oral health survey of 5-year-olds in 2019 in the UK, higher levels of dental

caries were observed in the 'Other Ethnic Groups' (44.3%) and Asian/Asian British (37%) than other groups (mixed, black/black British and white) (Public Health England, 2020). Likewise, a Swedish longitudinal cohort study reported increased risk of dental caries in 7-year-olds of immigrant parents from low and medium income countries compared to native children of the same age (Juliñ *et al.*, 2021).

Associations have also been noted between dental caries and shorter sleep durations (less than 8 hours per night) and media use (more than 1 hour/day) (Asaka *et al.*, 2020). A systematic review investigating the relationship between screen time behaviour and a cariogenic diet in children (less than 12 years of age) reported associations between screen time of 2–4 hours/per day and consumption of a potentially cariogenic diet (Shqair *et al.*, 2019).

Distal (parental education level and socioeconomic status) and proximal (parental oral health knowledge and behaviours, parental psychosocial and environmental factors such as cigarette smoking by mothers) factors were also associated with ECC (Early Childhood Caries) in children (Rai and Tiwari, 2018).

1.2.1.3.5 Medical Conditions

Various medical conditions may increase a person's risk of developing dental caries. For instance, conditions causing a dry mouth resulting from a disease or a side-effect from consuming a medication can increase the chances of developing dental caries (Hu *et al.*, 2016; Arany *et al.*, 2021). In addition, a person's inability to maintain their oral health and hygiene because of some physical and mental incapacity may also increase caries risk (Shyama *et al.*, 2001). There is a potential for complications during dental procedures in patients with some medical conditions such as haemophilia due to uncontrolled bleeding (Shastry *et al.*, 2014). A list of various general health conditions found to be associated with dental decay in children is shown in Figure 1.6.

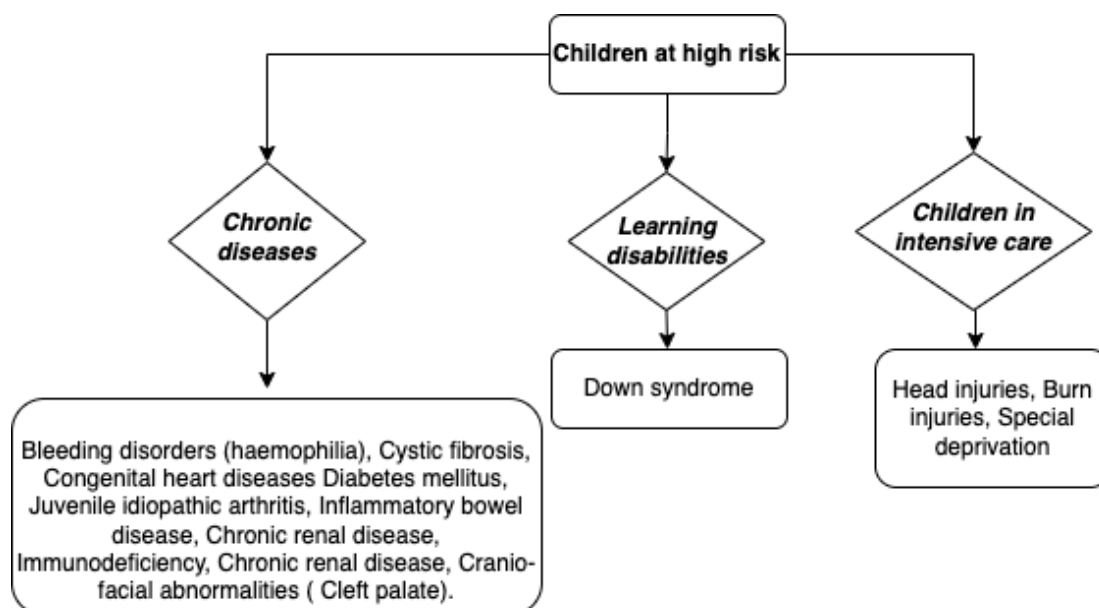


Figure 1.6 Relationship between various medical conditions and dental caries amended from Strategies to prevent dental caries in children and adolescents guidelines (Irish Oral Health Services Guideline Initiative, 2009).

1.2.1.4 The Role of Fluoride in the Prevention of Dental Caries

Fluoride exposure in the form of systemic fluoride (water fluoridation) and /or topical application (toothpaste and varnish) reduces dental caries experience in children (de Sousa *et al.*, 2019; Walsh *et al.*, 2019; Benson *et al.*, 2019). The last National Survey of Children's Oral Health in Ireland in 2002 reported that children living in areas without Community Water Fluoridation (CWF) suffered higher levels of dental caries than those from areas with CWF (Whelton *et al.*, 2006). Moreover, dental caries levels among 5, 12 and 15 year olds living in areas with CWF in the RoI were 43.5%, 33.3% and 39.5% respectively lower than their counterparts in Northern Ireland, which does not have CWF (Whelton *et al.*, 2006).

Fluorides ingested into the body which become incorporated into forming dental structures are called systemic fluorides (Sampaio and Levy, 2011). In the past, it was argued that systemic fluorides, when ingested during tooth development, resulted in structural improvements in the teeth, which were more resistant to acid attack (Cury *et al.*, 2019). However, results from clinical and laboratory studies have indicated that

the effect of fluoride on caries is primarily local (topical). The fluoride present in saliva provides a level of fluoride in the oral cavity that influences the caries process (Martínez-Mier, 2011; Cury *et al.*, 2019). The simplest way to maintain a constant source of fluoride in the oral cavity is through water fluoridation, not only by using this water for drinking but also for cooking food (Cury *et al.*, 2019). The preventive effects of systemic fluorides remain throughout an individual's lifespan. An illustration of fluoride metabolism through drinking water is shown in Figure 1.7.

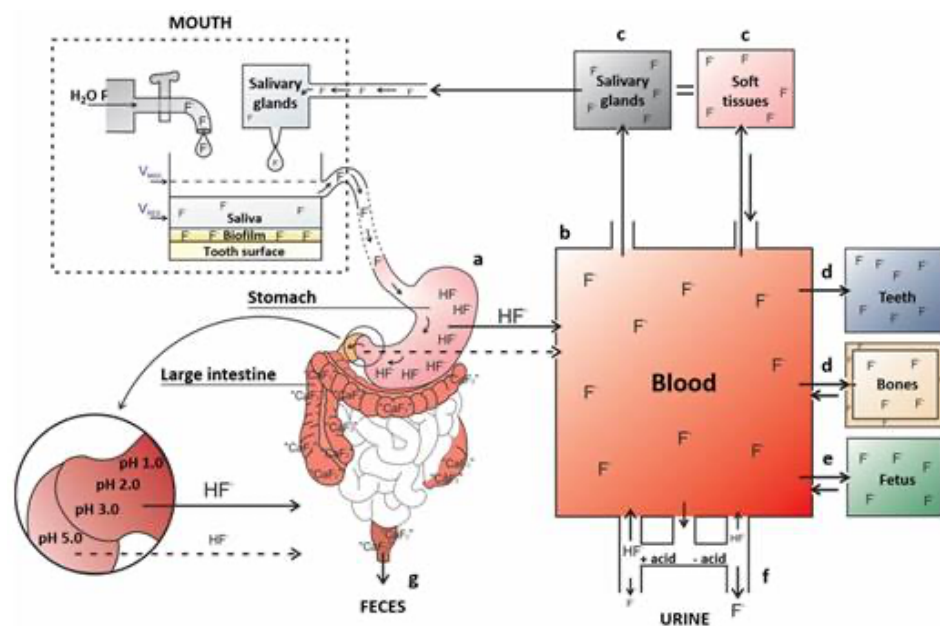


Figure 1.7 Illustration of fluoride mechanism from drinking water from Cury *et al.* (2019). F⁻ = Fluoride ion, HF = Hydrogen Fluoride, CaF₂ = Calcium Fluoride. Absorption of fluoride mainly occurs in stomach as HF (a), fluoride as fluoride ions (F⁻) is circulated in the blood (b) and distributed in the body. It is secreted in the oral cavity via salivary glands (c) and gets incorporated into hard tissues (d). Absorbed fluoride is secreted in urine and unabsorbed fluoride is excreted in faeces (f) (Cury *et al.*, 2019).

Topical fluoride such as fluoride toothpastes, mouth-rinses, varnishes and gels provide sustained elevated levels of fluoride in oral fluids which is available during the demineralisation/remineralisation cycle (Marinho *et al.*, 2003; Walsh *et al.*, 2019). Fluoride inhibits demineralisation and enhances remineralisation through a topical effect after the tooth has erupted (Jabin *et al.*, 2020). Fluoride at lower concentrations

is beneficial in preventing dental caries, especially at the plaque/saliva/enamel interface (Walsh *et al.*, 2019). When the pH level decreases after demineralisation, fluoride ions present at the tooth surface combine with dissolved calcium and phosphate ions to form less soluble fluorapatite-like crystals within the tooth (Jabin *et al.*, 2020). These fluorapatite crystals incorporated in the tooth enamel are more resistant to subsequent acid attacks (Jabin *et al.*, 2020). Mechanisms responsible for the preventive effects of fluoride against tooth decay have been summarised by Dhar and Bhatnagar (2009):

- 1) Fluoride decreases the solubility of enamel by converting more soluble hydroxyapatite crystals into less soluble fluorapatite crystals.
- 2) Fluoride has direct effects on bacteria in dental plaque and decreases their acid-producing ability.
- 3) Fluoride assists in the remineralisation of tooth surface areas demineralised by acids.

1.3 Conceptual Models of Child Oral Health

1.3.1 Overview

Dental problems in children, especially dental caries, are a major public health issue and require targeted interventions (Bagramian, Garcia-Godoy and Volpe, 2009; Paisi *et al.*, 2018). Population and individual-based programmes have demonstrated a wide range of effectiveness in the prevention of oral health problems (Jepsen *et al.*, 2017).

To improve childrens' oral health, policy makers and stakeholders may consider and utilise oral health conceptual models outlining the pathways which operate across the continuum of oral health determinants (Fisher-Owens *et al.*, 2007; Lee and Divaris, 2014). Various theoretical frameworks have been proposed to analyse the factors associated with childrens' oral health, most of which focussed on a multilevel approach. Research in child health and development has increasingly emphasised the role of comprehensive bioecological models which place the child at the centre of a multi-layered, interconnected and complex environmental system influencing the

development of a child during the course of their life (Fisher-Owens *et al.*, 2007; Johnson *et al.*, 2017).

One of the most studied conceptual models describing the development of oral diseases in population-based studies is the life-course approach. The life-course approach to epidemiology has been defined by Kuh as “the study of long term effects on later health or disease risk of physical or social exposures during gestation, childhood, adolescence, young adulthood and later adult life” (Kuh *et al.*, 2003).

The four life-course causal models proposed by Kuh are shown in Figure 1.8.

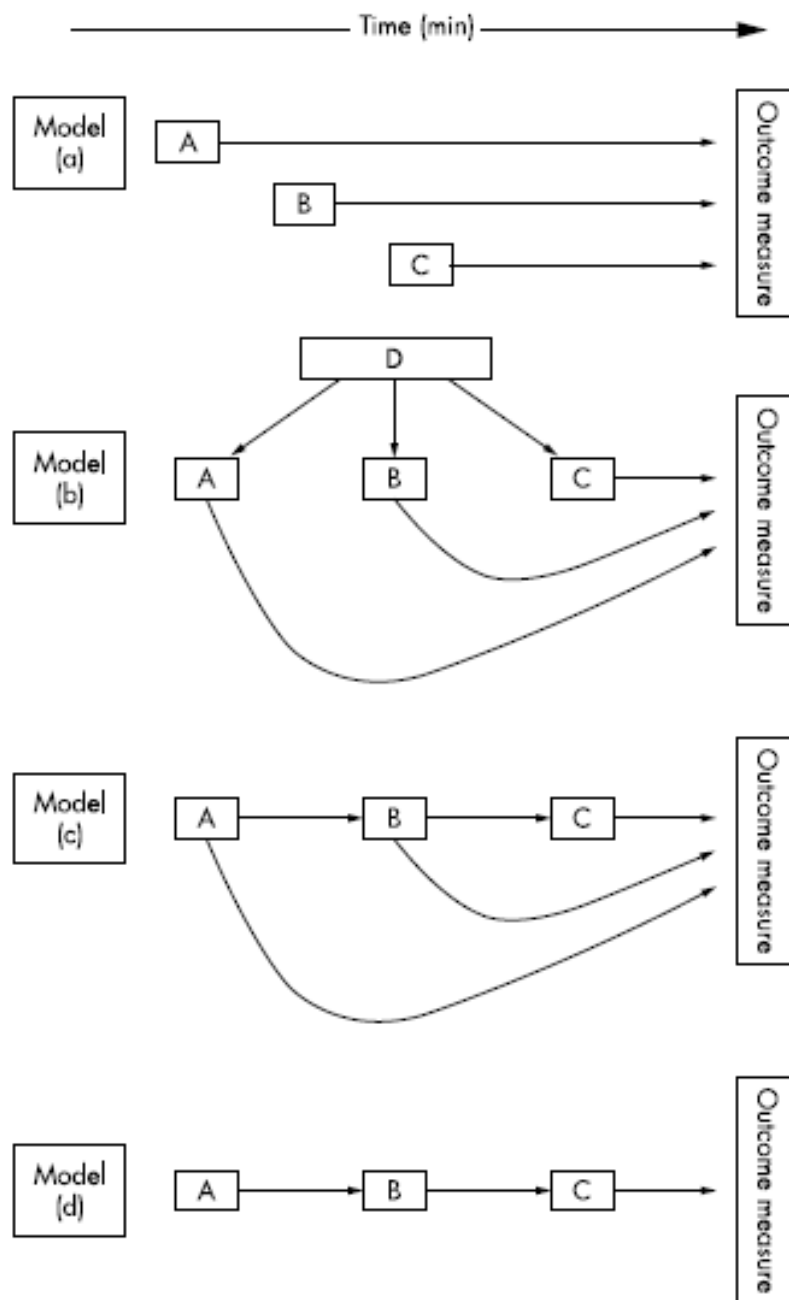


Figure 1.8 Life course causal models by Kuh *et al.* (2003).

Model A. Independent Accumulation of Risk Model - This model springs from the concept that life course exposures gradually accumulate in a person throughout the different stages of illnesses, injuries, environmental damages and lifestyle behaviours toxic to health. The risks associated with each exposure in this model are independent of each other.

Model B. Clustered Accumulation of Risk Model - This model is similar to the previous model except that, the risk factors are clustered together. These exposures are clustered because they are often related to the socioeconomic positions of an individual or their family in the community.

Model C. Chain of Risk Model (Additive Effect) - This model deals with sequential exposures that are related to each other such that one exposure is necessary for the other exposure to occur, in the form of a chain reaction. Every exposure has an independent effect irrespective of the later exposure. The concept of mediating and modifying factors can be explained on the basis of this model.

Model D. Chain of Risk Model (Trigger Effect) - This model is a special kind of chain of risk model. In this case the previous exposures have no independent effect on the risk of developing a disease and the last link in the chain precipitates the onset of the disease and has the only significant effect on disease risk.

The application of a life-course approach in oral health research should be considered as oral diseases are chronic, cumulative, occur across populations and may be measured accurately in epidemiological surveys (Nicolau *et al.*, 2007). Oral diseases which share risk factors with other chronic non-communicable public health issues may be an early marker for exposure to risk factors across the life course (Crall and Forrest, 2018). Prospective cohort studies are best placed to examine the life-course influences on oral health, but there is a lack of longitudinal studies gathering clinical oral health data (Heilmann, Tsakos and Watt, 2015).

Three birth cohort studies containing clinical data on oral health have been widely discussed in the literature. These studies include the Newcastle Thousand Families 1947 birth cohort in England, the Dunedin Multidisciplinary Health and Development Study in New Zealand (1972-73) and the Pelotas birth cohorts in Brazil (1993) (Pearce *et al.*, 2009; Silva, 1990; Victora and Barros, 2006).

Heilmann and colleagues proposed a theoretical framework which combined a life course and common risk factor approach with the social determinants of oral health (Heilmann, Tsakos and Watt, 2015). The life course framework for oral health as proposed by Heilmann is shown in Figure 1.9. The model emphasised on the role of socioeconomic status of an individual both during childhood and adulthood. In addition, the model highlighted the common risk factors associated with oral diseases and chronic health conditions. Moreover, the model suggested that exposure during a specific time window, the sensitive period, can have an irreversible effect on later oral health. For instance, disturbances at the time of tooth formation may result in irreversible damage to dental tissues, and these defects may predispose a tooth to dental caries (Heilmann, Tsakos and Watt, 2015).

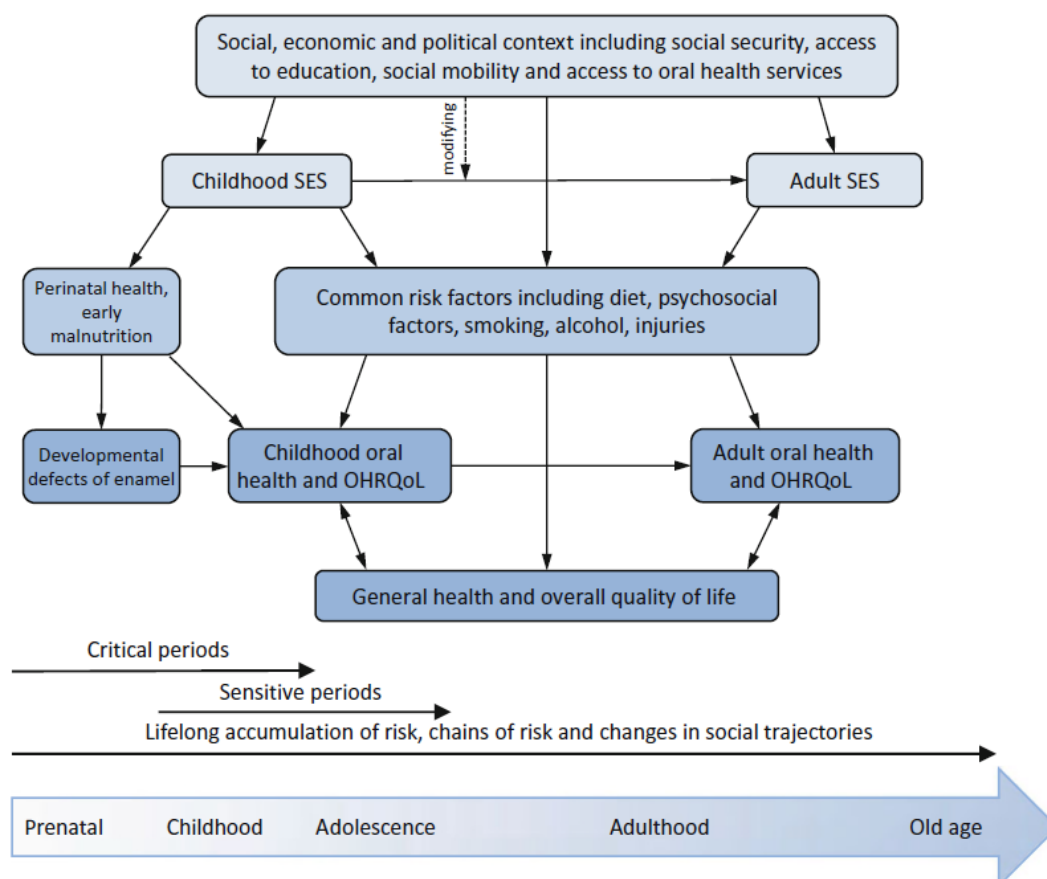


Figure 1.9 Life course framework for oral health proposed by Heilmann, Tsakos and Watt (2015). SES = Socio-economic status, OHRQoL = Oral Health-Related Quality of Life.

Bronfenbrenner and Morris have proposed a model for the scientific study of human development. The model outlined the child's relationship to the world as an evolving theoretical system over time (Bronfenbrenner and Morris, 2007). The child's developmental ecosystem was shown as a multi-layered set of interconnecting environmental systems having a differential influence on the child's development. This model has been called a bioecological model because there are interactions between a child's biological and surrounding environmental factors during their development. In this model, the child is placed inside concentric rings representing the ecology of human life. The distance of the layers from the child was proportional to their influence on the child's development. During the child's early developmental stages, the maximum influence was of the parents, siblings, immediate family members, school, healthcare facilities and the neighbourhood play areas/parks. These direct influences on the child together constitute the microsystem. Outside the microsystem is the mesosystem which describes the interactions among the contexts in the microsystem. All the infrastructures, institutions and settings which indirectly influence the quality and future outcomes of the child's life constitute the exosystem. The macrosystem is the last ring in the Bronfenbrenner's model consisting of the attitudes and ideologies of the culture as well as the financial and political design of the society. Time as a context in child development is presented as a chronosystem in Bronfenbrenner's model. The direct and indirect roles of various systems on the child's development as proposed in Bronfenbrenner's model are shown in Figure 1.10.

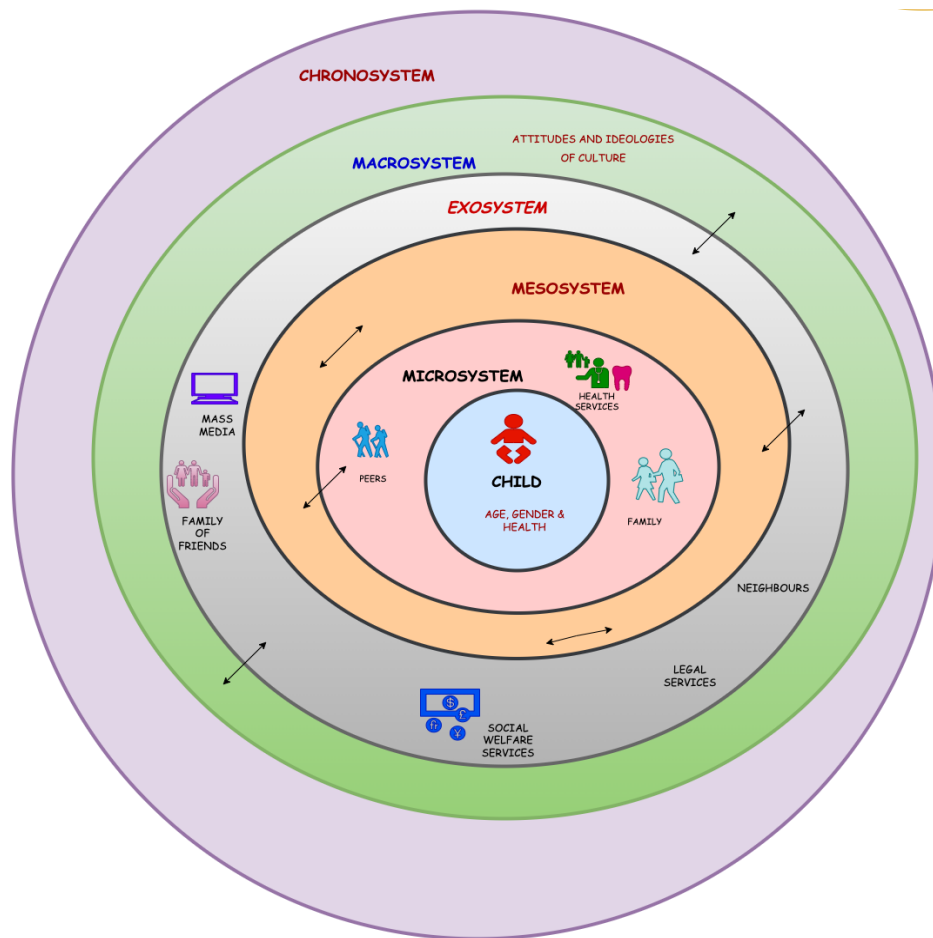


Figure 1.10 Bronfenbrenner's Bioecological Model of child development. Adapted from Garbarino (1982)

The social determinants of health have been divided into upstream societal influences (also called distal factors) and downstream influences (also known as proximal factors) (Krieger, 2008). The underlying assumptions of this model included: (1) that diseases are a result of several factors located within or outside the body, (2) the distal factors typically include social influences, (3) the proximal factors include the biological causes, and (4) in between these proximal and distal factors are levels which connect the two. These levels can be conceptualised as near to or far from the factors under consideration (Krieger, 2008). Marmot and Bell, to explain the aetiology of oral health conditions and patterns of health inequalities, have suggested a broader social determinants framework which included not only biological, psychosocial and environmental factors but also behavioural, economic and political factors (Marmot and Bell, 2011).

Fisher-Owens *et al.*, in their conceptual model, based on the level of influence (child level, family level and community level) have classified determinants of oral health into five domains: 1) genetics and biological factors, 2) the social environment, 3) the physical environment, 4) health behaviours, and 5) dental and medical care. The model also included a time element to acknowledge the dynamic and unique developmental trajectory of children's oral health (Figure 1.11). Furthermore, they introduced the concept of vulnerability and resilience in their model indicating that a child can successfully adapt to adversity at an individual or population level (Fisher-Owens *et al.*, 2007).

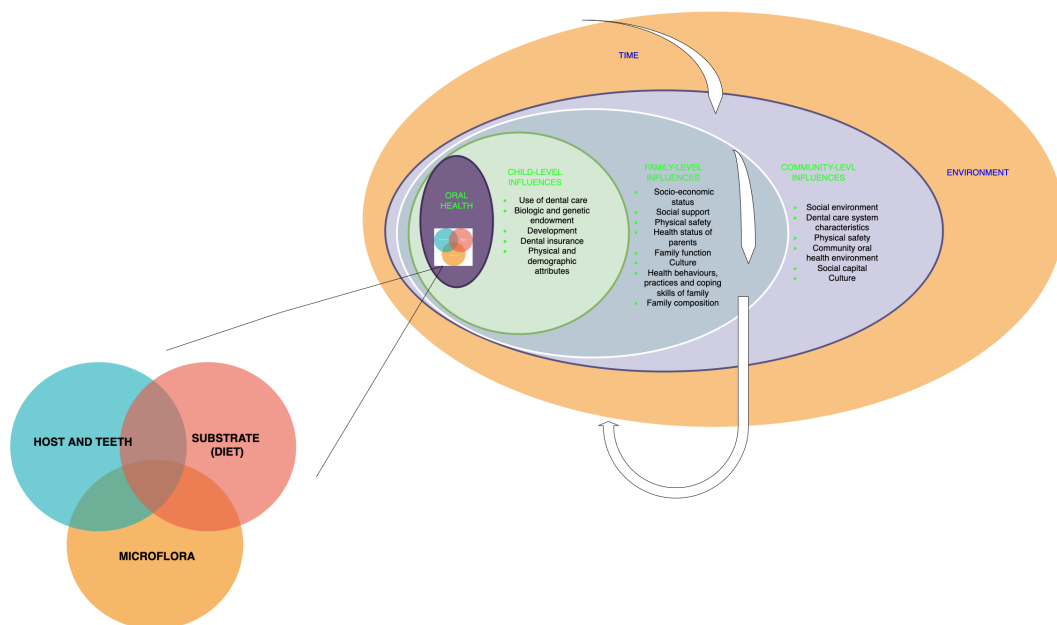


Figure 1.11 Child, family and community influences on oral health outcomes of children adapted from Fisher-Owens *et al.* (2007).

A proposed model unified the risk factors for early childhood caries (ECC) into broad social, environmental, maternal and child factors (Figure 1.12) (Seow, 2012). The factors directly influencing the mothers' psychological stress, depression, anxiety, health behaviours and beliefs were related to the environments of low socioeconomic status, social disadvantages and health inequalities. The model also demonstrated that the causative pathways involved in the development of ECC in children can be studied using a combination of quantitative and qualitative research (Seow, 2012).

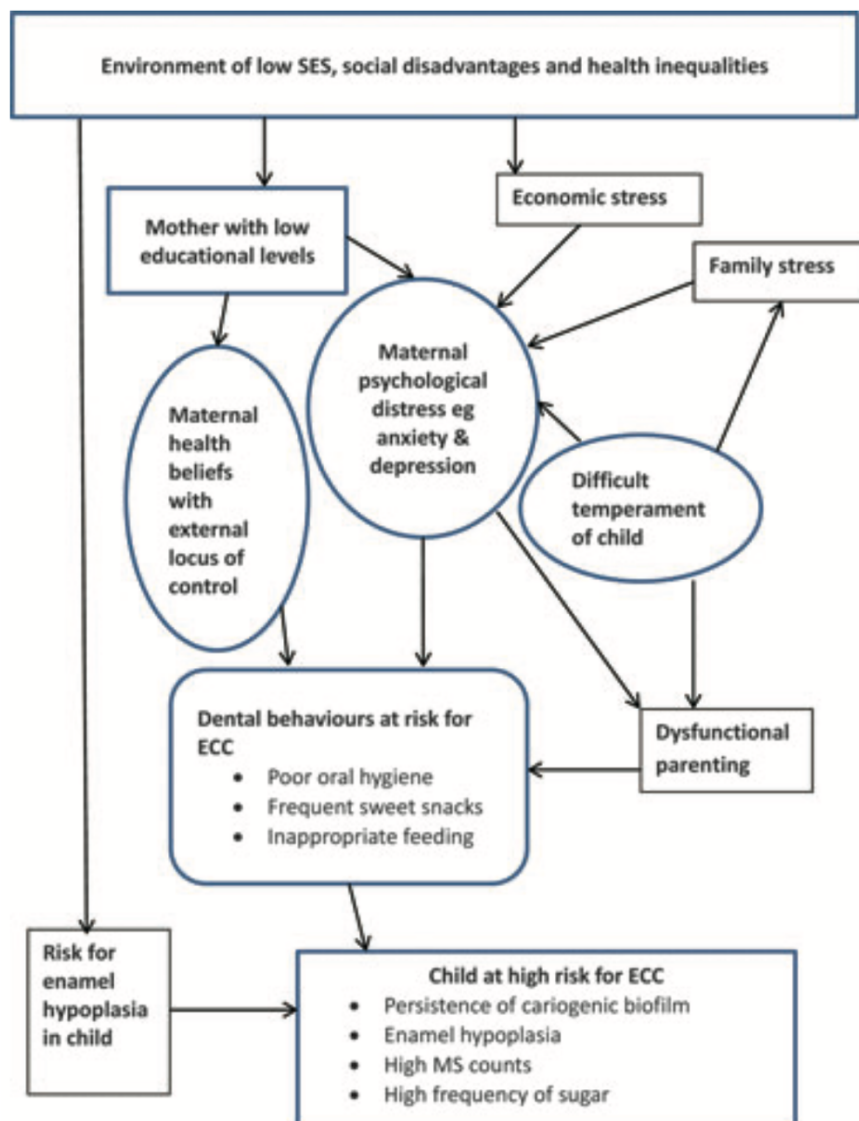


Figure 1.12 A unifying conceptual model for ECC illustrating the influence of social, environmental factors on mother and child. In addition, it shows the connections between environmental, maternal and child factors proposed by Seow (2012).

Casamassimo *et al.*, in their model, combined genetic/genomics research and behavioural sciences together with dental materials, health services and social sciences. They concluded that health policies informed by scientific endeavour have a potential to affect the social determinants of health which in turn influences population health, thereby leading to significant improvements in childrens' oral health (Casamassimo *et al.*, 2014). The scientific basis underlying oral health and its intersection with the policy are shown in Figure 1.13.

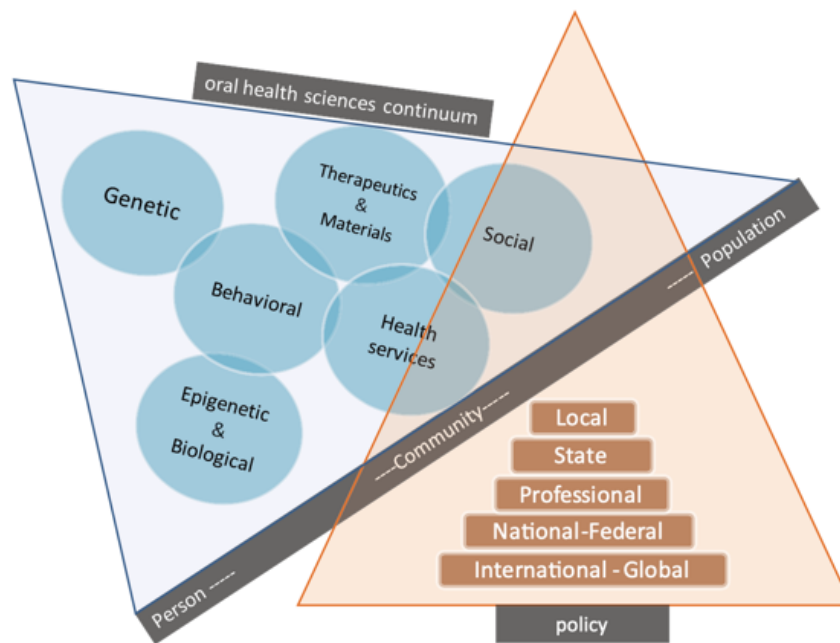


Figure 1.13 Conceptual framework for intersection of science and policy for child's oral health Casamassimo *et al.* (2014).

In agreement with the previously mentioned models, Lee and Divaris also proposed a theoretical framework that highlighted the importance of social determinants of oral health and illustrated pathways that operate across these determinants during the life course. This framework also proposed actions for eliminating sources of health inequalities and hence, oral health disparities (Lee and Divaris, 2014).

Inspired by the Fisher-Owen model, Johnson *et al.*, have conceptualised the ViCGen causal model for childhood oral health (Figure 1.14). The ViCGen birth prospective cohort, established in 2008, examined the relative contribution of environmental, biological and socio-behavioural factors on child oral health. This study was based on a socio-ecological approach and collected comprehensive survey data, including oral health assessments in two phases spanning over eight years. At each survey wave, questionnaires were completed by parents to provide information about mother's and child's health, socio-demographics, oral health-related behaviours, attitudes, knowledge, skills and practices in families. Food frequency questionnaires (44-item) were completed by the parents to report the dietary behaviours of the study child. A

modified International Caries Detection and Assessment System (ICDAS II) was used for oral health assessment and salivary samples were obtained from child and the mother for identification of bacterial species (Johnson *et al.*, 2017). During the 18 months period (from 18 months of age to 36 months of age), changes in the early childhood caries lesion progression were observed from sound to cavitated and vice versa (Johnson *et al.*, 2017). These are sensitive periods when the risk factors (cariogenic foods) and the preventive measures (toothbrushing with fluoridated toothpaste, visit to the dentist) may be introduced and can influence caries initiation and progression. This study reinforced the evidence for the introduction of behavioural and therapeutic interventions at optimal time points to modify future disease trajectories (Johnson *et al.*, 2017).

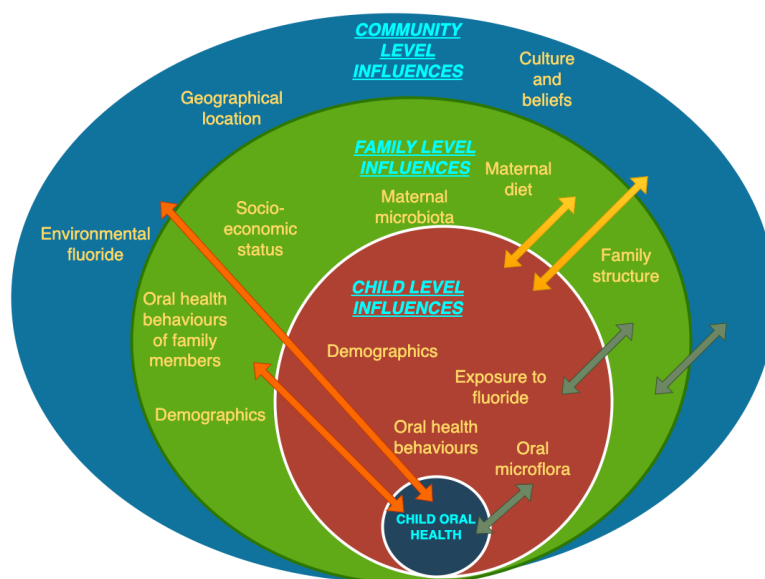


Figure 1.14 The VicGeneration Causal Model; a modification of Fisher and Owens model showing child, family and community influences on child oral health proposed by Johnson *et al.* (2017).

Crall and Forrest examined oral health from the perspective of Life Course Health Development (LCHD) model (2018). LCHD is a conceptual framework which advocates early and continuous investment in health development and helps explain the development of health and disease patterns across populations over time (Halfon and Hochstein, 2002).

There is a need for long-term longitudinal oral health life course studies with detailed and frequent data collection (Crall and Forrest, 2018). The authors also advocated interdisciplinary collaboration and open data access for promoting research for identifying causal pathways between risk factors and oral health outcomes (Crall and Forrest, 2018).

1.4 National Longitudinal Child Cohort Surveys and Harmonisation of Oral Health

Variables

Nationally representative oral health data are needed to effectively plan and evaluate oral health policies and services (Li *et al.*, 2018). However, this type of data is scarce due to the high costs involved and complexity of coordinating and conducting national oral health surveys (Patel *et al.*, 2016; Taylor *et al.*, 2023). The last National Children's Oral Health Survey in the Republic of Ireland (RoI) was completed almost twenty-one years ago (Whelton *et al.*, 2006). Self-reported oral health data from national birth and child cohort surveys provide an opportunity for estimating the distributions and prevalence of oral diseases in children over time and relating these findings to general health conditions and sociodemographic factors in the same cohort (Crowe *et al.*, 2016; Skafida and Chambers, 2018; Thornley *et al.*, 2021).

Secondary data analysis (analysis of data collected in the past by others for another primary purpose) provides a viable option for researchers when it is not feasible to independently collect data from a sufficiently large sample to investigate population oral health issues (Johnston, 2014; Ikeda, 2016). For efficient use of secondary data, data discovery, the ability to find data relevant to a research project is a critical component (Bauermeister *et al.*, 2023). However, for large-scale cohort surveys, data discovery may be challenging as these studies are under-documented and have varied data structures and labelling conventions (O'Neill *et al.*, 2019; Bauermeister *et al.*, 2023). Before attempting secondary data analysis, researchers should evaluate existing data quality and variable understanding by studying essential aspects of the methodology used to collect data (Kołczyńska and Schoene, 2018).

A pre-requisite for efficient data discovery and co-analysis of individual participant data is data harmonisation (Fortier *et al.*, 2016; Bauermeister *et al.*, 2023; Fortier *et al.*, 2023). This is a practice used to improve variable comparability (inferential equivalence), ensure content equivalence and reduce heterogeneity across multiple studies (Sánchez-Niubo *et al.*, 2020). In turn, this facilitates combining, pooling and integrating datasets from heterogeneous sources in a coherent manner (Adhikari *et al.*, 2021). Prospective harmonisation ideally occurs before data collection and requires agreement between investigators on a standard set of variables, compatible data collection tools and standard operating procedures (Adhikari *et al.*, 2021). Even though prospective harmonisation ensures a high degree of homogeneity across studies, implementation of this approach is not always suitable or feasible (Fortier *et al.*, 2016; Adhikari *et al.*, 2021). With a retrospective harmonisation approach, researchers define a core set of variables to be generated and evaluate the harmonisation potential of the already collected information across the studies involved (Fortier *et al.*, 2011; Fortier *et al.*, 2016; Fortier *et al.*, 2019; Fortier *et al.*, 2023). Data harmonisation provides an infrastructure supporting the reuse of survey data by making data findable, accessible, interoperable, and reusable (FAIR) (Wilkinson *et al.*, 2016).

Over the last few decades, there have been multiple harmonisation initiatives related to population health and disease (Fortier *et al.*, 2023). These initiatives can be classified as 1) hypothesis-specific initiatives across multiple datasets and 2) initiatives targeting a broad range of objectives (Fortier *et al.*, 2023; Bauermeister *et al.*, 2023). Several national and international harmonisation initiatives have been created to study the developmental origins of health and disease. The following comprehensive health and disease data harmonisation projects have been discussed widely: 1) the EU Child Cohort Network, involved nineteen pregnancy and childhood cohorts, with a combined sample of more than 250,000 children and their parents (Jaddoe *et al.*, 2020); 2) the ENRIECO project, focussed on environment and child health included 37 cohorts, situated in 19 European countries, with a combined total of more than 350,000 subjects (Vrijheid *et al.*, 2012); 3) the Research Advancement through Cohort

Cataloguing and Harmonisation (ReACH), included 26 Canadian studies studying Canadian mother and/or children (Bergeron *et al.*, 2020); 4) the Maternal, infant, Child and Youth Research Network (MICYRN), an inventory of forty-six Canadian birth cohort studies to enrich research in maternal and child health across Canada (Joly *et al.*, 2012); 5) the Global Pregnancy CoLab, facilitated pregnancy and placental research and its online database, COLLECT, allows collection of minimal and optimal clinical datasets to accompany basic and applied science studies (Myatt, Roberts and Redman, 2017); 6) the Biobank Standardisation and Harmonisation for Research Excellence in European Union (BioSHare) project, included eight population based studies in six European countries (Doiron *et al.*, 2013); 7) the European Determinants of Diet and Physical Activity (DEDIPAC) data harmonisation platform, included 114 unique datasets (Lakerveld *et al.*, 2017) and 8) the CLOSER consortium, established in 2012, included 19 cohort studies in the UK across biomedical and social science domains (O'Neill *et al.*, 2019). Other data harmonisation initiatives were domain-specific, and focused on only a limited number of studies. For instance, the harmonisation of the health and risk factor questionnaire data of the Canadian Partnership for the Tomorrow Project included 12 cohort studies (Fortier *et al.*, 2019), 2) data harmonisation in cancer epidemiology research (Rolland *et al.*, 2015), 3) the harmonisation of physical activity data for the International Children's Accelerometry database (ICAD) (Atkin *et al.*, 2017), 3) the data harmonisation of two pregnancy cohorts studies conducted in Alberta, Canada (Adhikari *et al.*, 2021), and 4) the harmonisation potential evaluation of the neurodegeneration variables across four population cohorts (Bauermeister *et al.*, 2023).

1.5 Analysis of Oral Health-Related Data in National Cohort Surveys

Open data science tools and a working knowledge of data visualisation and analytics are becoming increasingly important in the digital health era (Lowndes *et al.*, 2017; Joda *et al.*, 2018; Joda *et al.*, 2019; Schwendicke and Krois, 2022). Open science has been defined as “the concept of transparency at all stages of the research process, coupled with free and open access to data, code, and papers” (Hampton *et al.*, 2015). Open data science tools have been described as the tools which enable open science

when integrated into the scientific process of knowledge discovery (Lowndes *et al.*, 2017). Data visualisation has been defined as “an approach to data analysis that stresses a penetrating look at the structure of data” (Cleveland, 1993). Data visualisation facilitates data understanding through direct sensory experience (primarily visual) rather than logical reasoning (Dix, 2013). Therefore, an understanding and appreciation of human cognitive, perceptual, social and organisational factors may be required to design effective visualisations. Data visualisations can be broadly categorised as static and interactive visualisations. Static visualisations are fixed visualisations usually focussed on specific data, whether on paper or screen (Dix, 2013). In addition, static visualisations may not be adequate for exploring large-scale, complex and evolving datasets with varying degrees of granularity (LaValle *et al.*, 2010; Dix, 2013; Ellis and Merdian, 2015; Concannon, Herbst and Manley, 2019). Interactive visualisations are generally used for the rapid extraction and analysis of salient information from large-scale and multidisciplinary survey datasets (LaValle *et al.*, 2010; Ellis and Merdian, 2015). Specifically, interactive dashboards have been proposed as an excellent tool for analysing data from multiple sources for a variety of potential users (LaValle *et al.*, 2010).

1.5.1 Data Dashboards

Dashboards have been defined as “a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single screen so the information can be monitored at a glance” (Few, 2006). Dashboards use a combination of different visualisation methods and, generally, dashboards display data as tables, graphs or charts; however, interactivity can be added to increase their scope and coverage (Barnum *et al.*, 2019; Concannon, Herbst and Manley, 2019). The primary purpose of using different visualisation methods in a dashboard is to facilitate timely understanding of data from multiple sources (Sarikaya *et al.*, 2019). The term “faceted analytical display” has been used to describe the analysis of information using a set of interactive charts (primarily graphs and tables) simultaneously on a single screen, where each chart presents a different view of a common dataset (Few, 2006). For an interactive analytical dashboard, the data is presented (on the same or

separate screens) in a visual format that supports exploration and interrogation. The viewer can use an interactive filter to change the selected parameters and refresh the output or allow for incremental updates of the dashboard as the input data changes (Xie, Allaire and Grolemond, 2018). This increases the potential impact of the data analysis by allowing interactivity and dynamic visualisations in “real-time” (Ellis and Merdian, 2015). Interactive dashboards may be the ideal data technique for presenting and disseminating health-related information in an accessible format, as it assists in summarising data and alleviating information overload (Cheng *et al.*, 2011; Höhle, 2017; Concannon, Herbst and Manley, 2019; Loginova and Wohland, 2020). The process of creating a dashboard is described as “dashboarding” and has been outlined in detail by multiple authors (Few, 2006; Smith, 2013).

Monitoring and analysing large-scale epidemiological data obtained from national child cohort surveys can help improve our understanding of the risk factors associated with oral diseases (Moynihan and Petersen, 2004; Crowe *et al.*, 2016; Crowe, 2018). Deploying multiple sources of population-level oral health data in an accessible dashboard could help monitor trends, explore risk factors and provide support for policy decisions.

1.5.2 Reproducible Research

Replication is the gold standard to validate researcher claims. It is a standardised and disciplined approach to scientific discovery (Peng, 2011). To replicate, independent researchers analyse new data to generate evidence for or against a scientific hypothesis using the same methodology applied in the original research. However, for cohort surveys, replication of study findings is challenging as these surveys are expensive and technically complex (Peng, 2009). Therefore, for cases where replication may not be possible, reproducible research has been proposed as a minimum standard for evaluating the value of scientific claims (Peng, 2011; Boettiger, 2015). For research to be computationally reproducible, the data and the code used for analysis should be made available to independent researchers for them to recreate the findings (Peng and Hicks, 2021). The reproducibility spectrum as proposed by Peng

is shown in Figure 1.15. The extreme left of the spectrum are occupied by published results in journals with no data or code sharing while on the extreme right is the full replication. The extent of reproducibility of a study is determined by the amount of code and data shared (Peng, 2011).

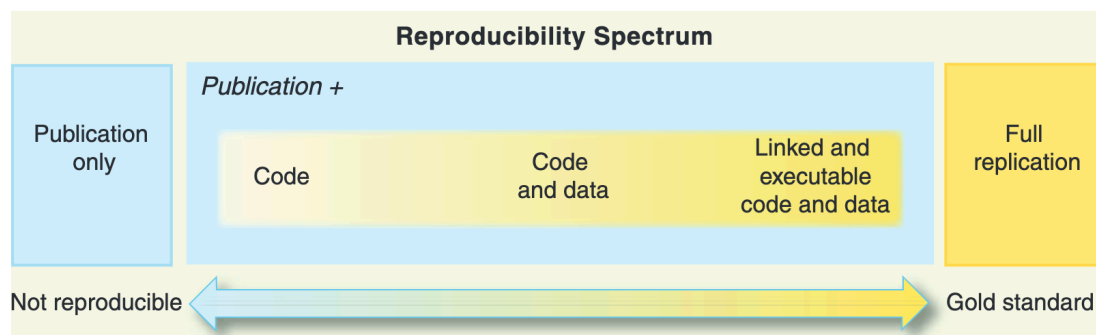


Figure 1.15 Reproducibility spectrum. Adopted from Peng (2011).

Reproducibility of research findings, collaboration among researchers, and effective communication among stakeholders could strengthen public trust and inform public health policies (Lowndes *et al.*, 2017; Joda *et al.*, 2018; Joda *et al.*, 2020). Extracting information from large-scale survey datasets using summary statistics and simple contingency tables with open-source programming language such as R is relatively straightforward and computationally reproducible (Lowndes *et al.*, 2017; Mount and Zumel, 2019). Communicating data analysis output through a dashboard can improve public awareness of research output and encourage greater transparency with other researchers who are able to assess initial findings easily. Integration with Git (a version control system) and deployment via GitHub pages (web pages hosted through a GitHub repository) promotes rapid communication, enhances collaboration and improves transparency and reproducibility. Ultimately, it is desirable to increase access for researchers, clinicians and policy makers to reported data analysis-visualisation that could benefit individual and population oral health (Twohig *et al.*, 2019; Schwendicke and Krois, 2022).

1.6 Diet, Nutrition and Oral Health in Children

1.6.1 Nutrition and Diet

Diet and nutrition are fundamental to maintaining the overall health of an individual. Diet is considered one of the most important lifestyle-related risk factors for a number of chronic diseases (World Health Organisation, 2003; Darnton-Hill, Nishida and James, 2004). Diet refers to the total amount of food consumed whereas nutrition is a scientific term which involves the process of utilising food for growth, development, metabolism, repairing tissues and includes several sub-processes such as ingestion, digestion, absorption, assimilation and excretion (Zohoori, 2020). The dietary patterns of people vary according to differences in the availability of food, socio-economic status, culture, geographical location, religious beliefs, lifestyle, convenience, and health status. The dietary patterns can range from vegan, lacto-ovo vegetarian, pollotarian, pescatarian, flexitarian to omnivorous (Zohoori, 2020). There is a bi-directional relationship between nutrition and health status. Nutritional deficiencies cause health problems and the nutrition status of a person is affected by changes in their health status (Behrman and Deolalikar, 1988).

The description of a healthy diet has evolved over time. Dietary research has provided an improved understanding of the different components of foods and essential nutrients (Palacios, 2006; Ndanuko *et al.*, 2016; Botelho *et al.*, 2020).

1.6.2 Determinants of Nutrition and Eating

Food choices, eating behaviours and patterns of nutrition are some of the most complex and abstract concepts to explain. While some nutritional experts believe that parts of eating behaviours are innate and intrinsic (to an individual/family), many others believe that they are learned and modified as a person develops and evolves (Birch, Savage and Ventura, 2007; Higgs, 2015; Scaglioni *et al.*, 2018). Moreover, there is a fascinating diversity of food choices and eating behaviours across populations. On an average day, a person may make as many as two hundred food decisions and hence it is fair to say that nutrition and eating are a result of the interplay between individual, social, behavioural and environmental factors (Stok *et al.*, 2017).

Key determinants of dietary choice are:

- 1) Biological determinants: Hunger/satiety and taste/palatability are the biological determinants that are reported to affect an individual's food choice. Individuals prefer different foods according to their level of hunger and the satiation effect of food. Low energy density foods are more satiating than energy dense foods (Kirkmeyer and Mattes, 2000; Rozin, 2006). The taste preferences in humans are inborn and evolutionary; newborns and infants have been reported to have a preference for foods with sweet tastes and reluctance towards bitter tastes (Yeomans, Blundell and Leshem, 2004; Mennella, 2014).
- 2) Physical determinants: Physical determinants like access to different food types; education about the nutritive value of various foods and their effects on health; skills necessary to prepare and cook different foods and lastly the time involved in accessing, cooking and eating a food type influence the choice for that food (Popkin, Duffey and Gordonlarsen, 2005; Köster, 2009).
- 3) Social determinants such as occupational class, culture and social context determine the food choices in individuals and populations (Shepherd, 1999). It was believed that an individual's food choices are mediated by their attitudes and cultural beliefs (Shepherd, 1999).
- 4) Psychological determinants: Studies have reported that people select food according to their mood and stress levels (Oliver and Wardle, 1999; Zellner *et al.*, 2006). Laboratory settings have confirmed that emotional eaters consumed greater quantities of sweet and fatty foods when they were stressed than during stress-free periods (Oliver, Wardle and Gibson, 2000).
- 5) Economic determinants: The monetary cost of the food is a major determinant of food choice. It affects some populations more than others (Pollard, Kirk and

Cade, 2002). Individual or household income is a major determinant of food choice (Burns, Cook and Mavoa, 2013).

1.6.3 Dietary Assessment Methods

The four main approaches to comprehensively evaluate the nutritional status of individuals are: dietary assessment, anthropometrics, clinical examination and biochemical parameters (Gibson, 2005). A dietary assessment of an individual or individuals (in a household or population group) is an evaluation of their food/nutrient intake and dietary patterns over time (Gibson, 2005). A list of dietary assessment methods used to estimate the food and nutrient consumption at national, household and individual level as described by the Food and Agriculture Organisation (FAO) of the United Nations (UN) are summarised in Figure 1.16. Direct methods of dietary assessment collect and use primary dietary data from individuals while the indirect methods rely upon the secondary data for dietary assessments (Food and Agriculture Organization, 2018).

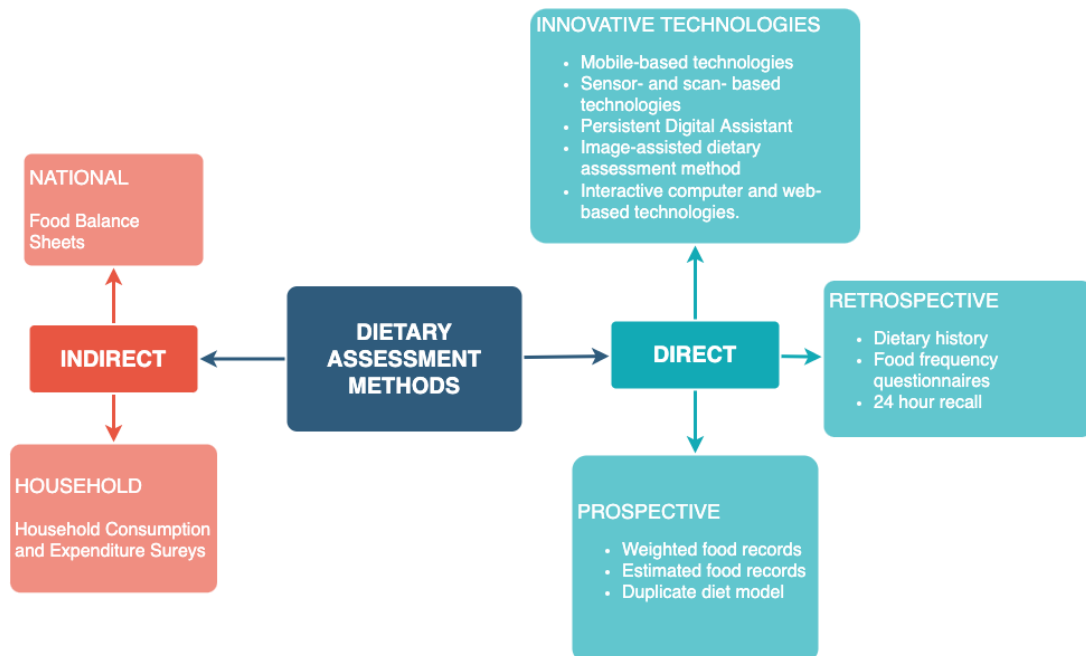


Figure 1.16 Dietary assessment methods adapted from Food and Agriculture Organization (2018).

1.6.3.1 Indirect Methods

Methods of dietary assessment which rely on secondary information (obtained from food expenditure, agricultural statistics, food supply to/within an area etc.) to estimate foodstuffs available for consumption are referred to as indirect methods. The most notable among these are Food Balance Sheets (FBC) and Household Consumption and Expenditure Surveys (HCES) (Food and Agriculture Organization, 2018). FBCs are suitable for estimating food consumption at a national level, while HCESs are useful for providing food consumption information at household levels (Food and Agriculture Organization, 2018). Since both of these methods do not obtain primary dietary data directly from individuals, they cannot evaluate dietary assessment at an individual level. The main application of these methods is to look for trends in food availability and consumption across different geographical areas and times (Naska *et al.*, 2008; Al Hasan *et al.*, 2019).

1.6.3.2 Direct Methods

Direct methods are classified into prospective and retrospective methods based on the time at which food consumption was recorded. While prospective methods record diet during food consumption, retrospective methods are dependent on the recollection of information about food that has already been consumed (Food and Agriculture Organization, 2018). Moreover, these methods can largely be grouped into qualitative (food type) and quantitative (food type and amount). The choice of an appropriate method for dietary assessment depends on the size, design and purpose of the study; research constraints in terms of finance, staff availability, time, respondent characteristics and the level of accuracy required (Thompson and Byers, 1994; Shim, Oh and Kim, 2014).

1.6.3.2.1 Retrospective Direct Methods

Retrospective methods include food frequency questionnaires (FFQ), 24-hour recalls, and dietary history (Food and Agriculture Organization, 2018). These methods collect information on food and beverages already consumed by an individual. These methods are highly dependent on the memory of the respondent and their ability to

correctly recall the type and amount of food and beverages consumed over a reference period of time (Thompson and Subar, 2017; Dao *et al.*, 2019). Individuals may quantify the amounts of food consumed with the help of food models, food pictures, and standard household measuring utensils such as cups and spoons (Shim, Oh and Kim, 2014).

Food Frequency Questionnaires (FFQ)

The dietary behaviour patterns of respondents over a certain time period can be assessed using the food frequency questionnaire (FFQ) method (Thompson and Subar, 2017). FFQs usually comprise of a list of food items (usually close-ended), and a section with different frequency options to choose from, and therefore aims to record habitual intake (Farshchi *et al.*, 2017). These can be either self-administered or interviewer-administered. The data can be collected over a day, week, month or even a year (Shim, Oh and Kim, 2014). Studies have also used FFQs with additional information on portion sizes and/or quantity of food consumed (Nöthlings *et al.*, 2007). The list of food items to be included in a FFQ could be obtained after a thorough literature review and from previous dietary assessment reports, focus group discussions and pilot 24-hour recalls (Farshchi *et al.*, 2017).

The FFQ is the preferred method for large-scale studies because it is economical and needs less time for data collection and processing than other dietary assessment methods (Shim, Oh and Kim, 2014). FFQ could assess the habitual consumption of food over an extended time period without any influence on the eating behaviours of study respondents (Farshchi *et al.*, 2017). The major limitation of FFQ method is that inaccuracies may result from an incomplete listing of all possible foods, errors in estimation of usual serving sizes, problems with memory and recall, and inadequate response levels to record the usual intake frequency (Thompson and Byers, 1994; Farshchi *et al.*, 2017). The list of the foods included in a FFQ is crucial as there is a risk that shorter FFQs may underestimate while the longer FFQs may overestimate the average food intake of an individual (Feskanich *et al.*, 1993). FFQs have been designed for specific populations. The estimation of the true usual food intake of the population

by a FFQ depends on the knowledge about the constellations of complex dietary patterns of the studied population (Thompson and Subar, 2017). Multiple 24-hour recalls, food records (weighted and estimated) and biomarkers have been used to validate FFQs (Thompson and Subar, 2017; Farshchi *et al.*, 2017).

24-Hour Dietary Recall

This is a retrospective food intake assessment method in which a participant is asked to recall and describe all the food and drink items consumed in the last 24 hours or the previous day (Farshchi *et al.*, 2017). The interviewer can collect this information either via a phone call or a face-to-face interview (Farshchi *et al.*, 2017). The dietary data collected over phone versus face-to-face interviews are essentially similar so there is no advantage of using one method over the other (Brustad *et al.*, 2003). The 24-hour recall method relies on well-trained interviewers, preferably nutritionists, to collect and record the information from each participant. They need to possess a good understanding of the food options available in the marketplace, common food and cooking preparation methods, as well as the prevalent local, traditional and regional foods (Shim, Oh and Kim, 2014; Foster and Bradley, 2018).

A single 24-hour recall may be insufficient in representing an individual's usual food intake because of the daily variation in the intake of foods (Thompson and Subar, 2017). Repeated 24-hour recalls or multiple recalls conducted over several days were shown to be more reflective of an individual's actual eating patterns (Hartman *et al.*, 1990; Ma *et al.*, 2009). Higher reproducibility was guaranteed with four or five recalls compared to repeating the recall in only two or three instances (Rankin *et al.*, 2012).

Similar to the FFQs, the 24-hour recall method results in inaccurate dietary assessments because of memory or recall bias (Shim, Oh and Kim, 2014). However, structured interviews with specific probes may help respondents remember their eating and drinking events throughout the day over different time periods (Food and Agriculture Organization, 2018). In addition, 24-hour recall interviews could also enable the exploration of items not initially reported (snacks, butter on toasts, how

food was prepared, beverages) (Naska, Lagiou and Lagiou, 2017). The 24-hour recall method may be challenging for children and elderly because of their ability to recall food items correctly is noticeably lower than young adults (Farshchi *et al.*, 2017). A single day 24-hour recall per respondent can be considered to assess the mean intakes of food of a population. While, for individuals, multiple 24-hour recalls may be a better choice (Gibson, 2005). A single weighed food record with trained observers and biomarkers have been suggested for the validation of a 24-hour dietary recall (Crawford *et al.*, 1994; Bingham, 1997; Wark *et al.*, 2018).

In summary, the main strength of using the FFQs and 24-hour recall methods are: 1) they are simple to arrange/organise, 2) no special training is needed, and 3) a detailed intake data can be obtained with little recall bias in most cases (Shim, Oh and Kim, 2014). In addition, these methods are cost effective, time saving and suitable for small-scale epidemiological studies. Another key advantage is the ease of use for those with low levels of literacy who usually make meals at home. However, these methods are also prone to errors as the reported individual dietary consumption may not be accurate and not suited to those people who frequently dine outside the home (Farshchi *et al.*, 2017).

Diet History

A dietary history refers to a detailed assessment of usual food intake and its variation over a longer duration, typically six months to a year (Gibson, 2005). The dietary history method, first described by Burke, comprised of three main parts: a food list, an in-depth interview to determine usual food intake and eating patterns, and a three-day record including estimates of portion sizes to be used as cross-checks (Burke, 1947). However, the original method proposed by Burke was considered impractical due to its dependence on trained personnel to conduct interviews (Gibson, 2005). Computerised versions have become more common these days which can be either self or interviewer administered (Ngo *et al.*, 2009). However, these too cause a high respondent burden as a result of the extensive time input required when conducting dietary histories (Food and Agriculture Organization, 2018). Dietary history is well

suited to individual clinical usage but is not applicable to larger studies because of reliance on trained nutritionists to complete these assessments (Farshchi *et al.*, 2017). This method could estimate over and under-nutrition as it records the usual food or nutrient intake of respondents over an extended period of time (Shim, Oh and Kim, 2014). It can also provide insights on food items that are not regularly consumed and does not interfere with normal eating habits of a person (Thompson and Subar, 2017). One of the main drawbacks of this method is its labour-intensive and time-consuming nature, and hence may not be suitable for young children and elderly respondents as well as for large epidemiological surveys (Farshchi *et al.*, 2017).

1.6.3.2.2 Prospective Direct Methods

Prospective methods of dietary assessment record the food and beverage intake at the time of consumption. The most common and well-studied prospective direct methods include: 1) the weighed food record, 2) an estimated food record and 3) the duplicate meal method (Thompson and Subar, 2017). These methods are generally dependent on the level of respondent literacy and numeracy skills (Kolar *et al.*, 2005).

Food Records (Estimated and Weighed)

A food record typically records the amount and type of food consumed over a span of 4-7 days in the form of a food diary (Gibson, 2005). In this open-ended prospective approach, the subject records all the foods and beverages consumed while eating, hence making it easier for the participants to record their food intake without any recall issues (Ortega, Pérez-Rodrigo and López-Sobaler, 2015). The amount of food consumed can be measured using a measuring scale or estimations made by the participants. The food records measured by means of a measuring scale are termed “weighed food records”, and those recorded using household estimations are called “estimated food records” (Rutishauser, 2005). The leftover food and drink items are also recorded so that the consumed weight of the item can be calculated. The food records can be collected in the form of structured/unstructured diary entries (Rutishauser, 2005).

To improve food record reliability, respondents are trained to report the food intake in terms of the name of the item consumed, preparation and cooking methods used, portion sizes and recipes (Farshchi *et al.*, 2017). For children and dependents, other responsible people such as parents, caretakers and guardians keep records on their behalf (Livingstone, Robson and Wallace, 2004). The food records should be reviewed by a trained nutritionist/dietician after the first and last day of food recording to ensure that no food has been omitted. In addition, during these visits, portion sizes are discussed and interpreted and any detail that might have been missed during food recording, such as, the use of additional salt, sugar sauces etc. are added (Cantwell *et al.*, 2006).

Duplicate Meal Method

The duplicate meal method involves placing duplicates (amount and type) of food items and beverages consumed by the respondent over a specific period of time. These duplicates are then weighed (either by the respondents themselves or a field worker) and sent to a laboratory for further analysis to assess the nutrient content of the food items consumed (Bingham, 1987). In addition to keeping aside the duplicates, respondents are also required to maintain a weighed food diary reporting all types and quantities of food and beverages consumed (Melnik *et al.*, 2012). The food diary helps to verify the accuracy and completeness of the duplicate food records (Lightowler and Davies, 1998). For institutional and metabolic studies, this method of dietary assessment is usually considered the most accurate to assess trace element intake because the study respondents do not have direct control over the portion sizes of the foods consumed (Shim, Oh and Kim, 2014). For validating duplicate meal methods, biological markers of food intake, analysed in urine and faeces, have been used (Johansson *et al.*, 1998). Similar to other prospective methods of dietary assessment, this method is time-consuming, expensive and adds a significant time and effort burden on the respondents (Bingham, 1991). In addition, this method is impractical to use in large-scale population studies due to high cost and manpower requirements (Shim, Oh and Kim, 2014).

Different dietary assessment methods have been summarised in Table 1.1.

Table 1.1 Comparison of different dietary assessment methods used in epidemiological studies Amended from Moynihan *et al.* (2009); Shim, Oh and Kim (2014); Farshchi *et al.* (2017).

Dietary method	Description	Benefits	Limitations
24-hour Recall (24HR)	Subjects recall all food consumed in previous 24h through interview.	Intake is quantified, less subject burden, does not alter eating behaviour, does not require a literate population for interviewer provided version.	Possible recall bias, trained interviewer required, possible interviewer bias, daily variation and habitual food intake may be missed.
Repeat 24-hour Recall	24h recall repeated on several occasions.	Suitable for obtaining average dietary intakes and range of intake in populations. Reliability increases with increased number of recalls.	Less accurate measurement of portion size, relies on subject recall, high staff cost and burden, requires multiple recalls over several months to capture habitual intake.
Food Frequency Questionnaires	Self-administered questionnaires in which subject indicates their usual frequency of consumption of each food from a given list of foods for a specific period.	Less subject burden, less staff cost and time burden, can be shorter and provides emphasis on foods rich in a specific nutrient or a specific group of foods, does not alter the eating behaviour, captures habitual intake, suitable for classifying subjects into bands of intake and for relative ranking of individuals within the study population, easy to apply to large surveys.	Relies on subject recall, specific to study groups and research aims, uses closed ended questionnaires, unsuitable for assessing absolute intakes of nutrients or for comparing levels of intake to dietary recommendations, bias with overestimation of consumption of good foods or underestimation of bad foods, does not provide meal pattern information.
Dietary History	Detailed one to one dietary interview with a dietician on present or past dietary intake.	Evaluate meal patterns and details of food intake, less subject burden, record details of the methods of food preparation, suited to measuring normal habitual intake of individuals and for comparing intake with dietary recommendations.	High staff cost and burden, relies on subject memory, not suitable for people with irregular meal patterns, quantify the relative amount and not the absolute amount, not suitable for epidemiological studies.

Table 1.1 Continued...

Dietary method	Description	Benefits	Limitations
Estimated Food Record	Subject records all foods and drinks consumed over a set number of days in a purpose designed diary using household measures to estimate portion sizes.	Can provide typical meal and food pattern information, allows self-monitoring that can influence behaviour change, recorded at the time of eating with no reliance on memory providing reliable data intake, intake is quantified.	Researcher assigns portion weight and so takes more researcher time, high staff cost and burden, high subject burden, requires a literate and motivated population, may influence both the food type and amount eaten.
Weighed Food Record	The subject weighs and records all food consumed over a period of time, e.g. one week.	Provides an accurate assessment of food and nutrient intake and may be applied to collection of all types of dietary data e.g. assessment of individual intake.	Subject may change usual food intake because of requirement to weigh food. Eating out is problematic, requires subject literacy and requires high level of subject cooperation that may introduce selection bias.
Duplicate meal method	Duplicates of the food and drinks consumed are placed and then weighed. Nutrient content of the food items is assessed in the laboratory.	Best to assess trace elements intake in institutional and metabolic studies.	Requires much subject cooperation. Only suited to small studies as chemical analysis is costly in terms of time and resources.

1.6.4 Relationship between Diet, Nutrition and Oral Health

Diet and nutrition play a fundamental role in determining the health and well-being of an individual (Moynihan, 2005). While nutrition deals with the systemic effects of nutrients in the consumed food groups; diet is normally described in terms of composition, consistency, pattern and frequency of food intake (Zohoori, 2020). The relationship between oral health and nutrition/diet is described in the literature as being multi-directional and synergistic (Moynihan and Petersen, 2004). Various oral diseases including oral manifestations of different systemic diseases impact an individual's food intake and may disturb the nutritional balance (Sheiham, 2006). On the other hand, diet and nutrition also have an impact on the growth and development of oral hard and soft tissues (Moynihan, 2005). For example, during foetal development, deficiencies of energy, protein, calcium, phosphorus, iodine, iron and vitamins A, C and D can affect the development of skull, jaw bones and teeth (Zohoori, 2020). In addition, even after tooth eruption, nutritional and dietary influences can affect tooth development and mineralisation (Gasmi Benahmed *et al.*, 2021).

Dental caries and an individual's dental status may influence their dietary habits and diet composition, which in turn affects their general health and quality of life (Sheiham, 2006). Untreated painful dental caries and loss of tooth/teeth were reported to result in an inability to chew certain food types, which consequently led to nutritional deficiencies in children (Moynihan, 2005).

1.7 Sugars and Oral Health in Children

1.7.1 Overview

One of the earliest references to sugar consumption by humanity can be traced back several thousand years ago to the island of New Guinea. The inhabitants discovered a pleasurable-tasting grass, which is referred to as 'sugarcane' nowadays. By 1000 BC, it had made its way to Asia and by 500 AD Indians had begun using it for therapeutic purposes in the form of a powder (Chow, 2017). By 1500 AD, the demand for sugar grew in Europe but was limited only to a handful of wealthy people. Queen Elizabeth

I of England (1533-1603) had a fondness towards sweet food which caused 'blackening' of her teeth (Lagerweij and van Loveren, 2020). It took another 300 years for sugar to change status from being a luxury item for the rich to a common staple of the masses. By 1800, it was estimated that more than 50% of the British population had decayed teeth attributable to the cheap and mass production of sugar (Lagerweij and van Loveren, 2020). The average annual sugar consumption per person in Europe was reported to be 50 kg in the 1900s (Chow, 2017). During the period 2018-20, the average per capita consumption of sugar by the high income countries was approximately 38 kg/cap (Cormann and Dongyu, 2021).

1.7.2 Terminology, Classification and Definition of Sugars

The term 'sugar' is commonly used in everyday communication. It is however not easy to define and measure it as different definitions of sugars exist in different contexts. For example, chemical classification, dietary recommendations, research studies, regulations, and food labelling all use different definitions of sugars.

1.7.2.1 Sugars: Chemical Classification

Carbohydrates are divided into three groups based on the degree of polymerisation (DP): mono and di-saccharides (DP = 1-2), oligosaccharides (DP = 3-9) and polysaccharides (DP greater than or equal to 10). The term 'sugar' is generally intended to mean all 'dietary sugars' whether naturally occurring or added to foods. By definition, dietary sugars include all monosaccharides (glucose, galactose, fructose) and disaccharides (sucrose, maltose, lactose). Sucrose, a disaccharide sugar with a sweetness value of 1, is used as a reference to define the sweetness of sugars. The relative sweetness scale of common sugars ranges from Fructose (sweetest with a relative sweetness value of 1.17), followed by Sucrose (1.00), Glucose (0.74), Maltose (0.33), Galactose (0.32) to Lactose (least sweet with a relative sweetness value of 0.16) (Moskowitz, 1970; Fidler Mis *et al.*, 2017).

1.7.2.2 Sugars: Terminology in Dietary Recommendations and Research

The WHO defines “free sugars” as ‘monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook, or consumer (i.e. added sugars), plus sugars naturally present in honey, syrups, fruit juices, and fruit juice concentrates (i.e. non-milk extrinsic sugars)’ (World Health Organisation, 2015). The same definition of free sugars was adopted by the UK Scientific Advisory Committee on Nutrition (2015). A slightly different approach to defining sugars was adopted by the European Food Safety Authority (EFSA) where they defined sugars as “total sugars” including both indigenous sugars naturally present in foods such as fruits, vegetables, cereals and lactose in milk products, and added sugars. The term ‘added sugars’ refers to sucrose, fructose, glucose, starch, hydrolysates (glucose syrups, high fructose syrups, isoglucose) and other isolated sugar preparations used as such or added during food preparation and manufacturing (Bresson *et al.*, 2009). The definition of ‘added sugars’ as per the United States Dietary Reference Intakes includes sugars and syrups that are added to foods during processing and preparation but excludes naturally occurring sugars (i.e. lactose in milk and fructose in fruits) (Institute of Medicine, 2005). The US and EFSA definitions of ‘added sugars’ in contrast to the definition of ‘free sugars’ by WHO and SACN do not include sugars present in unsweetened fruit and fruit juice concentrates. In addition, the US definition of ‘added sugars’ does not include sugars found in jams, jellies and fruit spreads while the EFSA definition excludes honey, all of which are included in the definition of ‘free sugars’. The use of different terminologies for sugars in dietary recommendation and the fact that free sugars are chemically indistinguishable can pose problems while reporting sugar consumptions for children (Fidler Mis *et al.*, 2017). It has been observed that sugar consumption is often underestimated in epidemiological studies (Rangan *et al.*, 2014). Another commonly used term ‘fermentable carbohydrate’ includes free sugars, glucose polymers, fermentable oligosaccharides and highly refined starches (Sheiham and James, 2015b).

1.7.2.3 Sugars: Terminology in Regulations and Food Labelling

The terms used to describe sugar consumption in regulations and on food labels are different from those used in dietary recommendations. In Europe, it is mandatory to declare the amount of 'total sugars' on food labels but not of 'added/free sugars' (Bresson *et al.*, 2009). The recommended compositional requirements of infant formulas do not support the addition of sucrose, fructose or glucose, and only lactose is permitted (Koletzko *et al.*, 2005; Agostoni *et al.*, 2014). It is however common for infant formulas made out of protein hydrolysates to include glucose and sucrose added to them to enhance taste, and the addition of sucrose and fructose is also considered acceptable for follow-on formulas (Agostoni *et al.*, 2014).

It is important to note that the WHO and UK SACN definitions of free sugars do not include human milk and infant formulas (World Health Organisation, 2015; Scientific Advisory Committee on Nutrition, 2015). Regulation No. 1924, on Nutrition and Health Claims on Foods permits the use of the words 'no added sugars' and 'naturally occurring sugars' on foods for infants and children but these claims do not comply with the WHO definition of free sugars and naturally occurring sugars (intrinsic sugars) (European Parliament and the Council of the European Union, 2006). Therefore, in relation to the current terminology in European regulations and food labelling, 'free sugars' remain hidden and the consumers may not be able to make informed decisions for the choice of sugar-free foods and beverages.

1.7.3 Current Recommendations for Intake of Sugars

1.7.3.1 WHO Recommendations (World Health Organisation, 2015)

In 2015, the WHO issued guidelines on the intake of free sugars to reduce the risk of non-communicable diseases in children and adults, emphasising prevention and control of dental caries and unhealthy weight gain. The WHO recommendations were derived from research evidence obtained after analyses of observational studies in children suggesting a positive association between the prevalence of dental caries and high levels of free sugar intake. Specifically, free sugar intake of greater than 10% of total energy intake resulted in higher rates of dental caries (Moynihan and Kelly, 2014). In addition, a positive log-linear dose-response relationship between dental

caries and free sugars intake was seen across all studies, at free sugar intake levels below 5% of total energy intake (equivalent to roughly 10 kg/person/year). However, the quality of evidence from the national populational studies was very low and from cohort studies was of moderate quality (World Health Organisation, 2015).

The following were the recommendations issued by WHO in relation to free sugar intake in adults and children:

- 1) Strong Recommendation:
 - (i) Reduction of the intake of free sugars throughout the life course.
 - (ii) Reduction of the intake of free sugars to less than 10% of total energy intake (recommended for both adults and children).
- 2) Conditional Recommendation: Further reducing the intake of free sugars to below 5% of total energy intake would have additional benefits in reducing the risk of dental caries in children and adults.

The strong recommendations can be adopted as policy in most situations, whereas the conditional recommendations are made in cases where “policy-making will require substantial debate and involvement of various stakeholders for translating them into action” (World Health Organisation, 2015).

1.7.3.2 SACN Recommendations (Scientific Advisory Committee on Nutrition, 2015)

The UK SACN review recommended that the free sugar intake of children over 2 years of age should not exceed 5% of total dietary energy. They further recommended that free sugar intake should be replaced by starches, sugars contained within the cellular structure of food, and lactose naturally present in milk and milk products for people with healthy body mass indices (BMI). However, for overweight individuals, it was recommended that the reduction of free sugar intake should contribute towards a decrease in the total energy intake (Scientific Advisory Committee on Nutrition, 2015).

1.7.3.3 AHA Recommendations (Vos et al., 2017)

The American Heart Association (AHA) recommendations state that children below the age of 2 years should consume less than or equal to 25 grams of added sugar per day (which is equivalent to approximately 100 kcal or 6 teaspoons). These recommendations were issued with an objective to decrease the risk factors (excess weight gain and obesity, elevated blood pressure and uric acid levels, dyslipidaemia and non-alcoholic fatty liver disease) associated with cardiovascular disease, insulin resistance and type II diabetes mellitus among children (Vos et al., 2017).

1.7.3.4 ESPGHAN Recommendations (Fidler Mis et al., 2017)

The European Society for Paediatric and Gastroenterology, Hepatology and Nutrition (ESPGHAN) in their position paper recommended that infants should be given only water for thirst (after the introduction of solid food) and should not be provided any sugar containing drinks in bottles or training cups. They further recommended that the habit of children sleeping with a bottle should be discouraged (Fidler Mis et al., 2017).

1.7.3.5 Scientific Recommendations for Healthy Eating Guidelines in Ireland

A) Guidelines for the general population aged 5 years and above (2011): Foods rich in calories, fat, salt and sugar (for example, biscuits, cakes, confectionary and savoury snacks) may be consumed, but in limited amounts: ‘Not Too Much and Not Too Often’ (Food Safety Authority of Ireland, 2011).

B) Guidelines for children aged between 1 and 5 years (2020): For children in the age group of 1 to 5 years, consumption of foods such as crisps, cakes, biscuits, confectionary, sugar-coated breakfast cereals etc., was not recommended. Small amounts of sugar however could be added to nutrient-dense foods (example, milk puddings, custards, jam on wholemeal bread, stewed fruit etc.) to make them acceptable and palatable to kids. To protect the dental health of children, snacking on sugary foods and drinks was not recommended. Among the drinks recommended for this age group included only water and milk. Consumption of sugary and acidic drinks

should be restricted and kept to mealtimes if at all consumed (Food Safety Authority of Ireland, 2021).

Dietary guidelines and sugar recommendations issued by selected national and international agencies are summarised in Table 1.2.

Table 1.2 International and national healthy eating guidelines and sugar recommendations. Amended from Erickson *et al.* (2017).

Guideline, Year	Guideline title	Qualitative recommendation	Quantitative recommendation	Types of sugar in relevant evidence	Basis for recommendation
WHO, 2015	Sugar Intake for Adults and Children	“Reduce intake of free sugars throughout the life course”	“In both adults and children, WHO recommends reducing the intake of free sugars to less than 10% of total energy intake”; “WHO suggests further reduction of the intake of free sugars to below 5% of total energy intake”	Sucrose, added sugar, total sugars, free sugars, Sugar Sweetened Beverages (SSBs), fructose, and sweet foods	Dental caries and weight gain
Public Health England/SACN, 2015	Carbohydrates and Health	“The consumption of sugars-sweetened beverages should be minimised in both children and adults”	“The population average intake of free sugars should not exceed 5% of total dietary energy for age groups from 2 years upwards”	Total sugars, individual sugars, SSBs, sweet food, fruit juice, and non-milk extrinsic sugars	Excess energy intake
U.S Department of Agriculture, U.S Department of Health and Human Services, 2015	2015-2020 Dietary Guidelines for Americans	NA	“Consume less than 10% of calories per day from added sugars”	Not applicable; diet modelling used for evidence	Nutrient displacement

Table 1.2 Continued...

Guideline, Year	Guideline title	Qualitative recommendation	Quantitative recommendation	Types of sugar in relevant evidence	Basis for recommendation
Institute of Medicine, Food and Nutrition Board, 2002	Dietary Reference intakes for Energy, Carbohydrate and Fibre, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids	NA	"A maximal intake level of 25% or less of energy is suggested to prevent the displacement of foods that are major sources of essential micronutrients"	Total sugar, added sugar, and non-milk extrinsic sugars	Nutrient displacement (the displacement of nutrient-rich foods with low-nutrient foods i.e. processed foods in the diet)
Ministry of Health of Brazil, Secretariat of Health Care, Primary Health care Department, 2014	Dietary Guidelines for Brazilian population	NA	"Use oils, fats, salt, and sugar in small amounts for seasoning and cooking foods and to create culinary preparations"	Not applicable (NA)	Excess energy intake
National Health and Medical Research Council, Department of Health and Aging, Australian Government	Australian Dietary Guidelines	NA	"Limit intake of foods and drinks containing added sugars such as confectionary, sugar-sweetened soft drinks and cordials, fruit drinks, vitamin waters, energy and sports drinks"	SSBs, energy-dense snack, fruit juice, sucrose, and total sugar	Weight gain, dental caries and bone health

Table 1.2 Continued...

Guideline, Year	Guideline title	Qualitative recommendation	Quantitative recommendation	Types of sugar in relevant evidence	Basis for recommendation
Ministry of Health, New Zealand, 2012; partial revision 2015	Food and Nutrition Guidelines for Healthy Children and Young People (Aged 2-18 years)	“Prepare foods or choose pre-prepared foods, snacks and drinks that are low in fat (especially saturated fat), low in sugar (especially added sugar), low in salt (if using salt, use iodised salt)”	NA	NA	To ensure optimal growth and prevent nutritional deficiencies, obesity and diet-related chronic diseases
Nordic Council of Ministers, 2012	Evidence-based Guideline of the German Nutrition Society	“The consumption of sugar-sweetened beverages should be limited”	NA	Sweets, SSBs, fructose, and glucose	Excess energy intake
Food Safety Authority of Ireland, 2011	Specific Recommendations for Healthy Eating Guidelines in Ireland	“Healthy eating can be enjoyed with limited amounts of ‘other food’ like biscuits, cakes, savoury snacks, and confectionary. These foods are rich in calories, fat, sugar and salt so remember- “NOT too MUCH and NOT too OFTEN”	NA	Total sugar	Dental caries

Table 1.2 Continued...

Guideline, Year	Guideline title	Qualitative recommendation	Quantitative recommendation	Types of sugar in relevant evidence	Basis for recommendation
Food Safety Authority of Ireland, 2020	Scientific Recommendations for Food-Based Dietary Guidelines for 1 to 5 Year-olds in Ireland	“Foods such as confectionary, cakes, crisps, biscuits, sugar-coated breakfast cereals, etc. are not recommended for 1-5 year-olds. “Small amounts of sugar can be added to nutrient-dense foods (stewed fruit, milk puddings, jam on wholemeal bread, etc.) in order to increase palatability and acceptability. Snacking on sugary foods and drinks should be avoided in order to protect dental health”. “Water and milk are the only drinks recommended for this age group. Sugar-containing and acidic drinks should be limited, and if consumed at all, should be kept to mealtimes”.	NA	Total sugar, free sugars	Life-long healthy eating Dental caries and weight gain

1.7.4 Current Levels of Dietary Sugar Intake and Sugar-Rich Foods and Drinks

It is difficult to compare sugar-rich foods and drinks consumption among populations across countries because of variations in the definitions of sugars (Moynihan *et al.*, 2018). The current global food market is supplied with cheap and abundant sugars. Per capita sucrose consumption of the population, as reported in the collected/available data, does not capture the actual amount of free sugars consumed from all sources. Sugars contained in sweeteners such as corn syrups, fruit juices and honey, and mono and disaccharides other than sucrose are usually not included in these data (Moynihan *et al.*, 2018).

The contribution of added sugars towards total daily energy intake has been estimated to be approximately 14% for 2 to 9 year olds in Europe and 2 to 18 year olds in the US (Fidler Mis *et al.*, 2017). In particular, the National Health and Nutrition Examination Survey (NHANES) data from the US indicated that added sugars provided 13.4% of total energy intake in children aged 2-5 years, while it was reported to be 17.3% for adolescents (Welsh *et al.*, 2011). According to the National Diet and Nutrition Survey of England (published in January 2019), the consumption of free sugars in children has significantly dropped over time (Public Health England and Food Standards Agency, 2019). The reported decrease in the free sugar intake (as a percentage of total energy intake) of children was found to be 2.7, 2.4 and 3.5 percentage points for age groups 1.5 to 3 years, 4 to 10 years and 11 to 18 years, respectively over the time period of 9 years from 2008-2009 to 2016-2017 (Public Health England and Food Standards Agency, 2019).

Similarly, a decrease in the mean intake of free sugars for children in the age range of 5 to 12 years was reported in National Children's Food Survey II (NCFS II) 2017-18 (Irish Universities Nutrition Alliance, 2019). The reported mean intake of free sugars was 9.5% of total energy intake in 2019 compared to 16% of total energy intake in 2003-2004. In addition, it was found that approximately 40% of children had higher intakes of free sugars than the recommended 10% of total energy intake (Irish Universities Nutrition Alliance, 2019). Moreover, for preschool Irish children (aged 1-4 years),

approximately one-fourth of the total energy intake came from total sugars, and the non-milk sugars contribution towards total energy intake increased with age from 16% in 1 year olds to 20% in 4 year olds (Irish Universities Nutrition Alliance, 2012). The main contributors to non-milk sugars were fruit and fruit juices. In addition, the consumption of sugar-rich foods, such as cakes, biscuits, confectionary and sweet beverages also increased with increase in age from 1 to 4 years (Irish Universities Nutrition Alliance, 2012).

A research group based at Dublin Dental University Hospital (Trinity College Dublin) and University College Dublin linked the National Pre-school Nutrition Survey (NPNS) and Growing Up in Ireland (GUI) datasets for three-year-old children in Ireland. The study analysed the combined dataset and calculated the mean daily total sugar and free sugar intakes and frequency for the 3-year-olds (Crowe *et al.*, 2020). It was found that approximately two-thirds of Irish 3-year-olds were consuming greater than 10% of total energy intake (maximum intake of free sugar recommended by WHO), and the median frequencies of total and free sugar consumption were 5 times per day (4.0-6.0) and 4 times per day (3.0-5.0), respectively (Crowe *et al.*, 2020).

1.7.5 Sugars and Dental Caries

Consumption of high-sugar foods and beverages is considered to be the single most important risk factor for the development of dental caries (Burt and Pai, 2001; Touger-Decker and Van Loveren, 2003; Zero, 2004; Sheiham and James, 2015b; Moynihan, 2016). According to the WHO, limiting sugar intake to less than 10% of total energy intake and even further to less than 5% minimises the risk of dental caries throughout the life course (World Health Organisation, 2015). The evidence suggesting the role of dietary sugar consumption as a risk factor for dental caries comes from various observational and experimental studies, human plaque pH studies, enamel slab experiments, animal studies and incubation studies of oral bacteria and dietary substrates *in vitro* (Moynihan and Petersen, 2004). The strength of evidence of the association between dental caries and dietary sugars is derived from the multiplicity

of studies rather than the power of any one study alone (Moynihan and Petersen, 2004).

1.7.5.1 World-Wide Epidemiological Observational Studies

Soon after Miller had postulated the chemo-parasitic theory of dental caries development, multiple studies were conducted with the aim to elicit the association between fermentable sugar consumption and dental caries (Lagerweij and van Loveren, 2020). Among the main studies linking intake of sugars and levels of dental caries at country level, the studies undertaken by Sreebny, Woodward and Walker were of particular importance (Moynihan and Petersen, 2004). While Sreebny correlated the dental caries experience of the primary and permanent dentitions with sugar supplies data in populations of children not exposed to the benefits of fluoride, Woodward and Walker in their analyses focussed on the association between the two presuming that fluoride was present in the community (Moynihan and Petersen, 2004). From the data analysis by Sreebny, it was calculated that for every 25 grams of sugar per day, there was an increase in the DMFT/dmft score by one unit (Sreebny, 1982).

Woodward and Walker concluded that sugar availability accounted for 28% of the variation in the level of dental caries in children (Woodward and Walker, 1994). The weaker association between per capita sugar availability and levels of dental caries in industrialised countries could be explained by the consumption of many sugars other than sucrose leading towards a higher total sugar intake. Also, the availability of adequate amounts of fluoride in community water supplies in industrialised nations as well as the use of fluoride dentifrices may also be considered a confounder (Woodward and Walker, 1994). In a systematic review investigating the effect of restricting sugar intake on dental caries included studies conducted between 1950 and 2011 (Moynihan and Kelly, 2014). The authors reported that the effects of caries on the dentition are lifelong and that reduced intake of sugar, to less than 10% of total energy intake, resulted in significantly lower caries levels.

1.7.5.2 Experimental Human Studies

There is a scarcity of human intervention studies where the dietary consumption of sugars has been altered and the development of caries was monitored. This is because it is hard to truly control diets for longer time periods necessary to measure changes in caries development as well as due to ethical constraints (Moynihan and Petersen, 2004; Lagerweij and van Loveren, 2020). Most notable among such human intervention studies were the Vipeholm study conducted in an adult mental institution in Sweden between 1945 and 1953 and the Turku study that was completed in Finland in 1970 (Gustafsson *et al.*, 1954; Scheinin *et al.*, 1975). The Vipeholm study investigated the effects of sugary food consumption at different times of the day on the development of dental caries. The intervention group was divided into three classes according to the type of food given to the participants.

- 1) Sucrose Group: This group consumed an extra 300 grams of sucrose solution at meal times only.
- 2) Bread Group: This group consumed an additional 345 grams of sugar in the form of sweetened bread at meal times only.
- 3) Chocolate Group: This group consumed 100 grams of extra sugar at meal times only. In addition, there were other groups that were given extra sugar in between meal times. This included:
 - a) A chocolate group (4x15 grams of sugar in chocolate)
 - b) A caramel group consuming caramels 4 times per day (22 caramels per day i.e. 70 grams of sugar)
 - c) An 8 toffee group consuming 8 toffees handed to them (40 grams of sugar)
 - d) A 24 toffee group consuming 24 toffees (120 grams of sugar) available to them at all times of the day.

The control group, on the other hand, received extra calories through fat. The dietary regimes were given in two periods: 1) first carbohydrate period (1947-1949) and 2) the second carbohydrate period (1949-1951). It was observed that after 4 years, the number of DMFT had increased considerably across all groups arranged in the

descending order as follows: 24 toffee group > 8 toffee group > caramel group > chocolate group > bread group > sucrose group > control group. It was also found that sugar consumption even in large amounts had very little to no effect on caries development (1-2 DMFT increase in two years) if consumed up to 4 times a day at mealtimes only. However, increased sugar consumption in-between meals was significantly related to increased dental caries experience (5 DMFT increase in two years) (Gustafsson *et al.*, 1954).

An important controlled intervention study was carried out in Turku, Finland, in 1970. The aim was to evaluate the effect of substituting sucrose in a normal diet with either fructose or xylitol on caries development. The study participants ranged from 12-53 years of age and were divided into three groups consuming a diet with sucrose, fructose or xylitol, respectively as the sole sweetener for a time period of 25 months. Dental caries increments were monitored by the same person throughout the study duration, and both pre-cavitation lesions and cavitated teeth were recorded. It was found that there was a reduction in the incidence of dental caries by approximately 85% in those who substituted sugars for xylitol in their diet. However, the participants in the sucrose group and fructose group on average developed 7 and 4 carious lesions respectively (Scheinin *et al.*, 1975).

The main objective behind these studies was to identify the best strategy for sugar reduction to prevent dental caries. The solution to this problem lies in addressing three key issues, outlined by Bernabe *et al.*:

- a) The shape of the dose-response relationship between sugars and dental caries,
- b) Frequency versus amount of sugar consumption on dental caries levels, and
- c) Role of fluoride in the relationship between sugars and caries (Bernabe *et al.*, 2016).

1.7.5.3 Dose-Response Relationship between Sugars and Caries

Sheiham was the first to demonstrate a sigmoid-shaped dose-response curve between sugar consumption and levels of dental caries at the population level. These findings were based on the country-level data analysed by Sreebny (1982) and the effect of

wartime diets on dental caries in Japan by Tacheuki (1962). It was suggested that a sugar intake of less than approximately 15 kg/person/year was associated with no dental decay in most of the populations, while those consuming between 15-35 kg/person/year showed a steep increase in the rate of caries. Beyond 35 kg/person/year, however, the dose-response curve flattened (Sheiham, 1983; Sheiham, 1991; van Loveren, 2019).

Sheiham and James, in a subsequent study, in 2014, re-examined the quantitative relationship between sugar consumption and the progressive development of dental caries. The authors used data from the Japanese studies and concluded that the dose-response relationship was log-linear or arithmetically curvilinear, as shown in Figure 1.17 (Sheiham and James, 2014a). The chosen diagnostic level of caries in these studies was cavitation, a late stage of caries. In children with teeth which had erupted 7-8 years ago, a log-linear increase in the rate of caries incidence was observed for sugar consumption between less than 1 kg sugar/caput/year (0.05% energy intake [E]) and 5-7.5 kg sugar/caput/year (2.7% - 4.1% E) (Sheiham and James, 2014a).

These studies also provided insights regarding differential susceptibility to caries by post-eruptive tooth age and tooth type. Mandibular first molars were found to be most susceptible to caries, while maxillary incisors were least susceptible (Figure 1.17). The incidence of dental caries was found to be higher in mandibular molars when compared to maxillary molars at different levels of sugar intake (Sheiham and James, 2014a).

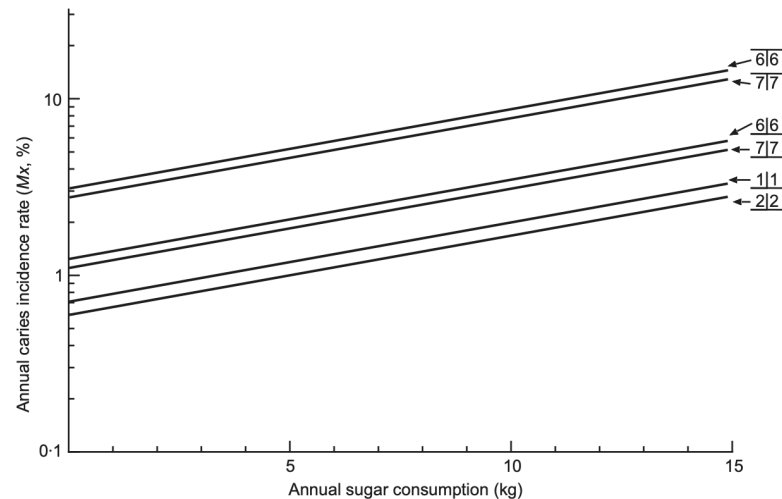


Figure 1.17 The relationship between annual sugars consumption and annual caries incidence rates on a log-linear scale. The lines represent the regression lines for the correlation between sugar consumption and caries incidence rates for first and second molars, tooth number 6 and tooth number 7 respectively. The upper molars are shown with the bar above while the lower molars are the teeth with bar at the bottom. Tooth number 1 and 2 are lower central and lateral incisors. For molars the incidence of cavitation was twice in comparison to incisors at a given dose of sugar adopted from (Sheiham and James, 2014a).

Bernabe and co-workers reported a linear relationship between frequency and amount of sugar consumption to dental caries experience in a group of adults in Finland (2016). For every additional occasion of sugar intake and every 10 grams of extra sugar consumed per day, it was found the DMFT value increased by 0.15 and 0.10 units, respectively (Bernabe *et al.*, 2016). Similarly, a systematic review and meta-analysis explored the dose-response association between sugar-sweetened beverage consumption and the risk of dental caries (Valenzuela *et al.*, 2021). The authors reported a non-linear dose-response relationship between amount of sugar sweetened beverage consumed and dental caries existed (Valenzuela *et al.*, 2021). However, the major limitation of the review that all the ten included studies were cross-sectional.

In conclusion, different authors found different dose-response relationship between sugar intake and dental caries ranging from none to linear, non-linear to a log-linear.

1.7.5.4 Frequency versus Amount

Because of the strong correlation ($r = 0.64$) between the amount and frequency of sugar intake, it was difficult to separately evaluate their effect on caries development as an increase or decrease in either one leads to a similar effect on the other (Bernabe *et al.*, 2016). However, there is no consensus on which plays a more dominant role in relation to dental caries development. According to some authors, the evidence in favour of the amount and frequency of sugar intake is similar, while others suggested that the total amount of sugar intake has a stronger association with caries progression (Moynihan, 2002; Bernabe *et al.*, 2016). Bernabe *et al.*, reported that the amount of sugar intake remained statistically significant with DMFT scores in a mutually adjusted model even though the coefficient was as low as 0.09 DMFT units (2016).

The famous Vipeholm study of Sweden provided primary evidence for the belief that the frequency of sugar consumption was an important aetiological factor for caries development (Gustafsson *et al.*, 1954). Establishing the threshold values for the number of exposures (frequency of sugar intake) per day to induce dental caries is a difficult task but is extremely necessary for reducing the risk of caries development. In 2005, a research study was conducted in the Netherlands on 9-year-old children to explore the thresholds for sugar intake frequency per day (Dusseldorp, Kamphuis and Schuller, 2015). The author compared the dental outcomes of sugar intake in children with a frequency of more than 7 times a day versus less than 7 times a day. The cut-off value of 7 was based on the nationally recommended maximum frequency of sugar intake per day in the Netherlands. An increased caries experience in the primary dentition of 9 year olds but not in the permanent dentition was associated with more than 7 moments of sugar containing food and drinks consumption. The authors supported the usage of recommending up to 7 moments of sugar consumption throughout the day (Dusseldorp, Kamphuis and Schuller, 2015).

In a Brazilian longitudinal study, independent associations of breastfeeding frequency, baby-bottle use frequency and other food intake frequency for 1-year-old children

with the experience of early childhood caries (ECC) at 3 years of age were explored (Feldens *et al.*, 2018). Increased prevalence of dental caries at 3 years of age was found to be associated with higher feeding frequency at a younger age (1 year) (Feldens *et al.*, 2018). Notably, this association remained significant even after controlling for the total amount of sugars (carbohydrates) consumed, supporting the concept that feeding frequency may have a direct role in caries development independent of the amount of sugars consumed (Feldens *et al.*, 2018). In addition, a UK cross-sectional study on the consumption frequency of added sugars and dental caries in British children indicated that the daily consumption frequency of drinks and foods with added sugars was significantly associated with dental caries (Hong *et al.*, 2018). Similar results were reported in a longitudinal prospective study in Scotland for children aged under 5 years (Skafida and Chambers, 2018).

These data provide a scientific basis to support the advice given by dental health professionals to reduce the frequency of sugar intake to minimise the risk of dental caries development. However, it is important to also take into consideration the type of products consumed (sugar-sweetened beverages, fruit drinks, sweets and candy, sweetened dairy products contributing to the intake of sugar), level of parental education, parental diet as well as their socio-economic background while providing dietary recommendations to children (Moynihan, 2002; Faber *et al.*, 2013; Leech *et al.*, 2015). In addition, it is equally important to consider the current nutritional status of the child before any such recommendations are issued (Moynihan, 2002).

1.7.5.5 Sugars-Caries Relationship and Fluoride

The incidence of dental caries in industrialised nations has dropped significantly in recent decades, however the consumption of sugar has remained relatively constant (Moynihan, 2016). The main reason for the observed decline in caries incidence may be attributed to the use of fluoridated toothpaste (Marinho *et al.*, 2003; Petersen and Lennon, 2004). Even though the widescale use of fluoridated toothpaste has helped reduce caries incidence in children, it is still prevalent in adolescents and adults (Sheiham and James, 2015b). In addition, water fluoridation has also been recognised

as an effective public health intervention to dental caries prevention (Newbrun, 1989; Parnell, Whelton and O'Mullane, 2009; Rugg-Gunn *et al.*, 2016).

Zero, in 2004, suggested that the role of fluoride in altering the dose-response relationship between sugars and caries was by effecting a delay in cavitation for a given level of sugars (2004). The association between the amount of sugar consumed and dental caries varied because of the differences in the level of exposure to fluoridated toothpastes (Bernabe *et al.*, 2016). The DMFT levels for every 10 grams of additional sugar consumed was found to increase by 0.08 units in adults using fluoridated toothpaste daily while for those not using fluoridated toothpaste daily, the increase in DMFT levels reached a value of 0.26 (Bernabe *et al.*, 2016). An Australian cross-sectional study quantified the excess risk of childhood dental caries in children due to the interaction between high sugar intake and low exposure to water fluoridation (Ha *et al.*, 2021). The authors reported a positive linear association between the number of sugar exposures (frequency of sugar intake) and dental caries (positive association), however, the association between water fluoridation and dental caries was a negative inverse relationship (Ha *et al.*, 2021). The authors concluded that children exposed to low water fluoride levels and high sugar intake simultaneously were at a greater risk of developing dental caries compared to children exposed to either of these two risk factors independently (Ha *et al.*, 2021). In other words, the interaction between the lack of exposure to fluoridated water and high sugar intake was associated with a greater level of caries than would be the case if there was no interaction.

1.7.5.6 More Studies

Baghlaf *et al.* in their systematic review investigated the association between free sugars consumption around bedtime and dental caries in children aged 3-16 years. Authors reported a positive association between the two. However, the quality of evidence was classified as “very low” because only observational studies were included in the review, and the included studies failed to control for plausible confounders (2018).

1.7.6 Dietary Starches and Dental Caries

The association between high sugar intake and dental caries has been well described and established in the literature (Moynihan and Kelly, 2014; Sheiham and James, 2015a; World Health Organisation, 2015). However, the cariogenicity of other fermentable carbohydrates is debatable (Bradshaw and Lynch, 2013). The Food and Agriculture Organisation of the United Nations and the WHO in their global dietary recommendations suggested a carbohydrate rich diet intake of greater than 55% of total energy intake (World Health Organisation, 2003). The WHO also recommend reducing the intake of free sugars to <5%-10% of total energy intake, indirectly indicating the need to include starches in the diet to achieve the required energy intake (2015). Starches are considered the principal constituent of the human diet. A major share of daily calories, proteins, minerals and vitamins are provided by means of cereal grains (Lingstrom, van Houte and Kashket, 2000). In Western diets, 40-75% of total dietary intake consists of starches, particularly in the form of wheat-based grains found in a variety of processed foods such as breakfast cereals, pizzas, breads, buns, pastas and croissants (Kopp, 2019).

Chemically, starch is a polymer chain composed of alpha-glucopyranose units ($C_6H_{10}O_5$). Starch consists of two types of polymer chains: amylose (linear structure) and amylopectin (branched structure). Dietary starches have been classified as slowly digestible starches (SDS e.g. whole grains, legumes), rapidly digestible starches (RDS e.g. processed starches) and resistant starches (ungelatinised starch) (Englyst and Hudson, 1996). Starch molecules are located within starch granules of various shapes and sizes. Gelatinisation is the process of mechanical rupture and disintegration of starch granules to release starch molecules. Gelatinisation occurs during food preparation through the use of heat and mechanical forces (Mörmann and Mühlemann, 1981). When ingested in the mouth, these gelatinised starches undergo enzymatic breakdown and are hydrolysed by salivary and bacterial amylases into glucose, maltose, maltotriose, and low molecular weight dextrin (Mörmann and Mühlemann, 1981). These starch-derived sugars can be fermented by plaque bacteria to produce acids and result in a decrease in local pH values in biofilm which in turn,

favours demineralisation of teeth (Scannapieco, Torres and Levine, 1993; Kashket, Zhang and Van Houte, 1996). Even though commercial processing methods help to make dietary starches more digestible than usual methods of cooking (baking and boiling), they also increase the cariogenicity of foods, as demonstrated by studies on human pH response (Björck *et al.*, 1984). Experimental animal studies provided evidence about the cariogenic potential of dietary starches, while the results from human epidemiologic studies were largely inconclusive (Hancock, Zinn and Schofield, 2020).

The UK SACN (Scientific Advisory Committee on Nutrition) concluded that “there was insufficient or inconsistent evidence in relation to total starch intake and dental caries” (2015). After the publication of this report, two systematic reviews were conducted to explore the relationship between the consumption of food starches and dental caries (Halvorsrud *et al.*, 2019; Hancock, Zinn and Schofield, 2020). Halvorsrud *et al.*, included 4 cohort studies, 1 ecological study, 1 non-randomised intervention and 13 experimental laboratory studies. The authors reported that there was no evidence of an association between total starch intake and dental caries (2019). However, the data used to support the connection between increased rapidly digestible starches (RDSs) intake and dental caries incidence was of low quality (Halvorsrud *et al.*, 2019). The evidence from experimental studies indicated that RDS becomes cariogenic when hydrolysed by amylase into sugars in the mouth. Also, RDS requires a minimum threshold of 45 minutes for hydrolysis to occur in the mouth to cause a drop in plaque pH and subsequently demineralisation of dental hard tissues. The authors suggested that the main determinant of the cariogenic potential of RDS starches was their oral retentiveness (e.g. food entrapped between or stuck with teeth) (Halvorsrud *et al.*, 2019).

Another review explored the relationship between the intake frequency and amount of processed sugar- and starch-containing foods and dental caries (Hancock, Zinn and Schofield, 2020). This review included five prospective cohort studies and concluded that for children and adolescents, an increase in the intake frequency of processed

sugars and starch-containing foods was associated with a higher experience of dental caries. However, the relationship between the total amount of processed sugar- and starch-containing foods and dental caries was inconclusive, similar to Halvorsrud's findings (Hancock, Zinn and Schofield, 2020).

Therefore, while giving dietary advice, it is important that dental professionals, health practitioners and other healthcare workers should not recommend restricting total carbohydrates, but should be able to distinguish less healthy types and sources of starch (e.g. RDS) from the healthier ones (carbohydrates from fruits, vegetables and wholegrain cereals) to promote health and well-being and prevent chronic diseases, including dental caries (Halvorsrud *et al.*, 2019).

1.7.7 Cariogenic Foods

Cariogenic foods are those that cause dental caries. The three commonly considered models to evaluate the cariogenic potential of food are the animal model (rat model with automatic feeding machines), enamel demineralisation model, and approaches to assess the plaque pH changes with the use of foods (Curzon and Hefferren, 2001). Different foods and drinks that have been considered potentially cariogenic are listed in Table 1.3.

Table 1.3 Potentially Cariogenic foods as described by Moynihan (2002) and Public Health England and Department of Health (2017).

Moynihan (2002)	Public Health England and Department of Health (2017)
Biscuits; Cakes and pastries; Sugars, syrups, caloric sweeteners; Ice creams Fruit juices; Sugared Breakfast cereals (Ready to eat breakfast cereals, RTEBC); Carbonated beverages (non-diet); Squashes, Cordials, fruit juice drinks; Chocolate confectionary; Non-chocolate confectionary; Tinned fruit in syrup; Rice puddings and custards; Desserts	Sugar soft drinks; Sweet and chocolate confectionary; Cakes and biscuits; Buns, pastries, fruit pies; Puddings; Table sugar; Sugary breakfast cereals; Jams, preserves, honey; Ice cream and sorbets; Fruit juices and smoothies; Milk based beverages with added sugars; Sugar containing alcoholic drinks; Dried fruits; Sugars and sweet sauces

Analysis of the Growing Up in New Zealand found that dietary consumption of high sugary and refined starch diet was strongly associated with incidence of dental caries (Thornley *et al.*, 2021). Specifically, foods and drinks which showed a positive association with dental caries included sugar-sweetened soft drinks, white bread, fruit juices, confectionary cakes, ice-creams, noodles, rice porridge, refined breakfast cereals and take-away foodstuffs. While those with a negative association with dental caries were whole-meal or whole-grain breads, brassicas and cheese (Thornley *et al.*, 2021).

The relationship between dietary trajectories and early childhood caries (ECC) has also been explored across different countries. For instance, in a multi-ethnic Asian cohort study in Singapore, the authors found no association between the frequency and amount of sugary foods and ECC occurrence in children (Hu *et al.*, 2019). In another study in Australia, no statistically significant or clinically relevant association was observed between sugary food intake trajectories and early childhood caries after adjusting for confounders (Manohar *et al.*, 2021). However, the findings from a study in Brazil were suggestive of an association between trajectory of sugar consumption and ECC in children after adjusting for confounders (Echeverria *et al.*, 2022). The differences in the results from these studies may be attributed to the variations in sample populations, methods of dietary assessments and methods of analysing data.

1.7.8 Breastfeeding, Milk/Milk Products, 100% Fruit-Juices and Dental Caries

The WHO and UNICEF recommended that “children initiate breastfeeding within the first hour of birth and be exclusively breastfed for the first 6 months of life. Also, infants should be breastfed on demand and from the age of 6 months, children should begin eating safe and adequate complementary foods while continuing to breastfeed for up to 2 years and beyond” (World Health Organisation, 2024a). Victoria *et al.* in a review of the studies from low and middle income countries concluded that there was a 2-3 times increased risk of ECC in children with a history of breastfeeding for more than 12 months and nocturnal feeding (2016). The authors suggested a lack of oral hygiene after feeding as the possible reason for this association (Victoria *et al.*, 2016).

Similarly, Tham *et al.* and Cui *et al.* have also reported that the risk of early childhood caries increased with a breastfeeding duration of greater than 12 months (Tham *et al.*, 2015; Cui *et al.*, 2017). However, Moynihan and co-workers concluded that breastfeeding for up to 2 years of age did not increase early childhood caries risk (Moynihan *et al.*, 2019). The difference in the findings of this review from the earlier reviews could be attributed to the use of cross-sectional studies and the lack of adjustment of important confounders, such as diet and hygiene in both reviews. More recently, two prospective cohort studies, one in the Netherlands and the other in Australia, have also reported a prolonged duration of breastfeeding (>12 months) was associated with an increased risk of dental caries at 6 years and 3-4 years of age respectively (van Meijeren-van Lunteren *et al.*, 2021; Manohar *et al.*, 2021). In both studies, the frequency and timing of breastfeeding as well as the role of hygiene factors were not evaluated.

Milk and milk products have been considered to be anticariogenic (Moynihan, 2000; Johansson, 2002). Dror and Allen in their review reported an inverse association between milk and/or dairy product intake and dental caries in both the primary and permanent dentitions (2014). The majority of studies found negative associations between consumption of yogurt and cheese and dental caries. However, the authors also note that all eleven studies included in their review were observational and most of them were not adjusted for dietary consumption of added sugars (Dror and Allen, 2014). The constituents of dairy products such as calcium, phosphorous, lipids and casein have been shown to exhibit anti-cariogenic properties (Aimutis, 2004). Casein phosphopeptide found in yoghurt was found to inhibit dental demineralisation and facilitated remineralisation in in-vitro studies (Ferrazzano *et al.*, 2008). Casein incorporated into the salivary pellicle led to a decrease in bacteria binding to the tooth surface (Schüpbach *et al.*, 1996).

The postulated mechanisms by which cheese reduces dental caries include (i) increase in the concentration of calcium in saliva and plaque, and (ii) increased buffering capacity from salivary stimulation and (iii) protein adsorption on the tooth hence,

resulting in the restoration of neutral plaque pH following sugar intake (Dror and Allen, 2014; Giacaman, 2018).

To investigate the relationship between 100% fruit juice and dental health, Liska and colleagues carried out a systematic review and included 5 prospective cohort studies and 9 randomised control trials (Liska, Kelley and Mah, 2019). The findings from prospective studies in children and adolescents found no relationship between dental caries and tooth erosion and the consumption of 100% fruit juices. However, the data from randomised control trials reported that consumption of 100% fruit juices was associated with dental caries and dental erosion in adults using in-situ intra-oral enamel appliances (Liska, Kelley and Mah, 2019). The difference in the results from prospective and interventional studies could be due to the differences in the populations studied, children and adolescents in prospective and adults in interventional studies. Moreover, compared with observational studies, interventional studies utilised high intake and consumption approaches.

1.8 Obesity and Dental Caries in Children – the Common Risk Factor Approach

Dental caries and obesity are two of the most common public health concerns. These are largely preventable health conditions affecting children (Hayden *et al.*, 2013; Paisi *et al.*, 2019). Poor dietary and nutritional behaviours, established at a young age, were associated with an increased risk of obesity and dental caries (Whitaker *et al.*, 1997; Simmonds *et al.*, 2016; Jordan *et al.*, 2016; Lock *et al.*, 2019).

Childhood overweight and obesity have been described a global pandemic. The WHO has estimated that about 37 million children under the age of 5 years were overweight or obese in 2020 (World Health Organisation, 2024b). In 2022, the number of overweight and obese children and adolescents aged 5-19 years was more than 390 million. The prevalence of overweight and obesity among children and adolescents has increased approximately four folds between 1990 and 2022, from 8% to 20% (World Health Organisation, 2024b). According to the WHO, childhood overweight and obesity are critical biomedical risk factors associated with higher chance of obesity

in adulthood and afterwards leading to other chronic non-communicable life threatening conditions such as type 2 diabetes, hypertension and certain cancers (Lakshman, Elks and Ong, 2012; World Health Organisation, 2024b).

The most accepted hypothesis in relation to the association between dental caries and obesity is that the two share some common risk factors (Chi, Luu and Chu, 2017). A conceptual model of common risk factors associated with dental caries and obesity in children has been proposed, as shown in Figure 1.18.

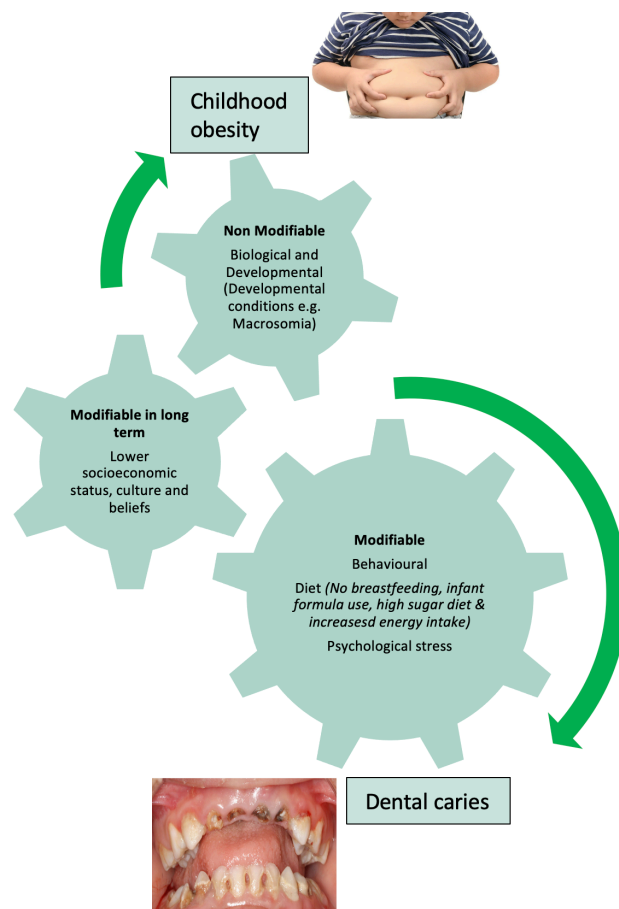


Figure 1.18 Conceptual model illustrating the common risk factors for dental caries and childhood obesity adapted from Chi, Luu and Chu (2017).

Multiple risk factors have been found to be associated with dental caries and obesity. Therefore, the traditional methods of prevention by targeting individual risk factors associated with each disease will not be effective (Sheiham and Watt, 2000; Kumar, 2015).

Therefore, a common risk factor approach, targeting interventions and policies towards common risk factors associated with multiple diseases, should be considered (Chi, Luu and Chu, 2017). This integrated approach supports targeting a limited number of risk factors which may have an impact on a large number of diseases and could be more economical and more efficient than an individual disease specific approach (Sheiham and Watt, 2000). For global health objectives, public health strategy “must focus on health promotion and disease prevention, through controlling the modifiable common risk factors” (Jin *et al.*, 2016). It was proposed that oral and general health research should focus on identifying common risk factors for oral health and general health conditions (Watt and Sheiham, 2012). This approach could be used for planning interventions for prevention and improvement of dental caries and obesity in children and adults (Chi, Luu and Chu, 2017; Ravaghi *et al.*, 2020).

1.9 Oral Health Inequalities

The prevalence of dental caries in children of high-income countries has plateaued in the last three decades. Still, dental caries continues to rise among children of low-socioeconomic status families, leading to increasing inequalities between socioeconomic groups (Peres *et al.*, 2020b).

1.9.1 Socioeconomic Inequalities in Oral Health

With the increasing evidence of the association between oral health and social determinants of health (SDOH), oral health research is no longer solely focused on biological and dietary factors (Fisher-Owens *et al.*, 2007; Marmot and Bell, 2011). SDOH play a major role in the development of oral diseases and health inequalities (Petersen, 2005; Petersen *et al.*, 2005; Peres *et al.*, 2007a; Peres *et al.*, 2019). Oral health inequalities (or health disparities) are “the unfair, unjust, avoidable, unnecessary and systematic differences in oral health outcomes between population groups with different levels of wealth, prestige or power” (Krieger, 2001; Tsakos, Watt and Guarnizo-Herreño, 2023). Several factors interact at different levels to influence population health and, consequently, health inequalities (Shavers, 2007).

Socioeconomic disparities are the most fundamental causes of oral health inequalities (Adler and Newman, 2002; Sabbah *et al.*, 2009; Marmot and Bell, 2011). Socioeconomic oral health inequalities are a universal phenomenon (Petersen *et al.*, 2005). There is a global consensus that the levels of oral diseases are higher in more deprived populations than their better-off counterparts (Sisson, 2007; Schwendicke *et al.*, 2015). Across the social hierarchy, oral health inequalities existed in a consistent and graded manner, with oral health being worse with each lower position in the social hierarchy (Peres *et al.*, 2019). Moreover, the evidence for the existence of oral health inequalities, synthesised in systematic reviews, has shown consistent associations between poorer oral health and socioeconomic disadvantage (Schwendicke *et al.*, 2015; Costa *et al.*, 2018; Knorst *et al.*, 2021). Furthermore, the WHO (World Health Organisation), in its Global Health Strategy, has recognised “a very strong and consistent association between SES (income, educational level and occupation) and the prevalence and severity of oral diseases across populations in high, middle and low-income countries” (World Health Organisation, 2023).

1.9.1.1 Components of Socioeconomic Status

Socioeconomic status (SES) has been defined as “the relative position of a family or individual on a hierarchical social structure, based on their access to or control over wealth, prestige and power” (Mueller and Parcel, 1981). SES impacts health by determining three major determinants of health: environmental exposure, health behaviour and access to health care services (Adler and Newman, 2002). In epidemiological studies, the most commonly used SES measures are education (e.g., highest educational level completed or years of education completed), occupation (e.g., employment status, specific occupational group or aggregate occupational groups) and income (individual annual income, annual household income or family income) (Adler and Newman, 2002; Braveman *et al.*, 2005; Shavers, 2007). Each measure captures a distinct aspect of SES, impacts different health outcomes, needs different policies, and may be correlated with other measures but are not interchangeable (Adler and Newman, 2002; Shavers, 2007). Moreover, the use of a single measure for capturing the SES in oral health inequalities research has been

criticised and not recommended because single measures lack conceptual clarity and seem to disregard established psychometric techniques (Locker, 2000; Wamala, Merlo and Boström, 2006; Lee and Divaris, 2014). In the Children's National Oral Health Survey in the Republic of Ireland in 2002, along with the occupational class, Medical Card ownership of the family was also used as a surrogate for deprivation (Whelton *et al.*, 2006). The Medical Card eligibility in the RoI is based on a means test for the population under 70 years of age unless a disability exist (Citizens Information Board, 2023).

1.9.1.2 Pathways to Socioeconomic Oral Health Inequalities

Three explanatory models (behavioural/cultural, psychosocial, and materialistic) have been proposed to explain socioeconomic health inequalities (Townsend, Whitehead and Davidson, 1992; Bartley, 2017). All three models postulated that the differential distribution of health determinants across socioeconomic groups explained the socioeconomic inequalities (Floor, Frank and Johan, 2005; Richter *et al.*, 2009; Hiyoshi *et al.*, 2014). These models can also be applied to determine the causes of social inequalities in oral health (Sisson, 2007; Tsakos, Watt and Guarnizo-Herreño, 2023). The potential role of each explanatory model in defining oral health inequalities has been discussed below:

a) Behaviour/Cultural pathway

The behaviour hypothesis argues that people from lower social positions are more likely to participate in unfavourable/risky health behaviours than those from higher social positions; consequently, their health is worse than those from higher social positions (Townsend, Whitehead and Davidson, 1992). Health behaviours display a clear social gradient; the lower an individual's social class, the greater their chances of indulging in health-compromising behaviours (Bartley, 2017).

Studies have demonstrated that oral health-compromising behaviours (smoking, lack of oral hygiene, high sugar foods and drinks intake and irregular dental attendance) tend to cluster in the same individuals and are more common in those belonging to

lower than higher socio-economic class (Locker, 2000; Sabbah *et al.*, 2009). In addition, research evidence from population studies has confirmed an association between dental diseases and poor oral health behaviours (Moynihan, 2005; Thomson *et al.*, 2010; Broadbent *et al.*, 2011; Sheiham and James, 2015a). There is a social gradient for oral health and oral health behaviours, and the dual relationship of oral health behaviours with oral health on one side and SES measures on the other suggests behaviours may play an important role in explaining social health inequalities in oral health (Thomson *et al.*, 2000; Maliderou, Reeves and Noble, 2006; Sabbah *et al.*, 2014).

Several studies have examined the role of oral health behaviours in explaining social inequalities in the oral health of children, adolescents and adults (Sanders, Spencer and Slade, 2006; Wamala, Merlo and Boström, 2006; Sabbah *et al.*, 2009; Polk, Weyant and Manz, 2010; Sabbah *et al.*, 2014; Broadbent *et al.*, 2016; Duijster *et al.*, 2017; Bernabé, Humphris and Freeman, 2017; Guarnizo-Herreño *et al.*, 2019; Novrinda *et al.*, 2019; Stein, Cunha-Cruz and Hugo, 2021; Åstrøm, Lie and Özkaya, 2021; Mariëlle *et al.*, 2021).

The evidence suggests that oral health disparities could be eliminated or reduced by providing better access to preventive dental services and positive changes in the health behaviours of individuals (Wamala, Merlo and Boström, 2006; Sabbah *et al.*, 2009; Guarnizo-Herreño *et al.*, 2019; Stein, Cunha-Cruz and Hugo, 2021). However, others have argued that oral health disparities can not be improved solely by behavioural interventions (Sanders, Spencer and Slade, 2006; Polk, Weyant and Manz, 2010; Sabbah *et al.*, 2014). Moreover, the behaviour explanation has also been opposed by the theoretical model, which suggests that culture is the main determinant of behaviour choices and hypothesised that cultural norms of behaviour differ between the social positions (Sisson, 2007). In addition, there is also a possibility of “intervention-generated inequalities” where public health interventions targeted to promote individual health behaviours are taken up predominantly by those belonging to the higher SES (Hiyoshi *et al.*, 2014; Guarnizo-Herreño *et al.*, 2019).

b) Material Pathway

The material explanation focuses on the role of structural, material and economic constraints in health inequalities (Bartley, 2017). It argues how living circumstances (e.g. housing conditions, financial difficulties), income and financial resources enable one to secure goods and services that are important for a healthy life, such as adequate housing, a healthy diet, access to health and public services and protection from factors that are detrimental to health (Richter *et al.*, 2009; Duijster *et al.*, 2017; Tsakos, Watt and Guarnizo-Herreño, 2023). Specifically, for oral health inequalities, it has been proposed that material factors, such as financial difficulties experienced by people in the lower SES groups, can restrict an individual's ability to afford the quality dental care and a healthy diet required for maintaining a healthy dentition (Sisson, 2007; Duijster *et al.*, 2017; Tsakos, Watt and Guarnizo-Herreño, 2023). It has been hypothesised that material factors could affect oral health either directly or indirectly via behavioural and psychosocial factors (Floor, Frank and Johan, 2005; Sisson, 2007). Financial difficulties can result in psychological distress, which, via neurobiological pathways, affects oral health (Sabbah *et al.*, 2009). When compared with higher SES groups, lower SES groups purchase higher amounts of foods and drinks rich in free sugars, a well-known risk factor for dental caries (Maliderou, Reeves and Noble, 2006; Sisson, 2007).

c) Psychosocial Pathway

The psychosocial pathway emphasises the role of perceptions of control and social standing in influencing health and, hence, explaining health inequalities (Bartley, 2017). Those belonging to lower SES groups are hypothesised to experience higher levels of psychosocial stress and lower levels of social support than higher SES groups, which in turn are shown to affect health directly or indirectly (Tsakos, Watt and Guarnizo-Herreño, 2023). Psychological stress has been suggested as a significant risk factor for periodontal diseases in adults (Genco *et al.*, 1999; Peruzzo *et al.*, 2007). In young children, significant associations between parental stress and the development of dental caries have been reported (Gavic *et al.*, 2018; Chouchene *et al.*, 2021; Sheethal, Shiva and Manju, 2023). The proposed mechanisms through which

psychosocial factors could impact oral health include their influence on oral health behaviours and impact on biological responses resulting in elevated inflammatory burden (Tsakos, Watt and Guarnizo-Herreño, 2023).

It has been suggested that these pathways are not mutually exclusive, and it is likely that a combination of these pathways underlie SES inequalities in oral health (Singh *et al.*, 2016). The evidence on the role of these pathways in explaining SES inequalities mainly comes from cross-sectional studies and was, therefore, limited in explaining casual relationships (Singh *et al.*, 2016; Tsakos, Watt and Guarnizo-Herreño, 2023). Only a few longitudinal studies have investigated the role of these factors in explaining SES inequalities (Sabbah *et al.*, 2014; Fleitas Alfonzo, Bentley and Singh, 2022). However, these studies have used a limited set of SES measures and only a subset of behaviour, material or psychosocial factors.

In addition to the behavioural, material and psychosocial explanations, the life-course approach has also been proposed to explain oral health inequalities. The life-course theory suggests that the oral health status of an individual at a given age is the outcome of the effect of biological, environmental and social advantages and disadvantages experienced over an individual's entire lifespan (Heilmann, Tsakos and Watt, 2015). In the life-course approach, the main lines of enquiry related to (Nicolau *et al.*, 2007):

- a. the accumulation of risks model, also called the cumulative model, measures exposures throughout life which have a cumulative effect on health.
- b. the critical period model, an exposure occurring at a specific life stage or critical period of development influencing disease outcome much later on life.
- c. critical period with effect modifier, exposures in early life interacting with exposures later in life, either decreasing or increasing the risk of disease.
- d. chain of risk model, another version of the accumulation model, where one beneficial/adverse exposure tends to lead to another beneficial/adverse exposure.

1.10 Conclusions

Best available peer-reviewed evidence is required to inform public health policies for improving population oral health. There is a lack of periodic national oral health surveys in the Republic of Ireland. Self-reported oral health data from national birth and child cohort surveys provide an opportunity for estimating the distributions and prevalence of oral diseases in children over time and relating these findings to general health conditions and sociodemographic factors in the same cohort (Crowe *et al.*, 2016; Skafida and Chambers, 2018; Thornley *et al.*, 2021). This research hopes to encourage secondary data analysis of national cohort surveys and the use of data-driven tools to explore risk factors for dental diseases and study oral health inequalities in Irish children and adolescents.

1.11 Aims and Objectives

The main aim of this thesis is to analyse oral health of children and adolescents in Ireland using data from Irish national cohort surveys.

Objectives:

- 1) To review all children's dental health surveys at National, Regional and County-levels conducted in the Republic of Ireland from 1950 to 2021 and describe trends in dental caries prevalence. The secondary objective was to compare the dental caries experience of children living in areas with and without Community Water Fluoridation (CWF).
- 2) To evaluate the harmonisation potential of oral health-related questionnaire data from selected nationally representative birth/child cohort surveys in high-income countries.
- 3) To demonstrate the development of an analytical, interactive dashboard for researchers using oral health-related data from three Irish national child surveys.
- 4) To study the association between family socioeconomic status at 13 years of age and the young person's (parent and self-reported) dental health at 17/18 years of age.

In addition, the role of behavioural, material and psychosocial factors in explaining socioeconomic inequalities in young persons' oral health was investigated.

CHAPTER 2

2. General Methodology

2.1 Overview

The initial phase of this research systematically reviewed the oral health surveys conducted in the Republic of Ireland (RoI) over the last seven decades (Section 2.2). The second phase of this study focussed on comparing and evaluating the harmonisation potential of oral health-related questionnaires among nationally representative birth/child cohort surveys with similar survey methodologies (Section 2.3). The third phase involved developing a dashboard to facilitate interactive analysis of oral health data in the Growing Up in Ireland (GUI) infant, GUI child cohort surveys and the second National Children's Food Survey (NCFS) (Section 2.4). Finally, during the last stage of this research, the analysis focussed on investigating socioeconomic oral health inequalities among Irish adolescents using data from the first three waves of the GUI child cohort survey (Section 2.5). The four research phases and the methodological steps used are outlined in Figure 2.1.

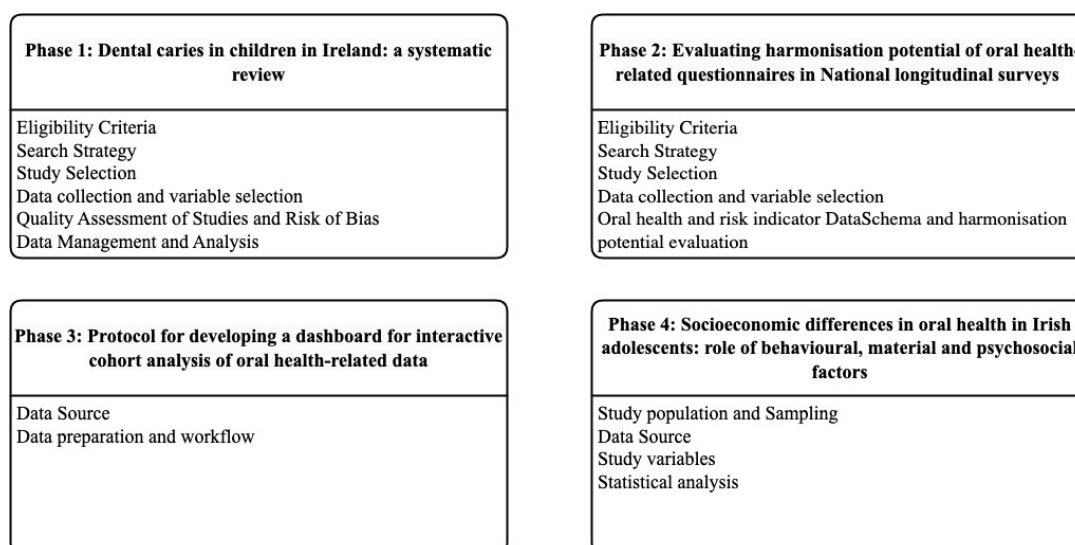


Figure 2.1 List of research phases and methodological steps utilised in this research.

2.2 Phase 1. Dental Caries in Children in Ireland: A Systematic Review

This section used a systematic review approach to summarise dental caries trends in Irish children over the last seven decades. Table 2.1 outlines the eligibility criteria used for study selection.

Table 2.1 Eligibility criteria according to modification of Population, Intervention/exposure, Comparator, Outcome, and study design P(I/E)COS as Condition, Context and Population (CoCoPop) criteria.

Inclusion Criteria	Exclusion Criteria
Population • Children < 18 years of age • Any socio-economic status • Any gender, ethnicity, culture, or race	• Adults • Children with medical conditions and other Oro-facial abnormalities
Context • Children living in the Republic of Ireland • Studies representative of the country, Health Board or County	• Children living outside Ireland • Studies with samples that were not representative of the population being examined
Condition (Outcomes) • Dental caries experience in children measured by validated dmft(s)/DMFT(S)^a, dft(s)/DFT(S)^b, dt(s)/DT(S)^c • Percentage of children with a caries free dentition (dmft/DMFT= 0)	• Non-validated measures of dental diseases
Study designs • Human observational studies ❖ Case- control ❖ Cohort/longitudinal (prospective, retrospective) ❖ Cross-sectional ❖ Cross-sectional nested within a cohort • Studies published in the English language only	• Studies conducted outside Ireland • Qualitative studies • Case reports and case series • Quasi-experiments or randomised control trials • Systematic reviews, literature reviews and review protocols

^aDecayed, Missing or Filled Teeth/Surfaces, ^bDecayed, or Filled Teeth/Surfaces, ^cDecayed Teeth/Surfaces.

By convention, the scores are referred to by lower case letters (dmft) for primary teeth and upper case letters (DMFT) for permanent teeth (Klein, Palmer and Knutson, 1938).

2.2.1 Search Strategy

A literature search was conducted up to 24 June 2022. The following electronic databases were searched: MEDLINE (OVID), Embase, PubMed, Scopus, Web of Science, Cochrane, Lenus Ireland and Google Scholar. The Dublin Dental University

Hospital (DDUH) library database was also searched for grey literature. Search strategies using combinations of keywords and specific medical subject headings (MeSH) terms were drafted for individual databases in collaboration with the Librarian in the DDUH library. The search strategies included relevant terms for dental health surveys, dental diseases including dental caries and other conditions, children and the Republic of Ireland (Tables S1-6, Appendix A, Supplementary file 1). In addition, a manual search of the reference lists of all eligible studies was completed.

2.2.2 Study Selection

Screening and evaluation of identified studies was carried out using Rayyan software for systematic reviews (a free web and mobile app, that helps the initial screening of titles and abstracts (<http://rayyan.qcri.org>)) (Ouzzani *et al.*, 2016). Duplicates were removed using an automated tool and cross checked manually before deletion. The studies were screened by reading titles and abstracts and full-text of the shortlisted studies were evaluated.

2.2.3 Data collection and variable selection

A standardised data extraction form was developed based on the checklist provided by the methodological working group of the Joanna Briggs Institute, Adelaide, South Australia, for conducting a systematic review of observational studies (Munn *et al.*, 2015). The form was calibrated and pilot-tested using five excluded studies. Based on the sample representation, included studies were categorised into National, Regional (Health Board) and County-level surveys. The following information was extracted from the included studies: first and corresponding author, years of publication and survey, study design and setting, sample size, dental caries measures, key findings and funding sources.

2.2.4 Quality Assessment of Studies and Risk of Bias

The methodological quality and risk of bias assessment of included studies was performed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Studies Reporting Prevalence Data (Munn *et al.*, 2015). The studies with a final score of seven

or more were classified as having low risk of bias, between four and six as moderate risk and with scores less than four were classified as high risk (Table S7, Appendix A, Supplementary file 2).

2.2.5 Data Management and Analysis

During the data extraction process, data inconsistencies were identified. Missing and inconsistent data issues were resolved after consultation with the two researchers (DOM and JM) from the 1984 and 2002 National Children's Dental Health Surveys in the RoI. All data files were converted into .csv format and exported to R for data transformation and analysis (R Core Team, 2022).

2.3 Phase 2. Evaluating the harmonisation potential of oral health-related questionnaires in National Longitudinal Surveys

This section compared the oral health-related questionnaires used in national child and birth cohort surveys across different countries. It also evaluated the potential for data harmonisation between and within cohort surveys. In order to evaluate the harmonisation potential of study-specific variables, the Maelstrom Research guidelines for retrospective data harmonisation were followed (Fortier *et al.*, 2016). The Maelstrom checklist is presented in Chapter 4 of this thesis, Table 4.1.

The eligibility criteria were defined as shown in Table 2.2. To locate potential birth and child cohort surveys, the web-based, freely accessible database Birthcohorts.net4 (<https://www.birthcohorts.net/>) and the cohort network of the Society for Longitudinal and Life Course Studies (<https://www.slls.org.uk/pages/longitudinal-studies>) were used. In addition, the reference lists of two recently conducted scoping reviews on birth cohort studies were also searched (Peres *et al.*, 2022; Counihan *et al.*, 2023).

Table 2.2 Eligibility Criteria

Inclusion criteria	Exclusion criteria
Birth and child cohort survey	Not nationally representative
Nationally representative survey	Low or middle-income country survey
Survey from a high income English speaking country	Started data collection before 2000
Baseline data collection after the year 2000 with plans for future data collection	Discontinued surveys
Covering broad range of internationally recognised child health outcomes	
Parent/self-reported oral health-related data collected through at least one follow-up	

2.3.1 Data extraction and variable selection

A standardised data extraction form was developed, and the following information was extracted: the study name, country name, cohort baseline and follow-up calendar years, sample size, study child age, and the percentage response from the original sample. Study-specific questionnaire data were collected from the published questionnaires for each wave across all surveys. The primary focus of this study was to include oral health and related modifiable factors questionnaires (e.g., diet behaviours, oral hygiene measures, dentist visit behaviour, dental services use, general health and weight status). The collected questionnaires were classified into three domains and fifteen constructs were devised to build a common data model (Fortier *et al.*, 2010) (Table 2.3).

Table 2.3 Domains and constructs included for harmonisation potential evaluation of parent/self-reported oral health-related questionnaire data in nationally representative birth/child cohort studies

Domain	Construct	Description
Oral health status	Dental injury	Whether the study child had dental injuries. And, the number of times the study child had been taken to the hospital, emergency, health centre, or dentist as a result of dental injuries.
	Dental treatments	Type and number of dental treatments received by the study child

Table 2.3 Continued...

Domain	Construct	Description
Oral health status	Dental problems	Type and number of dental problems the study child presented with
	Parent/Self-perceived oral health status	Parent/study child's subjective perception of their oral health status
Oral health behaviours	Toothbrushing frequency	Daily toothbrushing frequency of the study child
	Toothbrushing supervision	Supervision of the study child by their parents while they cleaned their teeth
	Toothbrushing assistance	Assistance provided to the study child while toothbrushing
	Toothbrushing starting age	Study child's toothbrushing starting age
	Toothpaste use	Type of toothpaste used by the study child for cleaning their teeth
	Night brushing	Toothbrushing before going to bed
	Dentist visit behaviour	Study child's dental visit patterns
	Dental services use	Accessibility and use of community dental services
General health, body weight status and diet	Parent/Self-perceived general health	Parent/study child's subjective perception of general health status
	Parent/Self-perceived weight status	Parent/study child's subjective perception of weight status
	Dietary behaviour	Study child's usual eating patterns as reported by the parent or the study child themselves

2.3.2 Evaluating Harmonisation Potential

A final list of DataSchema variables was created using a consensus approach among the study authors (Appendix B, Supplementary file S3). When defining the DataSchema variables, questionnaires and data dictionaries were referenced. Standardised specifications, including the name, label, format, description, and categories, were followed to define the DataSchema variables. A harmonisation status (whether a study could construct or not each of the DataSchema variables) was assigned to each wave of the included surveys. A complete harmonisation status was assigned to studies that used the exact question wording and categories as defined for the DataSchema variables and to studies in which survey items could be transformed or combined to match the created DataSchema variable. An incomplete status was assigned to the survey wave when the required information to match the DataSchema variable was incomplete or missing in the survey questionnaires.

Additional detail related to steps involved in evaluating harmonisation potential of study specific variables is provided in Chapter 4 of this thesis.

2.4 Phase 3. Protocol for Developing a Dashboard for Interactive Cohort Analysis of Oral Health-Related Data

The main data sources for this analysis were the Growing Up in Ireland (GUI) surveys (infant and child) and the second National Children's Food Survey (NCFS) carried out by the Irish Nutrition University Alliance (IUNA) in 2017–18. The GUI and NCFS II surveys are described in the following sections:

2.4.1 Growing Up in Ireland Study

Growing Up in Ireland (GUI) is a multi-domain longitudinal study carried out jointly by the Department of Children, Equality, Diversity, Integration and Youth (DCEDIY) and the Central Statistics Office (CSO) (DCEDIY and CSO, 2023). On behalf of DCEDIY, before January 2023, the study was carried out jointly by a team of researchers from the Economic and Social Research Institute (ESRI) and Trinity College Dublin (TCD) (DCEDIY and CSO, 2023). The study began in 2006 and has followed two study cohorts: Cohort '98 (comprised of 8,500 nine-year old children born in the year 1998, also called the Child Cohort) and Cohort '08 (consisted of 11,000 nine-months old children born in the year 2008, also called the Infant Cohort). Currently, the members of the Infant Cohort are aged about 15 years while those of Child Cohort are 25 years old. The conceptual framework for Growing Up in Ireland is based on the bioecological model proposed by Urie Bronfenbrenner, which placed the child at the centre, surrounded and influenced by multiple layers such as the child's characteristics, immediate family, neighbours and community services (Bronfenbrenner and Morris, 2007).

The timeline, year of survey, data collection method, age of study child, and sample size at each wave of the two surveys are presented in Table 2.4.

Table 2.4 Timeline of the GUI cohort surveys (DCEDIY and CSO, 2023).

Cohort	Wave	Year of data collection	Age of study child	Sample size	Data collection
GUI infant					
	1	2008-09	9 months	11,134	Face-to-face interview
	2	2010-11	3 years	9,793	Face-to-face interview
	3	2013	5 years	8,712	Face-to-face interview
	4	2016	7 years	5,344	Postal questionnaire
	5	2017-18	9 years	7,770	Face-to-face interview
	6	2021-22	13 years	6,655	Computer aided telephonic interview and online
GUI Child					
	1	2007-08	9	8,568	Face-to-face interview
	2	2011-12	13	7,525	Face-to-face interview
	3	2015-16	17/18	6,216	Face-to-face interview
	4	2018-19	20	5,190	Face-to-face interview
	Covid	2020	22	2,277	Online

The three main focus areas of the GUI surveys are:

- 1) Physical health and development
- 2) Educational achievement and intellectual capacity
- 2) Social/emotional/behavioural well-being

Similarly, the thematic objectives of the GUI surveys are outlined below:

- 1) To describe the lives and chart the development of Irish children at critical life stages, from birth to adulthood,
- 2) To identify the key factors influencing the child's growth and development and study the effects of early life experiences on later life,
- 3) To study the variations in children's lives and identify the factors leading to social inequalities, ill health and deprivation,

- 4) To create a data bank of Irish children's lives over the years and help in the development of evidence-informed policies and services for children and their families.

2.4.1.1 Sampling Frame and Study Design

The GUI Infant cohort sampling frame utilised the Child Benefit Register maintained by the Department of Social Protection (Thornton *et al.*, 2013). A simple systematic random sample of infants born between 1st December 2007 and 30th June 2008 was selected for the survey. Stratification was completed by parental marital status, county of residence, nationality and number of children in the claim (Thornton *et al.*, 2013).

The Department of Education provided the sampling frame for the GUI Child cohort survey. Sampling was completed in two stages: first, a random sample of primary schools was selected from all the primary schools in the Republic of Ireland, and in the second stage, a random sample of children in the 9-year-old age group was recruited from the selected schools (Murray *et al.*, 2010). The school population was stratified according to county, disadvantage status, religious dominance, gender mix and categorical size (total number of 9-year-olds) (Murray *et al.*, 2010). GUI surveys follows a fixed panel design and, only those children selected at the first wave were followed in subsequent waves. There was no provision for the addition of new participants to the survey.

2.4.1.2 Reweighting the Data

Statistical re-weighting is a standard procedure undertaken before data analysis to accommodate the differences between the structure of the population and the completed sample (McNamara, O'Mahony and Murray, 2020). GUI survey data were re-weighted. The Economic and Social Research Institute (ESRI) employed the GROSS software system and used a minimum distance algorithm for re-weighting GUI survey data (McNamara, O'Mahony and Murray, 2020). Two statistical adjustment factors were provided with the GUI data: (i) Weighting factor – weights to the total number of children in the GUI sample and (ii) Grossing factor – grosses to the total number of children in Ireland.

2.4.2 National Children's Food Survey II (NCFS II)

2.4.2.1 Study Population

The NCFS II sample consisted of approximately 600 children and was representative of children aged 5 to 12 years living in the Republic of Ireland. The survey was conducted from April 2017 to May 2018 (Irish Universities Nutrition Alliance, 2019; Kehoe *et al.*, 2023).

2.4.2.2 Sampling Frame and Study Design

The Department of Education and Skills, Ireland, provided the sampling frame. A random sample of primary schools in Ireland was generated and was stratified by demographic and socio-economic variables. This survey followed a cross-sectional survey design (Irish Universities Nutrition Alliance, 2019; Kehoe *et al.*, 2023).

2.4.2.3 Data Collection Instruments

Food diaries were used to record each study participants' dietary behaviour over four consecutive days (one weekend day included). Digital food scales were used to weigh the foods, including any leftovers. For foods where weighing was not possible, researchers used age-appropriate photographic food atlases, standard portion sizes and household measures at subsequent visits to quantify the amount of food consumed by the study child.

During the survey, a total of three home visits were made by the researchers. During their first visit, they demonstrated how to complete the food diary and the use of weighing scales. The second visit was scheduled 24-36 hours into the recording period to review the food diary. Lastly, during the final visit (one to two days after the end of the recording period), the researchers reviewed the last days and collected the food diaries (Irish Universities Nutrition Alliance, 2019). Full details of the GUI and NCFS II surveys are available at the following links:

GUI surveys: <https://www.growingup.ie/about-growing-up-in-ireland/>

NCFS II survey: <https://www.iuna.net/surveyreports>

2.4.3 Ethical approval

The GUI and NCFSII surveys were conducted according to the guidelines laid down by the Declaration of Helsinki. Ethical approval for the GUI project was received from a Research Ethics committee convened by the Department of Health and Children, while approval for the IUNA project was obtained from the Clinical Research Ethics Committee of the Cork Teaching Hospitals, University College Cork. Data for the GUI surveys was obtained from the Irish Social Science Data Archive (ISSDA, University College Dublin, (<http://www.ucd.ie/issda>)) and the NCFSII data files were obtained from the IUNA Database Management Committee.

2.4.4 Data preparation and workflow

Data preparation and workflow are outlined in Figure 2.2. All datasets were imported from either .sav or .csv formats into R studio (RStudio Team, 2022). GitHub was used for version control (<https://github.com/>). Unweighted data were used for analysis. Data cleaning and variable transformations were used for each individual wave. Only subjects who participated in all waves of the GUI cohort surveys were included. The main grouping variables were gender and social class. Specific functions were created to generate bar-plots and tables. The R Markdown files and packages created for importing data files, variable renaming, full joins for longitudinal analysis and simple descriptive analysis including frequency tables and bar plots are available for download at <https://github.com/oral-health-nutrition/oral-health-nutrition.github.io>.

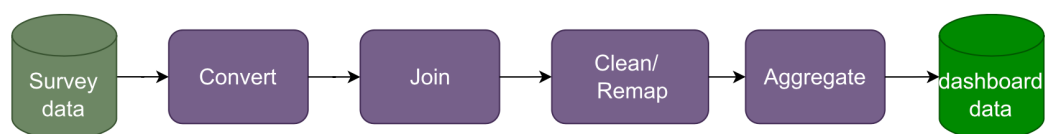


Figure 2.2 Workflow from data import to dashboard development.

The R packages used at different stages of the data preparation and workflow are shown in Figure 2.3.

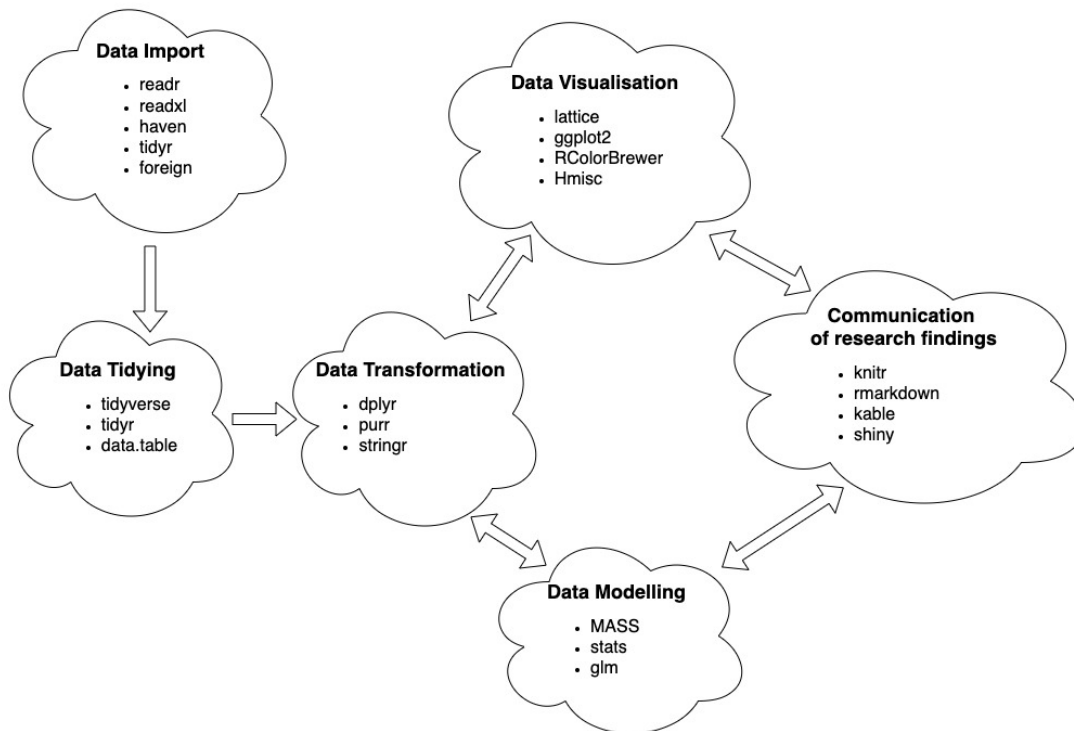


Figure 2.3. Selected R packages used for data preparation and analysis.

2.5 Phase 4. Socioeconomic Differences in Oral Health in Irish Adolescents: Role of Behavioural, Material and Psychosocial Factors

The association between early-life socioeconomic experiences and later-life oral health outcomes was explored in Irish adolescents. The potential role of early-life household material circumstances, study participants' oral health behaviours, and their parents' psychosocial factors in explaining socioeconomic differences in oral health outcomes were investigated. Data collected during the first three waves of the GUI child cohort survey were used. A total of 6,039 households who responded in all three waves were included in the analysis. The GUI data has been reweighted or statistically adjusted to ensure they were nationally representative of the age groups longitudinally (Murray *et al.*, 2010; McNamara *et al.*, 2021).

2.5.1 Study variables

2.5.1.1 Outcome Measures

The outcome measures were the oral health outcomes available in wave 3 of the GUI cohort survey when the study participants were 17/18 years of age. Two measures of oral health were used as the main outcome variables: Young persons' self-rated oral health (SROH) (young persons' self-reported oral health) and the number of permanent teeth with dental fillings the study participant had as reported by the primary caregivers (young persons' parent-reported oral health).

SROH is a measure used to assess an individual's oral health status and has been shown to be a valid and reliable indicator that displays oral health inequalities (Locker, Clarke and Payne, 2000; Wamala, Merlo and Boström, 2006; Sanders, Spencer and Slade, 2006; Sabbah *et al.*, 2009). This measure has been used extensively in public health research, particularly among young adults (Broadbent, Thomson and Poulton, 2006; Polk, Weyant and Manz, 2010; Duijster *et al.*, 2017).

For an individual, the number of teeth with dental fillings provides a quantitative estimate of the accumulated burden of dental caries experience (Broadbent *et al.*, 2011; Broadbent *et al.*, 2016). Self/parent-reported dental fillings, dental caries and other similar oral health outcomes have previously been used in large-scale epidemiological surveys (Levin, Shpigel and Peretz, 2013; Silva *et al.*, 2014; Aida *et al.*, 2017; Goldfeld *et al.*, 2019; Sanchez *et al.*, 2020; Matsuyama, Fujiwara and Aida, 2023).

2.5.1.2 Socioeconomic Position Measures (Main Explanatory Variables)

Measures of socioeconomic position were the main explanatory variables used. The PCG's highest level of education, equivalised household income, family occupational class and study child's medical card status were used to indicate the socioeconomic position. Socioeconomic measures were available for all three waves, however, for the analysis, this research has used information from wave 2 only.

2.5.1.3 Behavioural Factors

Behavioural factors were selected based on previously published literature (Sanders, Spencer and Slade, 2006; Sabbah *et al.*, 2014; Duijster *et al.*, 2017; Mariëlle *et al.*, 2021; Fleitas Alfonzo, Bentley and Singh, 2022). The four behavioural factors included in this analysis were daily toothbrushing frequency, dentist visit behaviour, sugary foods intake and sugary drinks intake.

2.5.1.4 Material Factors

Material factors selected were financial difficulties, Delivering Equality of Opportunity in Schools (DEIS) status, Private medical insurance and house ownership (Floor, Frank and Johan, 2005; Hiyoshi *et al.*, 2014; Duijster *et al.*, 2017; Novrinda *et al.*, 2019; Mariëlle *et al.*, 2021; Fleitas Alfonzo, Bentley and Singh, 2022)

2.5.1.5 Psychosocial Factors

Like the material factors, psychosocial factors were selected by following the literature on health and oral health inequalities (Sisson, 2007; Lee and Divaris, 2014; Hiyoshi *et al.*, 2014; Novrinda *et al.*, 2019; Tsakos, Watt and Guarnizo-Herreño, 2023). The following psychosocial variables were included: family structure, depression status, parenting stress and job stress.

2.5.1.6 Covariates

Based on previously published literature, some potential confounders of the association between socioeconomic status (SES) measures and self-reported oral health outcomes were selected: area of residence, main language spoken at home and PCG's country of birth (proxy for ethnicity) (Farkas, 2017; Hannigan *et al.*, 2020). The information on these variables was collected during wave 1 of the survey.

Directed Acyclic Graph (DAGs)

DAGs provide a simple way of graphically representing, communicating and understanding the casual structure thought to underlie a given exposure and outcome. In addition, DAGs specify relationships among other variables that may influence the outcome or exposure (Akinkugbe *et al.*, 2016; Tennant *et al.*, 2020). The

temporal ordering of the study variables (potential confounders, main explanatory variables, potential mediators and oral health outcomes) was implemented similar to previous studies (Fleitas Alfonso, Bentley and Singh, 2022) (Figure 2.4).

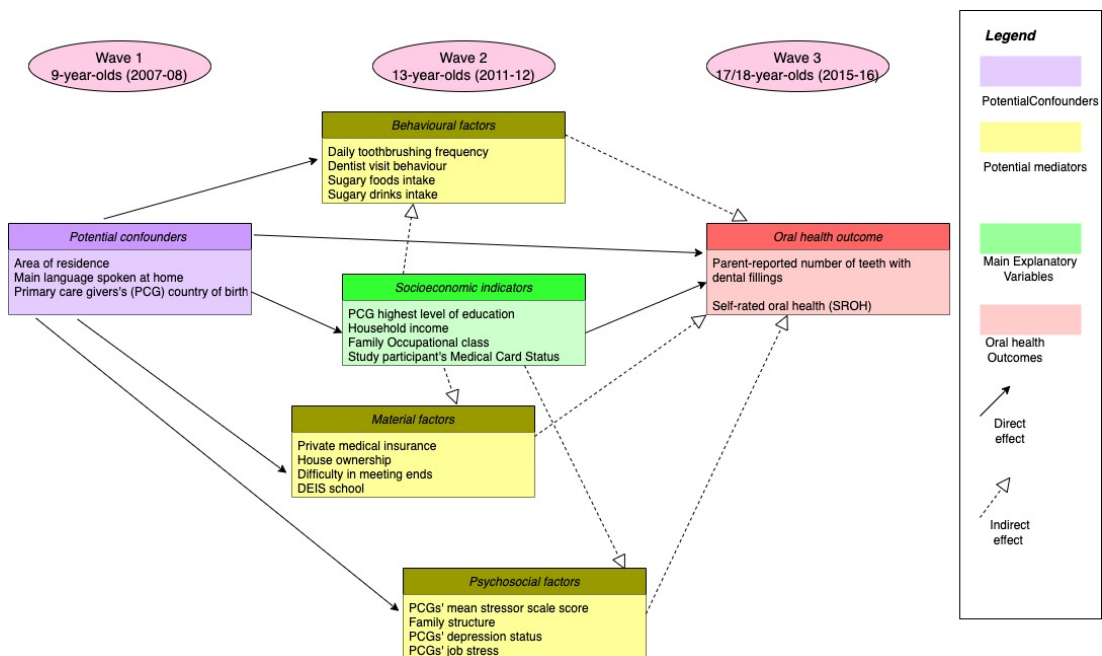


Figure 2.4 Directed acyclic graph describing the potential pathways in the relationship between socioeconomic measures at 13 years and young persons' oral health at 17/18 years of age.

As per the recommendations of studies on health and oral health inequalities, the study variables were transformed before the data were analysed, as shown in Table 2.5.

Table 2.5 Transformations of study variables' response categories and their value labels.

Variable	Original		Transformed
Covariates, Wave 1			
	Value	Response levels	Response levels (value)
Region	1.00	Urban	Urban (2.00)
	2.00	Rural	Rural (1.00)
Gender	1.00	Male	Male (1.00)
	2.00	Female	Female (2.00)
	8.00	Refusal	Missing (9.00)
	9.00	Don't know	
Main language spoken at home	1.00	English	English (3.00)
	2.00	Irish	Irish (2.00)
	3.00	Other	Other (1.00)
PCG born in Ireland	1.00	Yes	Yes (2.00)
	2.00	No	No (1.00)
	8.00	Refusal	Missing (999.00)
	9.00	Don't know	
Socioeconomic variables, Wave 2			
Family occupational class	1.00	Professional Managers	Professional managers (3.00)
	2.00	Managerial and Technical	
	3.00	Non-manual	Other non-manual/skilled manual (2.00)
	4.00	Skilled manual	
	5.00	Semi-skilled	Semi-skilled/unskilled manual (1.00)
	6.00	Unskilled	
	7.00	All other gainfully occupied and unknown	Missing (999.00)
	666.00	Validity no social class	
	777.00	Mum and dad not resident	
	888.00	Dad figure not resident	
Equivalised household annual income-Quintiles	1.00	Lowest	Lowest (1.00)
	2.00	2 nd	2 nd (2.00)
	3.00	3 rd	3 rd (3.00)
	4.00	4 th	4 th (4.00)
	5.00	Highest	Highest (5.00)

Table 2.5 Continued...

Variable	Original		Transformed
	Value	Response levels	Response levels (value)
PCG’s highest educational qualification level	1.00	None or primary	Primary or none (1.00)
	2.00	Lower secondary	Secondary (2.00)
	3.00	Higher secondary	
	4.00	TechVoc/UpperSec +Tec/Voc	
	5.00	Non Degree	
	6.00	Primary degree	Tertiary (3.00)
	7.00	Postgrad degree	
	98.00	Refusal	Missing (999.00)
	99.00	Don’t know	
Study participants’ medical card status	1.00	Yes, full card	Yes, full card (1.00)
	2.00	Yes, doctor only card	Yes, doctor only card (2.00)
	3.00	Not covered	Not covered (3.00)
	8.00	Refusal	Missing (999.00)
	9.00	Don’t know	
Oral Health Behaviours, Wave 2			
Study child brushing their teeth at least once daily	1.00	More than twice a day	Twice or more than twice a day (2.00)
	2.00	Twice a day	
	3.00	Once a day	Once a day (1.00)
	4.00	Less than once a day	Less than once a day/Rarely/Not at all (0.00)
	5.00	Rarely/Not at all	
	6.00	Not at all	
	8.00	Refusal	Missing (999.00)
	9.00	Don’t know	
Study child’s dentist visit behaviour	1.00	At least once a year	At least once a year (3.00)
	2.00	Once every two years	Occasional visit (2.00)
	3.00	Once every three years	
	4.00	Only when there is a problem	Problem visit/Never/Almost Never (1.00)
	5.00	Never/almost never	
	8.00	Refusal	Missing (999.00)
	9.00	Don’t know	
Study child’s frequency of consumption of sugary foods (Biscuits, doughnuts, cake, pie or chocolate)	1.00	Once	Once (2.00)
	2.00	More than once	More than once (1.00)
	3.00	Not at all	Not at all (3.00)
	8.00	Refusal	Missing (9.00)
	9.00	Don’t know	

Table 2.5 Continued...

Variable	Original		Transformed
	Value	Response levels	Response levels (value)
Study child’s frequency of consumption of sugary drinks (Soft drinks/minerals/cordial/squash (non-diet))	1.00	Once	Once (2.00)
	2.00	More than once	More than once (1.00)
	3.00	Not at all	Not at all (3.00)
	8.00	Refusal	Missing (9.00)
	9.00	Don’t know	
Material circumstances, Wave 2			
Degree of ease or difficulty of making ends meet	1.00	With great difficulty	With difficulty (1.00)
	2.00	With difficulty	
	3.00	With some difficulty	
	4.00	Fairly easily	No difficulty (0.00)
	5.00	Easily	
	6.00	Very easily	
	8.00	Refusal	Missing (999.00)
	9.00	Don’t know	
Private medical insurance	1.00	Yes	Yes (2.00)
	2.00	No	No (1.00)
	8.00	Refusal	Missing (999.00)
	9.00	Don’t know	
House ownership	1.00	Owner occupied (with/without mortgage)	Owner (2.00)
	2.00	Being purchased from a local authority	
	3.00	Rented from a local authority	Renters/Others/Rent free (1.00)
	4.00	Rented from a voluntary body	
	5.00	Rented from a private landlord	
	6.00	Living with and paying rent to parents	
	7.00	Occupied rent free- Parents or Job	
	8.00	Occupied rent free of rent from job	
	9.00	Other	
	98.00	Refusal	Missing (999.00)
	99.00	Don’t know	

Table 2.5 Continued...

Variable	Original		Transformed
	Value	Response levels	Response levels (value)
DEIS school status	1.00	Yes	Yes (1.00)
	2.00	No	No (2.00)
	8.00	Refusal	Missing (999.00)
	9.00	Don't know	
Psychosocial factors, Wave 2			
Family structure	1.00	Single parent 1 or 2 children	Single parent family (1.00)
	2.00	Single parent 3 or more children	Single parent family (1.00)
	3.00	Couple 1 or 2 children	Couple family (2.00)
	4.00	Couple 3 or more children	Couple family (2.00)
PCG depression status	1.00	Depressed	Depressed (1.00)
	0.00	Not depressed	Not depressed (2.00)
PCG Job stress	1.00	Very	Stressed (1.00)
	2.00	Fairly	
	3.00	Not very	Not stressed (2.00)
	4.00	Not at all	
	8.00	Refusal	Missing (999.00)
	9.00	Don't know	
	Oral health outcomes, Wave 3		
Young persons' self-reported oral health (Self-rated oral health, SROH)	1.00	Excellent	Optimal oral health (1.00)
	2.00	Very good	
	3.00	Good	
	4.00	Fair	Sub-optimal health (2.00)
	5.00	Poor	
	8.00	Refusal	Missing (999.00)
	9.00	Don't know	
Parent-reported young persons' oral health (Number of permanent teeth with dental fillings)	0.00	None	None (0.00)
	1.00	One	One (1.00)
	2.00	Two	Two (2.00)
	3.00	Three or more	Three or more (3.00)
	8.00	Refusal	Missing (999.00)
	9.00	Don't know	

2.5.2 Statistical Analysis

The summary statistics of the selected variables were reported using the number and percentages of study participants and means and standard deviation of the score

variables. Grouped bar charts and frequency tables were used to visualise two sets of distributions.

Logistic regression models were used to test the bivariate relationships between 1) SES measures and young persons' oral health (self- and parent-reported), 2) SES measures and behavioural/material/psychosocial factors, and 3) behavioural/material/psychosocial factors and young persons' oral health. However, the associations between SES measures and the parental stressor scale scores were studied using a one-factor ANOVA test. To evaluate the potential mediation of behavioural/material/psychosocial factors in the SES measures and the young persons' relationships, a series of logistic regression models were developed. In model 1, the relationship between an oral health outcome and the SES measure was studied after adjusting for wave covariates ('area of residence', 'the main language spoken at home', 'PCG's country of birth'). In the second model, model 2, the behavioural factors were added to model 1. Similarly, in models 3 and 4, material and psychosocial factors were added to model 1, respectively. In the final model, model 5, the relationship between an oral health outcome and SES measure was studied after simultaneously adjusting for covariates, behavioural, material and psychosocial factors.

For each model, the percentage change in ORs for the outcome (suboptimal oral health, one tooth with fillings, two teeth with fillings and three or more teeth with fillings) in the different response levels of SES measures due to the addition of correlates was calculated using the following formula (Floor, Frank and Johan, 2005; Richter, Moor and Lenthe, 2012):

$$PCOR = ((OR_{\text{Reference model}} - OR_{\text{Reference + more}}) / (OR_{\text{Reference model}} - 1)) * 100$$

Where $OR_{\text{Reference model}}$ = OR obtained in the first model, $OR_{\text{Reference + more}}$ = OR obtained by adding new variables in the reference model and PCOR = Percentage change in the magnitude of the first OR.

The percentage change in the OR of the reference model was used as an indicator of the magnitude of a possible mediating effect of behavioural, material and psychosocial factors in the association between oral health outcomes and SES measures (Wamala, Merlo and Boström, 2006). The change in the OR was set at 100% when an OR was lower than 1 because this study was interested in investigating the change in OR relative to the highest SES group, which by definition was 1 (Floor, Frank and Johan, 2005). The major limitation of the percentage change formula is that the percentage change can be similar for different absolute changes in ORs. However, the main advantage of using the above method is that it can be used to estimate the direct and indirect effects of explanatory factors (Floor, Frank and Johan, 2005). Data were analysed using R (R Core Team, 2022) and SPSS version. 27.0 using survey weights. Only young persons with complete data were included in the analysis. For all the analyses, a p-value of <0.05 was used to determine the statistical significance.

CHAPTER 3

3. Dental Caries in Children in Ireland: A Systematic Review

3.1 Introduction

Dental caries is the most common childhood disease worldwide (Peres *et al.*, 2019). In 2017, the global prevalence of dental caries in primary and permanent teeth were 531 million and 2.3 billion, respectively (James *et al.*, 2018b). The consequences of untreated dental caries in children include severe pain, reduced quality of life, lost study hours, sepsis, and decreased performance at school and sports (Peres *et al.*, 2019). In addition, the treatment cost of dental caries imposes a substantial economic burden on families and societies (Listl *et al.*, 2015; Patel, 2012; Righolt *et al.*, 2018).

Fluoride is effective in preventing dental caries (Jürgensen and Petersen, 2013). Fluoridation of public water supplies, use of fluoridated toothpastes, professionally applied topical fluorides and school-based fluoride mouthrinse are established public health programmes for dental caries prevention (Holland *et al.*, 1995; Petersen and Lennon, 2004). These programmes when coupled with healthier lifestyles, reduced sugar consumption, improved living conditions, access to oral health services and improved self-care practices have resulted in reductions in dental caries prevalences and severity in many countries (Featherstone, 1999; Petersen and Lennon, 2004; Petersen and Ogawa, 2016).

Community Water Fluoridation (CWF), the controlled addition of fluoride to the public water supply to prevent dental caries, is considered an effective and safe public health intervention (Ripa, 1993; James *et al.*, 2021; Government of Ireland, 1960; Cronin *et al.*, 2021). The Republic of Ireland (RoI) is the only European country with a legislative mandate for the fluoridation of the public water supplies as a core component of its oral health policy (Cronin *et al.*, 2021). CWF was first introduced in the RoI in County Dublin on July 15th 1964. Subsequently, it was introduced in County Cork on May 1965, and by 1970, most cities and larger towns in the country were fluoridated (Harding and O'Mullane, 2013). In 1981, approximately, 60% of the total population of Ireland was supplied with fluoridated drinking water (O'Mullane *et al.*, 1986). In the first National post-fluoridation children's oral health survey, in 1984 (65% of the total population supplied with CWF), it was reported that due to the introduction of CWF

at 0.8 to 1.0 ppm fluoride and widespread use of fluoridated toothpaste, the prevalence of dental caries had declined considerably among Irish children (O'Mullane *et al.*, 1986). However, between 1984 and 2002, an increase in the prevalence of dental fluorosis among Irish children, particularly in those living in areas with CWF had been reported (Whelton *et al.*, 2006). By 2002, 71% of the Irish population was supplied with CWF and there was an almost universal use of fluoridated toothpaste (more than 95% of toothpastes sold in Ireland were fluoridated). In 2007, to reduce the prevalence of dental fluorosis while maintaining reductions in dental caries, the level of fluoride in drinking water was adjusted from 0.8 - 1.0 to 0.6 - 0.8 ppm fluoride (target value of 0.7 ppm fluoride) (Government of Ireland, 2007; James *et al.*, 2021).

The first comprehensive review on the effectiveness of CWF reported that CWF was associated with an increased proportion of children without dental caries and a decreased number of teeth affected by dental caries (McDonagh *et al.*, 2000). A Cochrane systematic review in 2015 also supported the role of CWF as an effective public health intervention for reducing dental caries in children (Iheozor-Ejiofor *et al.*, 2015). With the introduction of CWF, the dmft/DMFT (decayed, missing and filled teeth) scores were reduced and the percentage of caries-free children increased. There was a 35% reduction in dmft, and a 26% reduction in DMFT in children living in areas with CWF compared to the median control group mean values. In addition, the percentage of caries-free children increased by 15% and 14% in primary and permanent dentitions. However, the majority (71%) of the included studies, which provided data for analysis, were conducted before 1975 and the universal introduction of fluoridated toothpaste to the market (Iheozor-Ejiofor *et al.*, 2015). More recently, a systematic review evaluated the effectiveness of CWF in the context of the widespread use of fluoridated toothpaste in Brazil (Belotti and Frazão, 2021). The authors reported that between 1998 and 2010, a mean difference in the dmft between children living in areas with and without CWF was -2.28 and -1.12 for 5 to 8-year-olds and 3 to 12-year-olds, respectively. For children aged 7-12 years, between 1998 and 2018, the mean difference in the DMFT between areas with and without CWF was -0.61. In addition, between 1998 and 2018, caries prevalence in the primary

(3 to 8 year-olds) and permanent (7 to 12 year-olds) dentitions of children living in areas with CWF areas was 142% and 57%, respectively lower than those living in areas without CWF (Belotti and Frazão, 2021). Public health policy in countries with mandatory CWF advocates for frequent studies to update scientific evidence on the efficacy and safety of CWF (Belotti and Frazão, 2021).

Periodic dental health surveys at National, Regional (Health Board) and County levels have been conducted in the RoI to estimate the prevalence and severity of dental caries among Irish children. For National surveys the selected samples of children were nationally representative (O'Mullane *et al.*, 1986; Whelton *et al.*, 2006). Similarly, for Regional and County surveys, the selected samples of children were representative of the Regions and Counties, respectively (South Eastern Health Board, 1998/'99; James *et al.*, 2021). In the RoI, there are twenty six counties which have been grouped respectively from 1971 to 1999 as the eight Regional Health Boards (Eastern Health Board [EHB], Western Health Board [WHB], North-Western Health Board [NWHB], Southern Health Board [SHB], Mid-Western Health Board [MWHB], Midland Health Board [MHB], North-East Health Board [NEHB], and South-Eastern Health Board [SEHB]). Each Health Board was assigned a functional area (comprising of two or more counties) for their operation (Houses of the Oireachtas, 1947; Houses of the Oireachtas, 1999). In 1999, the Eastern Regional Health Authority (earlier the EHB) was divided and three new health areas were created resulting in a total of ten Health Boards in the RoI (Houses of the Oireachtas, 1999). County Dublin is the most populous County in the RoI, and in 2022, the population of Dublin was 1.45 million persons which is approximately 28% of the country's total population (5.12 million) (Central Statistics Office, 2024).

Evidence based public health practice should use the best available peer-reviewed evidence (both quantitative and qualitative research) for evaluating the success and impact of public health interventions (Brownson, Fielding and Maylahn, 2009). The primary objective of this systematic review was to describe all children's dental caries surveys at National, Regional, and County-levels conducted in the Republic of Ireland

from 1950 to 2021 and summarise trends in dental caries. The secondary objective was to explore the effectiveness of CWF, qualitatively, by comparing dental caries experience in children living in areas with and without CWF.

3.2 Methods

The current review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Moher *et al.*, 2009). The protocol for this systematic review was registered in PROSPERO International Prospective Register of Systematic Reviews (CRD42022343732) (Booth *et al.*, 2012).

3.2.1 Eligibility Criteria

The eligibility criteria have been described according to the modification of the Population, Intervention/exposure, Comparator, Outcome, and Study Design P(I/E)COS as Condition, Context and Population (CoCoPop) criteria (Munn *et al.*, 2015). The eligibility criteria has already been outlined in Chapter 2 (Table 2.1).

3.2.2 Search Strategy

A literature search was conducted until 24 June 2022. The following electronic databases were searched: MEDLINE (OVID), Embase, PubMed, Scopus, Web of Science, Cochrane, Lenus Ireland and Google Scholar. The Dublin Dental University Hospital (DDUH) library database was also searched for grey literature. Search strategies using combinations of keywords and specific medical subject headings (MeSH) terms were drafted for individual databases in collaboration with the Librarian in the DDUH library. The search strategies included relevant terms for dental health surveys, dental diseases including dental caries and other conditions, children and the Republic of Ireland (Tables S1-6, Appendix A, Supplementary file S1). In addition, a manual search of the reference lists of all eligible studies was completed.

3.2.3 Study Selection

Screening and evaluation of identified studies was carried out using a web-based app for systematic reviews (Ouzzani *et al.*, 2016). Duplicates were removed using an

automated tool and later by manual checking before deletion. Two reviewers (VS and MOS) independently screened the studies by reading titles and abstracts. Disagreements were resolved through discussion. During the second stage of study selection, full texts of the shortlisted studies were accessed and independently evaluated for eligibility by the two reviewers. If additional information was required attempts were made to contact the study authors. The results were discussed and the conflicts resolved. The final selection of included studies was made after discussion with a third reviewer (MC). The flow diagram of the study selection process was completed based on the PRISMA checklist (Moher *et al.*, 2009).

3.2.4 Data Collection and Variable Selection

A standardised data extraction form was developed based on the checklist provided by the methodological working group of the Joanna Briggs Institute, Adelaide, South Australia, for conducting a systematic review of observational studies (Munn *et al.*, 2015). The form was calibrated and pilot tested using five excluded studies. Independent data extraction was performed by the two reviewers (VS and MOS) and later independently checked by the third reviewer (MC). Based on the sample representation, included studies were categorised into National, Regional (Health Board) and County-level surveys. The following information was extracted from the included studies: first and corresponding author, years of publication and survey, study design and setting, sample size, dental caries measures, key findings, and funding sources.

3.2.5 Quality Assessment of Studies and Risk of Bias

The methodological quality and risk of bias assessment of included studies was performed independently by two reviewers (VS and MOS) using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Studies Reporting Prevalence Data (Munn *et al.*, 2015). The JBI appraisal checklist has nine explicit criteria, and each item is assessed by scoring yes (= 1), no (= 0), unclear (= 0), and not applicable (= 0). Disagreements between the two reviewers (VS and MOS) regarding assigning scores to studies were resolved and, if necessary, final agreement was determined after

consulting the third reviewer (MC). The studies with a final score of seven or more were classified as having low risk of bias, between four and six as moderate risk and with scores less than four were classified as high risk (Table S7, Appendix A, Supplementary file S2).

3.2.6 Data Management and Analysis

During the data extraction process, data inconsistencies were identified. Missing and inconsistent data issues were resolved after consultation with the two authors (DOM and JM) of the 1984 and 2002 children's dental health surveys in the RoI. All data files were converted into .csv format and exported to R for data transformation and analysis (R Core Team, 2022).

3.3 Results

A total of 5,066 studies were identified from the databases and grey literature search. After removing duplicates ($n = 1,840$), a total of 3,226 titles and abstracts were screened as per the eligibility criteria. Sixty nine studies were identified for full-text review, and finally, thirty one studies were included in the systematic review. The list of the excluded studies ($n = 38$) and the reasons for exclusion were recorded (Table S9, Appendix A, Supplementary file S3). The inter-rater reliability for the entire search process was 94% (Cohen's kappa: 0.94). The study selection process is presented as a PRISMA flow diagram showing the identification, screening, eligibility, and included studies (Figure 3.1).

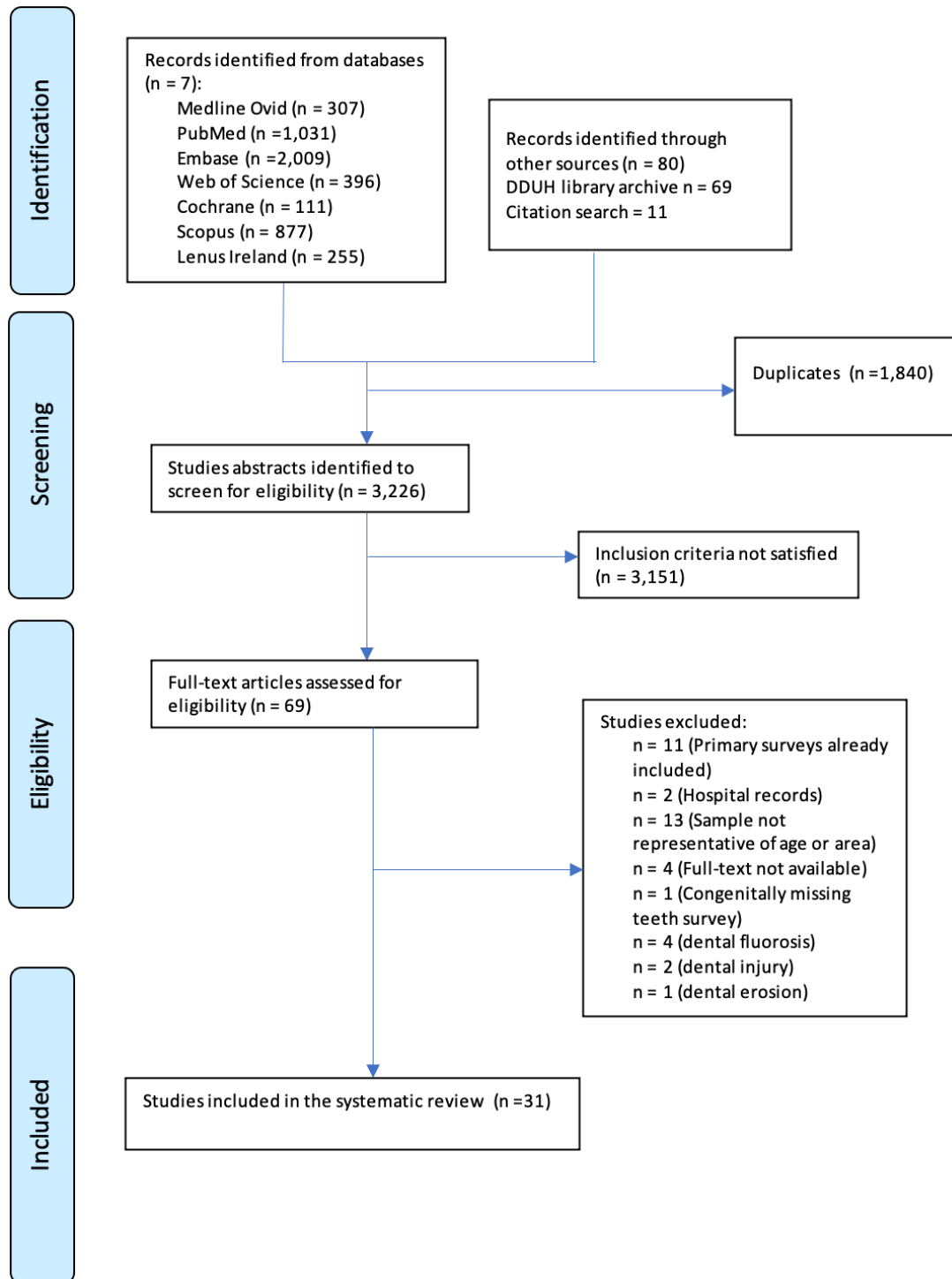


Figure 3.1 Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram of literature search and study selection process.

3.3.1 Study Characteristics

All included studies in the review were cross-sectional except for one study which was cross-sectional within a nested longitudinal study (James *et al.*, 2018a). A summary of the included studies is presented in Table S8 (Appendix A, Supplementary file S2). Three studies were conducted at the National-level (O'Mullane *et al.*, 1986; Medical Research Council of Ireland, 1953; Whelton *et al.*, 2006), eight were conducted at the Health Board level (Mid-Western Health Board, 1998; North Eastern Health Board, 1996; South Eastern Health Board, 1998/'99; Southern Health Board, 1995; Eastern Health Board, 1994; North Western Health Board, 1998; Eastern Health Board, 1997; Western Health Board, 1994), and the remaining twenty studies were County-level surveys (Department of Health (DoH), 1962a; Department of Health (DoH), 1963; Department of Health (DoH), 1964b; Department of Health (DoH), 1964a; Department of Health (DoH), 1965b; Department of Health (DoH), 1965a; Department of Health (DoH), 1962b; Collins and O'Mullane, 1970; O'Hickey and Pigott, 1981; O'Hickey and Pigott, 1983; Creedon and O'Mullane, 2001; Daly *et al.*, 1991; Lemasney, O'Mullane and Coleman, 1984; Thomas, 1972; Bolin *et al.*, 1997; Whelton, O'Keefe and O'Mullane, 1991; Oral Health Services Research Centre. University College Cork, 2018; Sagheri, McLoughlin and Clarkson, 2007; James *et al.*, 2021; Downer *et al.*, 1994). The results of seven County-level surveys conducted between 1961 and 1963 (Department of Health (DoH), 1962a; Department of Health (DoH), 1964b; Department of Health (DoH), 1963; Department of Health (DoH), 1964a; Department of Health (DoH), 1965b; Department of Health (DoH), 1965a; Department of Health (DoH), 1962b) were assumed to be representative of a National-level study in previous publications (Whelton *et al.*, 2006; O'Mullane *et al.*, 1988; O'Mullane *et al.*, 1986; Clarkson, McLoughlin and O'Hickey, 2003). In these publications, the samples of children selected to represent different age groups for each County in the County-level surveys were combined and interpreted as representative of the country (O'Mullane *et al.*, 1986; O'Mullane *et al.*, 1988; Clarkson, McLoughlin and O'Hickey, 2003; Whelton *et al.*, 2006).

The use of dmft/DMFT index (Klein, Palmer and Knutson, 1938) for clinical and epidemiological studies has been promoted because of its global acceptance, convenience, reproducibility and the advantage of comparing past dental caries data with future findings (Petersen, Ramon and World Health Organisation, 2013). Instead of recording the presence or absence of disease, this index records the stage of the disease (Petersen, Ramon and World Health Organisation, 2013). In this review, all included studies reported caries levels using the dmft/DMFT index (Klein, Palmer and Knutson, 1938). However, the dental caries diagnostic thresholds varied among the surveys. Twelve studies used the *Grade 4 (cavity into dentine) and above lesions* threshold (Department of Health (DoH), 1962a; Department of Health (DoH), 1963; Department of Health (DoH), 1964b; Department of Health (DoH), 1964a; Department of Health (DoH), 1965b; Department of Health (DoH), 1965a; Department of Health (DoH), 1962b; O'Hickey and Pigott, 1981; O'Hickey and Pigott, 1983; Thomas, 1972; Collins and O'Mullane, 1970; Daly *et al.*, 1991), one study (Medical Research Council of Ireland, 1953) used both *Grade 3 (deep pitting reaching down to dentine) and above lesions* and *grade 4 and above lesions* thresholds, one study (Lemasney, O'Mullane and Coleman, 1984) used the visual dentinal caries threshold described by Whittle and Downer (Whittle and Downer, 1979). One study (Downer *et al.*, 1994) used the visual dentinal caries threshold originally described by Backer-Dirks *et al.* (Dirks, Houwink and Kwant, 1961), eleven studies (Bolin *et al.*, 1997; Daly *et al.*, 1991; Mid-Western Health Board, 1998; North Eastern Health Board, 1996; Oral Health Services Research Centre. University College Cork, 2018; Sagheri, McLoughlin and Clarkson, 2007; Southern Health Board, 1995; Eastern Health Board, 1994; Eastern Health Board, 1997; Western Health Board, 1994; Whelton, O'Keefe and O'Mullane, 1991) used the cavitated dentinal caries (3C) threshold recommended by the WHO (Petersen, Ramon and World Health Organisation, 2013), and five studies (Creedon and O'Mullane, 2001; South Eastern Health Board, 1998/'99; James *et al.*, 2021; Whelton *et al.*, 2006; North Western Health Board, 1998) used both cavitated dentinal caries (3C) threshold recommended by the WHO (Petersen, Ramon and World Health Organisation, 2013) and the 1990s amended criteria of the British Association for the Study of Community Dentistry (BASCD) (3VC) (Pitts, Evans and Pine, 1997) for reporting caries experience

in children. The variations of dental caries diagnosis thresholds among the National dental health surveys are presented in Table 3.1.

Table 3.1 The diagnostic criteria and dental caries threshold used in the national surveys while reporting the level of dental caries in the primary and permanent dentition of Irish children.

Outcome variable	1952 Survey	1960s Survey	1984 Survey	2002 Survey
Mean dmft/DMFT count	Grade 4 and above lesions Comparable to the WHO examination criteria (3C).	Grade 4 and above lesions Comparable to the WHO examination criteria (3C).	Grade 4 and above lesions Comparable to the WHO examination criteria (3C).	WHO examination criteria(3C) (Petersen, 2003).
Percentage of caries-free children	Grade 3 and above lesions	Grade 4 and above lesions	Grade 4 and above lesions	BASCD criteria (3VC) criteria (Pitts, Evans and Pine, 1997)
Distribution of dmft/DMFT counts	Grade 3 and above lesions	Grade 4 and above lesions	Grade 4 and above lesions	BASCD criteria (3VC) criteria (Pitts, Evans and Pine, 1997)

The system of grading the degrees of caries which was adopted followed by the British Ministry of Health in the 1950s surveys in Britain. Six grades were recognised: Grade 1: Discoloration without destruction of enamel believed to be caused by caries; Grade 2: Pitting of enamel; Grade 3: Deep pitting reaching into dentine; Grade 4: Cavity into dentine; Grade 5: Large cavity penetrating deeply into dentine, generally of a few years' standing and with the pulp involvement; Grade 6: Cavity with definite and unmistakable evidence of periapical infection fistula on buccal gingiva or possibly on palatal mucosa in case of upper molar involvement. Abbreviations: WHO – World Health Organisation, BASCD- British Association for the Study of Community Dentistry, 3C – Dentinal cavity, and 3VC – Visual dentinal caries.

The age groups of children examined also varied among the National surveys. During the 1952 survey, children examined for the 5-year-old age group were aged 5 to 6 years, the 8-year-old age group were aged 8 to 9 years, and the 12-year-old age group were aged 12 to 13 years (Medical Research Council of Ireland, 1953). However, during

the 1960s surveys, examined children were 3 to 19 years old (Department of Health (DoH), 1962a; Department of Health (DoH), 1963; Department of Health (DoH), 1964b; Department of Health (DoH), 1964a; Department of Health (DoH), 1965b; Department of Health (DoH), 1965a; Department of Health (DoH), 1962b). For the 1960s surveys, the results for 5-year-olds were the combined average of the data for 4 and 5-year-olds; for 8-year-olds, the combined average of the data for 7 and 8-year-olds; for 12-year-olds, combined average for 11 and 12-year-olds; and for 15-year-olds, the combined average for 14 and 15-year-olds (O'Mullane *et al.*, 1986). For the 1984 and 2002 surveys, examined children were representative of 5, 8, 12, and 15-year-olds (O'Mullane *et al.*, 1986; Whelton *et al.*, 2006).

3.3.2 Dental Caries Trends

3.3.2.1 National Level

The mean $d_{3c}mft/D_{3c}MFT$ scores and percentage of caries-free children (mean $dmft/DMFT = 0$) in primary (5-year-olds) and permanent dentitions (8, 12, and 15-year-olds) of Irish children reported in the National dental health surveys are shown in Tables S10-12 (Appendix A, Supplementary file S4).

At the National level, the reductions in mean $d_{3c}mft/D_{3c}MFT$ scores were most apparent between the 1960s and 1984 surveys. During the period between 1984 and 2002 surveys, there were further declines in mean $d_{3c}mft/D_{3c}MFT$ scores (Figure 3.2). The percentage of children with caries-free primary and permanent dentitions increased between 1952 and 2002 (Figure 3.3).

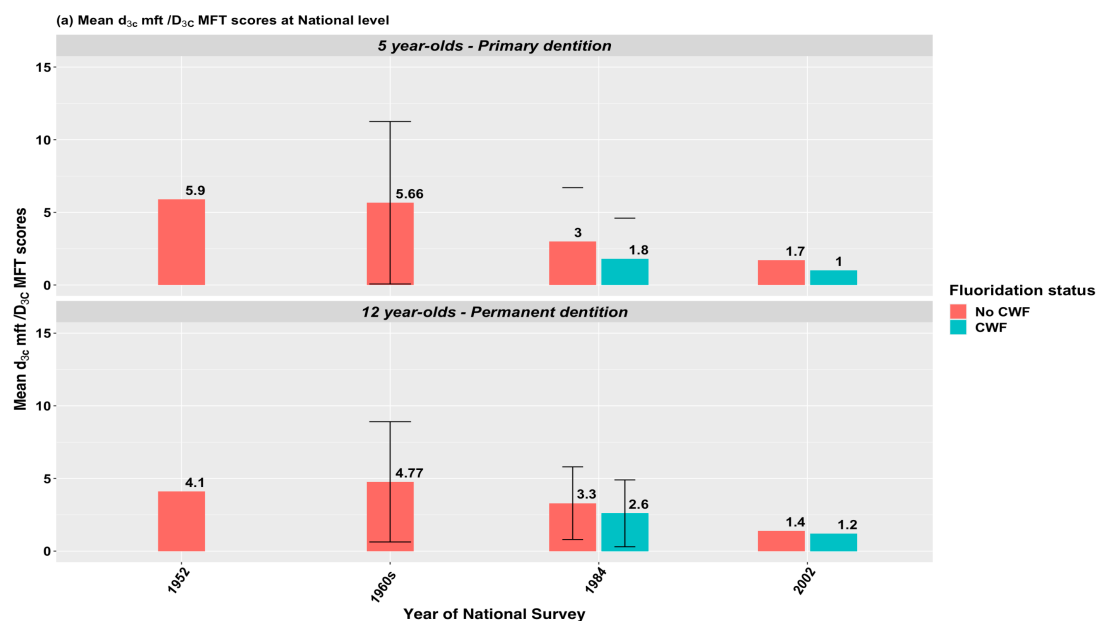


Figure 3.2 The mean $d_{3c}mft/D_{3c}MFT$ scores (mean $\pm$ standard deviation) at National level by fluoridation status: The x-axis represents the year of National surveys (1952, 1960s, 1984 and 2002) and the y-axis represents the mean $d_{3c}mft/D_{3c}MFT$ scores. Red and green colours represent the areas without and with Community Water Fluoridation (CWF), respectively. For reporting the mean $d_{3c}mft/D_{3c}MFT$ scores, the dental caries diagnostic threshold used during 1952, the 1960s and 1984 surveys was Grade 4 (cavity into dentine) and above lesions and 3C (cavity into dentine) in 2002 survey.

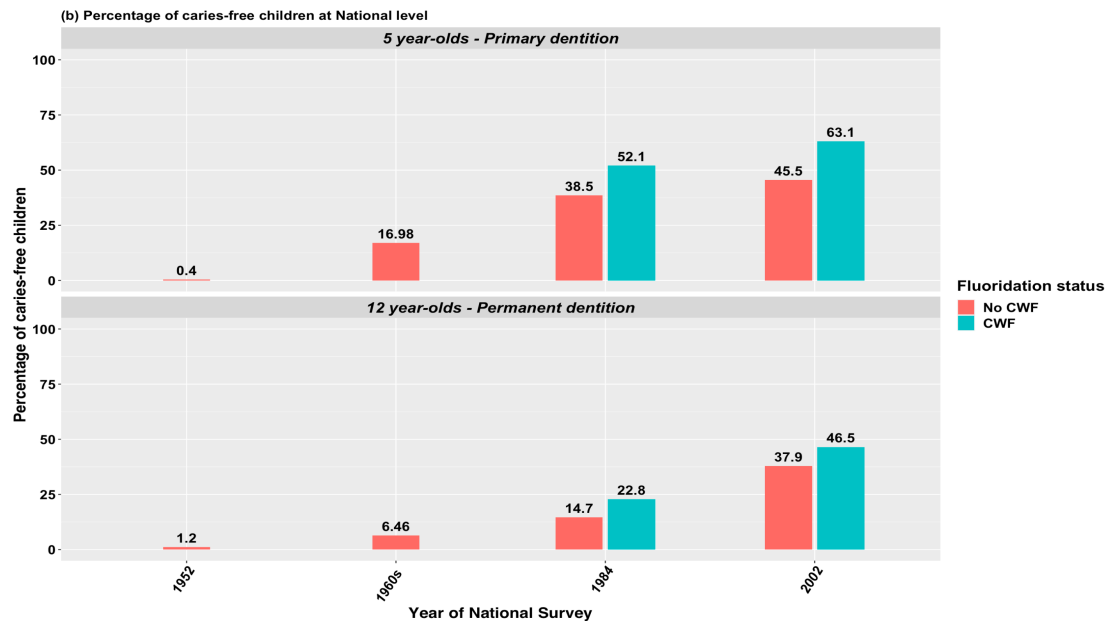


Figure 3.3 Percentage of caries-free children among 5 and 12-year-olds at National level by fluoridation status: For reporting the percentage of caries-free children, the dental caries diagnostic threshold used in the 1952 survey was Grade 3 (deep pitting reaching down to dentine) and above lesions, Grade 4 (cavity into dentine) and above lesions in the 1960s and 1984 survey, and 3VC (dental caries visible underneath the enamel without a detectable cavity through the enamel) in 2002 survey.

The percentage distributions of dmft/DMFT scores for 5, 8, 12 and 15-year-olds reported in 1952, the 1960s, 1984, and 2002 surveys are shown in Figure 3.4. The dmft/DMFT scores = 0 represent caries-free children and dmft/DMFT scores > 4 represent the percentage of children having greater than average caries experience (Petersen, 2003; Petersen, Ramon and World Health Organisation, 2013). Over the last seventy years, dental caries prevalence (dmft/DMFT > 0) and percentage of children having greater than average caries experience in the primary and permanent dentitions of 5 and 12-year-olds, respectively, have decreased. In addition, the decline in dental caries prevalence was higher for children living in areas with CWF than those without CWF.

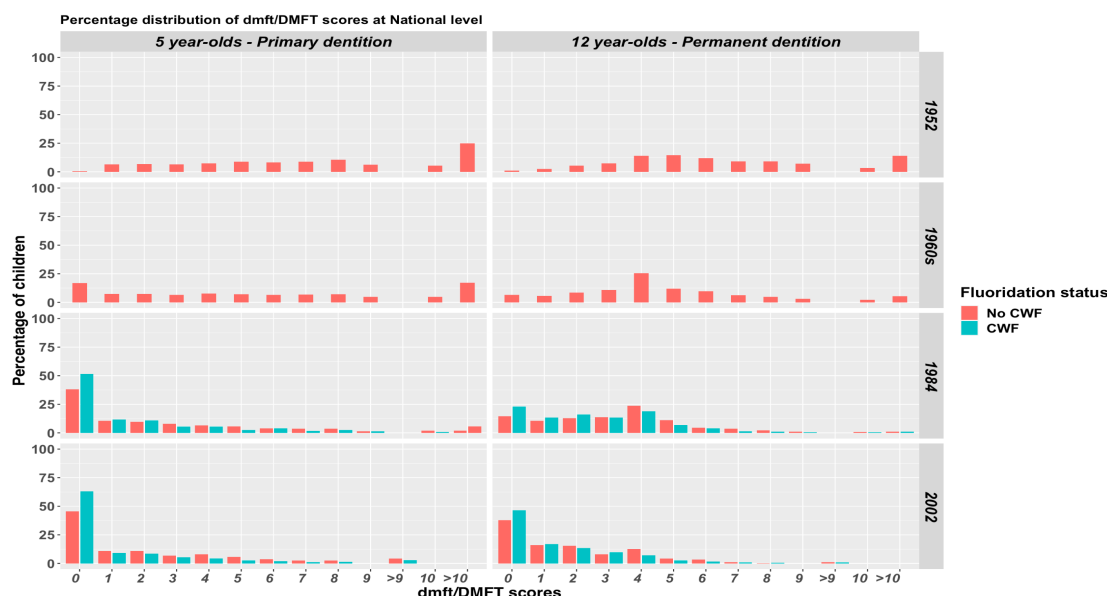


Figure 3.4 Percentage distribution of dmft/DMFT scores among 5 and 12-year-olds reported during the National surveys by fluoridation status: The x-axis represents dmft/DMFT scores and the y-axis represents percentage of children. The columns represent age groups and the rows represent year of National survey (1952, 1960s, 1984 and 2002). Red and green colours represent the areas without and with Community Water Fluoridation (CWF), respectively. For reporting the dmft/DMFT score distribution, the dental caries diagnostic threshold used in the 1952 survey was Grade 3 (deep pitting reaching down to dentine) and above lesions, Grade 4 (cavity into dentine) and above lesions in the 1960s and 1984 survey, and 3VC (dental caries visible underneath the enamel without a detectable cavity through the enamel) in 2002 survey.

3.3.2.1 Regional/Health Board Level

The mean $d_{3c}mft/D_{3c}MFT$ scores and percentage of caries-free children in primary (5-year-olds) and permanent dentitions (8, 12 and 15-year-olds) of Irish children reported in the Health Board Surveys are shown in Tables S13-16 (Appendix A, Supplementary file S4).

Between the 1960s and 1990s, mean $d_{3c}mft/D_{3c}MFT$ scores declined and percentage of caries-free children increased in all eight Health Board areas (Figures 3.5 and 3.6). Between the 1990s and 2002, mean $d_{3c}mft/D_{3c}MFT$ scores and percentage of caries-free children remained relatively unchanged. However, results from the North-Western and South-Eastern Health Boards surveys indicated that percentage of caries-free children decreased between the 1990s and 2002 (Figure 3.6). The change in the

mean $d_{3c}mft/D_{3c}MFT$ scores and percentage of caries-free children in primary (5-year-olds) and permanent dentitions (12-year-olds) has been described in detail below:

Primary dentition (5-year-olds)

a) Mean $d_{3c}mft$ levels

From 1961 to 1963, the mean $d_{3c}mft$ levels among the 5-year-olds ranged from 5.05 to 6.53. They were lowest (mean $d_{3c}mft$ 5.05) in the NEHB and were highest in the MWHB (mean $d_{3c}mft$ 6.25). However, in 1984, the mean $d_{3c}mft$ levels declined. Among the fluoridated groups (children living in areas with CWF) ranged from 1 to 2.5, with the lowest (mean $d_{3c}mft$ 1.0) in the NEHB and the highest (mean $d_{3c}mft$ 2.5) in the SHB; for the non-fluoridated group (children living in areas without CWF), the mean $d_{3c}mft$ ranged from 2.1 to 4.0, with the lowest (mean $d_{3c}mft$ 2.1) in the NEHB and the highest (mean $d_{3c}mft$ 4.0) in the SHB. Similarly, between 1991 and 1998, the mean $d_{3c}mft$ levels among the fluoridated group ranged from 0.9 to 1.7, with the lowest (mean $d_{3c}mft$ 0.9) in the EHB (1993) and the highest (mean $d_{3c}mft$ 1.7) in the MWHB (1997); for the non-fluoridated group, the mean $d_{3c}mft$ ranged from 1.7 to 2.9, with the lowest (mean $d_{3c}mft$ 1.7) in the EHB (1997) and the highest (mean $d_{3c}mft$ 2.9) in the MWHB (1997). Finally, in 2002, little change was observed in the mean $d_{3c}mft$ levels from the 1990s; for the fluoridated group, the mean $d_{3c}mft$ ranged from 0.8 to 1.6, with the lowest (mean $d_{3c}mft$ 0.8) reported in the EHB and the WHB and the highest (mean $d_{3c}mft$ 1.6) in the SEHB; for the non-fluoridated group, ranged from 1.6 to 1.9, with the lowest (mean $d_{3c}mft$ 1.6) in the MHB and the NEHB and the highest (mean $d_{3c}mft$ 1.9) in the NWHB and the SEHB.

b) Percentage of caries-free children

Between 1961 and 1963, the percentage of the 5-year-olds having no caries in their primary dentition ranged from 13 to 21%. Like the mean $d_{3c}mft$ levels, the highest percentage (21.30) was reported for the NEHB and the lowest (12.68) for the MWHB. However, in the 1984 survey, the percentage of caries-free in the fluoridated areas ranged from 39 to 66%, with the lowest (39%) in the SEHB and the highest (66%) in the NEHB. For the non-fluoridated group, the percentage ranged from 30 to 47%, with

the lowest (30) for the SHB and the highest (47) for the WHB. Similarly, from 1991 to 1998, the percentage of caries-free among the fluoridated group ranged from 62 to 70%, with the lowest (62%) for the MWHB (1997) and the highest (70%) for the EHB (1993) and SEHB (1998). For the non-fluoridated group, the percentage ranged from 45 to 53%, with the lowest (45%) for the MWHB (1997) and the highest (53%) for the SEHB (1998). The comparison among the health boards during this period was confined only to five health boards because data were unavailable for the NEHB, SHB and MHB. On the other hand, in 2002, the percentage of caries-free in the fluoridated areas ranged from 47 to 68%, with the lowest (47%) in the NEHB and the highest (68%) in the EHB and SHB. For the non-fluoridated group, the percentage ranged from 31 to 53%, with the lowest (31%) in the NWHB and the highest (53%) in the MHB.

Permanent dentition (12-year-olds)

a) Mean $D_{3c}MFT$ levels

From 1961 to 1963, the mean $D_{3c}MFT$ levels among the 12-year-olds at the health board level ranged from 4.2 to 5.3. They were lowest (mean $D_{3c}MFT$ 4.2) for the WHB and were highest for the EHB and SHB (mean $D_{3c}MFT$ 5.3). However, in 1984, the mean $D_{3c}MFT$ among those living in the fluoridated areas ranged from 2.2 to 3.3, with the lowest (mean $D_{3c}MFT$ 2.2) for the SEHB and EHB and the highest (mean $D_{3c}MFT$ 3.3) for the SHB. For the non-fluoridated group, the mean $D_{3c}MFT$ ranged from 2.5 to 4.1, with the lowest (mean $D_{3c}MFT$ 2.5) for the MHB and the highest (mean $D_{3c}MFT$ 4.1) for the SHB. Similarly, from 1991 to 1998, the mean $D_{3c}MFT$ levels for the fluoridated group ranged from 1.1 (EHB) to 1.6 (WHB) and for the non-fluoridated areas ranged from 1.5 (NWHB) to 2.1 (MWHB and WHB). In 2002, the mean $D_{3c}MFT$ levels among the fluoridated and non-fluoridated areas of the health board regions ranged from 1 to 1.5 and 1.1 to 1.9, respectively.

b) Percentage of caries-free children

During the 1960s, the percentage of 12-year-olds with no caries in their permanent teeth was below 10% for all health board regions, with the lowest (3.8%) and the highest (9%) percentages observed for the SHB and WHB, respectively. In 1984, the

proportion for the fluoridated group ranged from 14% (SHB) to 31% (SEHB), and the non-fluoridated group ranged from 10% (MWHB and SHB) to 25% (MHB). Similarly, during the 1990s, the percentage of caries-free living for the fluoridated group ranged from 42% (EHB, 1993) to 56% (NWHB) and for the non-fluoridated group ranged from 36% (MWHB) to 49% (NWHB). In addition, in 2002, the percentage of caries-free ranged from 36.2% (SEHB) to 52.3% (SHB) for the fluoridated and 24% (NWHB) to 46% (SHB) for non-fluoridated groups.

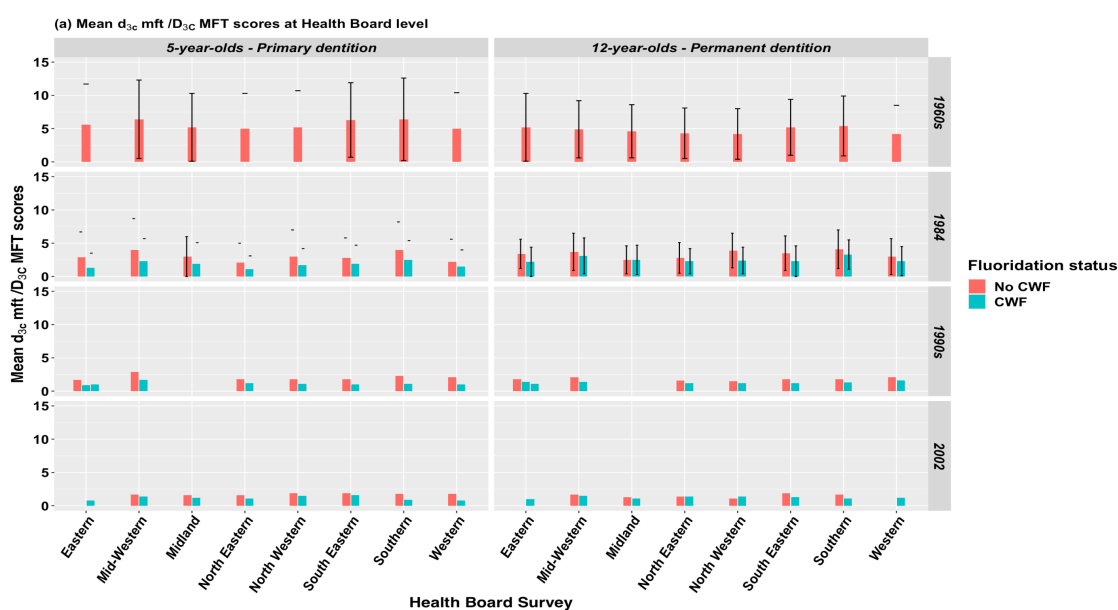


Figure 3.5 The mean $d_{3c}mft/D_{3c}MFT$ scores (mean $\pm$ standard deviation) at Health Board level by fluoridation status: The x-axis represents Health Board survey and y-axis represents mean $d_{3c}mft/D_{3c}MFT$ scores. Red and green colours represent the areas without and with Community Water Fluoridation (CWF), respectively. The columns represent age groups and the rows represent year of Health Board surveys. For reporting the mean $d_{3c}mft/D_{3c}MFT$ scores, the dental caries diagnostic threshold used in the 1960s, and 1984 surveys was Grade 4 (cavity into dentine) and above lesions and 3C (cavity into dentine) in the 1990s and 2002 surveys.

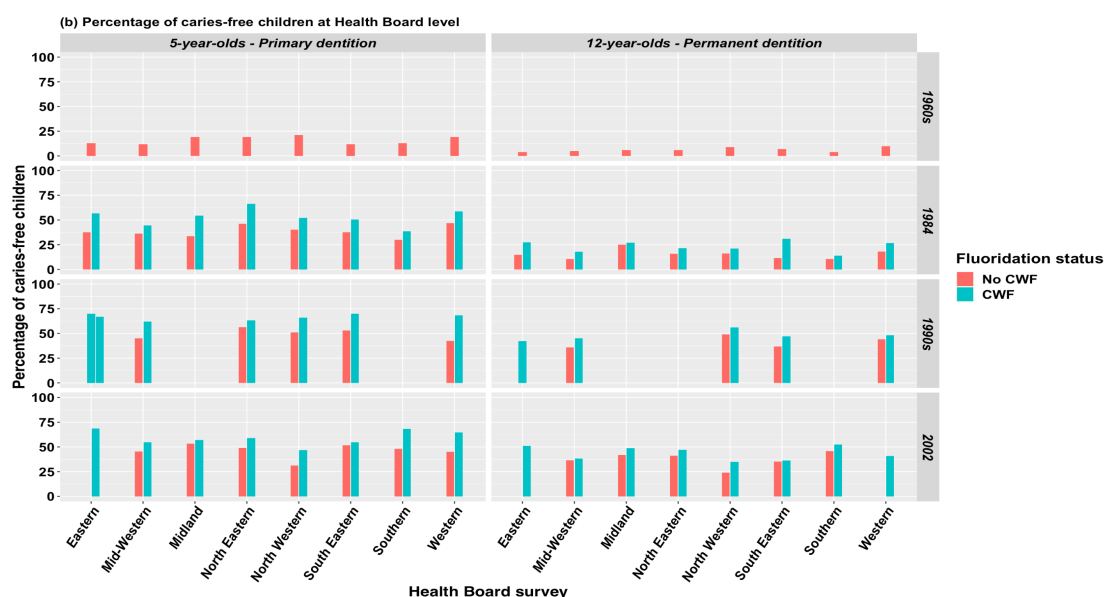


Figure 3.6 The percentage of caries-free children at Health Board level by fluoridation status: For reporting the percentage of caries-free children, the dental caries diagnostic threshold used in the 1960s and 1984 survey was Grade 4 (cavity into dentine) and above lesions, 3C (cavity into the dentine) in the 1990s, and 3VC (dental caries visible underneath the enamel without a detectable cavity through the enamel) in 2002 survey

3.3.2.3 County Level

At the County level, the data required for outlining dental caries trends in children were only available for County Dublin. The $d_{3c}mft/D_{3c}MFT$ scores and percentage of caries-free children reported during County Dublin dental health surveys are shown in Table S17 (Appendix A, Supplementary file S4).

Between 1961 and 1970, a reduction of almost 75% was observed in mean $d_{3c}mft$ scores for 5-year-olds. The decline in mean $d_{3c}mft$ scores continued in the 1980s and 1990s and then remained relatively unchanged over the last two decades. Between 1961 and 2014, the total reduction in mean $d_{3c}mft$ scores was approximately 88% (Figure 3.7). For 12-year-olds, mean $D_{3c}MFT$ scores declined by 50% between 1961 and 1975. Over the last four decades, a steady decline has been observed in reported mean $D_{3c}MFT$ scores for 12-year-olds. The total reduction in mean $D_{3c}MFT$ scores among 12-years-olds between the 1960s and 2014 was nearly 90% (Figure 3.7). In 2014, percentage of caries-free children among 5 and 12-year-olds living in County Dublin were 76% and 73%, respectively (Figure 3.8).

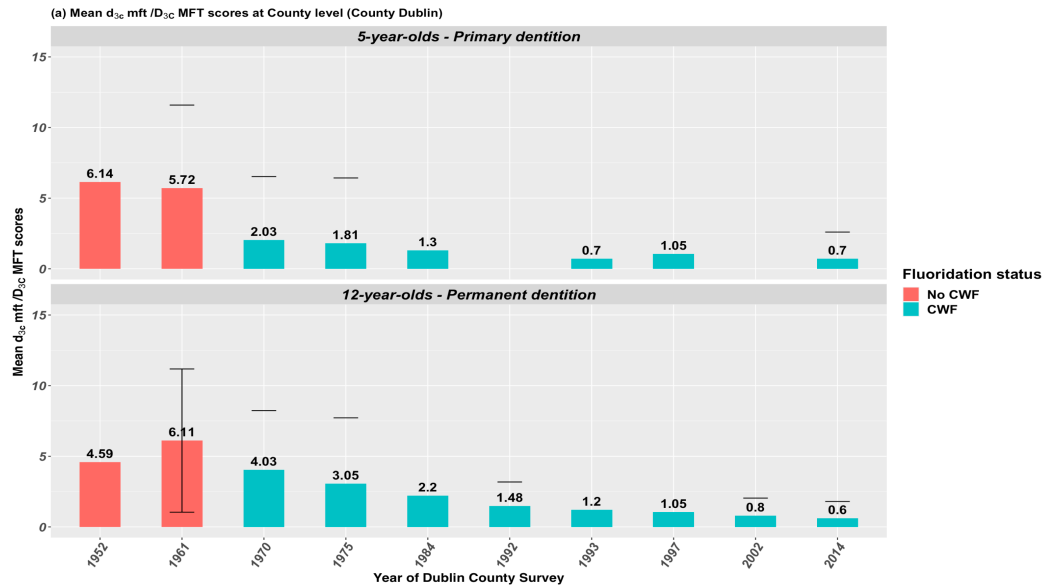


Figure 3.7 Mean $d_{3c}mft/D_{3c}MFT$ scores (mean $\pm$ standard deviation) at the County level (County Dublin) by fluoridation status: The x-axis represents the year of County Dublin survey and y-axis represents mean $d_{3c}mft/D_{3c}MFT$ scores. Red and green colours represent areas without and with Community Water Fluoridation (CWF), respectively. Upper plots represent the 5-year-olds and lower plots represent the 12-year-olds. For reporting the mean $d_{3c}mft/D_{3c}MFT$ scores, dental caries diagnostic threshold used in 1952, 1961, 1970, 1975, and 1984 surveys was Grade 4 (cavity into dentine) and above lesions and in the 1990s, 2002, and 2014 surveys was 3C (cavity into dentine).

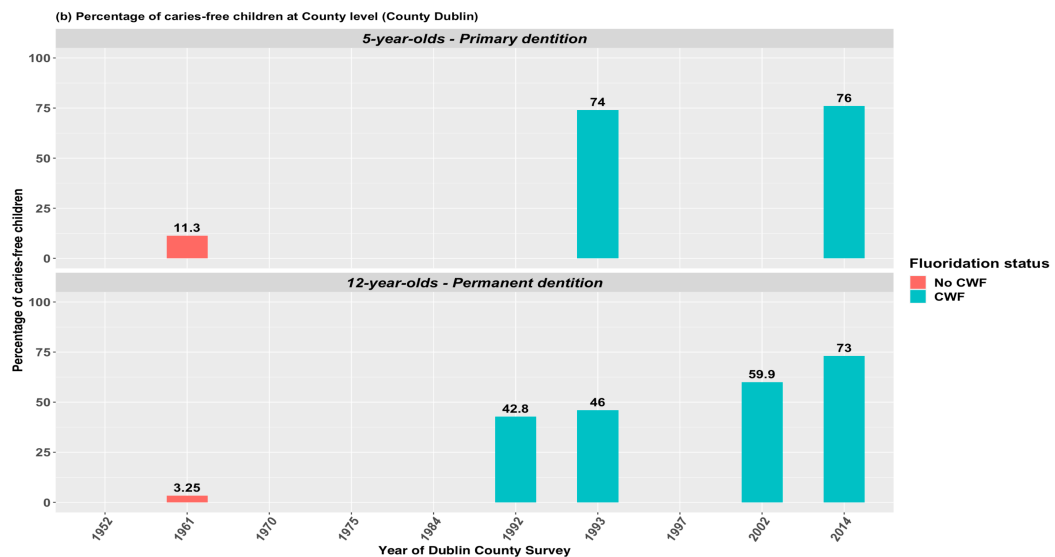


Figure 3.8 Percentage of caries-free children at the County level (County Dublin) by fluoridation status: The x-axis represents the year of County Dublin survey and y-axis represents percentage of caries-free children. For reporting the percentage of caries-free children, dental caries diagnostic threshold used in 1961 was Grade 4 (cavity into dentine) and above lesions, in the 1990s, 2002, and 2014 surveys was 3C (cavity into dentine). The 1992 survey used the visual criteria by Backer-Dirks et al (Dirks, Houwink and Kwant, 1961).

3.4 Discussion

This is the first systematic review summarising studies on the dental caries experience of Irish children at National, Regional, and County levels in the RoI over the last seven decades. There has been a marked reduction in dental caries prevalence in the primary and permanent dentitions of Irish children. A substantial decline in dental caries levels was evident in all surveys including those areas without CWF. The most recent dental health survey in the RoI for 5 and 12-year-olds was conducted for Counties Dublin, Cork and Kerry in the years 2013-14 (James *et al.*, 2018a). Approximately one-quarter of the population of Ireland lives in County Dublin with access to CWF (Oral Health Services Research Centre. University College Cork, 2018). In 2013-14, the mean DMFT scores for 12-year-olds living in County Dublin (0.6) were lower than those living in Northern Ireland (1.4) (Pitts, Chadwick and Anderson, 2015), while the percentage of caries-free 12-year-olds living in Dublin was higher (73%) than those living in Northern Ireland (48%) which does not have National CWF (Ravaghi *et al.*, 2015). The data obtained from the oral health country/area profile project database of the WHO (Malmo University and World Health Organisation, 2022) was used for international comparison of mean DMFT levels among 12-year-olds living in County Dublin with those living in the Western European countries, Australia, New Zealand, Canada, and the United States of America between 1950s and 2021, as shown in Figure 3.9. Between 2010 and 2021, the mean DMFT scores for 12-year-olds living in Dublin County (0.6) were lower than those living in Italy (1.2), Spain (0.79), Belgium (0.9), Sweden (0.70), the United Kingdom (0.74), Portugal (1.2), Switzerland (0.9), Finland (1.1), New Zealand (1.12) and Norway (0.98). However, the mean DMFT levels were higher than those living in Denmark (0.5) and Germany (0.5). The countries were grouped as having community water fluoridation (Ireland, United States of America, Australia, New Zealand), having salt fluoridation (France, Germany and Switzerland), and non-fluoridated (Denmark, the Netherlands, Sweden, Spain, United Kingdom, Portugal, Norway, Italy, Finland, Belgium, and Austria) (Cheng, Chalmers and Sheldon, 2007). The market share of fluoridated salts in Spain and Austria was 10% and 6%, respectively, therefore were classified as non-fluoridated countries (Götzfried, 2006). On the other hand, the market share of fluoridated salts in Germany, Switzerland, and

France was 65%, 88%, and 27%, respectively (Götzfried, 2006). Similarly, the percentage of the populations supplied with fluoridated water in the UK and Portugal was 9% and 1%, therefore these two countries were also classified as non-fluoridated (Cheng, Chalmers and Sheldon, 2007). The percentage of population supplied with fluoridated water in the United States was 73% (2018) (Centers for Disease Control and Prevention, 2018), Canada 39% (2022) (Public Health Agency of Canada, 2022), Australia 70% (2010) (Ha *et al.*, 2021), New Zealand 60% (2021) (Massey University, 2023), Republic of Ireland 71% (2017) (Cronin *et al.*, 2021), and Dublin 98% (1993) (Eastern Health Board, 1994). The comparability of the national data for DMFT scores among the 12-year-olds may have been affected because of variations in sampling techniques, diagnostic criteria, and methods to train and calibrate examiners employed during the national oral health surveys among the European countries (Patel *et al.*, 2016).

The observed reductions in dental caries were greater in younger than older age groups and children living in areas with CWF. The trends presented in this review were consistent with the results of previously published systematic reviews on the effectiveness of CWF (McDonagh *et al.*, 2000; Iheozor-Ejiofor *et al.*, 2015; Belotti and Frazão, 2021). Potential confounders of relevance to the association between dental caries and CWF include the use of other fluoride sources, specifically fluoridated toothpastes, socio-economic status (SES), oral health behaviours, sugar consumption/dietary habits and ethnicity (Iheozor-Ejiofor *et al.*, 2015).

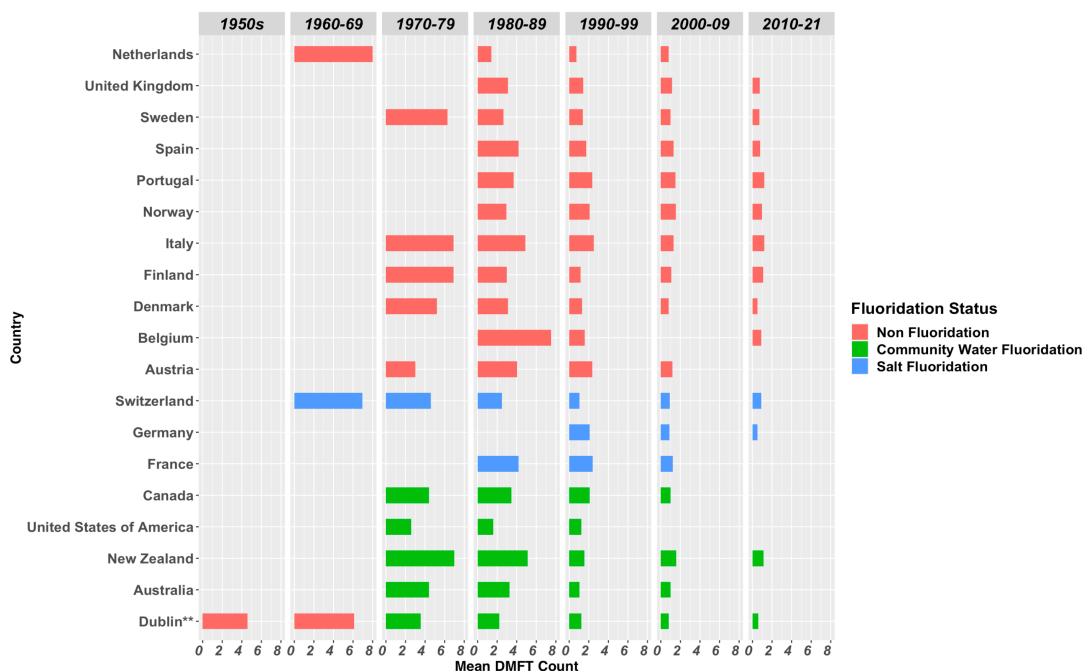


Figure 3.9 International comparison of mean DMFT scores among 12-year-olds living in the County Dublin over the last seven decades (from 1950s to 2021). The x-axis represents mean DMFT scores and the y-axis represents the countries. The countries were classified as: a) With Community Water Fluoridation (red bars), b) salt water fluoridation (blue bars), and c) no fluoridation (green bars). Country specific data for the 12-year-olds was obtained from the oral health country/area profile project database of the WHO (Malmo University and World Health Organisation, 2022).

Most of the included studies in the current review did not adjust for potential confounders. Therefore, the magnitude of the differences in caries levels among the two groups presented in the review should be interpreted with caution. The use of fluoridated toothpastes in early childhood and increased frequency of toothbrushing has probably contributed to the reduction in caries severity in children both with and without CWF (O'Mullane, Clarkson and Parnell, 2018; James *et al.*, 2021; Whelton *et al.*, 2006). Fluoridated toothpastes were introduced in the RoI in the early 1970s, and by the end of 2002 over 95% of the toothpastes sold in Ireland were fluoridated(Whelton *et al.*, 2006). The daily use of fluoridated toothpaste, ideally twice, has been suggested as the single most important factor responsible for caries decline among children in Western Europe between the 1960s and 1980s (Marthaler *et al.*, 1996; Marthaler, 2004). Findings from two Cochrane systematic reviews

concluded that the dental caries preventive effect of fluoridated toothpaste increased with higher baseline dental caries, increased frequency of use and increased fluoride concentration up to 1500 ppm of fluoride (Marinho *et al.*, 2003; Walsh *et al.*, 2019). In the RoI, the reduction in dental caries prevalence among children living without CWF has been attributed to the use of fluoridated toothpastes and benefits of fluoride obtained from consuming foods and drinks processed using fluoridated water (the “halo effect”) (Whelton *et al.*, 2006). Fluoride from other sources such as fluoridated mouthrinses, fluoride tablets and professional applications such as fluoride solutions, varnishes and gels may also have contributed to the decline. It should be noted that these measures were not routinely employed on a public health basis in Ireland except for the school fluoride mouthrinse programme in the Southern Health Board (Holland *et al.*, 1995).

The public dental services in the RoI has targeted fissure sealants as a key caries-preventive strategy for children (Irish Oral Health Services Guideline Initiative, 2010). In 2002, among the 8 and 12-year-olds living in areas with and without CWF, pit and fissure caries accounted for approximately 83% and 77% of the caries experience, respectively. For 15-year-olds, living in areas with and without CWF, 74% and 69% of the caries experiences were due to pit and fissure caries, respectively (Whelton *et al.*, 2006). In 2002, the prevalence of fissure sealants among 8, 12, and 15-year-olds were 47%, 70%, and 68%, respectively.

Information about Irish children’s SES, dietary behaviours and sugar consumption were not reported in most of the surveys. Therefore, the role SES and diet/sugar consumption as a risk factor could not be determined. During the early 1990s, the mean consumption of sugar in the RoI was approximately 55 kg/person/year (Food and Agriculture Organization of the United Nations, 2022) . In the late 1990s, the amount of sugar consumed had dropped to an average of 45 kg/person/year, while from 2000 to 2005, the mean consumption of sugar reduced by 40% to approximately 28 kg/person/year,. The next increase in sugar consumption to approximately 35 kg/person/year occurred between 2014 and 2019 (Food and Agriculture Organization

of the United Nations, 2022). The variations in dental caries diagnostic criteria among the included surveys may have impacted the findings of this review. While all included studies used the dmft/DMFT index, dental caries was diagnosed using different criteria across different studies. During the first three National surveys, a sharp probe was used to confirm the diagnosis of dentinal caries. This changed in the 2002 survey, when a ball-ended (0.5mm diameter) probe was used to confirm dentinal caries (Whelton *et al.*, 2006). Use of vigorous probing with sharp probes for caries diagnosis during epidemiology surveys ceased in the early 1990s (Neuhaus *et al.*, 2009). Round probes confirmed slightly fewer cavities than sharp explorers but the difference could not be quantified (Whelton *et al.*, 2006). Similarly, it was confirmed that a sharp probe reported greater number of caries lesions in a 'sticky' fissure than a blunt ball-ended probe (0.4mm) (Murray, Vernazza and Holmes, 2015). In the 2002 survey, it was stated that the impact of probes transition (from sharp to round), had minimal effect on the dental caries diagnosis (Whelton *et al.*, 2006).

The comparability of dental caries diagnostic criteria for the first three National surveys was discussed with the survey authors (DOM and JM) (personal communication). They confirmed that the threshold of *Grade 4 and above lesions* and the WHO 3C criteria (cavitation stage) were, essentially, similar. Using both these criteria dental caries was diagnosed only when the lesion had reached cavitation level (cavity into dentine). The caries diagnostic threshold of *Grade 3 and above lesions* used in the 1952 survey changed to *Grade 4 and above lesions* during the 1960s and 1984 survey. As a result of this transition it is possible that caries-free children were under-reported in the 1952 survey relative to the 1960s and 1984 surveys. Similarly, caries-free children may have been under-reported in the 2002 survey compared with the 1960s and 1984 surveys due to the change in the diagnostic threshold of 3C during the 1960s and 1984 surveys to 3VC during the 2002 survey. The comparability of criteria used in the 1952 and 2002 surveys to report caries-free children was discussed with the survey authors (DOM and JM) (personal communication). It was suggested that the methods used in the 1952 survey were not comparable to the visual (3VC) method of caries diagnosis because *Grade 1 and Grade 2 lesions*, usually included in the visual (3VC) method, were excluded in the 1952 survey. Similarly, dental caries

diagnostic thresholds varied among the National dental health surveys in the UK. During the 1973, 1983, and 1993 National surveys of children's oral health in the UK, the threshold for caries diagnosis was a dentinal cavity (3C) lesion. During the 2003 survey in the UK, the threshold was visual dentinal caries (3VC), and later in the 2013 survey in the UK, the threshold was enamel caries (Murray, Vernazza and Holmes, 2015). The dmft/DMFT scores reported using the 3VC criteria were approximately 20% higher than those reported using the 3C criteria (Whelton *et al.*, 2006). Wang *et al.* reported that the reported prevalence of dental caries by epidemiological surveys which only focussed on obvious decay (non-cavitated lesions into dentine and above) was 40% less than those which used clinical decay (non-cavitated enamel caries and above) as the diagnostic threshold (2021).

The main strength of the current review is that most of the included studies had low risk of bias, and the results may be viewed as the best available evidence. Literature searches were completed and personal communication with survey authors established. This review identified all children's dental health surveys conducted in the RoI, and presented trends in dental caries among the primary and permanent dentitions of Irish children at National, Regional and County levels. However, there were limitations, including trends described based on cross-sectional survey data, which lack internal validity and generalisability (Levin, 2006; Kundu *et al.*, 2015). Longitudinal data from birth cohort studies or cross-sectional surveys (conducted at periodic intervals and under similar condition) may be used to outline dental caries trends over time (Burt, 1997). Secondly, the contributions of the various components of the dmft/DMFT index, i.e. d(decayed), m(missing), and f(filled), towards the total count were unavailable for most of included studies. Therefore, it was challenging to compare and outline the burden of untreated dental caries trends among Irish children. Lastly, the quantitative assessment of the evidence (meta-analysis) could not be conducted because of the lack of data on the standard deviation of the mean dmft/DMFT for most of the included surveys.

Based on the findings of this review, the authors suggest, consistent with previous publications (Marthaler, 2004; O'Mullane *et al.*, 1986; Shen, Bernabé and Sabbah, 2021; Peres *et al.*, 2019; Antunes and Narvai, 2010; Patel *et al.*, 2016) that National oral health surveys should be conducted at regular intervals to monitor dental caries prevalence and incidence and an international consensus of protocols should be formulated for epidemiological surveys of dental caries in children.

3.5 Conclusions

Dental caries in children has consistently declined in the RoI in the last seven decades. Since the introduction of CWF, a greater reduction in dental caries has been reported among children living in areas with CWF compared to those without CWF.

CHAPTER 4

4. Evaluating Harmonisation Potential of Oral Health-Related Questionnaire in National Longitudinal Birth and Child Cohort Surveys

4.1 Introduction

Population-based cohort studies follow a sample or an entire population longitudinally and have been considered a valuable resource for investigating the developmental origins of health and disease (Szklo, 1998; Grimes and Schulz, 2002; Fortier *et al.*, 2023). Most oral diseases are chronic, cumulative, and have multifactorial aetiologies so are amenable to life course epidemiological studies (Crall and Forrest, 2018). A comprehensive understanding of oral disease risk factors and indicators (e.g., low socioeconomic status, poor oral hygiene practices, a diet high in free sugars, infrequent dental visits behaviour and inadequate fluoride exposure) is necessary for oral disease prevention (Fisher-Owens *et al.*, 2007; Peres *et al.*, 2022). These factors have been classified as modifiable (e.g., short-duration breastfeeding, sugary beverages intake, increased energy intake, poor child health, increased child weight, oral hygiene practices, fluoride exposure, oral health services use and increased stress) and non-modifiable (e.g., developmental conditions, low socioeconomic status and increased cultural acculturation) (Moynihan, 2005; Selwitz, Ismail and Pitts, 2007; Chi, Luu and Chu, 2017). Dental caries and obesity are two of the most common, largely preventable chronic health conditions affecting children, which are significant public health concerns (Hayden *et al.*, 2013; Paisi *et al.*, 2019). Poor dietary and nutritional behaviours, established at a young age, were associated with a higher probability of obesity and dental caries affecting the individuals throughout their lifetime (Whitaker *et al.*, 1997; Lock *et al.*, 2019).

Nationally representative oral health data are needed to effectively plan and evaluate oral health policies and services (Li *et al.*, 2018). However, this type of data is scarce due to the high costs involved and complexity of coordinating and conducting national oral health surveys (Patel *et al.*, 2016; Taylor *et al.*, 2023). The last National Children's Oral Health Survey in the Republic of Ireland (RoI) was completed almost twenty-one years ago (Whelton *et al.*, 2006). Self-reported oral health data from national birth and child cohort surveys provide an opportunity for estimating the distributions and prevalence of oral diseases in children over time and relating these findings to general health conditions and sociodemographic factors in the same cohort (Crowe *et al.*,

2016; Skafida and Chambers, 2018; Thornley *et al.*, 2021). In addition, they can provide useful information relating to family and environmental factors in a child's early life, oral health outcomes and long-term susceptibility to oral diseases during later life (Peres *et al.*, 2022; Fortier *et al.*, 2023).

In oral health epidemiology, domains are broad categories representing particular research fields, such as oral health status and oral health behaviours. Within the respective domains, constructs are theoretical concepts or ideas based on empirical observation, e.g., an individual's self-perceived oral health and daily toothbrushing frequency. The indicators or variables are more specific items/ measures used to measure these concepts. A single self-rated oral health (SROH) question with a response scale of five points (excellent, very good, good, fair and poor) is a useful and valid summary measure of people's oral health (Locker, Clarke and Payne, 2000; Thomson *et al.*, 2012).

Construct validity of a measure represents the degree to which it correctly measures its targeted construct or concept (O'Leary-Kelly and J. Vokurka, 1998). Secondary data analysis (analysis of data collected in the past by others for another primary purpose) provides a viable option for researchers when it is not feasible to independently collect data from a sufficiently large sample to investigate population oral health issues (Johnston, 2014; Ikeda, 2016). For efficient use of secondary data, data discovery, the ability to find data relevant to a research project is a critical component (Bauermeister *et al.*, 2023). However, for large-scale cohort surveys, data discovery may be challenging as these studies are under-documented and have varied data structures and labelling conventions (O'Neill *et al.*, 2019; Bauermeister *et al.*, 2023). Before attempting secondary data analysis of nationally representative cohort survey datasets, researchers should evaluate existing data quality and variable understanding by studying essential aspects of the methodology used to collect data (Kończyńska and Schoene, 2018).

A single cohort study data may be used to study disease distributions, exposure-outcome relationships, disease trends and changes over time among the same

individuals. However, collating, comparing and pooling data from multiple cohort studies facilitates validating, tracking and quantifying changing characteristics at the population level and across generations (O'Neill *et al.*, 2019). International comparisons of child oral health and well-being data have had a political and public impact (Bradshaw, Hoelscher and Richardson, 2006; Richardson and Ali, 2014). Data pooling increases statistical power, further facilitates replication of analyses, detection of smaller associations and investigation of rare events (Fortier *et al.*, 2016; Atkin *et al.*, 2017; Fortier *et al.*, 2019; Adhikari *et al.*, 2021).

A pre-requisite for efficient data discovery and co-analysis of individual participant data is data harmonisation (Fortier *et al.*, 2016; Bauermeister *et al.*, 2023; Fortier *et al.*, 2023). This is a practice used to achieve comparability between two or more variables by inferring a latent construct that the variables are considered to represent (Bauermeister *et al.*, 2023). This facilitates the coherent combination of varied datasets (Adhikari *et al.*, 2021; Sánchez-Niubo *et al.*, 2020). Prospective harmonisation ideally occurs before data collection. This requires agreement between investigators on a standard set of variables, compatible data collection tools and standard operating procedures (Adhikari *et al.*, 2021). Even though prospective harmonisation ensures a high degree of homogeneity across studies, implementing this approach is not always suitable or feasible (Fortier *et al.*, 2016; Adhikari *et al.*, 2021). Using retrospective harmonisation, researchers define a core set of variables to be generated and evaluate the harmonisation potential of the already collected information across the studies involved (Fortier *et al.*, 2011; Fortier *et al.*, 2016; Fortier *et al.*, 2019; Fortier *et al.*, 2023). Data harmonisation provides an infrastructure supporting the reuse of survey data by making data findable, accessible, interoperable, and reusable (FAIR) (Wilkinson *et al.*, 2016).

In the last twenty years, harmonisation initiatives for population health have increased significantly (Fortier *et al.*, 2023). These initiatives can be classified as 1) hypothesis-specific initiatives across multiple datasets or 2) initiatives targeting a broad range of objectives (Bauermeister *et al.*, 2023; Fortier *et al.*, 2023). These projects have included studies in the EU (Vrijheid *et al.*, 2012; Doiron *et al.*, 2013;

Lakerveld *et al.*, 2017; Jaddoe *et al.*, 2020), UK (O'Neill *et al.*, 2019; Bauermeister *et al.*, 2023) and Canada (Joly *et al.*, 2012; Fortier *et al.*, 2019; Bergeron *et al.*, 2020; Adhikari *et al.*, 2021).

Study Rationale

The global distribution of oral health-related birth cohort studies and available oral health data were summarised recently (Peres *et al.*, 2022). However, to the best of our knowledge, there has been no oral health-related questionnaire data harmonisation initiative for nationally representative birth/child cohort surveys. The primary aim of this chapter was to evaluate the harmonisation potential of oral health-related questionnaire data in selected nationally representative birth/child cohort surveys in high-income countries.

The objectives were to:

- a) Review and compare study-specific questionnaires published by each cohort survey across each wave.
- b) Evaluate the harmonisation potential of study-specific questionnaires.
- c) Identify data coverage gaps in existing questionnaires.
- d) Provide recommendations for the effective use of existing datasets and for improvement of future survey waves.

4.2 Methods

The Maelstrom Research guidelines for retrospective data harmonisation were followed for the harmonisation potential evaluation of the study-specific variables (Fortier *et al.*, 2016). The Maelstrom Research guidelines checklist has been presented in Table 4.1.

Table 4.1 The Maelstrom Research guidelines checklist for evaluating the harmonisation potential of the study-specific variables (Fortier et al., 2016).

Steps	Description
Step 0: Define the questions and objectives	The research question was defined in terms of population, exposure, comparator, outcome, and timing
Step 1: Assemble information and select studies	
Step 1a: Document individual study designs, methods, and content	Study specific information such as study design, timeline, population characteristics and data contents were gathered and documented
Step 1b: Select participant studies	Studies were selected based on the explicit selection criteria
Step 2: Define variables and evaluate harmonisation potential	The DataSchema variables were defined based on their relevance to the research question, likelihood to be generated across multiple studies and input from experts
Step 2a: Select and define core variables to be harmonised (DataSchema)	The DataSchema variables were clearly defined along with their data type, format, and level of heterogeneity
Step 2b: Determine the potential to generate the DataSchema variables making use of study-specific data items	The potential (or not) for each study wave to create DataSchema variables was assessed and documented

4.2.1 Study Selection

4.2.1.1 Eligibility Criteria

Inclusion criteria

- 1) A nationally representative birth/child cohort survey in an English-speaking (Countries where English is spoken as a first language by the majority of the population) high-income country.
- 2) Baseline data collection after the year 2000 with plans for future data collection.
- 3) Studying the growth and development of children at different age groups across a broad range of internationally recognised child outcomes.
- 4) Parent/self-reported oral health-related data collected through at least one follow-up.

Exclusion criteria

- 1) Not nationally representative.
- 2) Low or middle-income country survey.
- 3) Started data collection before 2000.
- 4) Discontinued surveys.

The main focus of the present study was to include cohort surveys from high-income countries sharing similar survey methodologies and themes/objectives. After initial screening using official survey documentation published online, survey wave questionnaires were used for the final selection of studies. Excluded studies and the reasons for their exclusion are presented in Appendix B, Supplementary file S1, Table S1.7.

4.2.2 Data Extraction and Variable Selection

A standardised data extraction form was developed, and the following information was extracted: the study name, country name, cohort baseline and follow-up calendar years, sample size, study child age, and the response percentage of the original sample. Study-specific questionnaire data were collected from the published questionnaires for each wave across all surveys. The primary focus of this study was to include questionnaires on oral health and related modifiable factors (e.g., diet behaviours, oral hygiene measures, dentist visit behaviour, dental services use, general health, and weight status). Survey questionnaires were reviewed, oral health and nutrition experts' opinions were sought, literature was searched and finally, using a consensus approach, the domains and constructs to be included in the present study were defined (Peres *et al.*, 2020a; Pabbla *et al.*, 2021; Peres *et al.*, 2022; Su *et al.*, 2022). The collected questionnaires were classified into three domains and fifteen constructs for building a common data model (Fortier *et al.*, 2010) as shown in Chapter 2 of this thesis (Table 2.3).

4.2.3 Oral Health and Risk Indicator DataSchema and Harmonisation Potential

Evaluation

A final list of DataSchema variables was created using a consensus approach among the study authors (Appendix B, Supplementary file S3). When defining the DataSchema variables, questionnaires and data dictionaries were referenced. Standardised specifications, including the name, label, format, description, and categories, were followed to define the DataSchema variables. A harmonisation status (whether a study could construct or not each of the DataSchema variables) was assigned to each wave of the included surveys. A complete harmonisation status was assigned to studies that used the exact question wording and categories as defined for the DataSchema variables and to studies in which survey items could be transformed or combined to match the created DataSchema variable. An incomplete status was assigned to the survey wave when the required information to match the DataSchema variable was incomplete or missing in the survey questionnaires. An example of harmonisation status assignment for the variable “TOOTH_BRUSH_FREQ_DAILY” across survey waves is shown in Table 4.2. Variable transformations to match the core variables included collapsing, renaming or changing assigned values to the categories of the variables (Table 4.2). The variable characteristics were reported using frequency tables of simple counts.

Table 4.2 An example of harmonisation status assignment across the survey waves for the DataSchema variable “TOOTH_BRUSH_FREQ_DAILY”.

Variable name: TOOTH_BRUSH_FREQ_DAILY; Label: Toothbrushing frequency; Description and coding: Number of times in a day the study child’s teeth were cleaned/brushed. Categories and Coding: Twice a day or more (1); Once a day (2); Less than once a day (3); Never (4); Missing (999)	
Cohort-specific questionnaires	Harmonisation status
LSAC B cohort survey wave 2, 3, 4, 5 and LSAC K wave 2, 3, 4: How often are the child’s teeth currently cleaned? GUS cohort survey wave 2: How often is a toothbrush used to clean a child’s teeth? Categories: More than twice a day (1); Twice a day (2); Once day (3); Less often than once a day (4); Don’t clean teeth (5); Missing ()	Complete (direct match to the DataSchema variable, but the “More than twice a day” and “Twice a day” categories were collapsed and classified as “Twice a day or more”. The category “Don’t clean teeth” was classified as “Never”.
GUI infant cohort wave 2: How often is a toothbrush used to clean child’s teeth? GUI infant cohort wave 5: How often does child brush his/her teeth? Categories: More than twice a day (1); Twice a day (2); Once day (3); Less often than once a day (4); Rarely (5); Not at all (6); Missing ()	Complete (direct match to the DataSchema variable, but the “More than twice a day” and “Twice a day” categories were collapsed and classified as “Twice a day or more”. The categories “Rarely” and “Not at all” were classified as “Never”.
GUN cohort study wave 2 How often are child’s teeth brushed? Categories: Twice a day or more (4); Once a day (3); Less than once a day (2); Never (1); Ref (98); DK (99)	Complete (direct match to the DataSchema variable, but categories value labels were changed to match DataSchema variable categories labels. The categories “Ref” and “DK” were classified as “Missing”.
GUN cohort study wave 5 How are child’s teeth brushed? Categories: Twice a day or more (5); Once a day (4); Less than once a day (3); Less than weekly (2); Never (1); Ref (98); DK (99)	Complete (direct match to the DataSchema variable, but categories value labels were changed to match DataSchema variable categories labels. The categories “Less than weekly” was classified as “Never” and categories “Ref” and “DK” were classified as “Missing”.

Table 4.2 Continued...

Cohort-specific questionnaires	Harmonisation status
GUN cohort study wave 8: How often are child's teeth brushed? Categories: More than twice a day (4); Twice a day (3); Once a day (2); Less than once a day (1); Ref (98); DK (99)	Complete (direct match to the DataSchema variable, but the "More than twice a day" and "Twice a day" categories were collapsed and classified as "Twice a day or more". The categories "Ref" and "DK" were classified as "Missing". Also, the value labels were changed to match the DataSchema variable categories.
MCS cohort study wave 5 and 6: How often does the child brush his/her teeth? Categories: Twice a day or more (1); Once a day (2); At least once a week but not daily (3); Less than once a week (4); Never (5); Missing	Complete (direct match to the DataSchema variable, but the categories "At least once a week but not daily" and "Less than once a week" were classified as "Less than once a day " and "Never", respectively.
GUI child study wave 1: Does the study child brush his/her teeth at least once per day? Categories: Yes (); No ()	Incomplete (Respondents were asked to report whether the study child brushes their teeth once a day, cannot be matched with the DataSchema variable)
GUS cohort survey wave 5: How often is a toothbrush with fluoride toothpaste used to clean child's teeth? Categories: More than once (); Once a day (); Less than once a day ()	Incomplete (Respondents were specifically asked to report the toothbrushing frequency using a fluoridated toothpaste)

GUI (Growing Up in Ireland); GUS (Growing Up in Scotland); LSAC B (Longitudinal Study of Australian Children Birth cohort; LSAC K (Longitudinal Study of Australian Children Kindergarten cohort; GUN (Growing Up in New Zealand) and MCS (Millennium Cohort Study).

4.3 Results

This study included seven nationally represented child cohort surveys namely, GUI (Growing Up in Ireland); GUS (Growing Up in Scotland); LSAC B (Longitudinal Study of Australian Children Birth cohort; LSAC K (Longitudinal Study of Australian Children Kindergarten cohort; GUN (Growing Up in New Zealand) and MCS (Millennium Cohort

Study). The assessment age, sample size, response percentage of the original sample and year of data collection for the included surveys are presented in Table 4.3. Sampling details, data collection methods, thematic objectives, funding and management of the included studies were summarised (Appendix B (Chapter 4), Supplementary file S1). With the exception of the GUI child and Longitudinal Study of Australian Children (LSAC) K cohort surveys, data collection started during the first year of the child's life. For the GUI child and LSAC K-cohort surveys, data collection started when the study children were 9 and 4-5 years of age, respectively. While a majority of surveys have collected childhood and early adolescent data the GUI child, LSAC K-cohort and MCS surveys have also captured late adolescence data. Participant response of the original sample in the last follow-up before the COVID-19 pandemic (excluding the online COVID-19 online surveys) ranged from 55% to 76%. The age groups surveyed at different waves were broadly comparable across cohort surveys.

4.3.1 Available Information in Survey Questionnaires

The study-specific questionnaires were summarised by cohort and age (Tables S2.1-11, Appendix B, Supplementary file S2). The most frequently investigated oral health construct was dental injury, followed by dental problems (teething, tooth decay or cavities, tooth pain or gum pain), dental treatments (teeth filled, teeth extracted or orthodontic treatment), and parent/self-perceived dental health status.

Daily toothbrushing frequency was the most frequently investigated construct for the oral health-related components domain. All cohort surveys included parent/self-perceived general health and weight status questionnaires in most survey waves.

A 24-hour recall was the most frequently used dietary assessment instrument with food frequency questionnaires being the next most utilised. Food diaries were rarely used while GUS (Growing Up in Scotland) and MCS surveys used screening instruments to record the typical daily intake of specific foods and drinks of interest, including fruit, vegetables, soft drinks (diet and non-diet), sweets and chocolates. The GUN survey

wave 8 asked the parents to recall and report the child's dietary intake over the last seven days.

Table 4.3 Summary of included surveys.

Child age	Cohort/year of data collection sample size at each wave (response % of the original sample)						
	GUI infant	GUI child	GUS	LSAC B cohort	LSAC K cohort	GUN	MCS
0-1 year	2008-09 11,134 (100)		2005-06 5,217(100)	2003-04 5,107 (100)		2010-11 6,853 (100)	2001-02 18,818 (100)
2 years			2006-07 4,512 (86.5)	2005-06 4,606 (90.2)		2011-12 6,327 (92.3)	
3 years	2010-11 9,793 (88)		2007-08 4,193 (80.4)				2003-04 15,808 (84)
4 years			2008-09 3,994 (76.6)	2007-08 4,386 (85.9)]	2003-04 4,983 (100)		
5 years	2013 8,712 (78.2)		2009-10 3,833 (73.5)			2014-15 6,156 (89.8)	2006 15,460 (82.15)
6 years			2010-11 3,657 (70.1)	2009-10 4,242 (83)	2005-06 4,464 (89.6)	2015-16	
7 years	2016 5,344 (48)						2008 14,043 (74.6)

Table 4.3 Continued...

	GUI infant	GUI child	GUS	LSAC B cohort	LSAC K cohort	GUN	MCS
8 years			2012-13 3,456 (66.2)	2011-12 4,077 (80)	2007-08 4,332 (86.9)	2017-19 5,241 (76.4)	
9 years	2017-18 7,770 (69.8)	2007-08 8,568 (100)					
10 years			2014-15 3,150 (60.4)	2013-14 3,764 (73.7)	2009-10 4,169 (83.7)		
11 years						2020 2,421 (35.3)	2012 13,469 (71.6)
12 years	2020		2017-18 2,917 (55.9)	2015-16 3,381 (66.2)	2011-12 3,956 (79.4)		
13-years		2011-12 7,525 (87.8)					
14 years			2019-20 2,669 (51.2)	2017-18 3,127 (61.2)	2013-14 3,537 (71)		2015 11,938 (63.4)
15 years							
16 years				2020 2,017 (39.5)	2015-16 3,089 (62)		

Table 4.3 Continued...

	GUI infant	GUI child	GUS	LSAC B cohort	LSAC K cohort	GUN	MCS
17 years		2015-16 6,216 (72.5)		2021 2,688 (52.6)			2018-19 10,345 (54.9)
18 years					2017-18 3,037 (60.9)		
19 years							
20 years		2018-19 5,190 (60.1)			2020 1,789 (35.9)		
21 years					2021 2,463 (49.4)		
22 years		2020					2022

GUI (Growing Up in Ireland); GUS (Growing Up in Scotland); LSAC B (Longitudinal Study of Australian Children Birth cohort); LSAC K (Longitudinal Study of Australian Children Kindergarten cohort); GUN (Growing Up in New Zealand); MCS (Millennium Cohort Study).

4.3.2 Survey Questionnaires Comparison

Age-wise distribution of survey questionnaires by construct and comparability between cohort surveys were summarised in Table 4.4. For the ten defined age groups (age range, 0-20 years), a comparable status was assigned when two or more surveys asked similar questions and used the same response categories. A non-comparable status was assigned when different questions or response categories were used across two or more surveys or when a single survey covered the construct. Generally, survey questionnaires were not consistent either across or within cohort surveys. For oral health and oral health-related components questionnaires, the least inconsistencies were observed for the LSAC surveys and the greatest for GUS and MCS.

Dietary questionnaires also differed both within and across the survey waves. For example, during GUI infant survey, a 24-hour recall method was used for children aged 3 years, which changed to a food frequency questionnaire for children aged 5 years and then back to a 24-hour recall for children aged 7/8 and 9 years. Parent/self-perceived general health and weight status questionnaires were broadly consistent in most surveys.

A brief illustration of the variation in the question wordings and response categories used across and within cohort surveys has been outlined in Table 4.5. In GUI infant cohort survey waves, parents were asked to describe the study child's current health, while in the GUI child cohort survey waves (waves 1 and 2), the question was framed differently as the parents were asked to describe the study child's health in the past year. During the GUI child cohort survey, for waves 3 and 4, study children were asked to describe their current health; however, the response levels differed from those used in waves 1 and 2.

Table 4.4 Age-wise distribution and comparison of survey questionnaires among the 50 waves of seven surveys.

Domain Construct	Age groups in years																			
	0-1		2-3		4-5		6-7		8-9		10-11		12-13		14-15		16-17		18-20	
	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
Oral health																				
• <i>Dental problems</i>		1, 3		3, 4	4, 6	3, 7	4, 5	3, 6	4, 5	3	4, 5	7	4, 5		4, 5			5		5
• <i>Dental treatments</i>						3		4		1, 4	4, 5		4, 5	2	4, 5			2, 5		
• <i>Parent/Self-perceived oral health status</i>						3			1, 6									2		2
• <i>Dental injury</i>		3, 4	6, 7	3, 4	1, 6, 7; 4, 5	3	4, 5	3, 7	4, 5	1, 3	4, 5	3, 7	4, 5		4, 5	7		5		5
Oral health related behaviours																				
• <i>Toothbrushing frequency</i>			1, 3, 4, 6		4, 6	3	4, 5		1, 4, 5, 6	2	5, 7 & 4, 5		4, 5	2	4, 5	7		5, 7		

• <i>Toothbrushing Supervision</i>				3		4				5, 6										

Table 4.4 Continued...

	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>	<i>C</i>	<i>NC</i>
• <i>Toothbrushing assistance</i>		3, 6		3, 4, 6		4, 6	4, 5			4										
• <i>Toothbrushing starting age</i>				3, 4		4	4, 5		4, 5			5								
• <i>Toothpaste use</i>				3, 6																
• <i>Night brushing</i>				6		3														
• <i>Dental visit behaviour</i>				1, 3, 6		1, 3, 6			1, 2, 6	3		7		2, 3		7		2, 5		2, 5
• <i>Dental services use</i>		4		3, 4		1, 3, 4, 5, 6		3, 4, 5, 6	4, 5	1, 2, 3, 6	4, 5		4, 5	2	4, 5			5		2
General health, weight and diet																				
• <i>Parent/Self-perceived general health status</i>	3, 4, 6	1	3, 4, 6	1	3, 4, 5, 6, 7	1	3, 4, 5, 7	1	3, 4, 5, 6	1, 2	3, 4, 5, 7		3, 4, 5	2	3, 4, 5, 7		2, 5, 7		2, 5	

Table 4.4 Continued...

	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
• <i>Parent/Self-perceived weight status</i>	4, 6		1, 4, 6		1, 4, 5, 6		4, 5		1, 2, 4, 5, 6		4, 5		2, 4, 5		4, 5, 7		5, 7	2		2, 5
• <i>Dietary behaviour</i>	1, 4	3, 6	2, 4	3, 6	1, 6; 4, 5; 3, 7		1, 4, 5		1, 2, 4, 5	6	4, 5	3, 6	2, 4, 5		4, 5	7	2, 5	7	2, 5	

GUI INFANT: 1; GUI CHILD: 2; GUS: 3; LSAC B: 4; LSAC K: 5; GUN: 6; MCS: 7. C: Comparable; NC: Not comparable.

Table 4.5 Illustration of the variations in the question wordings and response levels within and across cohort surveys. The parent/self-perceived general health status questions used in the Growing Up in Ireland surveys.

Survey	Question	Response levels
GUI infant cohort Wave 1, 2, 3, 4 & 5	How would you describe child's current health?	• Very healthy, no problems • Healthy, but a few minor problems • Sometimes quite well • Almost always unwell
GUI child cohort Wave 1 & 2	In general, how would you describe the study child's health in the past year?	• Very healthy, no problems • Healthy, but a few minor problems • Sometimes quite well • Almost always unwell
GUI child cohort Wave 3 & 4	In general, how would you say your current health is?	• Excellent • Very good • Good • Fair • Poor

GUI: Growing Up in Ireland.

4.3.3 Harmonisation Potential Evaluation

An oral health and risk indicator questionnaire DataSchema was compiled, which comprised 42 variables (Supplementary material for review S3). For each study wave, the potential (or not) to generate each DataSchema variable was evaluated. Of the 2100 harmonisation status assessments, 543 (26%) were considered complete. Approximately 50% (n = 21) of the DataSchema variables can be generated across at least 4 cohort surveys, while only 10% (n = 4) of variables can be generated across all surveys. For each survey, the DataSchema variables that can be generated ranged between 26% and 76% (Figure 4.1). The main reason for assigning an incomplete harmonisation status was the absence of information (construct not covered) in the survey questionnaires. The complete harmonisation exercise, including creating DataSchema variables, harmonisation rules, inclusion and exclusion reasons, proposed transformations of study variables to match DataSchema variables and harmonisation status assignments, are detailed in Appendix B, Supplementary file S3.

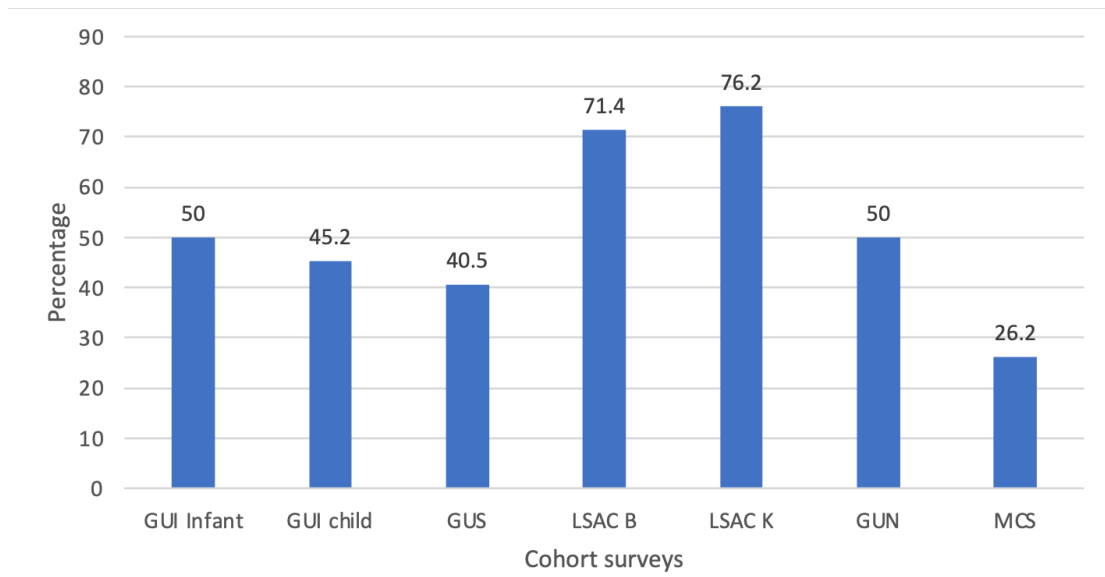


Figure 4.1 Percentage of DataSchema variables (n = 42) that could be generated across cohort surveys. GUI (Growing Up in Ireland); GUS (Growing Up in Scotland); LSAC B (Longitudinal Study of Australian Children Birth cohort; LSAC K (Longitudinal Study of Australian Children Kindergarten cohort; GUN (Growing Up in New Zealand); MCS (Millennium Cohort Study).

4.4 Discussion

As far as the authors are aware, this study, based on nationally representative child cohort surveys from five high-income countries (Ireland, England, Scotland, New Zealand, and Australia) conducted over the last two decades, is the first to evaluate the quality and comparability of oral health-related questionnaire data. A framework was developed for reviewing, collating and comparing study-specific questionnaire data across and within cohort surveys. The authors also demonstrated how data harmonisation can be used to improve the comparability of oral health-related variables both within and across survey datasets. This research adds to the extensive literature of harmonised initiatives undertaken for inferential equivalence, i.e. the potential for harmonisation of study-specific information from individual studies (Joly *et al.*, 2012; Vrijheid *et al.*, 2012; Atkin *et al.*, 2017; O'Neill *et al.*, 2019; Jaddoe *et al.*, 2020; Fortier *et al.*, 2019; Adhikari *et al.*, 2021; Bauermeister *et al.*, 2023).

The DataSchema (a set of 42 variables), created for the harmonisation potential evaluation of oral health-related questionnaire data, was applied to questionnaire data from seven cohort surveys. For each cohort survey, the DataSchema variables that can be generated ranged between 26% and 76%. The MCS survey had a score of 26% which was mainly the result of the non-availability of oral health-related questionnaires in the survey waves. The LSAC surveys scored between 71 to 76% due to consistent and comprehensive coverage of oral health-related questions across the survey waves. In addition, this study found that 50% (n = 21) of the DataSchema variables can be generated across at least 4 cohort surveys, while only 10% (n = 4) of variables can be generated across all surveys. The generation of the harmonised variables increased as the number of participating studies decreased. The present study results were consistent with the findings of the previous harmonisation potential evaluations (Fortier *et al.*, 2011; Fortier *et al.*, 2019; Adhikari *et al.*, 2021; Bauermeister *et al.*, 2023). Fortier *et al.*, while evaluating chronic diseases and risk factors questionnaire data across 53 studies (48 cohorts and 5 cross-sectional), reported that 38% of the created harmonised variables (n = 148) could be harmonised across all studies and the generation proportion increased to 50% when only nine studies (deemed facilitating harmonisation) were considered in the analysis (Fortier *et al.*, 2011). Similarly, during the evaluation of health and risk factor questionnaire data across 12 cohort survey datasets, the authors used 432 harmonised variables and found that the harmonised variables generation across all the datasets was 27%, which increased to 60% for at least 11 datasets. While harmonised variable generation increased with the exclusion of studies, for studies involving a limited number of studies (n = 2-4) at the project's initiation resulted in higher generation potential across the participating studies (Fortier *et al.*, 2016; Fortier *et al.*, 2023). For instance, Adhikari *et al.* evaluated two prospective pregnancy cohort studies for risk factors for pre-term birth and reported that out of the 20 harmonised variables, 18 (90%) were successfully harmonised (Adhikari *et al.*, 2021). Likewise, in a more recent study, authors reported 93% success in harmonising neurodegeneration variables (n = 120) across four diverse cohort datasets (Bauermeister *et al.*, 2023).

Variations in survey questionnaires across cohort surveys may be partially due to regional and language variations and within survey variations could arise due to adjustments to comply with maturing cohorts (Bath, Deeg and Poppelaars, 2010; Fortier *et al.*, 2019). In the current study, as the included cohort surveys had similar methodologies and were representative of English-speaking high-income countries, questionnaire data variations due to study design and cultural or language differences were unlikely. Therefore, the authors believed that the lack of standardised international oral health and risk factor questionnaires and consensus among the cohort survey coordinators could have been the main reason for the observed differences in survey questionnaires both within and across the surveys (Taylor *et al.*, 2023). In the absence of standardised formats for data collection, longitudinal studies gather inaccurate or unusable data (Joda *et al.*, 2019).

The authors followed a flexible approach for harmonisation potential evaluation which allowed for the inclusion of studies that may not be included if strict rules for text and construct matching were used. For example, in wave 2 of the GUI infant and GUS surveys, respondents were asked to report the number of times a toothbrush was used to clean the study child's teeth. However, other surveys asked, 'How often were the study child's teeth cleaned'. Even if the questions in wave 2 of the GUI infant and GUS surveys differed, the variability was accommodated, and the variables were matched with the DataSchema variable for daily toothbrush frequency.

For the reproduction of prior harmonisation works, comprehensive documentation covering study selection to the quality estimation of harmonised products has been recommended (Winters and Netscher, 2016; Fortier *et al.*, 2016; Atkin *et al.*, 2017). Our proposed harmonisation template can easily be updated as new variables become available from future waves and, thus, support the constant improvement of the content of cohort survey datasets. Furthermore, the created DataSchema template can be incrementally expanded to add non-modifiable risk indicators of dental diseases, such as socioeconomic status, ethnicity, and level of parental education. Moreover, cohort surveys from middle and low-income countries could also be added

to the list of nationally representative cohort surveys for evaluating harmonisation potential on a global stage.

4.4.1 Coverage Gaps in Existing Questionnaires

Identifying coverage gaps in survey questionnaires has two main advantages in that it: 1) provides evidence for the designing of questionnaires for future surveys, and 2) facilitates data users to appropriately interpret the quality of available data (Richardson and Ali, 2014). The data coverage gaps identified in the survey questionnaires of the majority cohort surveys by construct were summarised in Table 4.7.

Table 4.6 Oral health-diet questionnaires coverage gaps in national child cohort surveys.

Construct (supporting literature)	Coverage Gaps
Dental injury (Malikaew, Watt and Sheiham, 2003; Andersson, 2013)	Dental injury extent, dentition type (primary or permanent), number of teeth, number of untreated injuries, location of injury, and cause of injury
Dental problems (Sheiham, 2005; Tagliaferro <i>et al.</i> , 2006; Daher, Abreu and Costa, 2015; Dye, 2017; Peres <i>et al.</i> , 2022)	Other dental problems such as bleeding gums, dry mouth, dental crowding, enamel discolorations and defects, bad breadth, orofacial pain, and bruxism (teeth clenching or grinding)
Dental treatments (Luzzi, Chrisopoulos and Brennan, 2014; Peres <i>et al.</i> , 2022)	Preventive dental treatments (fluoride varnish, pit and fissure sealants), type of anaesthesia used during dental procedures (local or general), complex dental treatments (e.g., root canal treatments).
Parent/Self-perceived oral health status (Locker and Jokovic, 1996; Robinson, Nadanovsky and Sheiham, 1998; Locker, Clarke and Payne, 2000; Reissmann <i>et al.</i> , 2013)	Self-perceived oral health needs, impact of poor oral health on the study child's social and emotional needs
Toothbrushing behaviour (Marthaler, 2004; O'Mullane, Clarkson and Parnell, 2018; Davison, McLaughlin and Giles, 2019; Worthington <i>et al.</i> , 2019)	Age when starting toothpaste use, type of toothpaste used, use of dental floss or interdental brushes

Construct (supporting literature)	Coverage Gaps
Dentist visit behaviour (Sheiham, 1977; Duane <i>et al.</i> , 2017; Clarkson <i>et al.</i> , 2021)	Age and purpose of first dental visit, study child's dental fears and anxiety
Dental services use (Locker, Maggiras and Quiñonez, 2011; Onyejaka, Folayan and Folaranmi, 2016; Mayo, Farzam-Kia and Ghahari, 2021)	Frequency of dental service use and type of service received
Dietary behaviour (Whelton <i>et al.</i> , 2006; Ma <i>et al.</i> , 2009; Rankin <i>et al.</i> , 2012)	In between meals snacks, and use of multiple 24-hour recalls

4.4.2 Recommendations

The authors propose general recommendations for cohort survey co-ordinators planning future survey waves and researchers planning retrospective data harmonisation initiatives using cohort survey datasets, consistent with previous publications (Fortier *et al.*, 2010; Fortier *et al.*, 2011; Doiron *et al.*, 2013; Fortier *et al.*, 2016; Atkin *et al.*, 2017; Fortier *et al.*, 2019; Sánchez-Niubo *et al.*, 2020; Taylor *et al.*, 2023). These include:

- 1) Data sharing should be considered at the time of survey initiation, and survey participants should be informed of and consent to use their data beyond the primary study.
- 2) Funding agencies should mandate the sharing of publicly funded data.
- 3) Care must be taken before data collection at the design and validation stage such that the collected data complies with harmonisation and inter-linkable data standards (Joda *et al.*, 2018).
- 4) Data harmonising from multiple studies should be transparent, rigorous, and well-documented to ensure validity.
- 5) Harmonisation should be avoided for non-comparable data derived from different data collection methods.
- 6) In the absence of a clinical oral health examination the inclusion of a nested case-control study design to assess oral health in an existing national cohort

survey should be considered because of the availability of biological, social, behavioural, and general clinical data in these studies.

4.4.3 Strengths and Limitations

The main strength of this analysis is that the results may be viewed as the best available evidence for comparative cross-national longitudinal oral health research using questionnaire data. Sampling details and data collection methods used across the survey waves were evaluated. Outlining these details could facilitate understanding the level of homogeneity across the cohort surveys and potential sample sizes available for analysis (Doiron *et al.*, 2013). A consensus and iterative approach involving the authors was used for creating an oral health and risk indicator DataSchema. Although the included studies were pre-selected, they were nationally representative and shared similar thematic objectives, which ensured some degree of homogeneity. In addition, the data harmonisation process becomes more complex with an increasing number of studies or datasets (Adhikari *et al.*, 2021). Although variable selection, data coverage gaps and pairing rule definitions were undertaken through consensus and advice from subject experts, there is, inevitably, a degree of subjectivity. Oral health-related and other data collected using survey questionnaires rely on parent/self-reported information and are subject to recall bias. Finally, the actual cohort datasets were not acquired for each survey and harmonised versions were not generated to assess the output quality. In line with guidelines on the life course of a harmonisation initiative, future steps could include: 1) acquisition of cohort survey datasets, 2) processing each cohort data under the harmonised format and finally, 3) estimating the quality of the harmonised data (Fortier *et al.*, 2023).

4.5 Conclusions

A framework was developed for reviewing, collating and comparing oral health-related data across and within nationally representative cohort surveys. Data harmonisation can improve the comparability of variables both within and across survey datasets. For each cohort survey, the DataSchema variables that can be generated ranged between 26% and 76%. The generation of the harmonised variables

increased as the number of participating studies decreased. For future cohort survey waves, the authors advocate more consistency and standardisation in survey questionnaires within and between surveys.

CHAPTER 5

5. Protocol for Developing a Dashboard for Interactive Cohort Analysis of Oral Health-Related Data

5.1 Introduction

The most significant event in information dissemination after the invention of the printing press by Gutenberg is the digital revolution (Clarke, 2012). Moreover, recent advances in information technology have resulted in the collection of vast volumes of data globally (Joda *et al.*, 2019). The lack of sufficient detailed information on population health statistics challenges the use of an evidence-based decision making approach for planning, implementing and evaluating public health interventions (Concannon, Herbst and Manley, 2019). Fortunately, national and other large-scale epidemiological surveys collect detailed population data (rich in information from diverse disciplines), providing numerous research opportunities (Weston *et al.*, 2019). Therefore, given the exponential growth of digital data, oral health epidemiologists need to be prepared for a more data-driven approach whether utilising novel or more traditional surveillance data (Höhle, 2017; Joda *et al.*, 2019).

Open data science tools and a working knowledge of data visualisation and analytics are becoming increasingly important in the digital health era (Lowndes *et al.*, 2017; Joda *et al.*, 2018; Joda *et al.*, 2019; Schwendicke and Krois, 2022). Open science has been defined as “the concept of transparency at all stages of the research process, coupled with free and open access to data, code, and papers” (Hampton *et al.*, 2015). Open data science tools have been described as the tools that enable open science when integrated into the scientific process of knowledge discovery (Lowndes *et al.*, 2017). Data visualisation has been defined as “an approach to data analysis that stresses a penetrating look at the structure of data” (Cleveland, 1993). Data visualisation facilitates data understanding through direct sensory experience (primarily visual) rather than logical reasoning (Dix, 2013). Therefore, an understanding and appreciation of human cognitive, perceptual, social and organisational factors may be required to design effective visualisations (Dix, 2013). Data visualisations can be broadly categorised as static and interactive visualisations. Static visualisations are fixed visualisations usually focussed on specific data, whether on paper or screen (Dix, 2013). In addition, static visualisations may not be adequate for exploring large-scale, complex and evolving datasets with varying degrees of

granularity (LaValle *et al.*, 2010; Dix, 2013; Ellis and Merdian, 2015; Concannon, Herbst and Manley, 2019). Interactive visualisations are generally used for the rapid extraction and analysis of salient information from large-scale and multidisciplinary survey datasets (LaValle *et al.*, 2010; Ellis and Merdian, 2015). Specifically, interactive dashboards have been proposed as an excellent tool for analysing data from multiple sources for a variety of potential users (LaValle *et al.*, 2010).

Dashboards have been defined as “a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single screen so the information can be monitored at a glance” (Few, 2006). Dashboards use a combination of different visualisation methods and, generally, dashboards display data as tables, graphs or charts; however, interactivity can be added to increase their scope and coverage (Barnum *et al.*, 2019; Concannon, Herbst and Manley, 2019). The primary purpose of using different visualisation methods in a dashboard is to facilitate timely understanding of data from multiple sources (Sarikaya *et al.*, 2019). The term “faceted analytical display” has been used to describe the analysis of information using a set of interactive charts (primarily graphs and tables) simultaneously on a single screen, where each chart presents a different view of a common dataset (Few, 2006). For an interactive analytical dashboard, the data is presented (on the same or separate screens) in a visual format which supports exploration and interrogation. The viewer can use an interactive filter to change the selected parameters and refresh the output or allow for incremental updates of the dashboard as the input data changes (Xie, Allaire and Grolemond, 2018). This increases the potential impact of the data analysis by allowing interactivity and dynamic visualisations in “real-time” (Ellis and Merdian, 2015). Interactive dashboards may be the ideal data technique for presenting and disseminating health-related information in an accessible format, as it assists in summarising data and alleviating information overload (Cheng *et al.*, 2011; Höhle, 2017; Concannon, Herbst and Manley, 2019; Loginova and Wohland, 2020). The process of creating a dashboard is described as “dashboarding” and has been outlined in detail by multiple authors (Few, 2006; Smith, 2013).

National cohort surveys routinely collect data from different developmental age groups to monitor and track the development and health of children. The impact of these national cohort surveys on improved understanding of the factors affecting child health and well-being outcomes has been acknowledged as they continue to inform health policies and strategies (Emery, Pollock and Scherpenzeel, 2019). While there are obvious benefits for policy makers in analysing national survey data, there is also an onus on researchers to extract and disseminate findings in a useful and accessible manner (Emery, Pollock and Scherpenzeel, 2019; Concannon, Herbst and Manley, 2019). Monitoring and analysing large-scale epidemiological data obtained from national child cohort surveys can help improve our understanding of the risk factors associated with oral diseases (Moynihan and Petersen, 2004; Crowe *et al.*, 2016; Crowe, 2018). Deploying multiple sources of population-level oral health data in an accessible dashboard could help monitor trends, explore risk factors and provide support for policy decisions.

There is a growing need for researchers analysing large-scale survey datasets to work efficiently and transparently to promote understanding and trust among the research community (Lowndes *et al.*, 2017). Reproducibility of research findings, collaboration among researchers, and effective communication between cohort survey research stakeholders facilitate strengthening public trust and effectively inform public health policies (Lowndes *et al.*, 2017; Joda *et al.*, 2018; Joda *et al.*, 2020). The scientific community has proposed reproducible research as a minimum standard for evaluating the value of scientific claims for cases where independent replication may not be possible (Peng, 2011; Boettiger, 2015). For research to be computationally reproducible, the data and the code used for analysis should be made available to independent researchers for them to recreate the findings (Peng and Hicks, 2021). Extracting information from large-scale survey datasets using summary statistics and simple contingency tables with open-source programming language such as R is relatively straightforward and computationally reproducible (Mount and Zumel, 2019; Lowndes *et al.*, 2017). Communicating data analysis output through a dashboard can improve public awareness of research output and encourage greater transparency

with other researchers who are able to easily assess initial findings. Integration with Git (a version control system) and deployment via GitHub pages (web pages hosted through a GitHub repository) promotes rapid communication, enhances collaboration and improves transparency and reproducibility. Ultimately, what is desirable is increased access for researchers, clinicians and policy makers to reported data analysis-visualisation that could benefit individual and population oral health (Twohig *et al.*, 2019; Schwendicke and Krois, 2022).

Markdown is a lightweight markup library used for applying inline style to plain text documents for outputting (Xie, Allaire and Golemund, 2018). R Markdown is R's implementation of Markdown which is used by researchers for generating reproducible reports (Xie, Allaire and Golemund, 2018). *Flexdashboard* is a package developed for R Markdown for rapidly scaffolding the essential parts of a dashboard (Iannone, Allaire and Borges, 2018). A Flexdashboard layout can be created from a template within an R Markdown file. This template can be customised to provide the type of framework for visual display of the elements of a dashboard which can be either dynamic or static. Adding *R Shiny* (Chang *et al.*, 2022) to the Flexdashboard provides reactivity which allows viewers to change the parameters or variables and immediately see the results providing a dynamic rather than static dashboard.

While data-driven dashboards are commonly used as an information exploration and communication tool in a wide range of domains this tool has not been widely deployed in oral health epidemiology (Smith, 2013; Joda *et al.*, 2019; Schwendicke and Krois, 2022). The primary aim of this study was to demonstrate the development and usefulness of an analytical, interactive dashboard for researchers, policy makers, or those interested in exploring national cohort surveys who may not have sufficient training in data analytics or coding skills. In addition, the development and deployment of the dashboard with *R Markdown*, *Shiny* and *Flexdashboard*, using oral health-related data from multiple Irish national child surveys has also been demonstrated.

5.2 Methods

5.2.1 Pre-design evaluation

The objective in pre-design was to decide on the structure and data requirements, user interaction process, visualisation design, and key variable selection. The primary audience for the dashboard is the research community, including policy makers, who are interested in child oral health. The primary goal was to develop an interactive dashboard to explore multiple variables associated with child oral health using the datasets indicated in Table 5.1.

Table 5.1 Data Sources.

Survey	Initial sample size	Year of survey	Wave number	Child age (years)
Growing Up in Ireland infant cohort ^a	11134	2008	2, 3 and 5	3, 5 and 9
Growing Up in Ireland child cohort ^a	8500	2008	1, 2 and 3	9, 13, and 17/18
National Children Food survey II ^b	594	2017	2	5 to 12

^a <https://www.growingup.ie/about-growing-up-in-ireland/>

^b <https://www.iuna.net/surveyreports>

Simple interaction created by adding an input sidebar in the input structure allows the end-user to facet the data through filters before ‘knitting’ the R Markdown document and updates visualisations automatically as the user changes inputs. Simple statistical descriptives including frequency tables and bar plots along with the further displays stratified by gender and socioeconomic status were selected for input.

5.2.2 Dashboard Design

The R statistical programming language was used (within the R studio integrated developer environment) (RStudio Team, 2022) to import, clean, join and aggregate the data from the different data surveys, outlined in Table 5.1. R Markdown was used for basic data wrangling and statistical analysis. The *Flexdashboard* package was used to create the structure-elements of the dashboard and the *Shiny* package, which

allows for interactivity, was embedded within the Flexdashbroad framework within the R Markdown notebook (v.1.1.456) (Xie, Allaire and Grolemond, 2018; Iannone, Allaire and Borges, 2018; Chang *et al.*, 2022).

Consistency in presenting data in the dashboard is important for conveying information and this includes both visual consistency of the elements and data consistency of the labels. Visual consistency of the elements was handled through Flexdashboard and using functions to generate different graphs. Each function takes a variable to display and use consistent graphics parameters. Different surveys had different data designs, instruments, data structures and taxonomy. The key variables selected were chosen based on their known associations with oral health, cariogenic food and drink and weight status (Crowe *et al.*, 2017; Crowe *et al.*, 2020; Štefanová *et al.*, 2020; Gussy *et al.*, 2020; Peres *et al.*, 2022). These included: dental behaviour variables such as reported frequency of toothbrushing, dental attendance and reported history of fillings and extractions; dietary intake of food and drinks typically high in free sugars and BMI status (Cole, 2000). Visualisation design was simplified to standard frequency tables and bar-plots to provide easy interactivity for examining potential associations.

5.2.3 Data Sources

Data sources were static and included the national child cohort surveys listed in Table 5.1. The main data source was the national longitudinal survey of young people in Ireland, the Growing Up in Ireland (GUI) survey. The study began in 2006 and started collecting data in 2008 from two study cohorts: Cohort '98 (comprised of 8,500 nine-year old children born in the year 1998, also called the Child Cohort) and Cohort '08 (consisted of 11,134 nine-months old children born in the year 2008, also called the Infant Cohort). The second National Children's Food Survey (NCFS II) was carried out by the Irish Nutrition University Alliance (IUNA) in 2017–18 and included details on food and nutrient intakes, body weight, physical activity and eating behaviours in children aged 5 to 12 years.

Full details of the surveys are available at the links provided in Table 5.1. The GUI and IUNA/NCFSII surveys were conducted according to the guidelines laid down by the Declaration of Helsinki. Ethical approval for the GUI project was received from a Research Ethics committee convened by the Department of Health and Children while approval for the IUNA project was obtained from the Clinical Research Ethics Committee of the Cork Teaching Hospitals, University College Cork. Data for the GUI surveys was obtained from the Irish Social Science Data Archive (ISSDA, University College Dublin, <https://www.ucd.ie/issda/>) and the NCFSII data files were obtained from the IUNA Database Management Committee.

5.2.4 Data Preparation and Workflow

Data preparation and workflow is outlined in Figure 5.1. All datasets were imported from either .sav or .csv formats into R studio (RStudio Team, 2022). All documents related to this project (except the original data files) were version controlled using GitHub (with Git installed locally) via the R studio integrated development environment (IDE) or terminal command line. Wrangling (tidying and transformation) of the data was carried out for each individual wave before joining waves for longitudinal analysis. All data used for this analysis were unweighted. The R Markdown files and packages created for importing data files, variable renaming and renaming convention, full joins for longitudinal analysis and simple descriptive analysis including frequency tables and bar plots are available for download at <http://github.com/oral-health-nutrition/oral-health-nutrition.github.io.git>.

Programmatic renaming and conversion from the original data frames to a tidy data frame was carried out in R Markdown to help track the lineage of the transformations and integration of code with text. The data were remapped or relabelled to provide more useful descriptive names and ensure the response levels were correctly matched before the data were aggregated (Mount and Zumel, 2019). The main grouping variables were gender and social class. Specific functions were created to generate bar-plots and tables. The dashboard was then populated with the data and tested

before publishing with the version control. Only subjects who participated in all waves of the waves of the GUI cohort surveys were included.

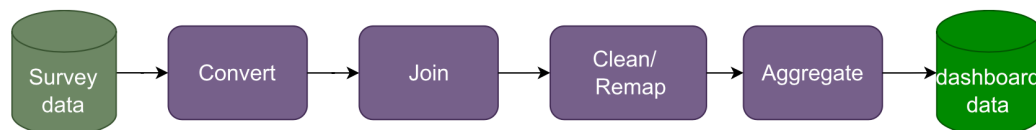


Figure 5.1 Workflow from data import to dashboard development

Ontology mapping minimises differences between survey questions from different waves, or different surveys, aimed at capturing the same information (Bath, Deeg and Poppelaars, 2010). While official data governance provided information about instruments used in questionnaires, ontology was not defined for many variables and the data was not harmonised between waves. For secondary analysis, the data harmonisation included remapping (reducing to common factors using the `forcats` package) and custom dictionaries for programmatic mapping. Variables which were derived from different dietary instruments such as dietary intake measurements or where the response levels did not match were remapped to facilitate cross-wave comparisons or for longitudinal analysis. Response levels were also reordered with custom configuration for effective data visualisation. Variables not reported directly such as BMI classification were calculated. The data were aggregated mainly using tidyverse packages such as `dplyr` and `ggplot2` and `kableExtra`.

5.3 Results

5.3.1 Dashboard Elements

The dashboard layout is structured by the YAML (YAML Ain't Markup Language) metadata at the start of the R Markdown document. The YAML is enclosed within three dashes above and three dashes below as shown in Figure 5.2. The YAML header controls the file format and output style. The Flexdashboard template (*flex_dashboard*) was selected within a new R Markdown document. R markdown provided the framework structure to the Flexdashboard and was also used to add text to explain various sections of the Flexdashboard. The layout was set to 'vertical layout:

scroll' to specify scrolling through multiple charts and the default column orientation set to 'orientation: rows'. To add interactivity, the runtime was set to 'runtime: shiny'. Theme appearance and colours were set using the default 'theme: cosmo'. The general guide about layout is that a page in the dashboard is generated by a first level section (any number of '=' characters) while a column or row is generated by a second-level section (any number of '-' characters). An input sidebar was added by inserting the '.sidebar' (enclosed within curly brackets) attribute to the first column (which also generates a typical Shiny-based dashboard) as shown in Figure 5.3. Finally, the dashboard was populated with text, user inputs and blocks of code to create bar plots and tables to communicate analysis results to the end-users. Survey type, wave of survey and variable selector were set as filter options in the drop-down column (Figure 5.4). Blocks of code were created by adding three backticks ('``') followed by 'r' (name of the programming language) within curly brackets, and finally ending with ('``') (Figure 5.4). To make an output reactive, we used Shiny's *select* and *render* functions which changes input to automatically render code and update output.

```
---
title: "Exploratory Data Analysis of aggregated surveys"
author: "DDUH"
date: "04/09/2021"
output:
  flexdashboard::flex_dashboard:
    vertical_layout: scroll
    orientation: rows
runtime: shiny
source_code: embed
theme: cosmo
---
```

Figure 5.2 The YAML code specifying the layout of the dashboard.

```

Inputs {.sidebar data-width=280}
-----

```{r echo=FALSE}

waveSurveySelector <- reactive({
 waveSelect <- wavesSelector['gui']
 if(input$survey == "NCFS II") {
 waveSelect <- wavesSelector['ncfs']
 }
 if(input$survey == "Child GUI") {
 waveSelect <- wavesSelector['child']
 }
 waveSelect
})

```

Figure 5.3 Generating a Shiny dashboard.

```

Overall summary {data-height=500 data-width=400}

Overall summary graph

```{r echo=FALSE}
renderPlot({
  target_var <- input$target_var
  with_missing <- input$missing_response
  survey <- input$survey
  if(survey == ncsfSurvey){
    p <- ncfsGroupPlot(ncfsDf, target_var, "GENDER")
  }else{
    p <- genBarPlot(target_var, survey, with_missing)
  }
  p
}, res = 72)
```

```

Figure 5.4 Use of custom function (genBarPlot()) for generating bar plots for oral health variables in national cohort surveys.

The final R Markdown document was rendered (using the 'Run' button) into a HTML document to view the dashboard locally. However, this produces a static HTML file. To create reactivity, the Flexdashboard must be deployed using a web server.

### 5.3.2 Deployment of Dashboard

The dashboard can be deployed using a personal or Shiny server. A Shiny account (free version) was set up at <http://www.shinyapps.io/> to enable publishing using an online service for hosting Shiny apps in the cloud. The repository hosting service Github also provides free web hosting on Github pages (<https://pages.github.com/>) which is neatly integrated with R studio and is useful for hosting documentation related to the dashboard or deploying a server-less dashboard. Essentially, GitHub Pages are public webpages hosted and published through GitHub. R studio connect is R studio's publishing platform and the R studio IDE has push-button publishing which conveniently provides sharing of Shiny applications with R studio Connect for R Markdown reports and dashboards. The dashboard can be accessed at <https://dduh.shinyapps.io/dduh/>.

Adding interactive controls or reactive expressions to the dashboard with Shiny generates the dynamic aspects of the components of the dashboard. Variables of interest to the viewer for a specific cohort wave (for GUI data) can be selected using 'survey', 'wave', 'variable to select' filters in the input panel. Once selected the dashboard generates output including bar-plots (and tables) for the selected variables. For example, for the GUI Child cohort at wave 3 (17/18 years old), the response is the number of fillings for the young person (Fig 5.5). At wave 2 (13 years old) the response was a binary (Yes/No) if the child had dental fillings carried out (Fig 5.6). For any variable of interest across any survey or wave the output is automatically stratified by gender and socio-economic status (Fig 5.7).



Figure 5.5 Response frequency of dental filings in GUI cohort 17/18 years old (wave 3).

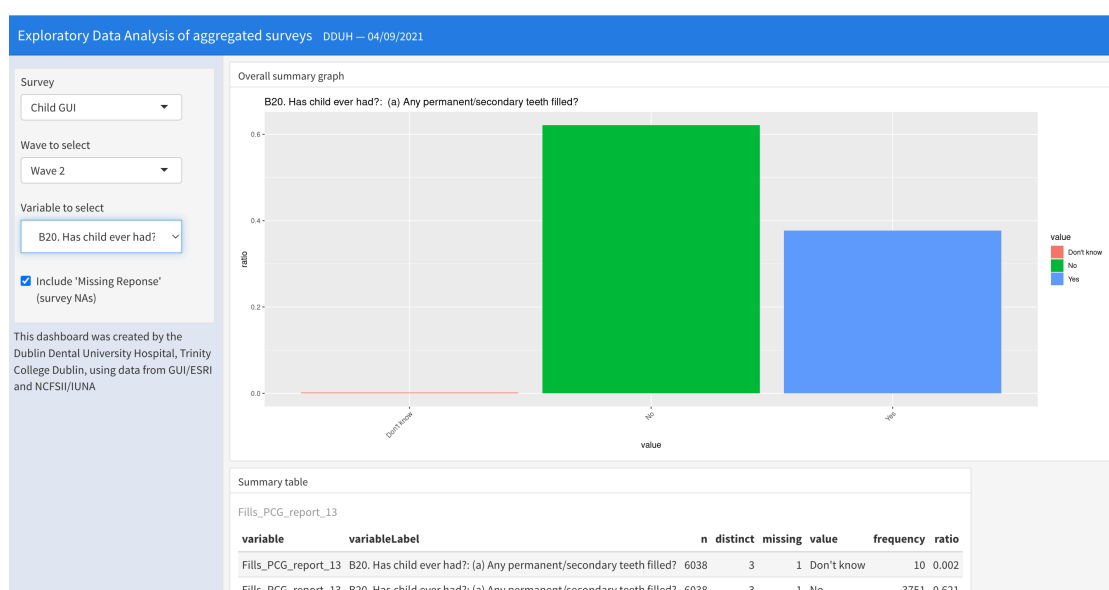


Figure 5.6 Response frequency of dental filings in GUI cohort 13 years old (wave 2).

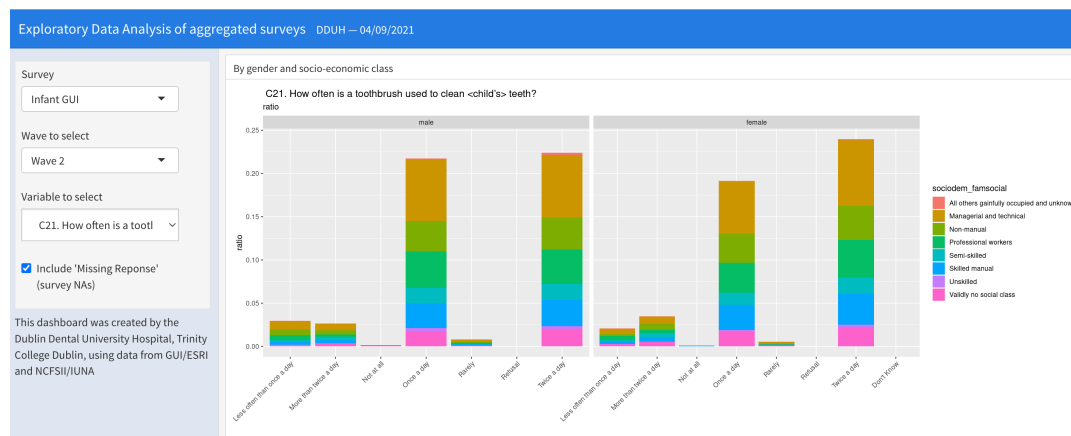


Figure 5.7 Tooth brushing frequency by gender and socio-economic class.

## 5.4 Discussion

This study demonstrated the development of an interactive dashboard which provides a template for other researchers to incorporate as part of their own data visualisations and dissemination. The R Flexdashboard framework with some Shiny attributes included creates a reactive document which can be deployed with a basic knowledge of R. Visualisation of national child cohort data in dashboards allows viewers to dynamically explore oral health related variables from several Irish cohort surveys without requiring multiple plots and tables and sharing of extensive documentation.

There is little empirical evidence data demonstrating the advantages of using data dashboards for public health policy or decision making (Joda *et al.*, 2019; Twohig *et al.*, 2019; Helminski *et al.*, 2022). However, this study suggested that there are a number of advantages to this type of data visualisation including: easy and interactive communication of descriptive statistics, data-driven hypothesis generation, faster dissemination of results, computational reproducibility, incremental (addition of further surveys) and accessible across multiple devices with potential for interactive learning.

As a research tool the dashboard is a rapid means of communicating exploratory descriptive results, an overall summary of variables or data-driven hypothesis

generation. Observation of longitudinal changes within cohort survey participants and inter-survey comparisons of similar variables can provide useful insights into age or cohort changes occurring in developing children. For example, for national representative surveys, comparing the prevalence of dental fillings or frequency of tooth brushing across cohort waves is a useful descriptive measure for policy makers. Similarly, a readily accessible measure of the trends in other oral health behaviours such as dental attendance or dietary consumption of sugar-sweetened beverages can provide support for public health action. In addition, machine learning models, predictive analytics and AI-based decisions may also be imbedded in these dashboards for predicting response rates and other child-oriented outcomes in the future waves of child cohort surveys (Golafshar *et al.*, 2021).

Missing data due to increased non-response and participant attrition is a well-recognised challenge in longitudinal data analysis (Ibrahim and Molenberghs, 2009). Okpara and colleagues suggested that failing to assess the robustness of the missing data results and exclusion of participants with missing data are common practices in longitudinal research and result in insufficient and unclear reporting of research findings (Okpara *et al.*, 2022). The dashboard developed in the present study allows end users to view descriptive analysis results, with or without having the missing responses, as shown in Figure 5.8. The addition of automated alerts in dashboards to help identify non-response rates for individual survey items may help the management of non-response and participant attrition for future survey waves (Murphy *et al.*, 2019; Okpara *et al.*, 2022).

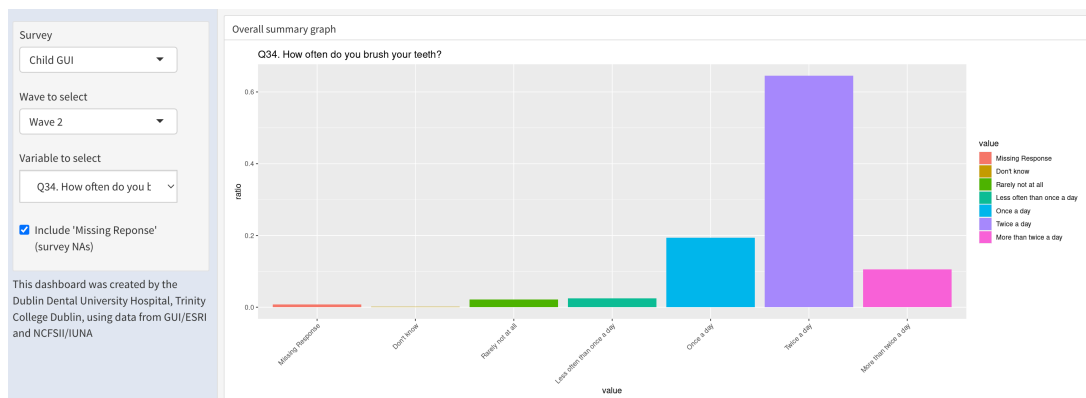


Figure 5.8 Tooth brushing frequency with missing responses in GUI child cohort at 13 year olds (wave 2).

Version control systems (VCS) facilitates researchers manage source code and track each version of the project (Zolkifli, Ngah and Deraman, 2018). Andy Hunt and Dave Thomas have termed version control systems “a giant UNDO key – a project-wide time machine” (Thomas and Hunt, 2019). In the R studio environment version control is neatly integrated with GIT which is hosted on GitHub. Git is a software version control system which allows researchers and collaborators to keep track of the code produced and the changes that any of the research team make to it. Version control is an essential element of any reproducible research project including R Markdown files used to create this dashboard. With a GitHub account (and Git installed) a repository can be created and linked to an R project as used in this dashboard project. As well as improving computational research reproducibility GitHub Pages can also be used to share other static content that can be ‘pushed’ from the repository such as a project related blog to improve visibility of the research and sharing of the R code used.

Another useful feature is that the dashboard can be displayed on multiple devices including tablets and mobile phones. This may provide an enhanced user experience for teaching environments, for example, and provide some interactive learning opportunities. It is important to note that while Flexdashboard provides an easy template to begin using dashboards there are more customisation options when using Shiny dashboard alone to create a dashboard. While storing data in SQL (Structured

Query Language) database would be more optimal, current restrictions on accessing the data files used in this manuscript do not permit this. It is important to note that using R to build dashboards is free, however, for building complex visualisations more advanced knowledge of R is required, which may be a time investment (Golafshar *et al.*, 2021). Other commercial dashboard softwares, such as Tableau (Beard and Aghassibake, 2021), Google Cloud Business Intelligence, and Microsoft Power Business Intelligence (Lachev and Price, 2015) are highly customisable with drill down features, allowing researchers to suit the specific need of presenting results to a larger population (Barnum *et al.*, 2019).

One of the issues in health sciences research is the lack of training of researchers whose primary field is neither visual design or data analytics (Höhle, 2017; Helminski *et al.*, 2022). Some commentators have proposed that data literacy should be a core competence in dental curricula (Schwendicke and Krois, 2022). Lowndes *et al.*, suggested lack of exposure (knowing the specific tools required) and confidence (to develop the skills to use these tools) as the main barriers to engagement of researchers with open science tools. Many of the toolbox of skills now required by researchers include an array of data techniques to allow them to reshape, transform, visualise and disseminate data. While a basic knowledge of R is sufficient for data preparation and dashboard development the learning curve for this more complex skillset is steep. Many of the open data science tools used in this project including distributed version control systems such as Git/GitHub, R Markdown for literate programming and RStudio projects are regarded as essential to meet the current standards for collaborative, efficient data analysis and communication. We suggest that, given the exponential growth of digital data, dental researchers need to be prepared for a more data-driven approach whether utilising novel or more traditional surveillance data (Höhle, 2017; Joda *et al.*, 2019). However, most dental researchers face a number of obstacles when analysing and disseminating research findings from secondary data including difficulties with data sharing, user capabilities, data literacy and standardisation (Joda *et al.*, 2019; Schwendicke and Krois, 2022).



The present study demonstrated the ease and speed of deployment of a cohort survey dashboard using a Flexdashboard template. However, because of the lack of standardisation of survey questions and other data collection instruments both within and across cohort surveys, the majority of time was spent on data wrangling, reorganising and harmonisation than actually building the dashboard. Data wrangling which describes the tidying and transformation of data is the most time-consuming and, arguably, demanding programming task compared to analysis and modelling (Smirnova *et al.*, 2018).

Developing an effective dashboard is only the first stage in communicating and disseminating research findings. Strategies to improve the uptake of dashboards and training for both researchers and end-users is essential to achieve any real beneficial outcomes (Helminski *et al.*, 2022). However, data dashboards appear to be a promising means of sharing and collaborating and are an example of how literate programming and dynamic documents can contribute to research reproducibility.

## **5.5 Conclusion**

Dashboard development requires minimal non-standard R coding which can be quickly created with open-source software. This manuscript provides an illustration of, and guidance for, the deployment of such a dashboard as a means of communicating descriptive results or for hypothesis generation for factors related to oral health.

## **CHAPTER 6**

### **6. Socioeconomic Differences in Oral Health in Irish Adolescents: Role of Behavioural, Material and Psychosocial Factors: Findings from a National Longitudinal Survey in Ireland**

## **6.1 Introduction**

Oral health is integral to overall health and affects an individual's physical, social, and psychological well-being (Sheiham, 2005). Poor oral health causes pain and discomfort and influences how an individual eats, speaks, smiles, looks and socialises (Jackson *et al.*, 2011). In addition, oral disease treatment costs impose a substantial economic burden on families and societies (Listl *et al.*, 2015; Patel, 2012; Righolt *et al.*, 2018). With an estimated prevalence of 3.5 billion cases globally, oral diseases have been ranked among the most common non-communicable diseases (World Health Organisation, 2023). In Ireland in 2017, nearly 40% of children aged 12 years had dental caries (Oral Health Services Research Centre. University College Cork, 2018). The improvement in oral health in Ireland has been attributed to the widespread use of fluoridated toothpaste since the 1980s and the fluoridation of public water supplies since the 1960s (Department of Health Ireland, 2019). The prevalence of dental caries in children living in high-income countries has plateaued over the last three decades. Still, dental caries continues to rise among children of lower socioeconomic status families, leading to increased inequalities between SES groups (Peres *et al.*, 2020b).

### **6.1.1 Socioeconomic Inequalities in Oral Health**

The social determinants of health (SDoH) play a major role in the development of oral diseases and health inequalities (Petersen, 2005; Petersen *et al.*, 2005; Peres *et al.*, 2007a; Peres *et al.*, 2019). Socioeconomic disparities are the most fundamental causes of oral health inequalities (Adler and Newman, 2002; Sabbah *et al.*, 2009; Marmot and Bell, 2011). Socioeconomic oral health inequalities are a universal phenomenon (Petersen *et al.*, 2005). There is a global consensus that the levels of oral diseases are higher in more deprived populations than their better-off counterparts (Sisson, 2007; Schwendicke *et al.*, 2015). The WHO (World Health Organisation), in its Global Health Strategy, has recognised “a very strong and consistent association between socioeconomic status (income, educational level and occupation) and the prevalence and severity of oral diseases across populations in high, middle and low-income countries” (World Health Organisation, 2023).

#### **6.1.1.1 Pathways to Socioeconomic Oral Health Inequalities**

Three explanatory models (behavioural/cultural, psychosocial, and materialistic) have been proposed to explain socioeconomic health inequalities (Townsend, Whitehead and Davidson, 1992; Bartley, 2017). The potential role of each explanatory model in defining oral health inequalities will be discussed below.

##### **a) Behaviour/Cultural Pathway**

The behaviour hypothesis argues that people from lower social positions are more likely to participate in unfavourable/risky health behaviours than those from higher social positions; consequently, their health is worse than those from higher social positions (Townsend, Whitehead and Davidson, 1992). A social gradient exists for oral health and oral health behaviours, and the dual relationship of oral health behaviours with oral health on one side and SES measures on the other suggests behaviours may play an important role in explaining social health inequalities in oral health (Thomson *et al.*, 2000; Maliderou, Reeves and Noble, 2006; Sabbah *et al.*, 2014). The evidence suggested that oral health disparities could be eliminated or reduced by providing better access to preventive dental services and positive changes in individuals' health behaviours (Wamala, Merlo and Boström, 2006; Sabbah *et al.*, 2009; Guarnizo-Herreño *et al.*, 2019; Stein, Cunha-Cruz and Hugo, 2021). However, others have argued that oral health disparities could not be improved solely by behavioural interventions (Sanders, Spencer and Slade, 2006; Polk, Weyant and Manz, 2010; Sabbah *et al.*, 2014).

##### **b) Material Pathway**

The material explanation focuses on the role of structural, material and economic constraints in health inequalities (Bartley, 2017). It has been proposed that material factors, such as financial difficulties experienced by people in the lower SES groups, can restrict an individual's ability to afford the quality dental care and a healthy diet required for maintaining a healthy dentition (Sisson, 2007; Duijster *et al.*, 2017; Tsakos, Watt and Guarnizo-Herreño, 2023). It has been hypothesised that material factors could affect oral health either directly or indirectly via behavioural and

psychosocial factors (Floor, Frank and Johan, 2005; Sisson, 2007). When compared with higher SES groups, lower SES groups purchase higher amounts of foods and drinks rich in free sugars, a well-known risk factor for dental caries (Maliderou, Reeves and Noble, 2006; Sisson, 2007).

### **c) Psychosocial Pathway**

The psychosocial pathway emphasises the role of perceptions of control and social standing in influencing health and, hence, explaining health inequalities (Bartley, 2017). Those belonging to lower SES groups are hypothesised to experience higher levels of psychosocial stress and lower levels of social support than higher SES groups, which in turn have been shown to affect health directly or indirectly (Tsakos, Watt and Guarnizo-Herreño, 2023). The proposed mechanisms through which psychosocial factors could impact oral health include their influence on oral health behaviours and impact on biological responses resulting in elevated inflammatory burden (Tsakos, Watt and Guarnizo-Herreño, 2023).

In addition to the behavioural, material and psychosocial explanations, the life-course approach has also been proposed to explain oral health inequalities. The life-course theory suggests that the oral health status of an individual at a given age is the outcome of biological, environmental and social advantages and disadvantages experienced over an individual's entire lifespan (Heilmann, Tsakos and Watt, 2015).

It has been suggested that these pathways are not mutually exclusive, and it is likely that a combination of these pathways underlie SES inequalities in oral health (Singh *et al.*, 2016).

To the best of our knowledge, no study has investigated the role of behavioural, material and psychosocial factors to explain socioeconomic differences in parent- and self-reported oral health in adolescents using a longitudinal study design.

### **6.1.2 Aims and Objectives**

This study was undertaken to a) study socioeconomic differences in a young person's parent and self-reported dental health at 17/18 years of age and b) investigate the role of behavioural, material and psychosocial factors in explaining socioeconomic inequalities in a young Irish persons' oral health.

#### ***Research Objectives:***

- 1) Study the relationship between SES measures (PCG's highest educational level, household/family income, family occupational class and medical card status of study participants) at 13 years of age and parent- and self-reported oral health outcomes (parent-reported number of permanent teeth with fillings and young person's self-rated oral health status) at 17/18 years.
- 2) Investigate the potential role of behavioural, material and psychosocial factors in explaining socioeconomic disparities in Irish adolescents' oral health.

## **6.2 Methods**

### **6.2.1 Study Population and Sampling**

Growing Up in Ireland (GUI) is a multi-domain, large-scale and nationally representative longitudinal study carried out jointly by the Irish Department of Children, Equality, Diversity, Integration and Youth (DCEDIY) and the Central Statistics Office (CSO) (DCEDIY and CSO, 2023). The study commenced in 2006 and collected comprehensive data on a nationally representative sample of children. The study has two cohorts described as the Infant cohort and Child Cohort (also called cohort'08 and cohort'98).

For the GUI child cohort, the sampling frame was provided by the Department of Education. Sampling was completed in two stages; firstly, a random sample of schools was selected from all the primary schools in the Republic of Ireland, and during the second stage, a random sample of children of the 9-years age group was recruited from the selected schools (Murray *et al.*, 2010). This longitudinal study follows a fixed panel design and only children selected at the first wave were followed in subsequent

waves (Table 6.1). There was no provision for addition of new participants to the survey. The school population was stratified according to county, disadvantaged status, religious dominance, gender mix and categorical size (total number of 9-year-olds) (Murray *et al.*, 2010).

Table 6.1 Growing Up in Ireland child cohort survey.

| <b>Child Cohort'98</b> | <b>Wave</b> | <b>Year of data collection</b> | <b>Age at the time of interview</b> | <b>Sample size</b> | <b>Data collection method</b> |
|------------------------|-------------|--------------------------------|-------------------------------------|--------------------|-------------------------------|
|                        | 1           | 2007-08                        | 9                                   | 8,568              | Face-to-face interview        |
|                        | 2           | 2011-12                        | 13                                  | 7,525              | Face-to-face interview        |
|                        | 3           | 2015-16                        | 17/18                               | 6,216              | Face-to-face interview        |
|                        | 4           | 2018-19                        | 20                                  | 5,190              | Face-to-face interview        |

The data were collected from the primary caregivers (PCG) or study participants using home interviews (conducted on Computer Assisted Interview (CAI) and Computer Assisted Self Interview (CASI) basis), school-based interviews (on a pen-paper basis) and food frequency and time use diaries (mail basis) (Thornton *et al.*, 2013). Further details of the GUI surveys are available at <https://www.growingup.gov.ie/>.

#### **6.2.1.1 Data Source**

The original GUI child cohort sample comprised 8,568 children aged nine years randomly selected from 910 primary schools in 2007. The study children were subsequently followed up at 13 (2011/12), 17/18 (2015/16) and 20 years (2018/19) (Table 6.1). This study has used data from the first three waves when the children in the Child cohort were nine, subsequently 13 and 17/18 years of age. The present study included 6,039 households that participated in all three waves. The GUI sample has been reweighted or statistically adjusted to ensure they are nationally representative of the age groups (Murray *et al.*, 2010).

### **6.2.2 Study Measures**

In this Chapter the longitudinal relationship between exposure and outcome has been investigated. Therefore, the outcome measures were selected from wave 3, the SES measures, behavioural factors, material factors and psychosocial factors from wave 2 and covariates (potential confounders) from wave 1 datasets.

#### **6.2.2.1 Outcome Measures**

Two measures of oral health were used as the main outcome variables: Self-rated oral health by the young persons and the number of permanent teeth with dental fillings the study participant had received which was reported by the primary caregivers.

#### **Self-Rated Oral Health (SROH)**

SROH is a measure used to assess an individual's oral health status and has been shown to be a valid and reliable indicator that displays oral health inequalities (Locker, Clarke and Payne, 2000; Wamala, Merlo and Boström, 2006; Sanders, Spencer and Slade, 2006; Sabbah *et al.*, 2009). This measure has been used extensively in public health research, particularly among young adults (Broadbent, Thomson and Poulton, 2006; Polk, Weyant and Manz, 2010; Duijster *et al.*, 2017). During wave 3 of the GUI child cohort survey, the self-rated oral health of young persons was measured by the survey item: , *"How would you rate your oral health? Responses were on a 5 point quality Likert scale: ...1) Excellent; 2) Very good; 3) Good; 4) Fair; 5) Poor.* In concordance with previous literature, for this analysis, the response choices were dichotomised into optimal (excellent, very good, good) and suboptimal (fair and poor) (Duijster *et al.*, 2017).

#### **Number of Permanent Teeth with Dental Fillings**

For an individual, the number of teeth with dental fillings provides a quantitative estimate of the accumulated burden of dental caries experience (Broadbent *et al.*, 2011; Broadbent *et al.*, 2016). Self/parent-reported dental fillings, dental caries and other similar oral health outcomes have previously been used in large-scale epidemiological surveys (Levin, Shpigel and Peretz, 2013; Silva *et al.*, 2014; Aida *et al.*,



2017; Goldfeld *et al.*, 2019; Sanchez *et al.*, 2020; Matsuyama, Fujiwara and Aida, 2023).

The number of permanent teeth with fillings were reported by the primary caregiver. The following survey item was used: “How many, if any, permanent teeth (i.e. secondary or adult) has the young person had filled? And the responses were: 1) None; 2) One; 3) Two; 4) Three or more”.

#### **6.2.2.2 Socioeconomic Position Measures (Main explanatory variables)**

Measures of socioeconomic position were the main explanatory variables and included the PCG’s highest level of education, equivalised household income, family occupational class and study child’s medical card status as reported by the PCGs.

##### **PCG's Highest Level of Education**

As in previous similar studies, the response levels were recoded into three levels:

1) None or primary; 2) Secondary level; 3) Tertiary level (Duijster *et al.*, 2017; Mikkonen *et al.*, 2020).

##### **Family Income (Equivalised Income Quintiles)**

In GUI surveys, an equivalised household income was created by considering household size and structure to ensure meaningful comparisons across households. First, disposable household income was recorded as total gross household income minus statutory deductions of income taxes and social insurance contributions. Equivalised household income was then calculated by dividing the disposable household income by the equivalised household size (weight assigned to each household member) (Quail *et al.*, 2014).

While assigning income quintiles, all households were ranked in terms of equivalised household income. The lowest 20 per cent were assigned to the bottom quintile, the next 20% to the 2<sup>nd</sup> quintile and so on – until the top 20% of households were assigned to the highest income quintile (Thornton *et al.*, 2011).

### **Occupation (Family Occupational Class)**

In the GUI surveys, PCG (primary caregivers) and SCG (secondary caregivers) social classes were derived from their occupations. During the interview, both caregivers were asked to provide their occupational details. The higher social class category of both partners in the household was taken as the household's social class (the dominance criteria) (Quail *et al.*, 2014). In this analysis, the three category household social class classification (Professional managers, Other non-manual/Skilled manual and Semi-skilled/Unskilled) provided in the original GUI wave 2 dataset has been used to report the family occupation.

### **Medical Card Status of Study Child**

In the Republic of Ireland, Medical Card ownership has been used as a surrogate for deprivation (Whelton *et al.*, 2006; Keane, Regan and Walsh, 2021). Medical Cards are issued by the regional Health Boards to individuals who cannot afford health care for themselves and their dependents. Entitlement to a Medical Card is based on a means test, and persons with a medical card are entitled to free primary, community and public hospital care (Citizens Information Board, 2023). In addition, Medical Cards can also improve access to care. Those with a Medical Card are entitled to public community services such as social worker services, physiotherapy, or public health nursing. Moreover, Medical Card families also receive free dental, ophthalmic, and aural services and appliances. Those over 70 years of age are also entitled to a Medical Card regardless of their income status (Citizens Information Board, 2023).

The information about the Medical Card status of the study child was collected using the survey item: *"Is child covered by a medical card? And the response options were: 1) Yes, full card, 2) Yes, doctor only card and 3) Not covered"*.

#### **6.2.2.3 Behavioural Factors**

Oral health behaviours have been defined as "the complex effect on the individual oral health of oral hygiene habits, nutritional preferences and the pattern of a person's utilisation of dental services" (Kirch, 2008). During the life course, oral health

behaviours can vary (Leary and Do, 2019). Up to the age of 10-12 years, a child's oral health behaviours are the parent's responsibility, and after that, children are supposed to take care of their oral health independently (Baumgartner, Wang and Wigen, 2022). The behavioural factors were selected based on previously published literature (Sanders, Spencer and Slade, 2006; Sabbah *et al.*, 2014; Duijster *et al.*, 2017; Mariëlle *et al.*, 2021; Fleitas Alfonzo, Bentley and Singh, 2022). The following four behavioural factors were selected: daily toothbrushing frequency, dental visit behaviour, sugary foods intake frequency and sugary drinks intake frequency.

The following behaviours have been considered unfavourable to oral health: a) less frequent toothbrushing (less than once a day or never); b) high dietary intake of non-diet soft drinks (once or more daily); c) high dietary intake of foods rich in free sugars (once or more than once daily); and d) visiting the dentist never or only when there is a dental problem (Sabbah *et al.*, 2014; Broadbent *et al.*, 2016; Duijster *et al.*, 2017; Su *et al.*, 2022).

#### **6.2.2.4 Material Factors**

Material factors selected were financial difficulties, Delivering Equality of Opportunity in Schools (DEIS) status, private medical insurance, house ownership (Floor, Frank and Johan, 2005; Hiyoshi *et al.*, 2014; Duijster *et al.*, 2017; Novrinda *et al.*, 2019; Mariëlle *et al.*, 2021; Fleitas Alfonzo, Bentley and Singh, 2022).

In the RoI, the DEIS programme recognises schools in areas with concentrated levels of disadvantage and is the Department of Education's main policy initiative to respond to educational disadvantage. In 2021/22, 884 schools were in the DEIS programme, serving approximately 20% of the overall school population (Department of Education, 2022).

#### **6.2.2.5 Psychosocial Factors**

Psychosocial factors were selected by following the literature on general and oral health inequalities (Sisson, 2007; Lee and Divaris, 2014; Hiyoshi *et al.*, 2014; Novrinda

*et al.*, 2019; Tsakos, Watt and Guarnizo-Herreño, 2023) The following variables were selected: a) Family structure, defined as whether the PCG lived alone with children or was married/cohabiting and the number of children (aged < 18 years) in the household; b) PCGs' depression status, defined using the 8-item short version of the Center for Epidemiological Studies Depression Scale (CES-D) (Hann, Winter and Jacobsen, 1999); c) PCGs' parental stress, defined using the parental stress scale score developed by Judy Berry and Warren Jones, 1995 (Quail *et al.*, 2014); d) PCG's job stress

#### **6.2.2.2 Covariates (Potential Confounders)**

Based on the previously published literature, some potential confounders of the association between SES measures and self-reported oral health outcomes were selected for inclusion in this analysis: area of residence, main language spoken at home and PCG's country of birth (a proxy for ethnicity) (Farkas, 2017; Hannigan *et al.*, 2020) (Duijster *et al.*, 2017; Fleitas Alfonzo, Bentley and Singh, 2022). These variables were selected from the wave 1 survey dataset.

A Directed acyclic graph describing the potential pathways in the relationship between socioeconomic measures at 13 years of age and young persons' oral health at 17/18 years of age has been outlined in Chapter 2 (Figure 2.4). The study variable transformations carried out before data analysis are shown in Chapter 2 of this thesis (Table 2.5).

#### **6.2.2 Statistical Analysis**

The summary statistics of the selected variables were reported using the number and percentages of study participants (for categorical variables) and mean and standard deviation (for continuous data). Grouped bar plots and frequency tables were used to visualise two sets of distributions:

1) Oral health outcomes by a) SES measures, b) Behavioural factors, c) Material factors and d) Psychosocial factors.

## 2) Behavioural, material and psychosocial factors by SES measures.

The bivariate associations between gender and study variables were analysed using Chi-square tests (for categorical variables) and an independent t-test (for continuous variables).

The conceptual model proposed by Baron and Kenny was used to test the mediating role of behavioural /material /psychosocial factors in the relationship between SES and oral health outcomes (1986).

The following four relationships were investigated:

- a) The relationship between SES measures (predictor) and young persons' oral health (outcome).
- b) The relationship between behavioural /material /psychosocial factors (mediator) and young persons' oral health (outcome).
- c) The relationship between SES measures (predictor) and behavioural /material /psychosocial factors (mediator).
- d) The relationship between SES measures (predictor) and young persons' oral health (outcome) after adjusting for behavioural /material /psychosocial factors (mediator).

This approach has already been used in previously published studies on general and oral health inequalities among adolescents and adults (Sanders, Spencer and Slade, 2006; Wamala, Merlo and Boström, 2006; Richter, Moor and Lenthe, 2012; Ravaghi *et al.*, 2012; Duijster *et al.*, 2017).

Logistic regression models were used to test the bivariate relationships between 1) SES measures and young persons' oral health (self- and parent-reported, 2) SES measures and behavioural /material /psychosocial factors, and 3) behavioural /material /psychosocial factors and young persons' oral health. Associations between SES measures and the parental stressor scale scores were determined using one-factor ANOVA. The potential mediation of behavioural /material /psychosocial factors in the

SES measures and young persons' relationships was evaluated using a series of logistic regression models (Table 6.2).

Table 6.2 Logistic regression models to evaluate the potential mediation of behavioural /material /psychosocial factors in the SES measures and young persons' relationships

| Model   | Variables added to the model                            |
|---------|---------------------------------------------------------|
| Model 1 | SES measure + Covariates + Outcome variable             |
| Model 2 | Model 1 + Behavioural factors                           |
| Model 3 | Model 1 + Material factors                              |
| Model 4 | Model 1 + Psychosocial factors                          |
| Model 5 | Model 1 + Behavioural + Material + Psychosocial factors |

The relationship between an oral health outcome and the SES measure after adjusting for covariates ('area of residence', 'the main language spoken at home', 'PCG's country of birth') was studied in Model 1. In Model 2, the behavioural factors were added to Model 1. Similarly, Models 3 and 4 added material and psychosocial factors to Model 1. In Model 5, the relationship between an oral health outcome and SES measures were examined after simultaneously adjusting for covariates, behavioural, material and psychosocial factors.

For each model, the percentage change in ORs (Odds Ratio) was calculated using the following formula (Floor, Frank and Johan, 2005; Richter, Moor and Lenthe, 2012):

$$PCOR = ((OR_{\text{Reference model}} - OR_{\text{Reference + more}}) / (OR_{\text{Reference model}} - 1)) * 100$$

Where  $OR_{\text{Reference model}}$  = OR obtained in the first model,  $OR_{\text{Reference + more}}$  = OR obtained by adding new variables in the reference model and PCOR = Percentage change in the magnitude of the first OR.

The percentage change in the OR of the reference model was used as an indicator of the magnitude of a possible mediating effect (Wamala, Merlo and Boström, 2006). The change in the OR was set at 100% when an OR was lower than 1 because this

study was interested in studying the change in OR relative to the highest SES group, which by definition was 1 (Floor, Frank and Johan, 2005). The major limitation of the percentage change formula is that the percentage change can be similar for different absolute changes in ORs. However, the main advantage of using the above method is that it can be used to estimate the direct and indirect effects of explanatory factors (Floor, Frank and Johan, 2005).

Weighted survey data were analysed using R (R Core Team, 2022) and SPSS version 27.0. Only young persons with complete data were included in the analysis. A p-value <0.05 was used to determine statistical significance.

## **6.3 Results**

### **6.3.1 Exploratory Analysis**

#### **6.3.1.1 Descriptive Results**

The distribution of the study variables for the total sample and grouped by gender is presented in Table 6.3. A total of 6,039 young persons participated in the first three waves of the GUI child cohort survey, of which approximately 49% were young males and 51% were young females. The number of respondents varies because the number of missing values for individual variables varied.

When the study participants were nine years of age, fifty-six per cent of the families were living in rural areas, about 82% reported English as the main language spoken at home, 94% of the primary caregivers (PCGs) were Irish citizens, and 85% of the PCGs were born in the Republic of Ireland.

When the study participants were 13 years old, about 3% of boys and 4% of girls had primary caregivers (PCGs) with only primary /no formal education, about 20 per cent of the participating families belonged to the lowest income quantile, the percentages of young males and girls from lower occupational-class (semi-skilled /Unskilled) families were 12% and 15%, respectively and approximately one-third of the boys and girls had a full medical card.

Sixty-seven per cent of boys and 80% of girls followed the recommended or greater than recommended daily toothbrushing guidelines of brushing teeth twice daily. Approximately 7% of boys and 4% of girls brushed their teeth less than once /rarely

/not at all. About 14% of children never attended /only attended a dentist for dental problems. Between 17-20% of the sample reported dietary intake of sugary foods and drinks more than twice a day.

More than half of the participating households reported financial difficulties in making ends meet. In the region, about half of the children were covered by private medical insurance. Approximately, 18% of the children were studying in DEIS schools, and about one-fifth of the families lived in rented/rent-free accommodations.

The PCGs' mean parental stressor scale score was 10.2 (4.17), and approximately 11% of the PCGs were depressed based on their Center for Epidemiological Studies Depression Scale (CES-D) scores. Approximately 20% of female study participants' PCGs were single parents, and for males, the percentage was 17%. About one-third of the study participants' PCGs reported having experienced job stress.

At 17/18 years, the number of permanent teeth with dental fillings the study participants had were reported by their parents. Approximately 16% and 18% of the young males and young females had three or more permanent teeth with dental fillings, respectively. Approximately 10% of young males and 4% of young females rated their oral health status as sub-optimal (fair/poor).



Table 6.3 Distribution of study variables among young males and females (N = 6,039)

| Variable name                                                  | Variable category                | Total n (%)  | Young Males n (%) | Young Females n (%) | p-value |
|----------------------------------------------------------------|----------------------------------|--------------|-------------------|---------------------|---------|
| Socio-demographic variables (Covariates) Wave 1                |                                  |              |                   |                     |         |
| Region<br>(n = 6,025)                                          | Rural                            | 3,375 (56.0) | 1,749 (56.9)      | 1,626 (55.1)        | 0.178†  |
|                                                                | Urban                            | 2,650 (44.0) | 1,327 (43.1)      | 1,323 (44.9)        |         |
| Main language spoken at home<br>(n = 6,035)                    | Other                            | 344 (5.7)    | 176 (5.7)         | 168 (5.7)           | 0.939†  |
|                                                                | Irish                            | 720 (11.9)   | 363 (11.8)        | 357 (12.1)          |         |
|                                                                | English                          | 4,971 (82.4) | 2,541 (82.5)      | 2,430 (82.2)        |         |
| Citizenship of PCG<br>(n = 6,033)                              | Not Irish                        | 361 (6.0)    | 183 (5.9)         | 178 (6.0)           | 0.893†  |
|                                                                | Irish citizen                    | 5,672 (94.0) | 2,896 (94.1)      | 2,776 (94.0)        |         |
| PCG’s Country of birth<br>(n = 6,035)                          | Outside Ireland                  | 898 (14.9)   | 457 (14.8)        | 441 (14.9)          | 0.925†  |
|                                                                | Ireland                          | 5,137 (85.1) | 2,623 (85.2)      | 2,514 (85.1)        |         |
| Socio-economic variables (Main explanatory variables) (Wave 2) |                                  |              |                   |                     |         |
| Primary care giver’s highest level of education<br>(n = 6,039) | None or primary                  | 213 (3.5)    | 102 (3.3)         | 111 (3.8)           | 0.041†  |
|                                                                | Secondary                        | 4,557 (75.5) | 2,294 (74.4)      | 2,263 (76.5)        |         |
|                                                                | Tertiary                         | 1,269 (21.0) | 686 (22.3)        | 583 (19.7)          |         |
| Family income – quintiles<br>(n = 5,586)                       | Lowest                           | 1,155 (20.7) | 573 (20.1)        | 582 (21.3)          | <0.001† |
|                                                                | 2 <sup>nd</sup>                  | 1,125 (20.1) | 562 (19.7)        | 563 (20.6)          |         |
|                                                                | 3 <sup>rd</sup>                  | 1,115 (20.0) | 517 (18.1)        | 598 (21.9)          |         |
|                                                                | 4 <sup>th</sup>                  | 1,146 (20.5) | 642 (22.5)        | 504 (18.4)          |         |
|                                                                | Highest                          | 1,045 (18.7) | 558 (19.6)        | 487 (17.8)          |         |
| Family class (Occupation)<br>(n = 5,481)                       | Semi-skilled/ Unskilled manual   | 740 (13.5)   | 341 (12.1)        | 399 (15.0)          | <0.001† |
|                                                                | Other non-manual/ Skilled manual | 2,035 (37.1) | 994 (35.1)        | 1,041 (39.3)        |         |
|                                                                | Professional managers            | 2,706 (49.4) | 1,494 (52.8)      | 1,212 (45.7)        |         |
| Medical card status<br>(n = 6,039)                             | Yes, full card                   | 2,096 (34.7) | 1,008 (32.7)      | 1,088 (36.8)        | 0.001†  |
|                                                                | Yes, doctor only card            | 141 (2.3)    | 66 (2.1)          | 75 (2.5)            |         |
|                                                                | Not covered                      | 3,802 (63.0) | 2,009 (65.2)      | 1,793 (60.7)        |         |

Table 6.3 Continued...

| Variable name                                                                          | Variable category                      | Total n (%)  | Young Males n (%) | Young Females n (%) | p-value |
|----------------------------------------------------------------------------------------|----------------------------------------|--------------|-------------------|---------------------|---------|
| Behavioural factors (Wave 2)                                                           |                                        |              |                   |                     |         |
| Toothbrushing frequency<br>(n = 5,962)                                                 | Less than once a day/Rarely/Not at all | 327 (5.5)    | 223 (7.3)         | 104 (3.6)           | <0.001† |
|                                                                                        | Once a day                             | 1,260 (21.1) | 779 (25.6)        | 481 (16.5)          |         |
|                                                                                        | Twice or more than twice a day         | 4,375 (73.4) | 2,036 (67.0)      | 2,339 (80.0)        |         |
| Dentist visit behaviour<br>(n = 6,037)                                                 | Problem visit/Never/Almost never       | 835 (13.8)   | 433 (14.0)        | 402 (13.6)          | 0.561†  |
|                                                                                        | Occasional visit                       | 1,145 (19.0) | 569 (18.5)        | 576 (19.5)          |         |
|                                                                                        | At least a year                        | 4,057 (67.2) | 2,081 (67.5)      | 1,976 (66.9)        |         |
| Sugary drinks intake<br>(Soft drinks/minerals/cordial/squash (not diet)<br>(n = 5,950) | More than once a day                   | 1,070 (18.0) | 587 (19.4)        | 483 (16.6)          | <0.001† |
|                                                                                        | Once a day                             | 1,706 (28.7) | 991 (32.7)        | 715 (24.5)          |         |
|                                                                                        | Not at all                             | 3,174 (53.3) | 1,454 (48.0)      | 1,720 (58.9)        |         |
| Sugary foods intake<br>(Biscuits, doughnuts, cake, pie or chocolate)<br>(n = 5,957)    | More than once a day                   | 1,180 (19.8) | 615 (20.3)        | 565 (19.3)          | 0.351†  |
|                                                                                        | Once a day                             | 2,968 (49.8) | 1,521 (50.1)      | 1,447 (49.5)        |         |
|                                                                                        | Not at all                             | 1,809 (30.4) | 897 (29.6)        | 912 (31.2)          |         |
| Material factors (Wave 2)                                                              |                                        |              |                   |                     |         |
| Financial difficulties (Difficulty in meeting ends)<br>(n = 6,036)                     | With difficulty                        | 3,631 (60.2) | 1,792 (58.2)      | 1,839 (62.2)        | 0.001†  |
|                                                                                        | Without difficulty                     | 2,405 (39.8) | 1,288 (41.8)      | 1,117 (37.8)        |         |
| Private medical insurance<br>(n = 6,037)                                               | No                                     | 3,030 (50.2) | 1,451 (47.1)      | 1,579 (53.4)        | <0.001† |
|                                                                                        | Yes                                    | 3,007 (49.8) | 1,631 (52.9)      | 1,376 (46.6)        |         |

Table 6.3 Continued...

| Variable name                                                                                       | Variable category                              | Total n (%)  | Young Males n (%) | Young Females n (%) | p-value |
|-----------------------------------------------------------------------------------------------------|------------------------------------------------|--------------|-------------------|---------------------|---------|
| DEIS school<br>(n = 5,593)                                                                          | Yes                                            | 1,015 (18.1) | 525 (18.3)        | 490 (18.0)          | 0.792†  |
|                                                                                                     | No                                             | 4,578 (81.9) | 2,347 (81.7)      | 2,231 (82.0)        |         |
| Homeownership<br>(n = 6,034)                                                                        | Renters/Rent free/Others                       | 1,155 (19.1) | 518 (16.8)        | 637 (21.6)          | <0.001† |
|                                                                                                     | Owners                                         | 4,879 (80.9) | 2,562 (83.2)      | 2,317 (78.4)        |         |
| Psychosocial factors (Wave 2)                                                                       |                                                |              |                   |                     |         |
| PCG Parental Stressor scale score<br>(n = 5,975)                                                    | Mean (SD)                                      | 10.2 (4.17)  | 10.36 (4.29)      | 10.23 (4.04)        | 0.214‡  |
| Family structure<br>(n = 6,039)                                                                     | Single parent family                           | 1,115 (18.5) | 532 (17.3)        | 583 (19.7)          | 0.014†  |
|                                                                                                     | Couple family                                  | 4,924 (81.5) | 2,551 (82.7)      | 2,373 (80.3)        |         |
| Depression status<br>(n = 5,978)                                                                    | Depressed                                      | 670 (11.1)   | 353 (11.6)        | 317 (10.8)          | 0.353†  |
|                                                                                                     | Not depressed                                  | 5,308 (87.9) | 2,695 (88.4)      | 2,612 (89.2)        |         |
| Job stress<br>(n = 5,680)                                                                           | Stressed                                       | 3,833 (67.5) | 1,918 (66.1)      | 1,915 (68.9)        | 0.022†  |
|                                                                                                     | Not stressed                                   | 1,847 (32.5) | 984 (33.9)        | 863 (31.1)          |         |
| Young persons' oral health (Outcome variables) (Wave 3)                                             |                                                |              |                   |                     |         |
| Young persons' Parent-reported oral health (Number of permanent teeth with fillings)<br>(n = 5,859) | None                                           | 2,978 (50.8) | 1,591 (53.5)      | 1,387 (48.1)        | <0.001† |
|                                                                                                     | One                                            | 879 (15.0)   | 428 (14.4)        | 451 (15.6)          |         |
|                                                                                                     | Two                                            | 1,029 (17.6) | 490 (16.5)        | 539 (18.7)          |         |
|                                                                                                     | Three or more                                  | 973 (16.6)   | 467 (15.7)        | 506 (17.6)          |         |
| Young persons' Self-reported oral health (self-rated oral health, SROH)<br>(n = 6,033)              | Optimal oral health (Excellent/Very good/Good) | 5,588 (92.6) | 2767 (89.8)       | 2821 (95.6)         | <0.001† |
|                                                                                                     | Sub-optimal oral health (Fair/Poor)            | 445 (7.4)    | 315 (10.2)        | 130 (4.4)           |         |

† Chi-square test; ‡ Independent t-test

### **6.3.1.2 SES Measures and Parent-Reported Oral Health**

Young persons' parent-reported oral health (study participants' number of permanent teeth with dental fillings) by four selected socioeconomic indicators (PCGs' highest level of education, family/household income, family occupational class and study participants' medical card status) is presented in Table 6.4 and Figure 6.1. The proportions of young persons with no permanent teeth with dental fillings (favourable outcome) were greater at higher levels of education, family income, family occupational class and medical card status. The differences in young males' and females' proportions for the parent-reported oral health outcomes by SES measures are shown in Table 6.5 and Figure 6.2. For the PCG educational measure, for the lowest (primary/no formal education), middle (secondary education) and highest (tertiary education) groups, the proportions of those having no teeth with dental fillings were 45%, 52% and 56%, respectively, for young males and 39%, 47% and 54%, respectively, for young females. Similarly, across the family income groups, the proportions of young males and females having no teeth with dental fillings increased from the lowest to the highest income group. The percentage of study participants with no teeth with dental fillings ranged from 48 to 52% for young males, and between 40 and 52% for young females. Likewise, across family occupational classes, for the lowest (semi-skilled/Unskilled), middle (non-manual/skilled) and highest (professional/managers) occupational groups, the proportions of young females with no teeth with dental fillings were 42%, 48% and 52%, respectively. However, the corresponding proportions for young males were 56%, 54% and 53%. Finally, for the study participants' medical card status groups, the percentage of young males having no teeth with dental fillings was 48% for those with a full medical card and 55% for those without a medical card. In contrast, for young females, the proportions with no teeth with dental fillings were 42% for medical card holders and 52% for non-holders.

Table 6.4 Young persons' parent-reported oral health (number of permanent teeth with dental fillings) at 17/18 years of age by socioeconomic status (SES) measures (PCGs' highest educational level, family income, family occupational class and study participants' medical card status) at 13 years of age.

| Socioeconomic measures                                        | Number of teeth with dental fillings at 17/18 years of age |               |              |              |                        |
|---------------------------------------------------------------|------------------------------------------------------------|---------------|--------------|--------------|------------------------|
|                                                               |                                                            | None<br>n (%) | One<br>n (%) | Two<br>n (%) | Three or More<br>n (%) |
| Primary care giver's highest level of education<br>(n = 5857) | None or primary                                            | 84 (43.1)     | 26 (13.3)    | 56 (28.7)    | 29 (14.9)              |
|                                                               | Secondary                                                  | 2217 (49.9)   | 675 (15.2)   | 783 (17.6)   | 765 (17.2)             |
|                                                               | Tertiary                                                   | 677 (55.4)    | 178 (14.6)   | 189 (15.5)   | 178 (14.6)             |
| Family income – quintiles<br>(n = 5421)                       | Lowest                                                     | 484 (44.2)    | 162 (14.8)   | 228 (20.8)   | 221 (20.2)             |
|                                                               | 2 <sup>nd</sup>                                            | 571 (52.3)    | 160 (14.7)   | 210 (19.2)   | 151 (13.8)             |
|                                                               | 3 <sup>rd</sup>                                            | 536 (48.7)    | 157 (14.3)   | 213 (19.3)   | 195 (17.7)             |
|                                                               | 4 <sup>th</sup>                                            | 585 (52.3)    | 175 (15.7)   | 171 (15.3)   | 187 (16.7)             |
|                                                               | Highest                                                    | 557 (54.9)    | 165 (16.3)   | 150 (14.8)   | 143 (14.1)             |
| Family class (Occupation)<br>(n = 5335)                       | Semi-skilled/ Unskilled manual                             | 349 (48.7)    | 81 (11.3)    | 144 (20.1)   | 142 (19.8)             |
|                                                               | Other non-manual/ Skilled manual                           | 1010 (50.8)   | 285 (14.3)   | 346 (17.4)   | 346 (17.4)             |
|                                                               | Professional managers                                      | 1388 (52.7)   | 433 (16.5)   | 422 (16.0)   | 389 (14.6)             |
| Medical card status<br>(n = 5858)                             | Yes, full card                                             | 915 (45.3)    | 295 (14.6)   | 415 (20.5)   | 396 (19.6)             |
|                                                               | Yes, doctor only card                                      | 71 (55.0)     | 21 (16.3)    | 21 (16.3)    | 16 (12.4)              |
|                                                               | Not covered                                                | 1991 (53.7)   | 563 (15.2)   | 593 (16.0)   | 561 (15.1)             |

Table 6.5 Young persons' parent-reported oral health (number of permanent teeth with dental fillings) at 17/18 years of age by socioeconomic status (SES) measures (PCGs' highest educational level, family income, family occupational class and study participants' medical card status) at 13 years of age and by gender.

| Socioeconomic measures                                                           |                                     | Young Males<br>Number of teeth with dental fillings |              |              |                        | Young Females<br>Number of teeth with dental fillings |              |              |                        |
|----------------------------------------------------------------------------------|-------------------------------------|-----------------------------------------------------|--------------|--------------|------------------------|-------------------------------------------------------|--------------|--------------|------------------------|
|                                                                                  |                                     | None<br>n (%)                                       | One<br>n (%) | Two<br>n (%) | Three or<br>More n (%) | None<br>n (%)                                         | One<br>n (%) | Two<br>n (%) | Three or<br>More n (%) |
| Primary care<br>giver's highest<br>level of education<br>(M = 2977; F =<br>2882) | None or primary                     | 45 (52.9)                                           | 13 (15.3)    | 19 (22.4)    | 8 (9.4)                | 39 (35.1)                                             | 14 (12.6)    | 37 (33.3)    | 21 (18.9)              |
|                                                                                  | Secondary                           | 1179 (52.7)                                         | 325 (14.5)   | 363 (16.2)   | 369 (16.5)             | 1038 (47.1)                                           | 350 (15.9)   | 420 (19.1)   | 396 (18.0)             |
|                                                                                  | Tertiary                            | 367 (55.9)                                          | 91 (13.9)    | 108 (16.5)   | 90 (13.7)              | 310 (54.7)                                            | 87 (15.3)    | 82 (14.5)    | 88 (15.5)              |
| Family income –<br>quintiles<br>(M = 2758; F =<br>2664)                          | Lowest                              | 260 (48.2)                                          | 72 (13.4)    | 113 (21.0)   | 94 (17.4)              | 225 (40.5)                                            | 90 (16.2)    | 114 (20.5)   | 127 (22.8)             |
|                                                                                  | 2 <sup>nd</sup>                     | 306 (55.7)                                          | 83 (15.1)    | 86 (15.7)    | 74 (13.5)              | 265 (48.8)                                            | 77 (14.2)    | 124 (22.8)   | 77 (14.2)              |
|                                                                                  | 3 <sup>rd</sup>                     | 277 (54.0)                                          | 64 (12.5)    | 89 (17.3)    | 83 (16.2)              | 259 (44.0)                                            | 93 (15.8)    | 124 (21.1)   | 112 (19.0)             |
|                                                                                  | 4 <sup>th</sup>                     | 322 (52.0)                                          | 95 (15.3)    | 99 (16.0)    | 103 (16.6)             | 262 (52.5)                                            | 79 (15.8)    | 73 (14.6)    | 85 (17.0)              |
|                                                                                  | Highest                             | 305 (56.7)                                          | 86 (16.0)    | 77 (14.3)    | 70 (13.0)              | 252 (52.7)                                            | 79 (16.5)    | 73 (15.3)    | 74 (15.5)              |
| Family class<br>(Occupation)<br>(M = 2743; F =<br>2594)                          | Semi-skilled/ Unskilled<br>manual   | 184 (56.1)                                          | 31 (9.5)     | 50 (15.2)    | 63 (19.2)              | 165 (42.4)                                            | 50 (12.9)    | 94 (24.2)    | 80 (20.6)              |
|                                                                                  | Other non-manual/<br>Skilled manual | 524 (54.3)                                          | 134 (13.9)   | 153 (15.9)   | 154 (16.0)             | 486 (47.6)                                            | 151 (14.8)   | 193 (18.9)   | 192 (18.8)             |
|                                                                                  | Professional managers               | 778 (53.7)                                          | 229 (15.8)   | 224 (15.4)   | 219 (15.1)             | 610 (51.6)                                            | 205 (17.3)   | 198 (16.7)   | 170 (14.4)             |
| Medical card<br>status<br>(M = 2975; F =<br>2882)                                | Yes, full card                      | 468 (48.5)                                          | 120 (12.4)   | 201 (20.9)   | 175 (18.2)             | 447 (42.3)                                            | 176 (16.7)   | 214 (20.21)  | 220 (20.85)            |
|                                                                                  | Yes, doctor only card               | 42 (65.6)                                           | 11 (17.2)    | 6 (9.4)      | 5 (7.8)                | 30 (46.2)                                             | 10 (15.4)    | 14 (21.5)    | 11 (16.9)              |
|                                                                                  | Not covered                         | 1081 (55.5)                                         | 298 (15.3))  | 282 (14.5)   | 286 (14.7)             | 910 (51.7)                                            | 265 (15.1)   | 311 (17.7)   | 274 (15.6)             |

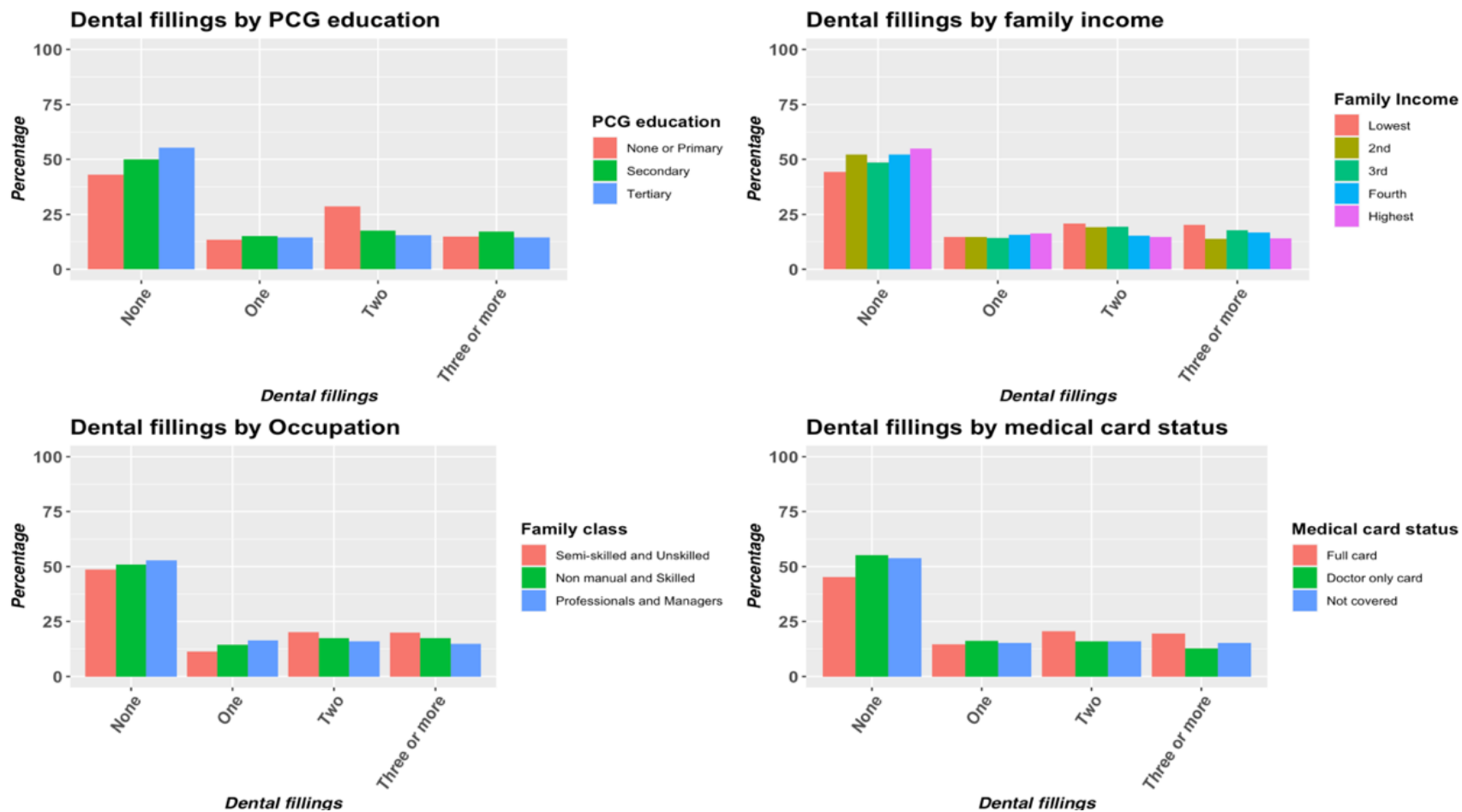


Figure 6.1 Young person's parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by SES measures (PCG educational, family income, family occupational and medical card status) at 13 years of age.

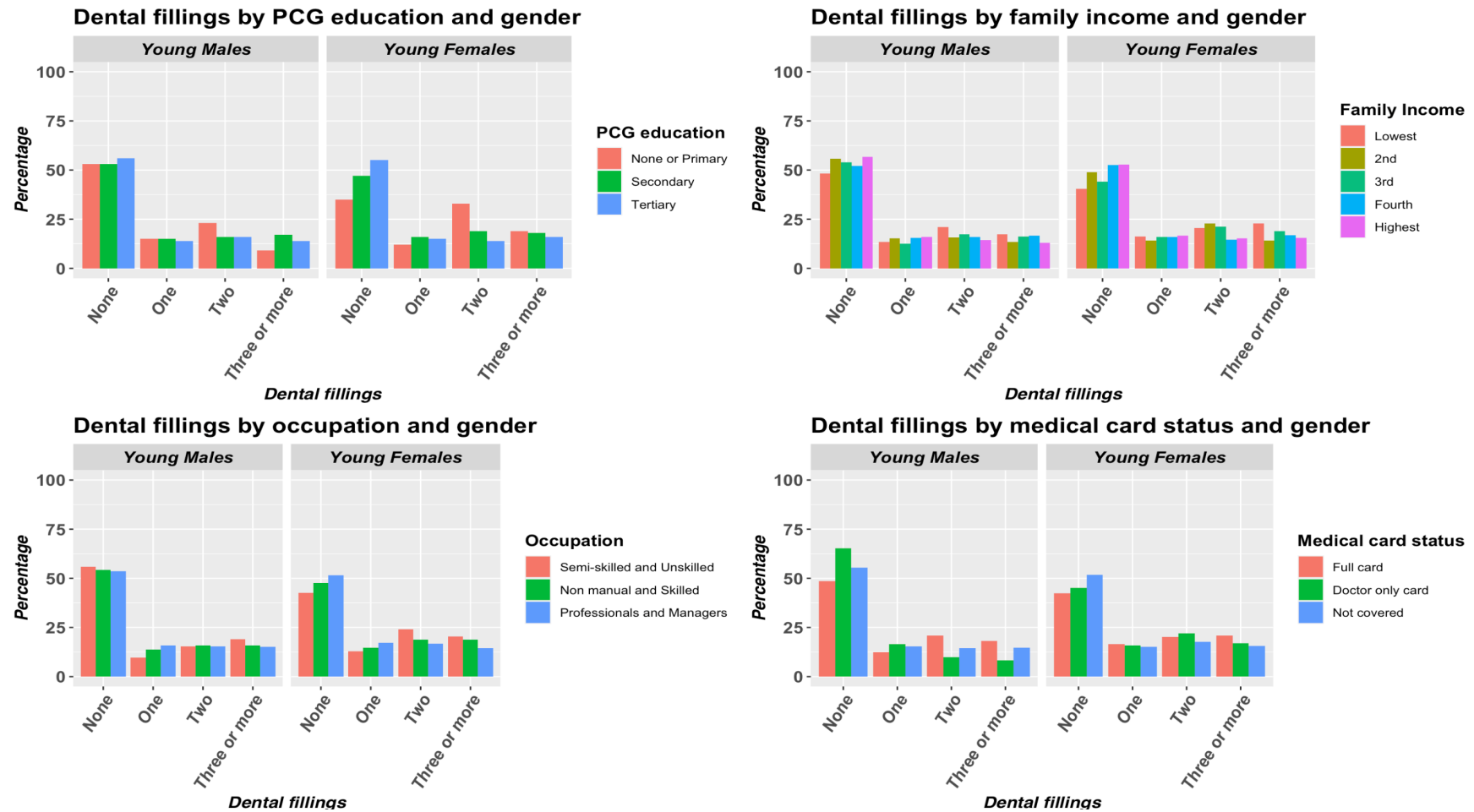


Figure 6.2 Young person's parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by SES measures (PCG educational, family income, family occupational and medical card status) at 13 years of age and by gender.



#### **6.3.1.3 SES Measures and Self-reported Oral Health**

Young persons' self-reported oral health (self-rated oral health, SROH) by four SES measures (PCG educational, family income, family occupational and medical card status) is presented in Table 6.6 and Figure 6.3. Compared with the higher social groups, the percentages of young persons with sub-optimal oral health were higher in the lower social groups. Thirteen per cent in the lowest educational category (primary/none) had sub-optimal SROH compared with 7% in the highest (tertiary) group. Similarly, the proportions of those with sub-optimal SROH in the highest income quintile group was lower (5.6%) than those in the lowest income group (8.4%). Across the occupation and medical card groups, there were no or minor differences in the percentages of those having sub-optimal oral health. Compared with young females, the differences in percentages of SROH outcomes across social groups were greater for young males (Table 6.6 and Figure 6.4).

Table 6.6 Young persons' self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by socioeconomic status (SES) measures (PCGs' highest educational level, family income, family occupational class and study participants' medical card status) at 13 years of age and by gender.

| Socioeconomic measures<br>(Main explanatory variables)                               |                                     | Total<br>Self-reported oral health |                     | Males<br>Self-reported oral health |                     | Females<br>Self-reported oral health |                     |
|--------------------------------------------------------------------------------------|-------------------------------------|------------------------------------|---------------------|------------------------------------|---------------------|--------------------------------------|---------------------|
|                                                                                      |                                     | Optimal<br>n (%)                   | Suboptimal<br>n (%) | Optimal n<br>(%)                   | Suboptimal<br>n (%) | Optimal<br>n (%)                     | Suboptimal<br>n (%) |
| Primary care giver's highest level<br>of education<br>(n = 6033; M = 3081; F = 2951) | None or primary                     | 184 (86.4)                         | 29 (13.6)           | 84 (82.4)                          | 18 (17.6)           | 100 (90.1)                           | 11 (9.9)            |
|                                                                                      | Secondary                           | 4222 (92.8)                        | 330 (7.2)           | 2052 (89.5)                        | 241 (10.5)          | 2170 (96.1)                          | 88 (3.9)            |
|                                                                                      | Tertiary                            | 1182 (93.2)                        | 86 (6.8)            | 631 (92.0)                         | 55 (8.0)            | 551 (94.7)                           | 31 (5.3)            |
| Family income – quintiles<br>(n = 6033; M = 2852; F = 2730)                          | Lowest                              | 1053 (91.6)                        | 97 (8.4)            | 502 (87.6)                         | 71 (12.4)           | 551 (95.5)                           | 26 (4.5)            |
|                                                                                      | 2 <sup>nd</sup>                     | 1021 (90.8)                        | 104 (9.2)           | 484 (86.3)                         | 77 (13.7)           | 536 (95.2)                           | 27 (4.8)            |
|                                                                                      | 3 <sup>rd</sup>                     | 1043 (93.5)                        | 73 (6.5)            | 468 (90.5)                         | 49 (9.5)            | 575 (96.0)                           | 24 (4.0)            |
|                                                                                      | 4 <sup>th</sup>                     | 1064 (92.9)                        | 81 (7.1)            | 587 (91.4)                         | 55 (8.6)            | 477 (94.8)                           | 26 (5.2)            |
|                                                                                      | Highest                             | 987 (94.4)                         | 58 (5.6)            | 513 (91.8)                         | 46 (8.2)            | 475 (97.3)                           | 13 (2.7)            |
| Family class (Occupation)<br>(n = 6033; M = 2828; F = 2646)                          | Semi-skilled/ Unskilled<br>manual   | 687 (92.8)                         | 53 (7.2)            | 302 (88.6)                         | 39 (11.4)           | 385 (96.5)                           | 14 (3.5)            |
|                                                                                      | Other non-manual/<br>Skilled manual | 1891 (93.2)                        | 138 (6.8)           | 903 (90.8)                         | 91 (9.2)            | 989 (95.5)                           | 47 (4.5)            |
|                                                                                      | Professional managers               | 2522 (93.2)                        | 183 (6.8)           | 1359 (91.0)                        | 134 (9.0)           | 1163 (96.0)                          | 48 (4.0)            |
| Medical card status<br>(n = 6031; M = 3080; F = 2950)                                | Yes, full card                      | 1921 (91.9)                        | 169 (8.1)           | 889 (88.3)                         | 118 (11.7)          | 1032 (95.3)                          | 51 (4.7)            |
|                                                                                      | Yes, doctor only card               | 132 (93.6)                         | 9 (6.4)             | 60 (90.9)                          | 6 (9.1)             | 72 (96.0)                            | 3 (4.0)             |
|                                                                                      | Not covered                         | 3535 (93.0)                        | 265 (7.0)           | 1817 (90.5)                        | 190 (9.5)           | 1717 (95.6)                          | 129 (4.4)           |

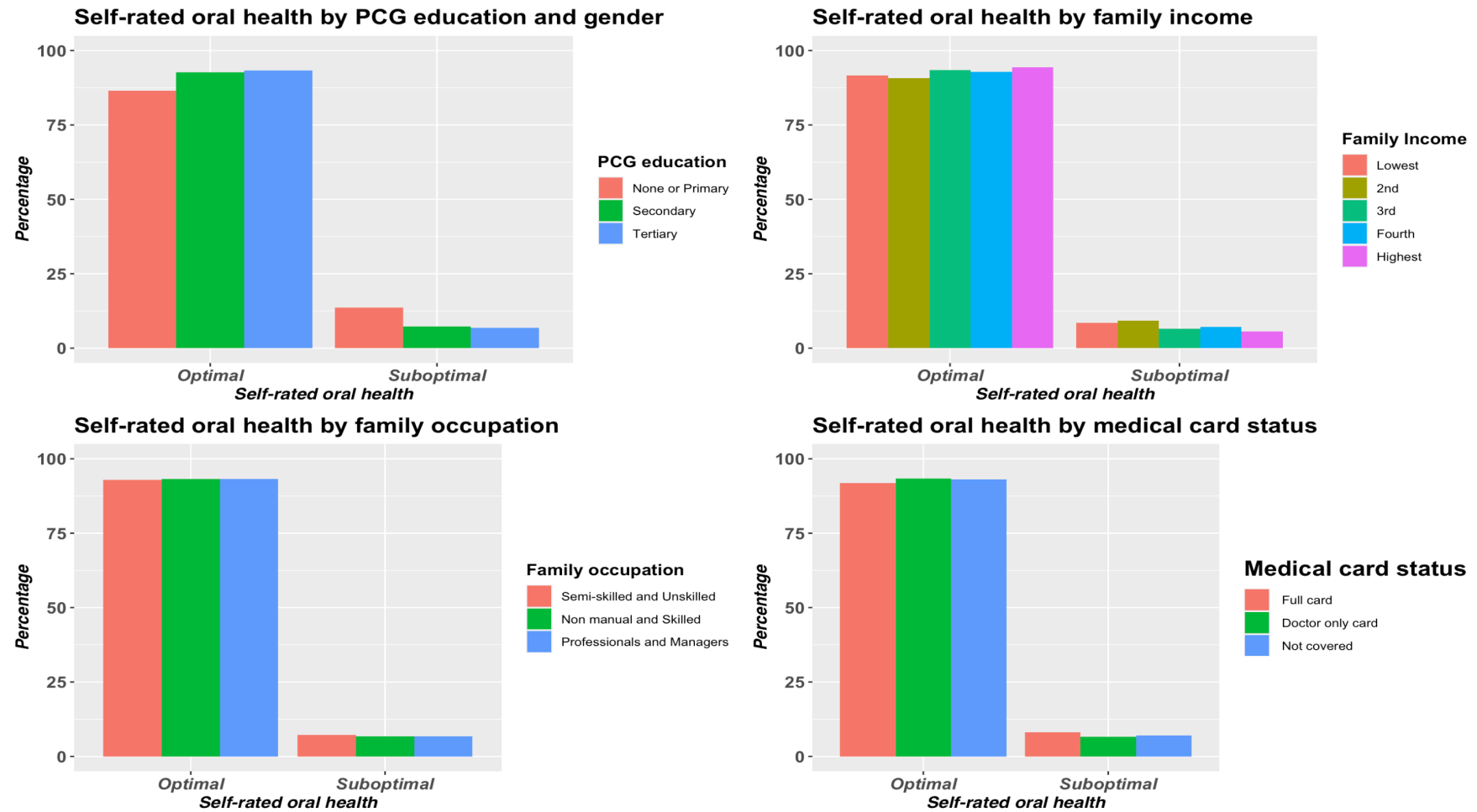


Figure 6.3 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by SES measures (PCG educational, family income, family occupational and medical card status) at 13 years of age.

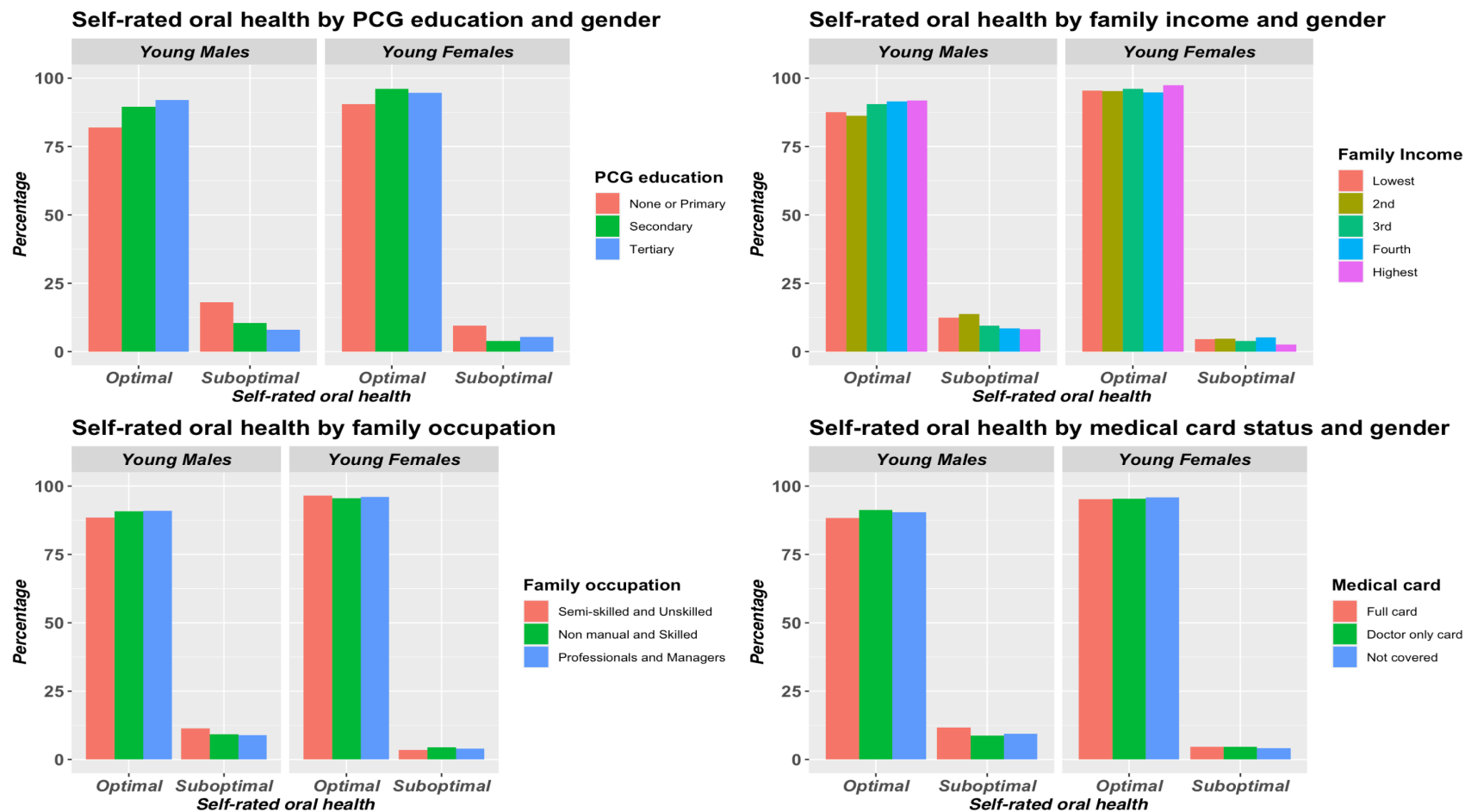


Figure 6.4 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by SES measures (PCG educational, family income, family occupational and medical card status) at 13 years of age and by gender.

#### **6.3.1.4 Behaviour Factors and Parent-reported Oral Health**

Figure 6.5 shows young persons' parent-reported oral health (study participants' number of permanent teeth with dental fillings) by four selected behaviour factors (daily toothbrushing frequency, dentist visit behaviour, sugary foods intake and sugary drinks intake). The young persons' parent-reported oral health showed a graded pattern across behavioural factors. The proportions of study participants with optimal parent-reported oral health (having no teeth with dental fillings) were higher for those who reported favourable oral health behaviours. On the other hand, the proportions of individuals with poor parent-reported oral health (two teeth with dental fillings or three or more teeth with dental fillings) increased as their health behaviours shifted from more favourable to less favourable. For example, young persons who infrequently brushed their teeth (less than once a day or never) at 13 years of age had higher proportions of three or more teeth with fillings (22%) than those who brushed their teeth once a day (18%), which were higher than those who brushed their teeth twice or more than twice daily (14%). Similarly, young persons who consumed sugary foods and drinks more than twice a day had a greater prevalence of two or more teeth with dental fillings than those who did not consume sugary foods or drinks. In contrast, young persons who never visited or visited the dentist only when there was a dental problem had lower percentages of two or more teeth with dental fillings than those who visited occasionally (once in two or three years). Occasional visitors had lower proportions of teeth with dental fillings than frequent dentist visitors (visiting the dentist at least once a year). Gender comparisons of the parent-reported oral health across behaviour factors are shown in Figure 6.6. Across the different behavioural categories, the differences in the proportions of those with poor parent-reported oral health (two or more teeth with dental fillings) were greater in young females than young males, Figure 6.6

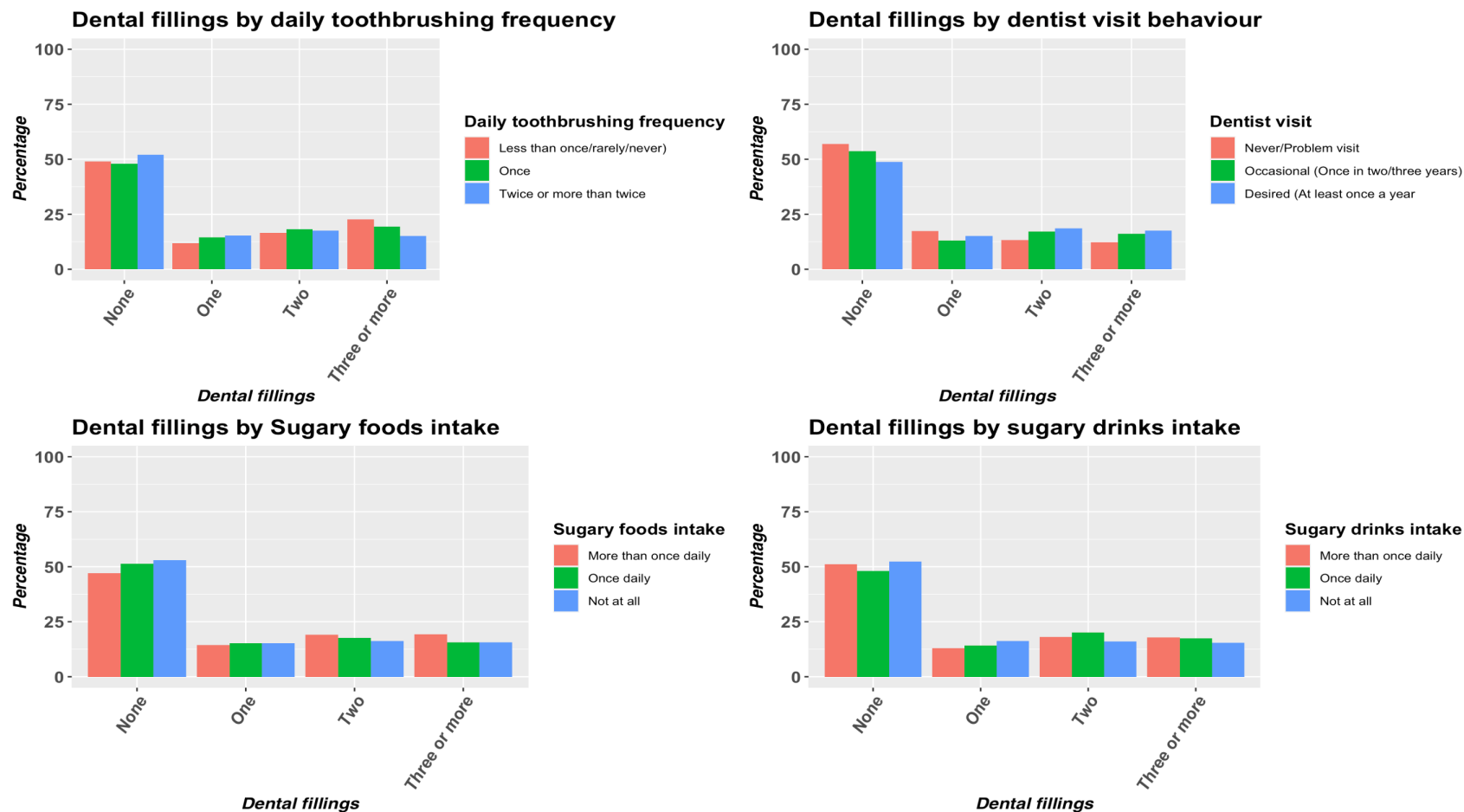


Figure 6.5 Young person's parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by behavioural factors (toothbrushing frequency, dentist visit behaviours, sugary drinks intake and sugary foods intake) at 13 years of age.

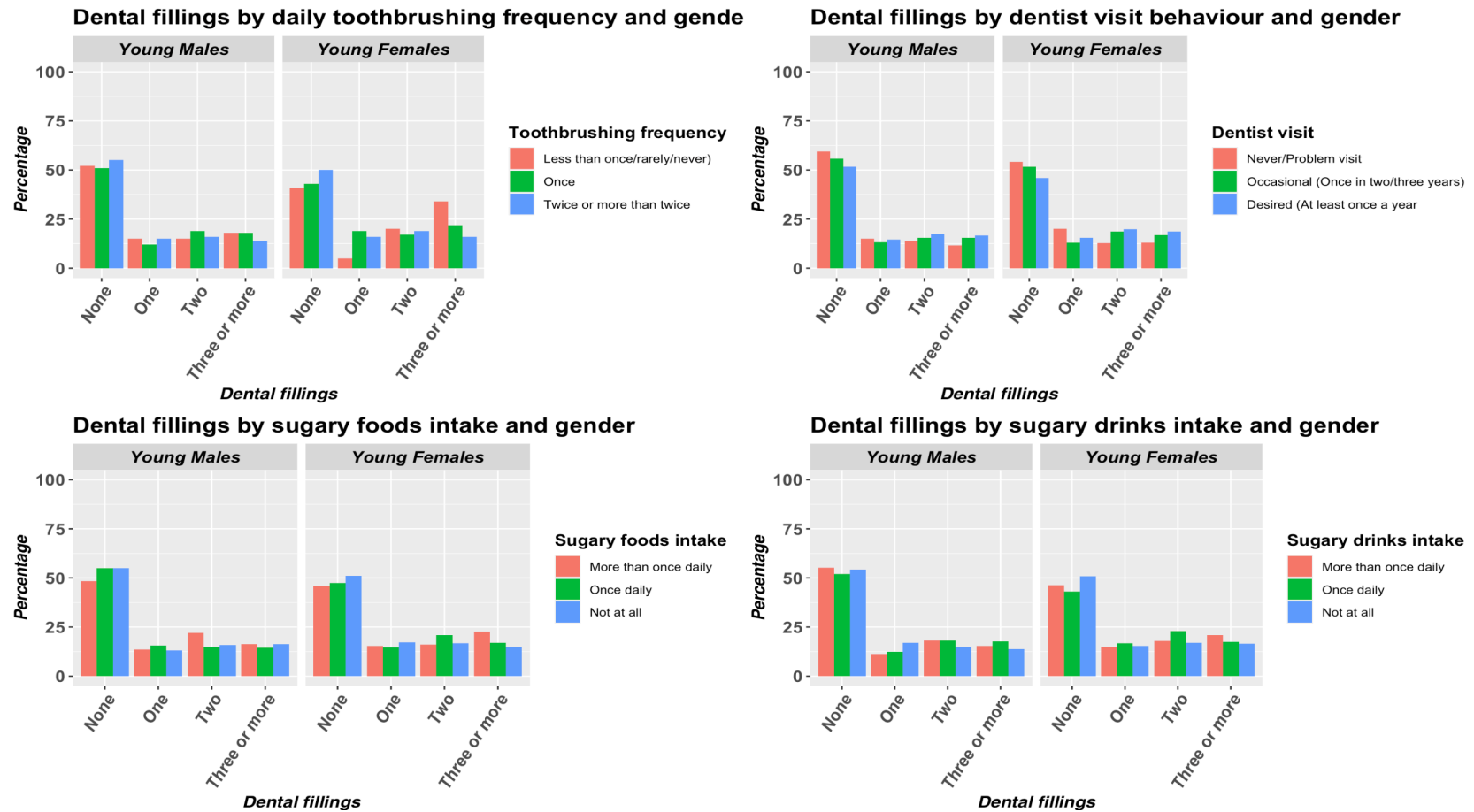


Figure 6.6 Young person's parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by behavioural factors (toothbrushing frequency, dentist visit behaviours, sugary drinks intake and sugary foods intake) at 13 years of age and by gender.

#### ***6.3.1.5 Behavioural Factors and Self-Reported Oral Health***

Figures 6.7 and 6.8 show young persons' self-reported oral health (self-rated oral health, SROH) by behavioural factors for the complete sample and by gender. For all four behavioural factors, the proportions of those with suboptimal oral health varied across the groups. The proportions of young persons with sub-optimal oral health were greater for those with less favourable oral health behaviours (daily toothbrushing frequency of less than once daily/never, no or problem-based dental visits and dietary intake of sugary foods and drinks once or more than once daily) than those with more favourable oral health behaviours (daily toothbrushing frequency of twice or more than twice, regular dental visits no dietary intake of sugary foods and drinks). The differences in the proportions of participants with sub-optimal oral health across behavioural groups were greater in males than females.



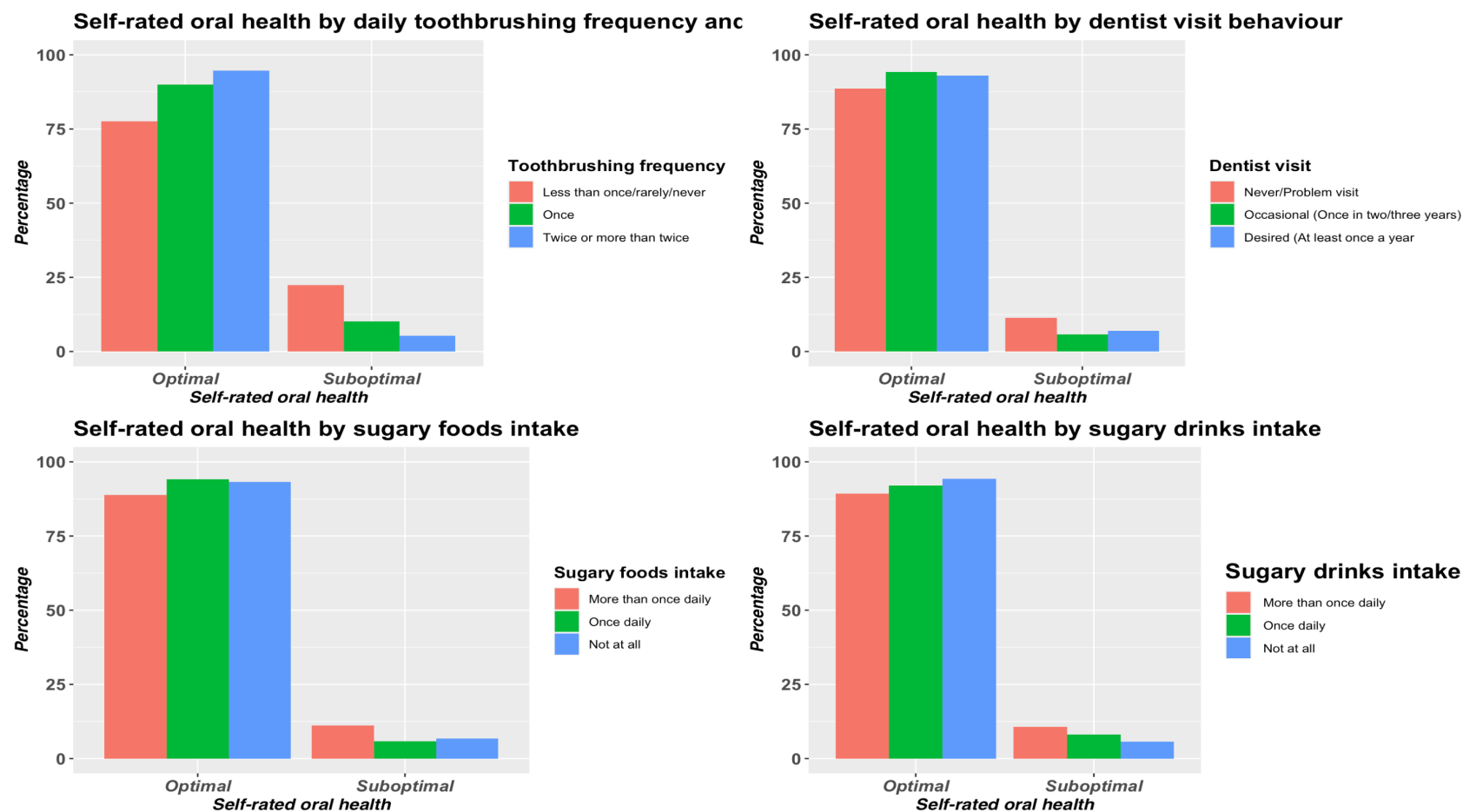


Figure 6.7 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by behavioural factors (toothbrushing frequency, dentist visit behaviours, sugary drinks intake and sugary foods intake) at 13 years of age.

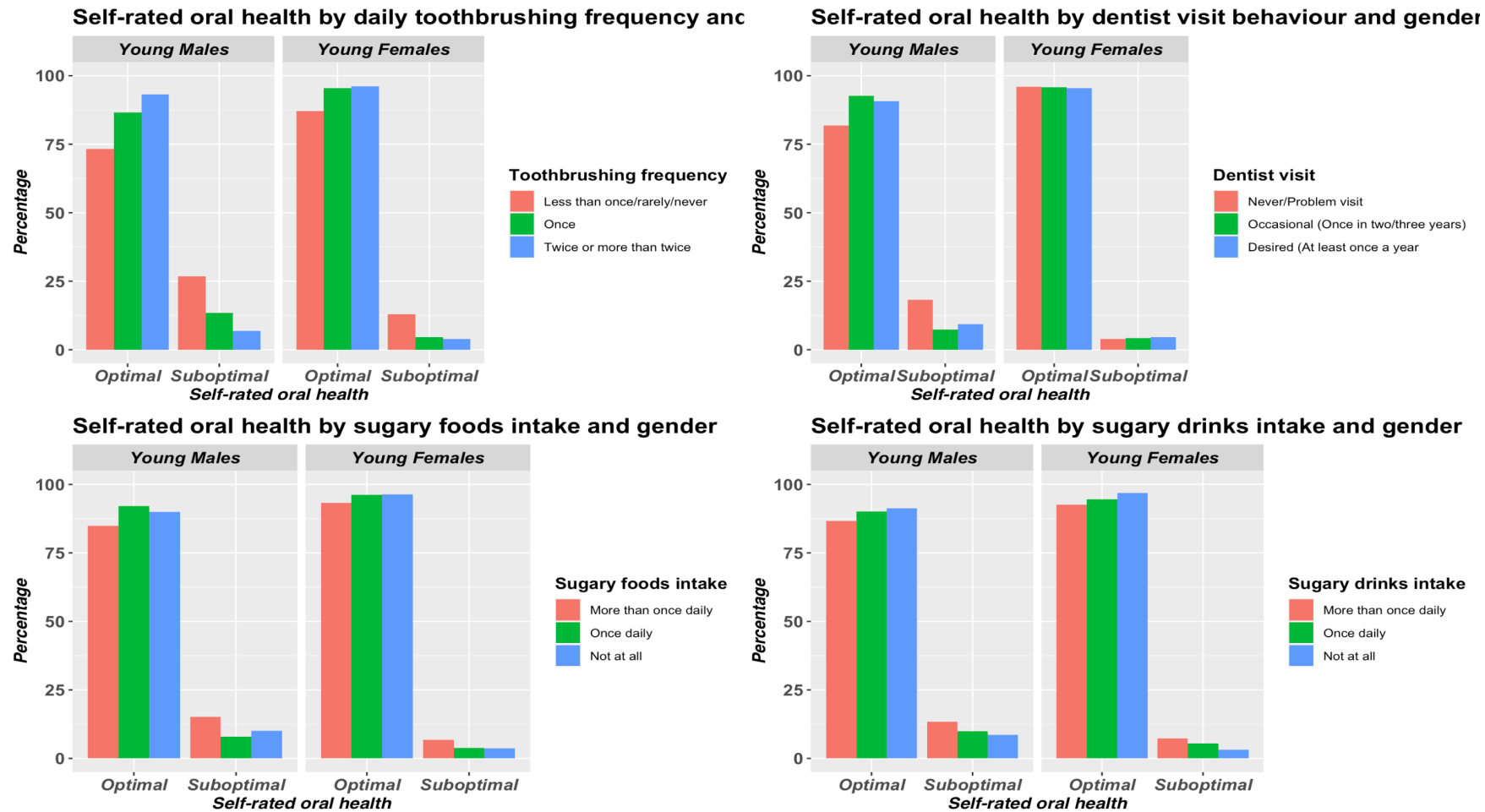


Figure 6.8 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by behavioural factors (toothbrushing frequency, dentist visit behaviours, sugary drinks intake and sugary foods intake) at 13 years of age and by gender.

#### ***6.3.1.6 Material Factors and Parent-Reported Oral Health***

Young persons' parent-reported oral health (study participants' number of permanent teeth with dental fillings) across material factors (financial difficulties, housing tenure, studying in a DEIS school and having private medical insurance) groups is shown in Figure 6.9.

There were differences in young persons' parent-reported oral health across different material groups for all four selected material factors. The proportions of young persons with no tooth with dental fillings and with one tooth with dental fillings were lower for those who, at 13 years, studied at DEIS schools, were from families with financial difficulties, lived in rented or other accommodations and had no private medical insurance than those who studied at non-DEIS schools and had no financial difficulties, a family-owned house and a private medical insurance. Figure 6.10 shows the differences between young males and females in the parent-reported oral health by material factors. There were no or slight differences in the proportions of young males and females with no teeth with dental fillings across the material factors' groups.

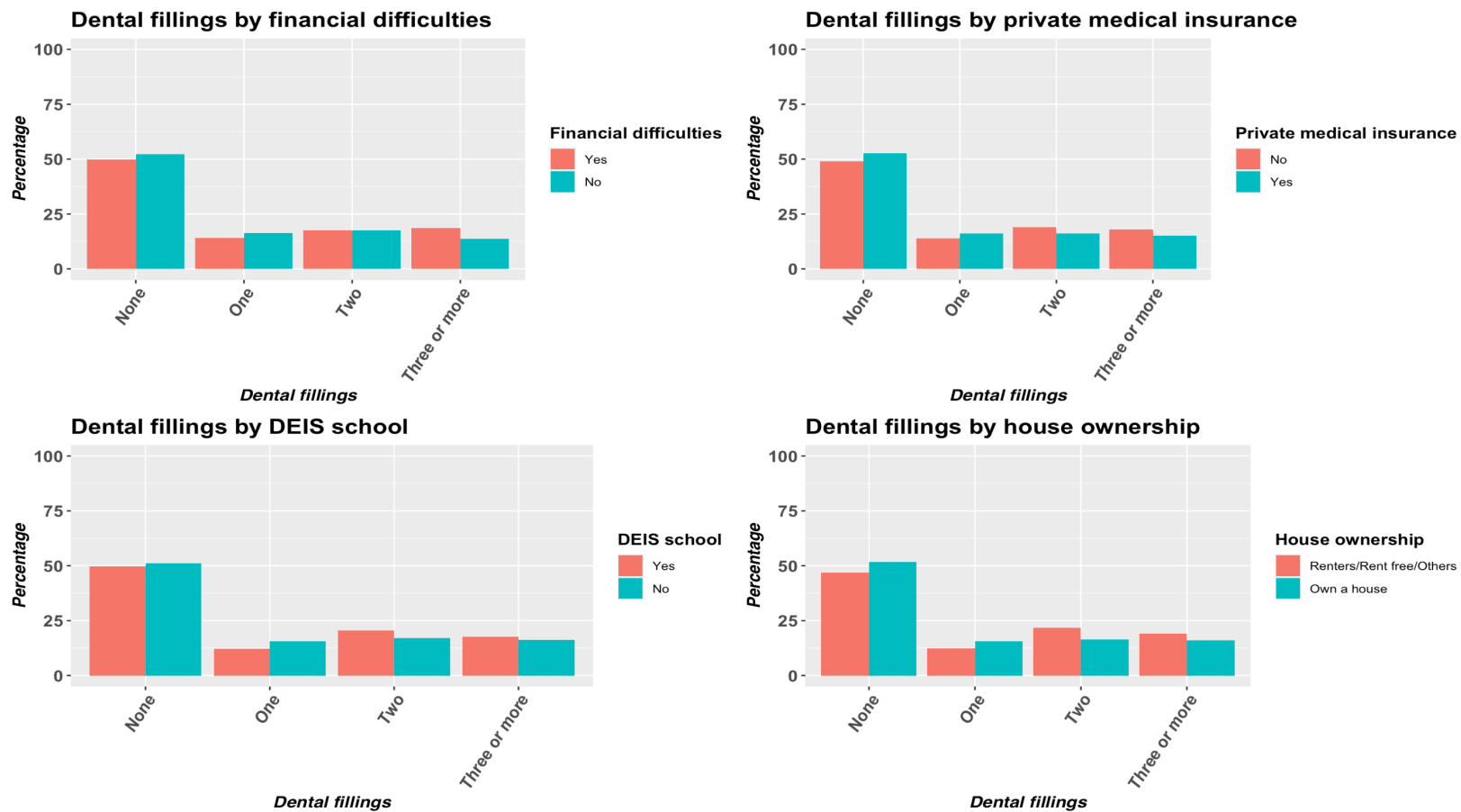


Figure 6.9 Young person's parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by material factors (financial difficulties, private medical insurance, DEIS school and house ownership) 13 years of age.

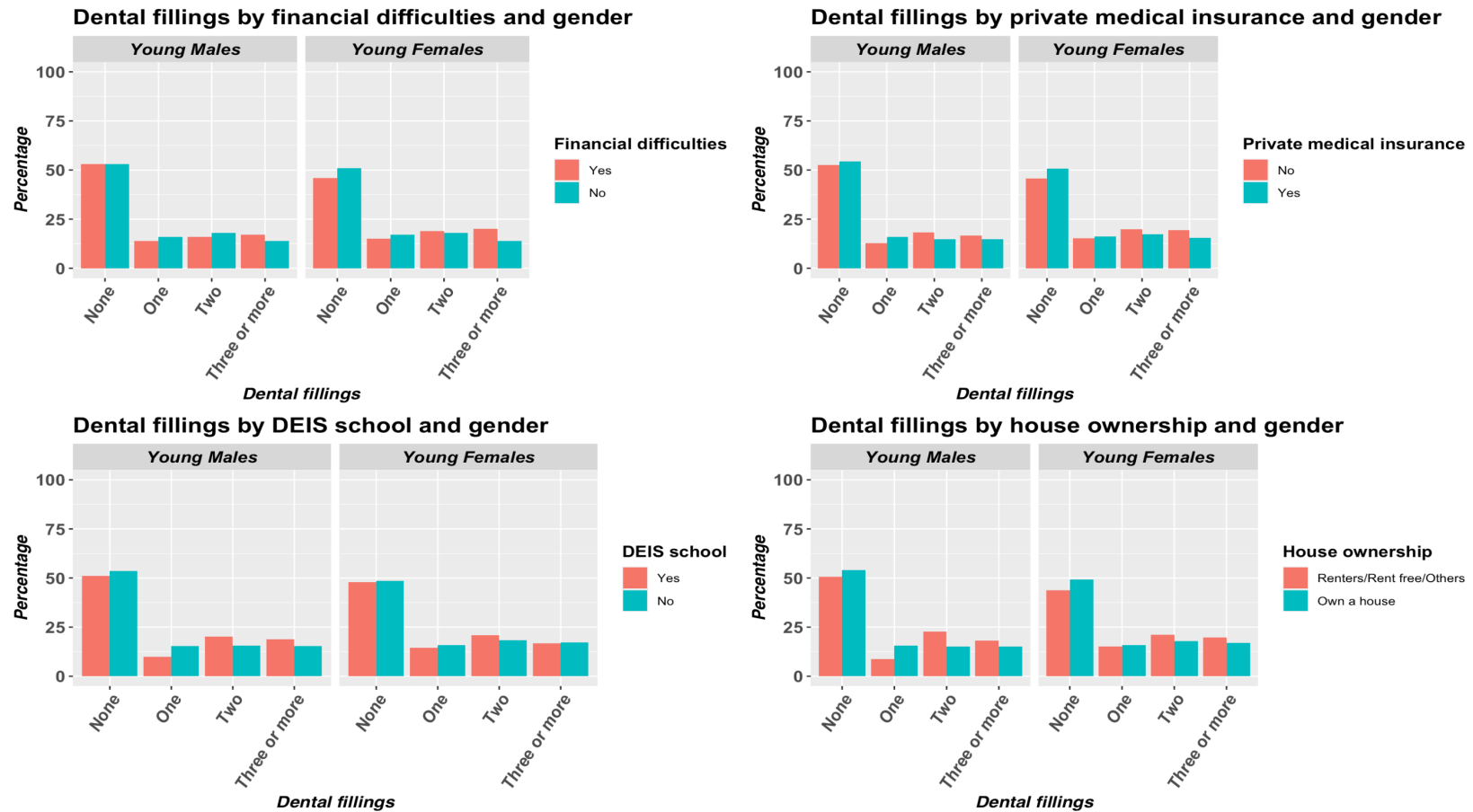


Figure 6.10 Young person's parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by material factors (financial difficulties, private medical insurance, DEIS school and house ownership) 13 years of age and by gender.

#### **6.3.1.7 Material Factors and Self-reported Oral Health**

Figure 6.11 shows young persons' self-reported oral health (self-rated oral health, SROH) by material factors. The young persons' SROH outcomes differed across the material groups. The percentages of young persons with sub-optimal oral health were greater in those who attended DEIS school, had no private insurance, were from families with financial difficulties and lived in rented or other accommodations when they were 13 years of age than their counterparts. The gender differences in young persons' SROH by material factors has been shown in Figure 6.12. The proportions of young males with sub-optimal oral health were higher for young males than young females across all material groups.

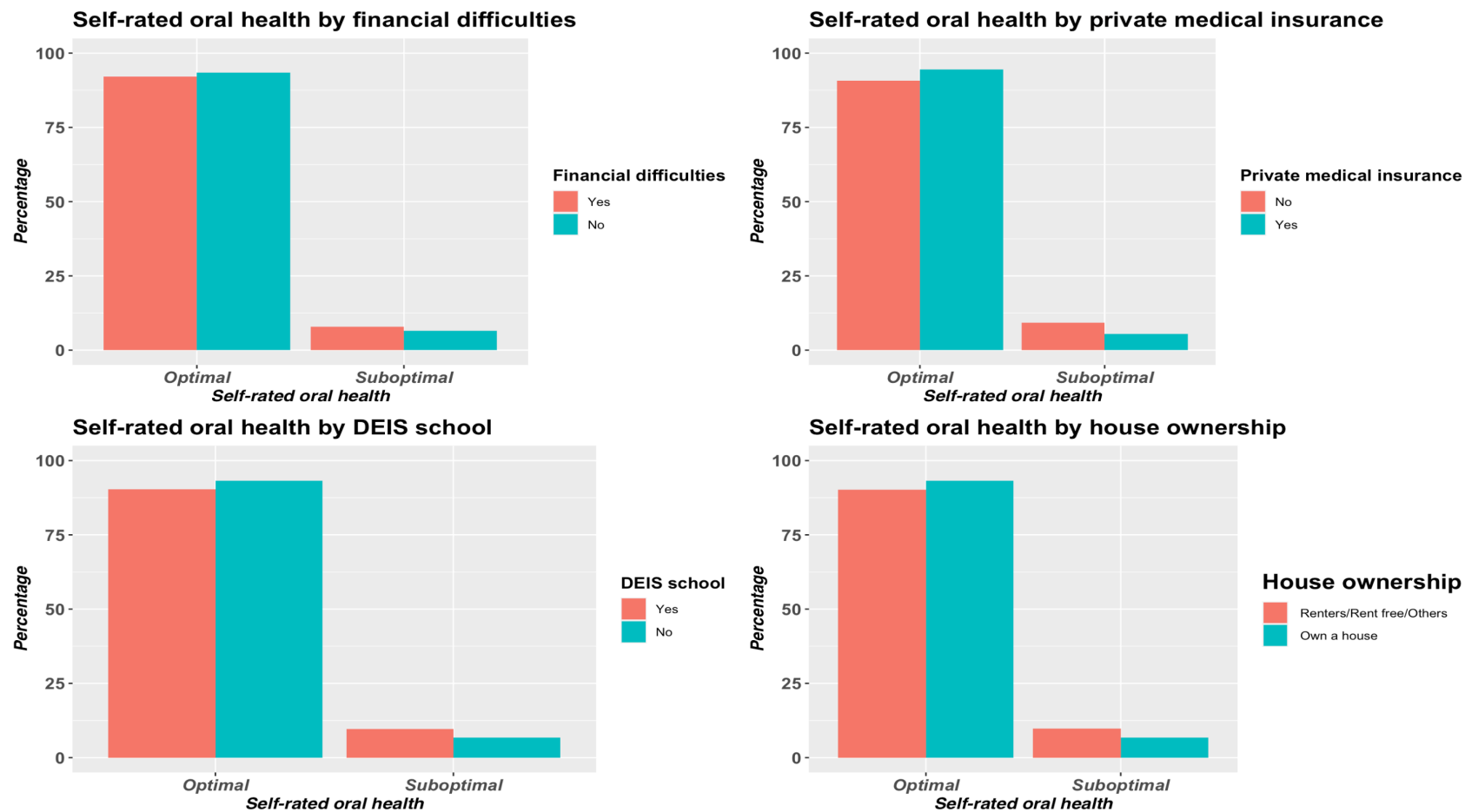


Figure 6.11 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by material factors (financial difficulties, private medical insurance, DEIS school and house ownership) at 13 years of age.

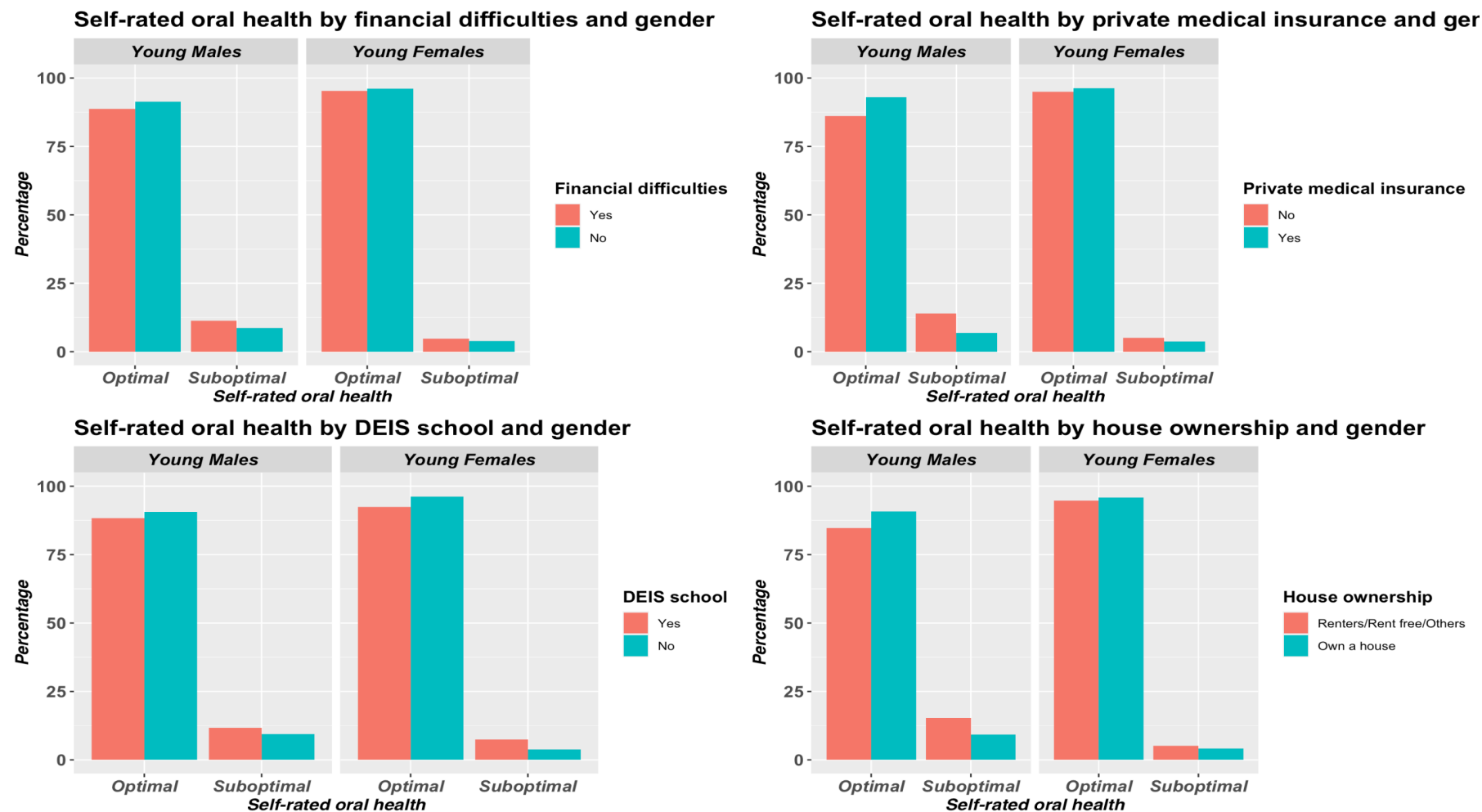


Figure 6.12 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by material factors (financial difficulties, private medical insurance, DEIS school and house ownership) at 13 years of age and by gender.



#### **6.3.1.8 Psychosocial Factors and Parent-Reported Oral Health**

Figure 6.13 demonstrates young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by psychosocial factors (parental stressor scale scores, PCGs' depression status, family structure, PCGs' job stress) at 13 years of age. Young persons' having three or more dental fillings had higher PCGs' mean parental stress scores than those with no teeth with dental fillings. Also, young persons with no teeth or one tooth with dental fillings had equivalent PCGs' mean parental stress scores.

The proportions of young persons with no teeth with dental fillings were greater for those who lived in two-parent families than those raised by single parents. Compared with participants with non-depressed PCGs, the proportions of those who had three or more teeth with dental fillings were higher for those with depressed PCGs. The proportions of those having no teeth with dental fillings were higher for those whose PCGs had job stress than the other group. The gender comparisons of young persons' parent-reported oral health by psychosocial factors are shown in Figure 6.14. For young males, the PCGs' mean parental stress scale scores were highest for those having three or more teeth with fillings, while for young females, the scores were greater for those with two teeth with dental fillings. For single-parent families, the proportions of those with two or more teeth with dental fillings were greater for young males than young females. For depression status and job stress groups, no differences in young persons' oral health were observed between the two genders.

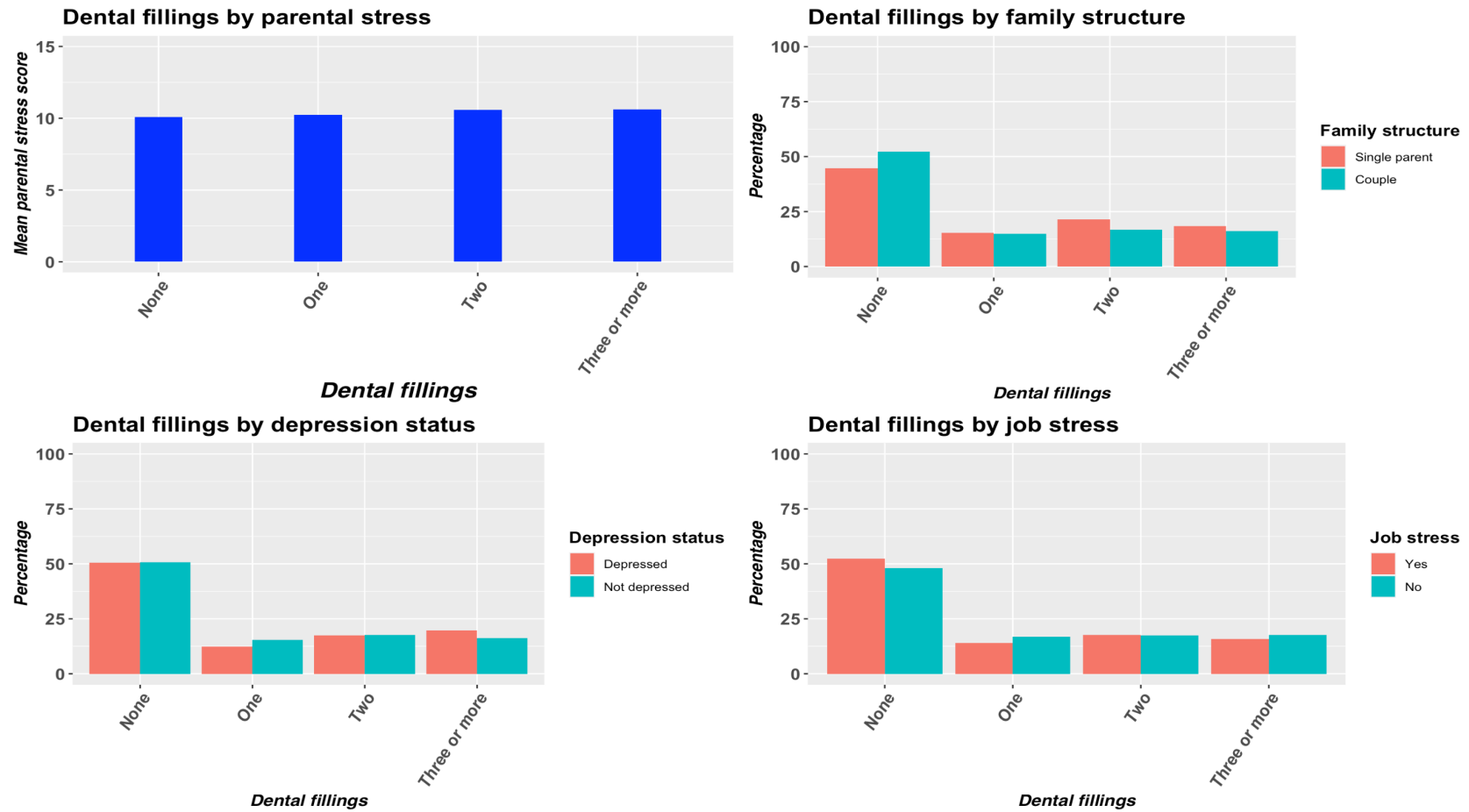


Figure 6.13 Young person's parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age by psychosocial factors (PCG parental stressor scale score, family structure, PCG depression status, and PCG job stress) at 13 years of age.

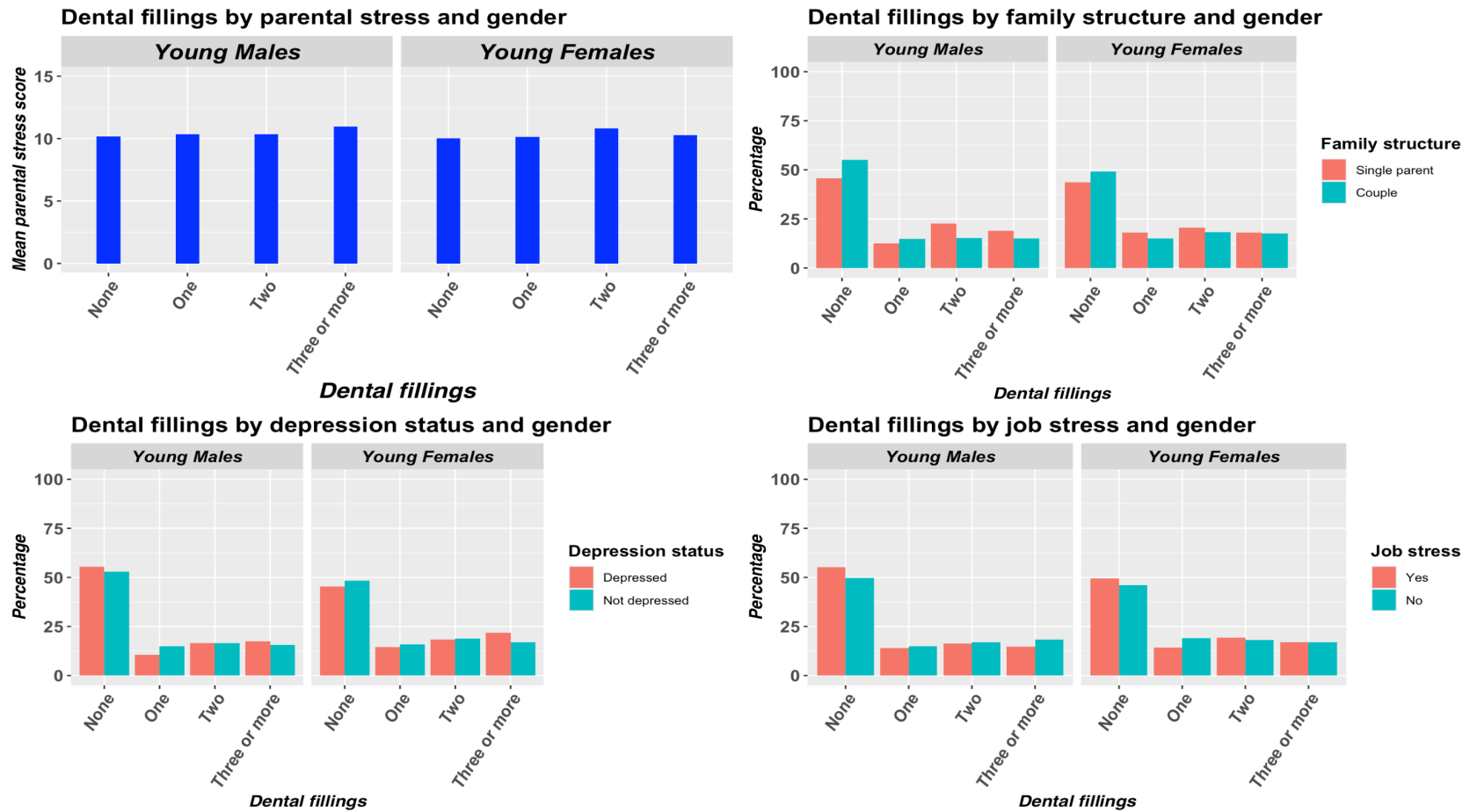


Figure 6.14 Young person's parent reported oral health (number of teeth with dental fillings) at 17/18 years of age by psychosocial factors (PCG parental stressor scale score, family structure, PCG depression status, and PCG job stress) at 13 years of age and by gender.

#### **6.3.1.9 Psychosocial Factors and Self-rated Oral Health**

Figure 6.15 shows the differences in young persons' self-reported oral health (self-rated oral health, SROH) by psychosocial factors. The PCGs' mean parental stress scores were lower for those with optimal oral health than those with sub-optimal oral health. The proportions of young persons with sub-optimal SROH were greater for those from single-parent families than those raised by two parents. There were no differences in the proportions of participants between the depression status and job stress groups. The PCGs' mean parental stress scale scores for those with sub-optimal SROH were higher for young males than young females (Figure 6.16). Similarly, for the depression, family structure and job stress groups, the proportions of young males with sub-optimal oral health were higher than young females.

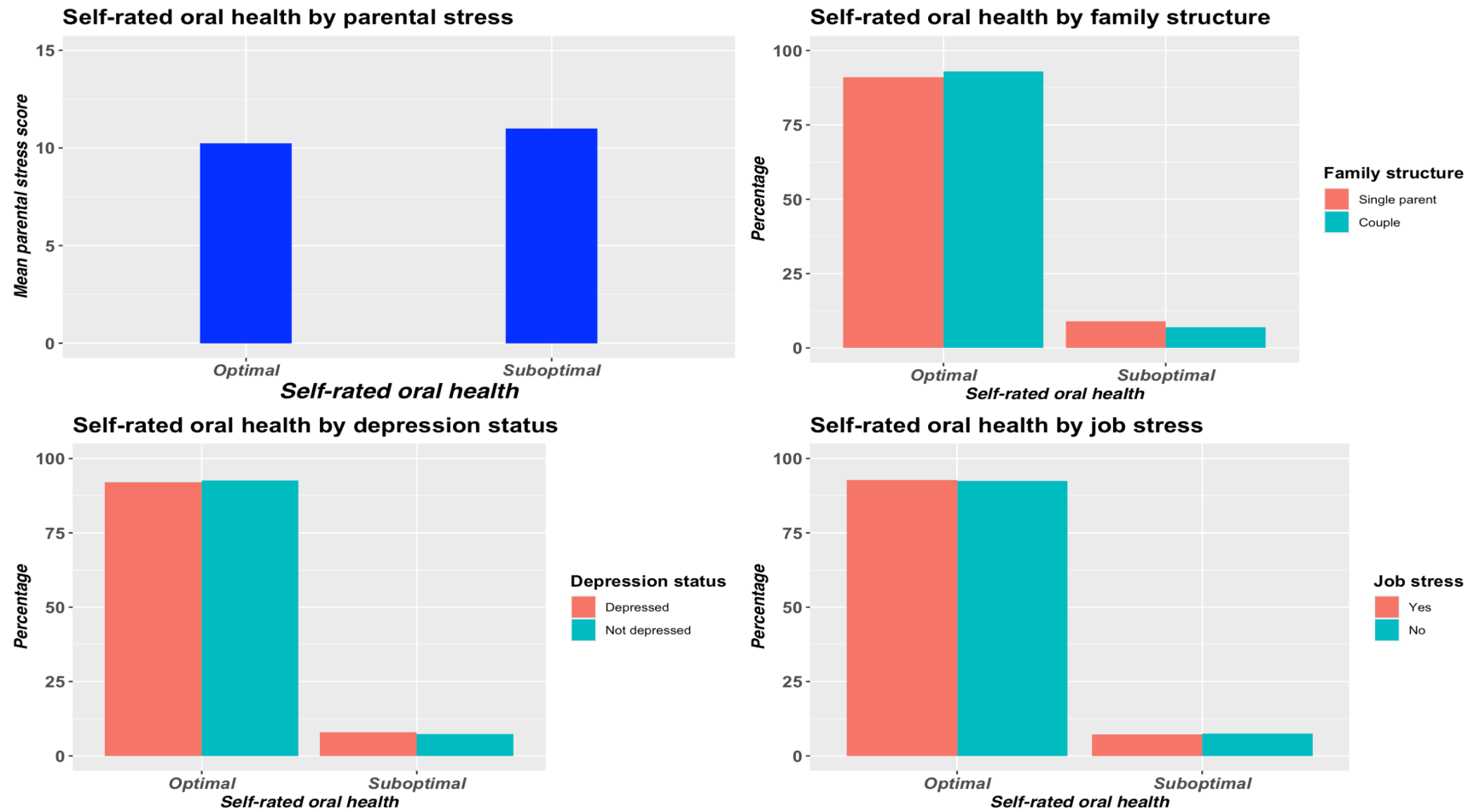


Figure 6.15 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by psychosocial factors (PCG parental stressor scale score, family structure, PCG depression status, and PCG job stress) at 13 years of age.

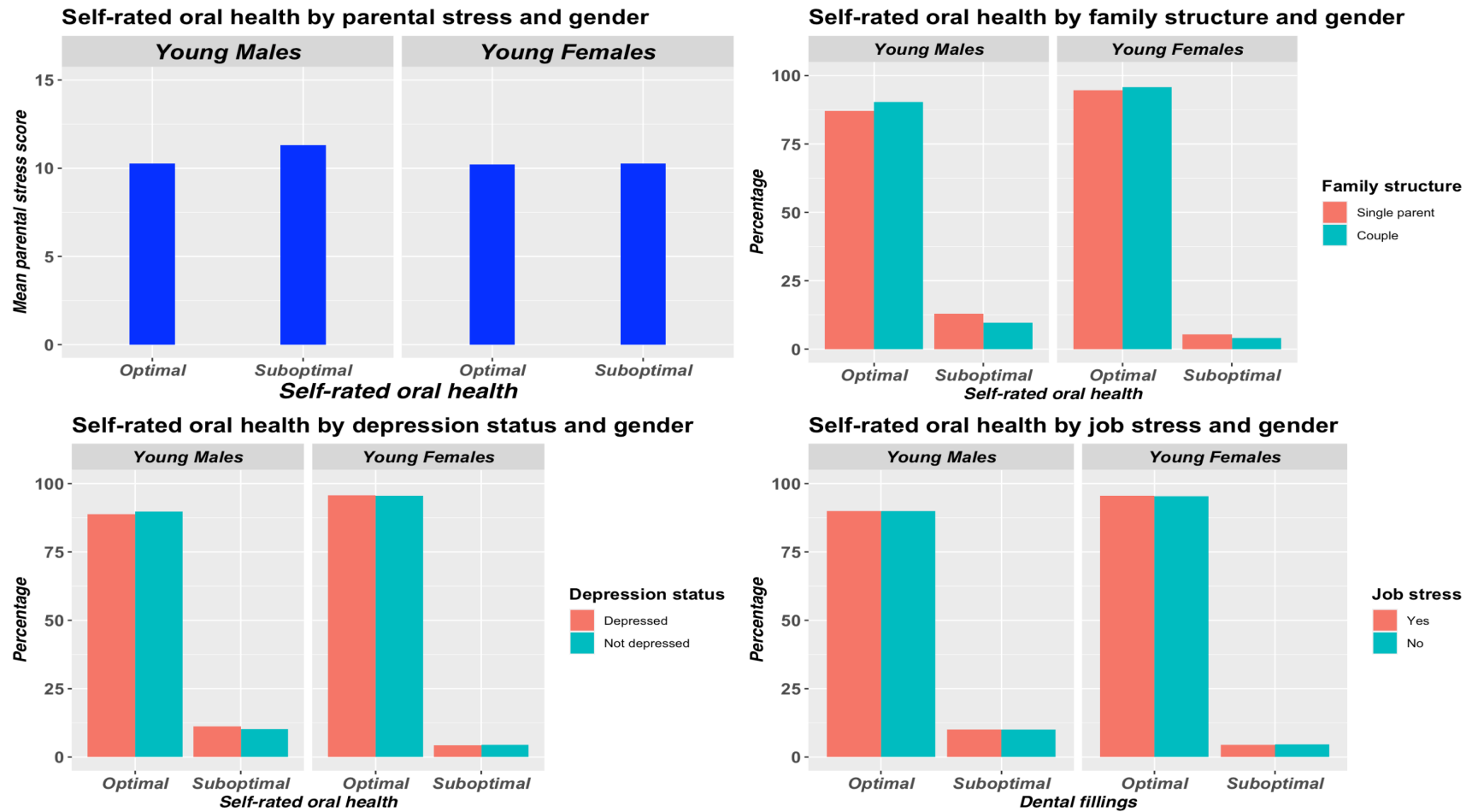


Figure 6.16 Young person's self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by psychosocial factors (PCG parental stressor scale score, family structure, PCG depression status, and PCG job stress) at 13 years of age and by gender.

#### **6.3.1.10 Behavioural, Material and Psychosocial Factors and SES Measures**

In general, the proportions of young persons with favourable outcomes (Behaviour factors: daily toothbrushing frequency twice or more than twice, visiting a dentist at least once a year and no daily dietary intake of sugary foods and drinks; Material factors: no financial difficulties, studying in a non-DEIS school, having private medical insurance and owning a house; Psychosocial factors: no parental stress, no depression, living in a two-parent family and no job stress) were greater in the higher socioeconomic groups than the lower socioeconomic groups (Appendix C, Figures S6.1 - S6.24).

#### **6.3.2 Explanatory analysis**

During explanatory analyses, data were analysed to statistically justify the relationship between study variables observed in the exploratory analysis.

##### **6.3.2.1 Association between SES measures and parent-reported oral health (Unadjusted analysis)**

Table 6.7 presents the associations between the four SES measures at 13 years and young persons' parent-reported oral health (number of permanent teeth with dental fillings) at 17/18 years. In unadjusted analysis, significant socioeconomic differences in young persons' parent-reported oral health (number of teeth with dental fillings) were found for both genders. For young males, two pairs of relationships, 'number of dental fillings' and household/family income and 'number of dental fillings' and medical card status, were statistically significant. In contrast, for young females, all four pairs of associations between young persons' parent-reported oral health and SES measures (PCGs highest educational level, family income, family occupation and medical card status) were significant (Table 6.8). For young males, the odds of having two or more teeth with dental fillings were higher for those in the lowest-income quintile group (OR<sub>Two teeth with fillings</sub>: 1.72; 95%CI: 1.24, 2.40; OR<sub>Three teeth with fillings</sub>: 1.58; 95% CI: 1.11, 2.24) compared with the highest-income quintile group. Similarly, compared with young males without a medical card, the odds of two or more fillings

(OR Two teeth with fillings: 1.65; 95%CI: 1.33, 2.03; OR Three teeth with fillings: 1.42; 95% CI: 1.13, 1.76) were higher for the full medical card holders.

For young females, when compared with the highest educational group (tertiary level), the odds of having two or more fillings increased for the 'secondary level educational' group (OR Two teeth with fillings: 1.54; 95%CI: 1.18, 2.02; OR Three teeth with fillings: 1.34; 95% CI: 1.03, 1.74). Furthermore, they increased for the lowest (none or primary) educational group (OR Two teeth with fillings: 3.56; 95%CI: 2.14, 5.95; OR Three teeth with fillings: 1.91; 95% CI: 1.07, 3.41). Similarly, compared with the highest income quintile group, the odds of two or more teeth with fillings showed an increase from third to lowest income quintile (OR 3rd quintile: OR Two teeth with fillings: 1.66; 95%CI: 1.19, 2.33; OR Three teeth with fillings: 1.48; 95% CI: 1.05, 2.08); OR lowest quintile: OR Two teeth with fillings: 1.76; 95%CI: 1.24, 2.48; OR Three teeth with fillings: 1.94; 95% CI: 1.38, 2.72). The odds of two teeth with dental fillings were higher for young females in the lowest ('semi-skilled/unskilled manual') occupational group (OR 1.75; 95%CI: 1.29, 2.36) than those in the highest ('professional managers') occupational group. Likewise, compared with young females in the 'professional managers' group, the odds of three or more teeth with dental fillings increased among young females in the 'other manual/skilled manual' group and further for those in the 'semi-skilled/unskilled manual' occupational group (OR skilled: 1.42; 95% CI: 1.12, 1.80); OR semi-skilled: 1.73; 95% CI: 1.26, 2.37). Finally, among the medical card groups, the odds of having one or more fillings were higher for full medical card holder young females than those with no medical card (OR One tooth with fillings: 1.35; 95%CI: 1.08, 1.68; OR Two teeth with fillings: 1.40; 95% CI: 1.14, 1.72; OR Three teeth with fillings: 1.63; 95% CI: 1.32, 2.02).



Table 6.7 Crude (unadjusted) associations between socioeconomic status (SES) measures (PCGs' highest educational level, family income, family occupational class and study participants' medical card status) at 13 years of age and young persons' parent-reported oral health (number of permanent teeth with dental fillings) at 17/18 years of age.

| Socioeconomic measures/indicators                             | Number of teeth with dental fillings |               |                                        |                                           |                                           |
|---------------------------------------------------------------|--------------------------------------|---------------|----------------------------------------|-------------------------------------------|-------------------------------------------|
|                                                               |                                      | None<br>n (%) | One<br>OR (95% CI) n (%)               | Two<br>OR (95% CI) n (%)                  | Three or More<br>OR (95% CI) n (%)        |
| Primary care giver's highest level of education<br>(n = 5857) | None or primary                      | 84 (43.1)     | 1.19 (0.75; 1.91)<br>26 (13.3)         | <b>2.37 (1.63; 3.455)***</b><br>56 (28.7) | 1.31 (0.83; 2.06)<br>29 (14.9)            |
|                                                               | Secondary                            | 2217 (49.9)   | 1.16 (0.96; 1.39)<br>675 (15.2)        | <b>1.26 (1.05; 1.51)*</b><br>783 (17.6)   | <b>1.31 (1.09; 1.57)**</b><br>765 (17.2)  |
|                                                               | Tertiary (Reference)                 | 677 (55.4)    | 178 (14.6)                             | 189 (15.5)                                | 178 (14.6)                                |
| Family income – quintiles<br>(n = 5421)                       | Lowest                               | 484 (44.2)    | 1.13 (0.88; 1.45)<br>162 (14.8)        | <b>1.75 (1.37; 2.22)***</b><br>228 (20.8) | <b>1.77 (1.39; 2.26)***</b><br>221 (20.2) |
|                                                               | 2 <sup>nd</sup>                      | 571 (52.3)    | 0.94 (0.74; 1.21)<br>160 (14.7)        | <b>1.37 (1.07; 1.73)*</b><br>210 (19.2)   | 1.02 (0.79; 1.32)<br>151 (13.8)           |
|                                                               | 3 <sup>rd</sup>                      | 536 (48.7)    | 0.99 (0.77; 1.27)<br>157 (14.3)        | <b>1.48 (1.16; 1.88)**</b><br>213 (19.3)  | <b>1.41 (1.11; 1.81)**</b><br>195 (17.7)  |
|                                                               | 4 <sup>th</sup>                      | 585 (52.3)    | 1.00 (0.79; 1.28)<br>175 (15.7)        | 1.10 (0.85; 1.39)<br>171 (15.3)           | 1.24 (0.97; 1.59)<br>187 (16.7)           |
|                                                               | Highest (Reference)                  | 557 (54.9)    | 165 (16.3)                             | 150 (14.8)                                | 143 (14.1)                                |
| Family class (Occupation)<br>(n = 5335)                       | Semi-skilled/ Unskilled manual       | 349 (48.7)    | <b>0.75 (0.57; 0.97)*</b><br>81 (11.3) | <b>1.36 (1.09; 1.170)**</b><br>144 (20.1) | <b>1.46 (1.16; 1.82)**</b><br>142 (19.8)  |
|                                                               | Other non-manual/ Skilled manual     | 1010 (50.8)   | 0.90 (0.76; 1.07)<br>285 (14.3)        | 1.13 (0.96; 1.33)<br>346 (17.4)           | <b>1.22 (1.03; 1.44)*</b><br>346 (17.4)   |
|                                                               | Professional managers (Reference)    | 1388 (52.7)   | 433 (16.5)                             | 422 (16.0)                                | 389 (14.6)                                |
| Medical card status<br>(n = 5858)                             | Yes, full card                       | 915 (45.3)    | 1.14 (0.97; 1.34)<br>295 (14.6)        | <b>1.52 (1.31; 1.76)***</b><br>415 (20.5) | <b>1.53 (1.32; 1.78)***</b><br>396 (19.6) |
|                                                               | Yes, doctor only card                | 71 (55.0)     | 1.04 (0.63; 1.71)<br>21 (16.3)         | 0.98 (0.59; 1.60)<br>21 (16.3)            | 0.82 (0.47; 1.41)<br>16 (12.4)            |
|                                                               | Not covered (Reference)              | 1991 (53.7)   | 563 (15.2)                             | 593 (16.0)                                | 561 (15.1)                                |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 6.8 Crude (unadjusted) associations between socioeconomic status (SES) measures (PCGs' highest educational level, family income, family occupational class and study participants' medical card status) at 13 years of age and young persons' parent-reported oral health (number of permanent teeth with dental fillings) at 17/18 years of age by gender.

|                                                                           |                      | <b>Males (M)</b><br><b>Number of teeth with dental fillings</b> |                                      |                                           |                                                | <b>Females (F)</b><br><b>Number of teeth with dental fillings</b> |                                      |                                                 |                                                |
|---------------------------------------------------------------------------|----------------------|-----------------------------------------------------------------|--------------------------------------|-------------------------------------------|------------------------------------------------|-------------------------------------------------------------------|--------------------------------------|-------------------------------------------------|------------------------------------------------|
| <b>Socioeconomic measures</b>                                             |                      | <b>None<br/>n (%)</b>                                           | <b>One<br/>OR (95% CI)<br/>n (%)</b> | <b>Two<br/>OR (95% CI)<br/>n (%)</b>      | <b>Three or More<br/>OR (95% CI)<br/>n (%)</b> | <b>None<br/>n (%)</b>                                             | <b>One<br/>OR (95% CI)<br/>n (%)</b> | <b>Two<br/>OR (95% CI)<br/>n (%)</b>            | <b>Three or More<br/>OR (95% CI)<br/>n (%)</b> |
| Primary care giver's highest level of education<br>(M = 2977<br>F = 2882) | None or primary      | 45 (52.9)                                                       | 1.13 (0.58; 2.20)<br>13 (15.3)       | 1.46 (0.82; 2.59)<br>19 (22.4)            | 0.70 (0.32; 1.55)<br>8 (9.4)                   | 39 (35.1)                                                         | 1.26 (0.65; 2.42)<br>14 (12.6)       | <b>3.56 (2.14; 5.95)***</b><br><b>37 (33.3)</b> | <b>1.91 (1.07; 3.41)*</b><br><b>21 (18.9)</b>  |
|                                                                           | Secondary            | 1179 (52.7)                                                     | 1.12 (0.86; 1.45)<br>325 (14.5)      | 1.05 (0.82; 1.34)<br>363 (16.2)           | 1.28 (0.99; 1.66)<br>369 (16.5)                | 1038 (47.1)                                                       | 1.19 (0.92; 1.56)<br>350 (15.9)      | <b>1.54 (1.18; 2.02)**</b><br><b>420 (19.1)</b> | <b>1.34 (1.03; 1.74)*</b><br><b>396 (18.0)</b> |
|                                                                           | Tertiary (Reference) | 367 (55.9)                                                      | 91 (13.9)                            | 108 (16.5)                                | 90 (13.7)                                      | 310 (54.7)                                                        | 87 (15.3)                            | 82 (14.5)                                       | 88 (15.5)                                      |
| Family income – quintiles<br>(M = 2758<br>F = 2664)                       | Lowest               | 260 (48.2)                                                      | 0.99 (0.69; 1.41)<br>72 (13.4)       | <b>1.72 (1.24; 2.40)***</b><br>113 (21.0) | <b>1.58 (1.11; 2.24)*</b><br>94 (17.4)         | 225 (40.5)                                                        | 1.27 (0.89; 1.80)<br>90 (16.2)       | <b>1.76 (1.24; 2.48)**</b><br>114 (20.5)        | <b>1.94 (1.38; 2.72)***</b><br>127 (22.8)      |
|                                                                           | 2 <sup>nd</sup>      | 306 (55.7)                                                      | 0.97 (0.69; 1.36)<br>83 (15.1)       | 1.11 (0.79; 1.57)<br>86 (15.7)            | 1.05 (0.73; 1.51)<br>74 (13.5)                 | 265 (48.8)                                                        | 0.92 (0.64; 1.31)<br>77 (14.2)       | <b>1.62 (1.15; 2.27)**</b><br>124 (22.8)        | 0.99 (0.69; 1.43)<br>77 (14.2)                 |
|                                                                           | 3 <sup>rd</sup>      | 277 (54.0)                                                      | 0.817 (0.57; 1.17)<br>64 (12.5)      | 1.27 (0.90; 1.80)<br>89 (17.3)            | 1.31 (0.92; 1.88)<br>83 (16.2)                 | 259 (44.0)                                                        | 1.12 (0.82; 1.62)<br>93 (15.8)       | <b>1.66 (1.19; 2.33)**</b><br>124 (21.1)        | <b>1.48 (1.05; 2.08)*</b><br>112 (19.0)        |
|                                                                           | 4 <sup>th</sup>      | 322 (52.0)                                                      | 1.05 (0.75; 1.46)<br>95 (15.3)       | 1.20 (0.86; 1.69)<br>99 (16.0)            | 1.39 (0.98; 1.959)<br>103 (16.6)               | 262 (52.5)                                                        | 0.96 (0.67; 1.37)<br>79 (15.8)       | 0.96 (0.66; 1.38)<br>73 (14.6)                  | 1.11 (0.77; 1.58)<br>85 (17.0)                 |
|                                                                           | Highest (Reference)  | 305 (56.7)                                                      | 86 (16.0)                            | 77 (14.3)                                 | 70 (13.0)                                      | 252 (52.7)                                                        | 79 (16.5)                            | 73 (15.3)                                       | 74 (15.5)                                      |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 6.8 Continued...

|                                                        |                                            | None<br>n (%) | One<br>OR (95% CI)<br>n (%)                | Two<br>OR (95% CI)<br>n (%)                   | Three or More<br>OR (95% CI)<br>n (%)        | None<br>n (%) | One<br>OR (95% CI)<br>n (%)                  | Two<br>OR (95% CI)<br>n (%)                  | Three or More<br>OR (95% CI)<br>n (%)        |
|--------------------------------------------------------|--------------------------------------------|---------------|--------------------------------------------|-----------------------------------------------|----------------------------------------------|---------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|
| Family class<br>(Occupation)<br>(M = 2743<br>F = 2594) | Semi-skilled/<br>Unskilled<br>manual       | 184 (56.1)    | <b>0.58 (0.38;<br/>0.87)**</b><br>31 (9.5) | 0.95 (0.68;<br>1.135)<br>50 (15.2)            | 1.21 (0.87; 1.67)<br>63 (19.2)               | 165 (42.4)    | 0.89 (0.63;<br>1.28)<br>50 (12.9)            | <b>1.75 (1.29;<br/>2.36)***</b><br>94 (24.2) | <b>1.73 (1.26;<br/>2.37)***</b><br>80 (20.6) |
|                                                        | Other non-<br>manual/<br>Skilled<br>manual | 524 (54.3)    | 0.87 (0.68;<br>1.11)<br>134 (13.9)         | 1.02 (0.80;<br>1.28)<br>153 (15.9)            | 1.04 (0.83; 1.32)<br>154 (16.0)              | 486 (47.6)    | 0.93 (0.73;<br>1.18)<br>151 (14.8)           | 1.22 (0.97;<br>1.54)<br>193 (18.9)           | <b>1.42 (1.12;<br/>1.80)**</b><br>192 (18.8) |
|                                                        | Professional<br>managers<br>(Reference)    | 778 (53.7)    | 229 (15.8)                                 | 224 (15.4)                                    | 219 (15.1)                                   | 610 (51.6)    | 205 (17.3)                                   | 198 (16.7)                                   | 170 (14.4)                                   |
| Medical card<br>status<br>(M = 2975<br>F = 2882)       | Yes, full card                             | 468 (48.5)    | 0.93 (0.73;<br>1.18)<br>120 (12.4)         | <b>1.65 (1.33;<br/>2.03)***</b><br>201 (20.9) | <b>1.42 (1.13;<br/>1.76)**</b><br>175 (18.2) | 447 (42.3)    | <b>1.35 (1.08;<br/>1.68)**</b><br>176 (16.7) | <b>1.40 (1.14;<br/>1.72)**</b><br>214 ( )    | <b>1.635 (1.32;<br/>2.02)***</b>             |
|                                                        | Yes, doctor<br>only card                   | 42 (65.6)     | 0.92 (0.46;<br>1.82)<br>11 (17.2)          | 0.58 (0.25;<br>1.36)<br>6 (9.4)               | 0.48 (0.19; 1.19)<br>5 (7.8)                 | 30 (46.2)     | 1.20 (0.59;<br>2.48)<br>10 (15.4)            | 1.42 (0.75;<br>2.71)<br>14 (21.5)            | 1.24 (0.61;<br>2.51)<br>11 (16.9)            |
|                                                        | Not covered<br>(Reference)                 | 1081 (55.5)   | 298 (15.3))                                | 282 (14.5)                                    | 286 (14.7)                                   | 910 (51.7)    | 265 (15.1)                                   | 311 (17.7)                                   | 274 (15.6)                                   |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

### ***6.3.2.2 Association between SES measures and self-reported oral health***

#### ***(Unadjusted analysis)***

In unadjusted analyses, the associations between young females' self-reported oral health (self-rated oral health, SROH) at 17 years and four SES measures (PCGs' highest educational level, family income, family occupation and medical card status) were not significant, as shown in Table 6.9. However, significant educational and income-related inequalities were found in young males' self-reported oral health (self-rated oral health, SROH) (see Table 6.9). Compared with the highest (tertiary level) educational group, the odds of sub-optimal SROH were higher for young males in the lowest (none or primary level) educational group (OR 2.52; 95% CI: 1.41, 4.49). Among the income quintile groups, the odds of sub-optimal SROH were higher for the lowest (OR<sub>Lowest</sub>: 1.59; 95% CI: 1.07; 2.35) and 2<sup>nd</sup> lowest income quintile groups (OR<sub>2<sup>nd</sup></sub>: 1.79; 95% CI: 1.21; 2.64) than the highest income quintile group.

Table 6.9 Crude (unadjusted) associations between socioeconomic measures (SES) measures (PCGs' highest educational level, family income, family occupational class and study participants' medical card status) at 13 years of age and young persons' self-reported oral health (self-rated oral health, SROH) at 17/18 years of age by gender.

|                                                                                             |                                      | Total<br>Self-rated oral health |                                                | Males<br>Self-rated oral health |                                                | Females<br>Self-rated oral health |                                                |
|---------------------------------------------------------------------------------------------|--------------------------------------|---------------------------------|------------------------------------------------|---------------------------------|------------------------------------------------|-----------------------------------|------------------------------------------------|
|                                                                                             |                                      | Optimal oral<br>health n (%)    | Suboptimal oral<br>health<br>OR (95% CI) n (%) | Optimal oral<br>health n (%)    | Suboptimal oral<br>health<br>OR (95% CI) n (%) | Optimal oral<br>health n (%)      | Suboptimal oral<br>health<br>OR (95% CI) n (%) |
| Primary care giver's<br>highest level of<br>education<br>(n = 6033<br>M = 3081<br>F = 2951) | None or primary                      | 184 (86.4)                      | <b>2.16 (1.38; 3.38)***</b><br>29 (13.6)       | 84 (82.4)                       | <b>2.52 (1.41; 4.49)**</b><br>18 (17.6)        | 100 (90.1)                        | 1.86 (0.89; 3.87)<br>11 (9.9)                  |
|                                                                                             | Secondary                            | 4222 (92.8)                     | 1.07 (0.84; 1.38)<br>330 (7.2)                 | 2052 (89.5)                     | 1.35 (0.99; 1.84)<br>241 (10.5)                | 2170 (96.1)                       | 0.72 (0.47; 1.10)<br>88 (3.9)                  |
|                                                                                             | Tertiary (Reference)                 | 1182 (93.2)                     | 86 (6.8)                                       | 631 (92.0)                      | 55 (8.0)                                       | 551 (94.7)                        | 31 (5.3)                                       |
| Family income –<br>quintiles<br>(n = 6033<br>M = 2852<br>F = 2730)                          | Lowest                               | 1053 (91.6)                     | <b>1.55 (1.11; 2.176)*</b><br>97 (8.4)         | 502 (87.6)                      | <b>1.59 (1.07; 2.35)*</b><br>71 (12.4)         | 551 (95.5)                        | 1.74 (0.88; 3.43)<br>26 (4.5)                  |
|                                                                                             | 2 <sup>nd</sup>                      | 1021 (90.8)                     | <b>1.71 (1.23; 2.39)**</b><br>104 (9.2)        | 484 (86.3)                      | <b>1.79 (1.21; 2.64)**</b><br>77 (13.7)        | 536 (95.2)                        | 1.83 (0.93; 3.60)<br>27 (4.8)                  |
|                                                                                             | 3 <sup>rd</sup>                      | 1043 (93.5)                     | 1.18 (0.83; 1.69)<br>73 (6.5)                  | 468 (90.5)                      | 1.18 (0.77; 1.80)<br>49 (9.5)                  | 575 (96.0)                        | 1.52 0.76; 3.02)<br>24 (4.0)                   |
|                                                                                             | 4 <sup>th</sup>                      | 1064 (92.9)                     | 1.29 (0.91; 1.82)<br>81 (7.1)                  | 587 (91.4)                      | 1.05 (0.69; 1.58)<br>55 (8.6)                  | 477 (94.8)                        | 2.03 (1.03; 3.99)<br>26 (5.2)                  |
|                                                                                             | Highest (Reference)                  | 987 (94.4)                      | 58 (5.6)                                       | 513 (91.8)                      | 46 (8.2)                                       | 475 (97.3)                        | 13 (2.7)                                       |
| Family class<br>(Occupation)<br>(n = 6033<br>M = 2828<br>F = 2646)                          | Semi-skilled/ Unskilled<br>manual    | 687 (92.8)                      | 1.06 (0.77; 1.46)<br>53 (7.2)                  | 302 (88.6)                      | 1.31 (0.90; 1.91)<br>39 (11.4)                 | 385 (96.5)                        | 0.86 (0.47; 1.58)<br>14 (3.5)                  |
|                                                                                             | Other non-manual/<br>Skilled manual  | 1891 (93.2)                     | 1.00 (0.80; 1.27)<br>138 (6.8)                 | 903 (90.8)                      | 1.02 (0.77; 1.35)<br>91 (9.2)                  | 989 (95.5)                        | 1.14 (0.76; 1.72)<br>47 (4.5)                  |
|                                                                                             | Professional managers<br>(Reference) | 2522 (93.2)                     | 183 (6.8)                                      | 1359 (91.0)                     | 134 (9.0)                                      | 1163 (96.0)                       | 48 (4.0)                                       |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 6.9 Continued...

|                                                           |                            |             |                                |             |                                 |             |                               |
|-----------------------------------------------------------|----------------------------|-------------|--------------------------------|-------------|---------------------------------|-------------|-------------------------------|
| Medical card status<br>(n = 6031<br>M = 3080<br>F = 2950) | Yes, full card             | 1921 (91.9) | 1.17 (0.96; 1.43)<br>169 (8.1) | 889 (88.3)  | 1.27 (0.99; 1.62)<br>118 (11.7) | 1032 (95.3) | 1.13 (0.78; 1.63)<br>51 (4.7) |
|                                                           | Yes, doctor only<br>card   | 132 (93.6)  | 0.94 (0.47; 1.84)<br>9 (6.4)   | 60 (90.9)   | 0.92 (0.39; 2.17)<br>6 (9.1)    | 72 (96.0)   | 1.11 (0.37; 3.34)<br>3 (4.0)  |
|                                                           | Not covered<br>(Reference) | 3535 (93.0) | 265 (7.0)                      | 1817 (90.5) | 190 (9.5)                       | 1717 (95.6) | 129 (4.4)                     |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

### **6.3.2.3 Association between behavioural factors and young persons' parent-reported oral health**

Tables 6.10 and 6.11 present the relationship between behavioural factors and young persons' parent-reported oral health (number of teeth with dental fillings). The unadjusted analysis found significant associations between behavioural factors and young persons' oral health for both genders. For young males, the odds of having two or more teeth with dental fillings were higher for those who brushed their teeth once a day (OR<sub>Two teeth with fillings</sub>: 1.28; 95% CI: 1.02, 1.61; OR<sub>Three teeth with fillings</sub>: 1.37; 95% CI: 1.08, 1.74) than those who followed the recommended tooth brushing guidelines of brushing their teeth twice or more a day. On the other hand, compared with regular dental visitors (at least once a year), the odds of having two or more teeth with dental fillings were lower in irregular visitors (never visited or visited only when there was a problem with their teeth) (OR<sub>Two teeth with fillings</sub>: 0.69; 95% CI: 0.51, 0.95; OR<sub>Three teeth with fillings</sub>: 0.61; 95% CI: 0.43, 0.85). For dietary intake of sugary drinks, compared with those who never consumed sugary drinks, for frequent consumers (once a day or more than once a day) of soft drinks, the odds of having one tooth with dental fillings were lower (OR<sub>more</sub>: 0.65; 95% CI: 0.48, 0.89); OR<sub>once</sub>: 0.76; 95% CI: 0.59, 0.98) and of having three or more teeth with dental fillings were higher (OR<sub>once</sub>: 1.33; 95% CI: 1.05, 1.68). Similarly, for sugary foods, the odds of having two teeth with dental fillings were higher for those who had sugary foods more than once a day (OR 1.58; 95% CI: 1.19, 2.09) than those who never consumed sugary foods.

For young females, compared with the reference group ('twice or more than twice'), the odds of having three or more teeth with dental fillings increased for 'once a day' group to 1.57 (95% CI: 1.20, 2.05) and to 2.61 (95% CI: 1.62, 4.21) for 'less than once/never' group. As with young males, the odds of having two or more teeth with dental fillings were lower for young females who were irregular visitors (OR<sub>Two teeth with fillings</sub>: 0.55; 95% CI: 0.39, 0.76; OR<sub>Three teeth with fillings</sub>: 0.59; 95% CI: 0.42, 0.82) than regular visitors. For the sugary foods and sugary drinks variables, the odds of having two teeth with dental fillings (OR<sub>drinks</sub>: 1.58; 95% CI: 1.25, 2.00); OR<sub>foods</sub>: 1.34; 95% CI: 1.06, 1.68) and three or more teeth with dental fillings (OR<sub>drinks</sub>: 1.38; 95% CI: 1.05,

1.82); OR<sub>foods</sub>: 1.69; 95% CI: 1.27, 2.25) were higher for the 'once a day' and 'more than once a day' groups, respectively, compared with the 'not at all' group.



Table 6.10 Crude (unadjusted) associations between behavioural factors (daily tooth brushing frequency, dentist visit behaviour, sugary foods intake and sugary drinks intake) at 13 years of age and young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age.

| Behavioural factors                                                                      |                                               | Number of teeth with dental fillings |                                         |                                           |                                           |
|------------------------------------------------------------------------------------------|-----------------------------------------------|--------------------------------------|-----------------------------------------|-------------------------------------------|-------------------------------------------|
|                                                                                          |                                               | None<br>n (%)                        | One<br>OR (95% CI)<br>n (%)             | Two<br>OR (95% CI)<br>n (%)               | Three or More<br>OR (95% CI)<br>n (%)     |
| Toothbrushing frequency<br>(n = 5782)                                                    | Less than once a day/Rarely/Not at all        | 154 (49)                             | 0.82 (0.57; 1.19)<br>37 (11.8)          | 1.00 (0.72; 1.38)<br>52 (16.6)            | <b>1.60 (1.19; 2.15)**</b><br>71 (22.6)   |
|                                                                                          | Once a day                                    | 587 (48)                             | 1.02 (0.84; 1.23)<br>177 (14.5)         | 1.12 (0.94; 1.33)<br>221 (18.1)           | <b>1.39 (1.17; 1.66)***</b><br>237 (19.4) |
|                                                                                          | Twice or more than twice a day<br>(Reference) | 2208 (52)                            | 654 (15.4)                              | 745 (17.5)                                | 639 (15.0)                                |
| Dentist visit behaviour<br>(n = 5855)                                                    | Problem visit/Never/Almost never              | 455 (56.9)                           | 0.99 (0.80; 1.22)<br>139 (17.4)         | <b>0.62 (0.49; 0.77)***</b><br>107 (13.4) | <b>0.59 (0.47; 0.75)***</b><br>98 (12.3)  |
|                                                                                          | Occasional visit                              | 598 (53.7)                           | <b>0.78 (0.64; 0.96)*</b><br>145 (13.0) | 0.83 (0.69; 1.00)<br>190 (17.1)           | 0.83 (0.69; 1.00)<br>181 (16.2)           |
|                                                                                          | At least a year<br>(Reference)                | 1923 (48.8)                          | 594 (15.1)                              | 731 (18.5)                                | 694 (17.6)                                |
| Sugary drinks intake<br>(Soft drinks/minerals/cordial/squash<br>(not diet)<br>(n = 5771) | More than once a day                          | 523 (51.1)                           | 0.82 (0.66; 1.02)<br>133 (13.0)         | 1.16 (0.95; 1.40)<br>186 (18.2)           | 1.19 (0.98; 1.45)<br>182 (17.8)           |
|                                                                                          | Once a day                                    | 799 (48.2)                           | 0.96 (0.80; 1.14)<br>236 (14.2)         | <b>1.36 (1.16; 1.60)***</b><br>333 (20.1) | <b>1.25 (1.05; 1.47)*</b><br>291 (17.5)   |
|                                                                                          | Not at all<br>(Reference)                     | 1619 (52.4)                          | 499 (16.2)                              | 497 (16.1)                                | 473 (15.3)                                |
| Sugary foods intake<br>(Biscuits, doughnuts, cake, pie or<br>chocolate)<br>(n = 5776)    | More than once a day                          | 543 (47.1)                           | 1.07 (0.86; 1.33)<br>167 (14.5)         | <b>1.32 (1.07; 1.62)**</b><br>221 (19.2)  | <b>1.40 (1.14; 1.72)**</b><br>223 (19.3)  |
|                                                                                          | Once a day                                    | 1485 (51.4)                          | 1.02 (0.86; 1.22)<br>438 (15.2)         | 1.12 (0.94; 1.32)<br>513 (17.8)           | 1.04 (0.87; 1.23)<br>453 (15.7)           |
|                                                                                          | Not at all<br>(Reference)                     | 917 (52.9)                           | 263 (15.2)                              | 283 (16.3)                                | 270 (15.6)                                |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 6.11 Crude (unadjusted) associations between behavioural factors (daily tooth brushing frequency, dentist visit behaviour, sugary foods intake and sugary drinks intake) at 13 years of age and young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age and by gender.

| Behavioural factors                               |                                            | Males (M)<br>Number of teeth with dental fillings |                             |                             |                                          | Females (F)<br>Number of teeth with dental fillings |                             |                             |                                          |
|---------------------------------------------------|--------------------------------------------|---------------------------------------------------|-----------------------------|-----------------------------|------------------------------------------|-----------------------------------------------------|-----------------------------|-----------------------------|------------------------------------------|
|                                                   |                                            | None<br>n (%)                                     | One<br>OR (95% CI)<br>n (%) | Two<br>OR (95% CI)<br>n (%) | Three or<br>More<br>OR (95% CI)<br>n (%) | None<br>n (%)                                       | One<br>OR (95% CI)<br>n (%) | Two<br>OR (95% CI)<br>n (%) | Three or<br>More<br>OR (95% CI)<br>n (%) |
| Toothbrushing frequency<br>(M = 2931<br>F = 2851) | Less than once a day/Rarely/Not at all     | 114 (52.5)                                        | 1.02 (0.68; 1.54)           | 0.98 (0.65; 1.48)           | 1.31 (0.89; 1.93)                        | 39 (40.6)                                           | 0.39 (0.15; 1.01)           | 1.29 (0.74; 2.25)           | <b>2.61 (1.62; 4.21)***</b>              |
|                                                   | Once a day                                 | 387 (51.0)                                        | 0.84 (0.65; 1.09)           | <b>1.28 (1.02; 1.61)*</b>   | <b>1.37 (1.08; 1.74)**</b>               | 200 (43.1)                                          | <b>1.38 (1.04; 1.82)*</b>   | 1.01 (0.76; 1.35)           | <b>1.57 (1.20; 2.05)***</b>              |
|                                                   | Twice or more than twice a day (Reference) | 1072 (54.8)                                       | 298 (15.2)                  | 310 (15.9)                  | 275 (14.1)                               | 1136 (49.6)                                         | 356 (15.5)                  | 435 (19.0)                  | 364 (15.9)                               |
| Dentist visit behaviour<br>(M = 2974<br>F = 2880) | Problem visit/Never/Almost never           | 243 (59.6)                                        | 0.89 (0.65; 1.21)           | <b>0.69 (0.51; 0.95)*</b>   | <b>0.61 (0.43; 0.85)**</b>               | 211 (54.1)                                          | 1.09 (0.81; 1.46)           | <b>0.55 (0.39; 0.76)***</b> | <b>0.59 (0.42; 0.82)**</b>               |
|                                                   | Occasional visit                           | 310 (55.9)                                        | 0.84 (0.63; 1.11)           | 0.83 (0.64; 1.09)           | 0.86 (0.66; 1.13)                        | 288 (51.6)                                          | <b>0.74 (0.55; 0.98)*</b>   | 0.83 (0.65; 1.07)           | 0.80 (0.62; 1.04)                        |
|                                                   | At least a year (Reference)                | 1037 (51.6)                                       | 294 (14.6)                  | 347 (17.3)                  | 333 (16.6)                               | 886 (45.9)                                          | 301 (15.6)                  | 384 (19.9)                  | 361 (18.7)                               |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 6.11 Continued...

|                                                   |                           | None<br>n (%) | One<br>OR (95% CI)<br>n (%)                 | Two<br>OR (95% CI)<br>n (%)                   | Three or<br>More<br>OR (95% CI)<br>n (%)    | None<br>n (%) | One<br>OR (95% CI)<br>n (%)        | Two<br>OR (95% CI)<br>n (%)                   | Three or<br>More<br>OR (95% CI)<br>n (%)      |
|---------------------------------------------------|---------------------------|---------------|---------------------------------------------|-----------------------------------------------|---------------------------------------------|---------------|------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Sugary drinks<br>intake<br>(M = 2926<br>F = 2844) | More than<br>once a day   | 309 (55.2)    | <b>0.65 (0.48;<br/>0.89)**</b><br>63 (11.3) | 1.20 (0.92;<br>1.58)<br>102 (18.2)            | 1.09 (0.82;<br>1.46)<br>86 (15.4)           | 214 (46.2)    | 1.07 (0.79;<br>1.45)<br>70 (15.1)  | 1.16 (0.87;<br>1.54)<br>83 (17.9)             | <b>1.38 (1.05;<br/>1.82)*</b><br>96 (20.7)    |
|                                                   | Once a day                | 497 (51.9)    | <b>0.76 (0.59;<br/>0.98)*</b><br>119 (12.4) | 1.26 (1.00;<br>1.59)<br>173 (18.1)            | <b>1.33 (1.05;<br/>1.68)*</b><br>168 (17.6) | 302 (43.0)    | 1.27 (0.98;<br>1.64)<br>117 (16.7) | <b>1.58 (1.25;<br/>2.00)***</b><br>161 (22.9) | 1.24 (0.97;<br>1.59)<br>122 (17.4)            |
|                                                   | Not at all<br>(Reference) | 765 (54.3)    | 239 (17.0)                                  | 210 (14.9)                                    | 195 (13.8)                                  | 854 (50.9)    | 260 (15.5)                         | 287 (17.1)                                    | 278 (16.6)                                    |
| Sugary foods<br>intake<br>(M = 2927<br>F = 2851)  | More than<br>once a day   | 288 (48.2)    | 1.18 (0.86;<br>1.63)<br>80 (13.4)           | <b>1.58 (1.19;<br/>2.09)***</b><br>132 (22.1) | 1.13 (0.84;<br>1.53)<br>97 (16.2)           | 255 (45.8)    | 0.99 (0.73;<br>1.35)<br>86 (15.4)  | 1.07 (0.79;<br>1.45)<br>90 (16.2)             | <b>1.69 (1.27;<br/>2.25)***</b><br>126 (22.6) |
|                                                   | Once a day                | 818 (55.1)    | 1.19 (0.93;<br>1.55)<br>232 (15.6)          | 0.93 (0.73;<br>1.19)<br>220 (14.8)            | 0.89 (0.70;<br>1.14)<br>215 (14.5)          | 667 (47.5)    | 0.91 (0.72;<br>1.16)<br>207 (14.7) | <b>1.34 (1.06;<br/>1.68)*</b><br>293 (20.9)   | 1.21 (0.95;<br>1.55)<br>238 (16.9)            |
|                                                   | Not at all<br>(Reference) | 464 (54.9)    | 110 (13.0)                                  | 134 (15.9)                                    | 137 (16.2)                                  | 453 (51.0)    | 174 (17.3)                         | 149 (16.8)                                    | 133 (15.0)                                    |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

#### **6.3.2.4 Association between behavioural factors and young persons' self-reported oral health**

Table 6.12 shows the association between behavioural factors and young persons' self-reported oral health (self-rated oral health, SROH). In unadjusted analysis, all four behaviour factors were significantly associated with SROH for young males. In contrast, for young females, three factors, with the exception of the dentist visit behaviour variable, were significantly associated with SROH.

In young males, compared with those who brushed their teeth twice or more than twice daily, the odds of sub-optimal health were higher for those who brushed once a day (OR 2.11; 95% CI: 1.61, 2.75) and less than once a day or never (OR 5.15; 95% CI: 3.85; 6.90). Similarly, the odds of sub-optimal SROH were higher for young males who never visited or visited the dentist only when there was a dental problem (OR 2.16; 95% CI: 1.62; 2.87) than for regular dental visitors (at least once a year). Likewise, the odds of sub-optimal SROH were higher for young males who consumed sugary drinks (OR 1.63; 95% CI: 1.21, 2.20) and foods (OR 1.59; 95% CI: 1.17, 2.18) more than once a day than those who never had sugary drinks and foods.

For young females, the odds of sub-optimal oral health were higher for those who brushed their teeth less than once a day or never (OR 3.65; 95% CI: 1.99, 6.72) than the 'twice or more than twice daily' group. There was a clear gradient in the odds of sub-optimal SROH among the 'sugary drinks intake' groups. Compared with non-consumers of sugary drinks, the odds of sub-optimal SROH were higher in the 'once a day' group (OR 1.79; 95% CI: 1.17, 2.74), which further increased for the 'more than once a day' group (OR 2.49; 95% CI: 1.61, 3.85). For sugary foods, compared with the reference group ('not at all'), the odds of sub-optimal SROH were higher for the 'more than once a day' group (OR 1.89; 95% CI: 1.18, 3.05).

Table 6.12 Crude (unadjusted) associations between behavioural factors (daily tooth brushing frequency, dentist visit behaviour, sugary foods intake and sugary drinks intake) at 13 years of age and young persons' self-reported oral health (self-rated oral health, SROH) at 17/18 years of age and by gender.

|                                                                  |                                                  | Total<br>Self-reported oral health |                                                   | Males<br>Self-reported oral health |                                                   | Females<br>Self-reported oral health |                                                   |
|------------------------------------------------------------------|--------------------------------------------------|------------------------------------|---------------------------------------------------|------------------------------------|---------------------------------------------------|--------------------------------------|---------------------------------------------------|
|                                                                  |                                                  | Optimal oral<br>health<br>n (%)    | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) | Optimal oral<br>health<br>n (%)    | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) | Optimal oral<br>health<br>n (%)      | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) |
| Toothbrushing<br>frequency<br>(n = 5960<br>M = 3036<br>F = 2923) | Less than once a<br>day/Rarely/Not at<br>all     | 253 (77.6)                         | <b>5.15 (3.85;<br/>6.90)***</b><br>73 (22.4)      | 163 (73.1)                         | <b>4.95 (3.51;<br/>6.07)***</b><br>60 (26.9)      | 90 (87.4)                            | <b>3.65 (1.99;<br/>6.72)***</b><br>13 (12.6)      |
|                                                                  | Once a day                                       | 1132 (89.9)                        | <b>2.00 (1.60;<br/>2.51)***</b><br>127 (10.1)     | 673 (86.5)                         | <b>2.11 (1.61;<br/>2.75)***</b><br>105 (13.5)     | 459 (95.4)                           | 1.18 (0.73; 1.89)<br>22 (4.6)                     |
|                                                                  | Twice or more than<br>twice a day<br>(Reference) | 4143 (94.7)                        | 232 (5.3)                                         | 1895 (93.1)                        | 140 (6.9)                                         | 2247 (96.1)                          | 92 (3.9)                                          |
| Dentist visit behaviour<br>(n = 6031<br>M = 3082<br>F = 2949)    | Problem<br>visit/Never/Almost<br>never           | 740 (88.6)                         | <b>1.70 (1.33;<br/>2.17)***</b><br>95 (11.4)      | 354 (81.8)                         | <b>2.16 (1.62;<br/>2.87)***</b><br>79 (18.2)      | 386 (96.0)                           | 0.87 (0.50; 1.49)<br>16 (4.0)                     |
|                                                                  | Occasional visit                                 | 1079 (94.2)                        | 0.81 (0.62; 1.07)<br>66 (5.8)                     | 527 (92.6)                         | 0.77 (0.54; 1.09)<br>42 (7.4)                     | 552 (95.8)                           | 0.91 (0.58; 1.45)<br>24 (4.2)                     |
|                                                                  | At least a year<br>(Reference)                   | 3767 (93.0)                        | 284 (7.0)                                         | 1886 (90.7)                        | 194 (9.3)                                         | 1881 (95.4)                          | 90 (4.6)                                          |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 6.12 Continued...

|                                                                                                               |                           | Optimal oral health<br>n (%) | Suboptimal oral health<br>OR (95% CI)<br>n (%) | Optimal oral health<br>n (%) | Suboptimal oral health<br>OR (95% CI)<br>n (%) | Optimal oral health<br>n (%) | Suboptimal oral health<br>OR (95% CI)<br>n (%) |
|---------------------------------------------------------------------------------------------------------------|---------------------------|------------------------------|------------------------------------------------|------------------------------|------------------------------------------------|------------------------------|------------------------------------------------|
| Sugary drinks intake<br>(Soft drinks/minerals/cordial/squash (not diet)<br>(n = 5950<br>M = 3032<br>F = 2919) | More than once a day      | 956 (89.3)                   | <b>1.99 (1.56; 2.55)***</b><br>114 (10.7)      | 508 (86.5)                   | <b>1.63 (1.21; 2.20)**</b><br>79 (13.5)        | 448 (92.6)                   | <b>2.49 (1.61; 3.85)***</b><br>36 (7.4)        |
|                                                                                                               | Once a day                | 1569 (92.0)                  | <b>1.46 (1.16; 1.84)**</b><br>137 (8.0)        | 892 (90.0)                   | 1.17 (0.88; 1.54)<br>99 (10.0)                 | 677 (94.6)                   | <b>1.79 (1.17; 2.74)**</b><br>39 (5.4)         |
|                                                                                                               | Not at all<br>(Reference) | 2995 (94.4)                  | 179 (5.6)                                      | 1328 (91.3)                  | 126 (8.7)                                      | 1666 (96.9)                  | 53 (3.1)                                       |
| Sugary foods intake<br>(Biscuits, doughnuts, cake, pie or chocolate)<br>(n = 5954<br>M = 3033<br>F = 2923)    | More than once a day      | 1049 (88.9)                  | <b>1.71 (1.31; 2.21)***</b><br>131 (11.1)      | 522 (84.9)                   | <b>1.59 (1.17; 2.18)**</b><br>93 (15.1)        | 526 (93.3)                   | <b>1.89 (1.18; 3.05)**</b><br>38 (6.7)         |
|                                                                                                               | Once a day                | 2791 (94.1)                  | 0.86 (0.68; 1.09)<br>175 (5.9)                 | 1401 (92.1)                  | 0.77 (0.58; 1.02)<br>120 (7.9)                 | 1390 (96.1)                  | 1.05 (0.68; 1.62)<br>56 (3.9)                  |
|                                                                                                               | Not at all<br>(Reference) | 1685 (93.2)                  | 123 (6.8)                                      | 807 (90.0)                   | 90 (10.0)                                      | 879 (96.3)                   | 34 (3.7)                                       |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

### **6.3.2.5 Association between material factors and young persons' parent-reported Oral Health**

Tables 6.13 and 6.14 outline the results of the unadjusted logistic regression analysis between material factors (financial difficulties, DEIS (Delivering Equality of Opportunity in Schools) school status, house ownership and private medical insurance) and young persons' parent-reported oral health (number of teeth with dental fillings). For males, all four pairs of associations between material factors and young persons' parent-reported oral health were significant. However, for young females, the relationship between young persons' parent-reported oral health and DEIS school was not significant.

For young males, there was a 1.27-fold increase in the odds of having three or more teeth with dental fillings in those from families with financial difficulties compared with those who lived in households with no financial difficulties (OR<sub>Three teeth with fillings</sub>: 1.27; 95% CI: 1.03, 1.58). Likewise, the odds of having two teeth with dental fillings were higher for those who attended DEIS schools than those who did not (OR<sub>Two teeth with fillings</sub>: 1.35; 95% CI: 1.04, 1.75). Similarly, the odds of having two teeth with dental fillings were higher for those who lived in rented accommodations than those who lived in houses owned by their parents (OR<sub>Two teeth with fillings</sub>: 1.58; 95% CI: 1.23, 2.03). Further, compared with private medical insurance holders, the odds of having two teeth with dental fillings increased among young males with no medical insurance cover to 1.27 (OR<sub>Two teeth with fillings</sub>: 1.27; 95% CI: 1.03, 1.55).

For young females, compared with the reference group (no financial difficulties), the odds of having three or more teeth with dental fillings were higher for those whose families had experienced financial difficulties (OR: 1.56; 95% CI: 1.25, 1.93). The odds of having two or more teeth with dental fillings were higher for those who lived in rented/other accommodations (OR<sub>Two teeth with fillings</sub>: 1.33; 95% CI: 1.05, 1.68; OR<sub>Three teeth with fillings</sub>: 1.31; 95% CI: 1.03, 1.67) than those who had parents-owned houses. Similarly, those without private medical insurance cover had increased odds of having two or more teeth with dental fillings than those covered with private medical insurance (OR<sub>Two teeth with fillings</sub>: 1.26; 95% CI: 1.03, 1.54; OR<sub>Three teeth with fillings</sub>: 1.37; 95% CI: 1.13, 1.70).

Table 6.13 Crude (Unadjusted) associations between behavioural factors (financial difficulties, DEIS school status, house ownership and private medical insurance cover) at 13 years of age and young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age.

|                                                                   |                              | Number of teeth with dental fillings |                                         |                                           |                                           |
|-------------------------------------------------------------------|------------------------------|--------------------------------------|-----------------------------------------|-------------------------------------------|-------------------------------------------|
|                                                                   |                              | None<br>n (%)                        | One<br>OR (95% CI)<br>n (%)             | Two<br>OR (95% CI)<br>n (%)               | Three or More<br>OR (95% CI)<br>n (%)     |
| Financial difficulties (Difficulty in meeting ends)<br>(n = 5856) | With difficulty              | 1753 (49.9)                          | 0.90 (0.77; 1.05)<br>496 (14.1)         | 1.04 (0.90; 1.20)<br>616 (17.5)           | <b>1.41 (1.21; 1.65)***</b><br>651 (18.5) |
|                                                                   | No difficulty<br>(Reference) | 1223 (52.3)                          | 383 (16.4)                              | 413 (17.6)                                | 321 (13.7)                                |
| DEIS school<br>(n = 5435)                                         | Yes                          | 488 (49.6)                           | <b>0.79 (0.64; 0.98)*</b><br>119 (12.1) | <b>1.25 (1.04; 1.50)*</b><br>203 (20.6)   | 1.12 (0.92; 1.35)<br>174 (17.7)           |
|                                                                   | No<br>(Reference)            | 2274 (51.1)                          | 696 (15.6)                              | 755 (17.0)                                | 726 (16.3)                                |
| Homeownership<br>(n = 5854)                                       | Renters/Rent free/Others     | 522 (46.8)                           | 0.87 (0.71; 1.07)<br>138 (12.4)         | <b>1.46 (1.23; 1.73)***</b><br>243 (21.8) | <b>1.31 (1.09; 1.57)**</b><br>212 (19.0)  |
|                                                                   | Owner<br>(Reference)         | 2453 (51.8)                          | 742 (15.7)                              | 783 (16.5)                                | 761 (16.1)                                |
| Private medical insurance<br>(n = 5859)                           | No                           | 1432 (48.9)                          | 0.94 (0.81; 1.09)<br>409 (14.0)         | <b>1.28 (1.11; 1.47)***</b><br>558 (19.1) | <b>1.28 (1.11; 1.48)***</b><br>529 (18.1) |
|                                                                   | Yes<br>(Reference)           | 1545 (52.7)                          | 471 (16.1)                              | 471 (16.1)                                | 444 (15.1)                                |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$



Table 6.14 Crude (Unadjusted) associations between behavioural factors (financial difficulties, DEIS school status, house ownership and private medical insurance cover) at 13 years of age and young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age and by gender.

|                                                                                  |                              | <b>Males (M)</b><br><b>Number of teeth with dental fillings</b> |                                            |                                               |                                                    | <b>Females (F)</b><br><b>Number of teeth with dental fillings</b> |                                      |                                             |                                                    |
|----------------------------------------------------------------------------------|------------------------------|-----------------------------------------------------------------|--------------------------------------------|-----------------------------------------------|----------------------------------------------------|-------------------------------------------------------------------|--------------------------------------|---------------------------------------------|----------------------------------------------------|
|                                                                                  |                              | <b>None<br/>n (%)</b>                                           | <b>One<br/>OR (95% CI)<br/>n (%)</b>       | <b>Two<br/>OR (95% CI)<br/>n (%)</b>          | <b>Three or<br/>More<br/>OR (95% CI)<br/>n (%)</b> | <b>None<br/>n (%)</b>                                             | <b>One<br/>OR (95% CI)<br/>n (%)</b> | <b>Two<br/>OR (95% CI)<br/>n (%)</b>        | <b>Three or<br/>More<br/>OR (95% CI)<br/>n (%)</b> |
| Financial difficulties<br>(Difficulty in meeting ends)<br>(M = 2974<br>F = 2883) | With difficulty              | 924 (53.5)                                                      | 0.87 (0.70;<br>1.08)<br>235 (13.6)         | 0.89 (0.73;<br>1.09)<br>271 (15.7)            | <b>1.27 (1.03;<br/>1.58)*</b><br>298 (17.2)        | 829 (46.4)                                                        | 0.93 (0.75;<br>1.15)<br>261 (14.6)   | 1.19 (0.98;<br>1.47)<br>345 (19.3)          | <b>1.56 (1.25;<br/>1.93)***</b><br>353 (19.7)      |
|                                                                                  | No difficulty<br>(Reference) | 665 (53.4)                                                      | 194 (15.6)                                 | 219 (17.6)                                    | 168 (13.5)                                         | 558 (51.0)                                                        | 190 (17.4)                           | 194 (17.7)                                  | 153 (14.0)                                         |
| DEIS school<br>M = 2782<br>F = 2656)                                             | Yes                          | 258 (51.1)                                                      | <b>0.67 (0.48;<br/>0.93)*</b><br>50 (9.9)  | <b>1.35 (1.04;<br/>1.75)*</b><br>102 (20.2)   | 1.28 (0.98;<br>1.66)<br>95 (18.8)                  | 230 (47.9)                                                        | 0.91 (0.68;<br>1.23)<br>69 (14.4)    | 1.16 (0.89;<br>1.50)<br>101 (21.0)          | 0.97 (0.73;<br>1.28)<br>80 (16.7)                  |
|                                                                                  | No<br>(Reference)            | 1220 (53.6)                                                     | 350 (15.4)                                 | 357 (15.7)                                    | 350 (15.4)                                         | 1054 (48.4)                                                       | 347 (15.9)                           | 398 (18.3)                                  | 377 (17.3)                                         |
| Homeownership<br>(M = 2974<br>F = 2880)                                          | Renters/Rent free/Others     | 251 (50.5)                                                      | <b>0.61 (0.43;<br/>0.85)**</b><br>44 (8.9) | <b>1.58 (1.23;<br/>2.03)***</b><br>112 (22.5) | 1.27 (0.97;<br>1.65)<br>90 (18.1)                  | 272 (43.9)                                                        | 1.08 (0.83;<br>1.41)<br>94 (15.2)    | <b>1.33 (1.05;<br/>1.68)*</b><br>231 (21.1) | <b>1.31 (1.03;<br/>1.67)*</b><br>123 (19.8)        |
|                                                                                  | Owner<br>(Reference)         | 1337 (54.0)                                                     | 385 (15.5)                                 | 378 (15.3)                                    | 377 (15.2)                                         | 1115 (49.3)                                                       | 357 (15.8)                           | 405 (17.9)                                  | 383 (16.9)                                         |
| Private medical insurance<br>(M = 2977<br>F = 2879)                              | No                           | 732 (52.5)                                                      | 0.82 (0.66;<br>1.02)<br>177 (12.7)         | <b>1.27 (1.03;<br/>1.55)*</b><br>254 (18.2)   | 1.16 (0.94;<br>1.42)<br>232 (16.6)                 | 700 (45.7)                                                        | 1.04 (0.84;<br>1.28)<br>232 (15.2)   | <b>1.26 (1.03;<br/>1.54)*</b><br>303 (19.8) | <b>1.37 (1.13;<br/>1.70)**</b><br>296 (19.3)       |
|                                                                                  | Yes<br>(Reference)           | 859 (54.3)                                                      | 252 (15.9)                                 | 236 (14.9)                                    | 235 (14.9)                                         | 685 (50.8)                                                        | 219 (16.2)                           | 235 (17.4)                                  | 209 (15.5)                                         |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

#### ***6.3.2.6 Association between material factors and young persons' self-reported oral health***

Table 6.15 presents the association between young persons' self-reported oral health (self-rated oral health, SROH) and material factors (financial difficulties, DEIS school status, house ownership and private medical insurance). From the four selected material factors, three for young males (financial difficulties, house ownership and private medical insurance) and one for young females (DEIS school) were significantly associated with young persons' SROH.

For young males, those who belonged to households with financial difficulties, the odds of having sub-optimal SROH were higher for those from households with no financial difficulties (OR 1.34; 95% CI: 1.05, 1.70). Similarly, the odds of having sub-optimal SROH were higher for those in the 'rented/other accommodation' group than those in the 'owners' group (OR 1.79; 95% CI: 1.36, 2.35). Likewise, the odds of having sub-optimal oral health increased to 2.16 (95% CI: 1.69, 2.75) for those not covered by private medical insurance compared to those who had private medical insurance. For young females, the odds of having sub-optimal SROH were higher for those who attended DEIS schools (OR 2.01; 95% CI: 1.35, 3.00) than those who did not.

Table 6.15 Crude (Unadjusted) associations between behavioural factors (financial difficulties, DEIS school status, house ownership and private medical insurance cover) at 13 years of age and young persons' self-reported oral health (self-reported oral health) at 17/18 years of age and by gender.

|                                                                                                 |                              | Total<br>Self-reported oral health |                                                   | Males<br>Self-reported oral health |                                                   | Females<br>Self-reported oral health |                                                   |
|-------------------------------------------------------------------------------------------------|------------------------------|------------------------------------|---------------------------------------------------|------------------------------------|---------------------------------------------------|--------------------------------------|---------------------------------------------------|
|                                                                                                 |                              | Optimal oral<br>health<br>n (%)    | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) | Optimal oral<br>health<br>n (%)    | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) | Optimal oral<br>health<br>n (%)      | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) |
| Financial difficulties<br>(Difficulty in meeting<br>ends)<br>(n = 6030<br>M = 3080<br>F = 2951) | With difficulty              | 3337 (92.1)                        | <b>1.25 (1.02;<br/>1.53)*</b><br>288 (7.9)        | 1589 (88.7)                        | <b>1.34 (1.05;<br/>1.70)*</b><br>203 (11.3)       | 1748 (95.3)                          | 1.19 (0.82; 1.74)<br>86 (4.7)                     |
|                                                                                                 | No difficulty<br>(Reference) | 2249 (93.5)                        | 156 (6.5)                                         | 1176 (91.3)                        | 112 (8.7)                                         | 1073 (96.1)                          | 44 (3.9)                                          |
| DEIS school<br>(n = 5591<br>M = 2870<br>F = 2720)                                               | Yes                          | 916 (90.3)                         | <b>1.48 (1.17;<br/>1.88)**</b><br>98 (9.7)        | 463 (88.4)                         | 1.26 (0.94; 1.71)<br>61 (11.6)                    | 453 (92.4)                           | <b>2.01 (1.35;<br/>3.00)***</b><br>37 (7.6)       |
|                                                                                                 | No<br>(Reference)            | 4268 (93.2)                        | 309 (6.8)                                         | 2124 (90.5)                        | 222 (9.5)                                         | 2144 (96.1)                          | 86 (3.9)                                          |
| Homeownership<br>(n = 6026<br>M = 3078<br>F = 2949)                                             | Renters/Rent<br>free/Others  | 1042 (90.3)                        | <b>1.48 (1.18;<br/>1.85)***</b><br>112 (9.7)      | 439 (84.7)                         | <b>1.79 (1.36;<br/>2.35)***</b><br>79 (15.3)      | 604 (94.8)                           | 1.26 (0.84; 1.88)<br>33 (5.2)                     |
|                                                                                                 | Owners<br>(Reference)        | 4540 (93.2)                        | 332 (6.8)                                         | 2325 (90.8)                        | 235 (9.2)                                         | 2215 (95.8)                          | 97 (4.2)                                          |
| Private medical<br>insurance<br>(n = 6032<br>M = 3081<br>F = 2949)                              | No                           | 2745 (90.7)                        | <b>1.76 (1.45;<br/>2.17)***</b><br>281 (9.3)      | 1250 (86.1)                        | <b>2.16 (1.69;<br/>2.75)***</b><br>201 (13.9)     | 1495 (95.0)                          | 1.39 (0.97; 1.99)<br>79 (5.0)                     |
|                                                                                                 | Yes<br>(Reference)           | 2842 (94.5)                        | 164 (5.5)                                         | 1517 (93.1)                        | 113 (6.9)                                         | 1325 (96.4)                          | 50 (3.6)                                          |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

### **6.3.2.7 Association between psychosocial factors and young persons' parent-reported oral health**

Table 6.16 and 6.17 present the association between psychosocial factors and young persons' parent-reported oral health (number of teeth with dental fillings) for complete sample and by gender. For young males, all four selected psychosocial factors (PCG depression status, Family structure, Job stress and PCG parental stressor scale score) were significantly associated with young persons' parent-reported oral health. On the other hand, for young females, three factors, except the PCG depression status, were significant. In the unadjusted analysis, for young males, the odds of having two or more teeth with dental fillings were higher for those who lived in single-parent families (OR<sub>Two teeth with fillings</sub>: 1.80; 95% CI: 1.40, 2.31; OR<sub>Three teeth with fillings</sub>: 1.53; 95% CI: 1.18, 1.99) than those who had both parents' support. Likewise, there was a 1.04-fold increase in the odds of having three or more teeth with dental fillings with every one unit increase in the PCG's mean parental stressor scale score. On the other hand, compared with the 'no job stress' group, the odds of having three or more teeth with dental fillings were lower for the 'stressed' group (OR<sub>Three teeth with fillings</sub>: 0.72; 95% CI: 0.58, 0.90).

For young females, compared with the 'couple family' group, the odds of having one tooth with dental fillings were higher for the 'single-parent' group (OR<sub>One tooth with fillings</sub>: 1.35; 95% CI: 1.04, 1.75). Similarly, there was a 1.05-fold increase in the odds of having two teeth with dental fillings with every one unit increase in the PCGs' mean parental stressor scale score. In contrast, the odds of having one tooth with dental fillings were lower for females whose PCGs experienced job stress (OR<sub>One tooth with fillings</sub>: 0.69; 95% CI: 0.55, 0.87) than those in the 'no job stress' group.

Table 6.16 Crude (Unadjusted) associations between psychosocial factors (PCG depression status, family structure, job stress, and PCG mean parental stress scale score) at 13 years of age and young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age.

|                                                 |                              | Number of dental fillings |                                          |                                             |                                            |
|-------------------------------------------------|------------------------------|---------------------------|------------------------------------------|---------------------------------------------|--------------------------------------------|
|                                                 |                              | None<br>n (%)             | One<br>OR (95% CI)<br>n (%)              | Two<br>OR (95% CI)<br>n (%)                 | Three or More<br>OR (95% CI)<br>n (%)      |
| PCG depression status<br>(n = 5802)             | Depressed                    | 329 (50.5)                | 0.80 (0.62; 1.04)<br>81 (12.4)           | 0.99 (0.79; 1.240)<br>113 (17.4)            | 1.20 (0.97; 1.49)<br>128 (19.7)            |
|                                                 | Not depressed<br>(Reference) | 2612 (50.7)               | 793 (15.4)                               | 905 (17.6)                                  | 841 (16.3)                                 |
| Family structure<br>(n = 5859)                  | Single parent family         | 480 (44.6)                | 1.21 (0.99; 1.47)<br>166 (15.4)          | <b>1.51 (1.27; 1.80)***</b><br>231 (21.5)   | <b>1.34 (1.11; 1.61)**</b><br>199 (18.5)   |
|                                                 | Couple family<br>(Reference) | 2498 (52.2)               | 714 (14.9)                               | 797 (16.7)                                  | 774 (16.2)                                 |
| Job stress<br>(n = 5522)                        | Stressed                     | 1951 (52.3)               | <b>0.69 (0.55; 0.87)**</b><br>525 (14.1) | 0.99 (0.79; 1.24)<br>661 (17.7)             | 0.93 (0.74; 1.17)<br>590 (15.8)            |
|                                                 | Not stressed<br>(Reference)  | 862 (48.0)                | 302 (16.8)                               | 314 (17.5)                                  | 317 (17.7)                                 |
| PCG Parental Stressor scale score<br>(n = 5799) |                              | 2942 (50.73)              | 10.01 (0.99; 1.03)<br>874 (15.07)        | <b>1.03 (1.01, 1.05)***</b><br>1018 (17.55) | <b>1.03 (1.01, 1.05)***</b><br>965 (16.64) |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Table 6.17 Crude (Unadjusted) associations between psychosocial factors (PCG depression status, family structure, job stress and PCG mean parental stress scale score) at 13 years of age and young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age and by gender.

|                                                           |                              | Males (M)<br>Number of dental fillings |                                            |                                               |                                                | Females (F)<br>Number of dental fillings |                                              |                                                |                                          |
|-----------------------------------------------------------|------------------------------|----------------------------------------|--------------------------------------------|-----------------------------------------------|------------------------------------------------|------------------------------------------|----------------------------------------------|------------------------------------------------|------------------------------------------|
|                                                           |                              | None<br>n (%)                          | One<br>OR (95% CI)<br>n (%)                | Two<br>OR (95% CI)<br>n (%)                   | Three or<br>More<br>OR (95% CI)<br>n (%)       | None<br>n (%)                            | One<br>OR (95% CI)<br>n (%)                  | Two<br>OR (95% CI)<br>n (%)                    | Three or<br>More<br>OR (95% CI)<br>n (%) |
| PCG depression status<br>(M = 2946<br>F = 2856)           | Depressed                    | 188 (55.5)                             | <b>0.67 (0.46;<br/>0.98)*</b><br>36 (10.6) | 0.96 (0.69;<br>1.31)<br>56 (16.5)             | 1.07 (0.78;<br>1.46)<br>59 (17.4)              | 141 (45.3)                               | 0.97 (0.68;<br>1.38)<br>45 (14.5)            | 1.05 (0.76;<br>1.45)<br>57 (18.3)              | 1.37 (1.00;<br>1.86)<br>68 (21.9)        |
|                                                           | Not depressed<br>(Reference) | 1382 (53.0)                            | 389 (14.9)                                 | 429 (16.5)                                    | 407 (15.6)                                     | 1230 (48.3)                              | 404 (15.9)                                   | 476 (18.7)                                     | 435 (17.1)                               |
| Family structure<br>(M = 2975<br>F = 2883)                | Single parent family         | 235 (45.8)                             | 1.02 (0.76;<br>1.38)<br>64 (12.5)          | <b>1.80 (1.40;<br/>2.31)***</b><br>116 (22.6) | <b>1.53 (1.18;<br/>1.99)**</b><br>98 (19.1)    | 245 (43.6)                               | <b>1.35 (1.04;<br/>1.75)*</b><br>101 (18.0)  | 1.27 (0.99;<br>1.62)<br>115 (20.5)             | 1.16 (0.90;<br>1.51)<br>101 (18.0)       |
|                                                           | Couple family<br>(Reference) | 1356 (55.1)                            | 364 (14.8)                                 | 373 (15.2)                                    | 369 (15.0)                                     | 1142 (49.2)                              | 350 (15.1)                                   | 424 (18.3)                                     | 405 (17.4)                               |
| Job stress<br>(M = 2818<br>F = 2704)                      | Stressed                     | 1025 (55.1)                            | 0.84 (0.67;<br>1.06)<br>259 (13.9)         | 0.86 (0.69;<br>1.07)<br>302 (16.2)            | <b>0.72 (0.58;<br/>0.90)**</b><br>274 (14.7)   | 926 (49.6)                               | <b>0.69 (0.55;<br/>0.87)**</b><br>266 (14.2) | 0.99 (0.79;<br>1.24)<br>359 (19.2)             | 0.93 (0.74;<br>1.17)<br>317 (17.0)       |
|                                                           | Not stressed<br>(Reference)  | 477 (49.8)                             | 143 (14.9)                                 | 163 (17.0)                                    | 175 (18.3)                                     | 385 (46.1)                               | 159 (19.0)                                   | 151 (18.1)                                     | 141 (16.9)                               |
| PCG Parental Stressor scale score<br>(M = 2943; F = 2856) |                              | 1571 (53.4)                            | 1.01 (0.98;<br>1.04)<br>425 (14.4)         | 1.01 (0.98;<br>1.04)<br>485 (16.5)            | <b>1.04 (1.02;<br/>1.07) ***</b><br>462 (15.7) | 1371 (48.0)                              | 1.01 (0.98;<br>1.03)<br>449 (15.7)           | <b>1.05 (1.02;<br/>1.07) ***</b><br>533 (18.7) | 1.02 (0.99;<br>1.04)<br>503 (17.6)       |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

#### ***6.3.2.8 Association between Psychosocial Factors and young persons' self-reported oral health***

Table 6.18 presents the association between psychosocial factors and young persons' self-reported oral health (self-rated oral health, SROH) for young males and females. The 'parental stressor scale scores' and 'family structure' variables were significantly associated with SROH for young males. However, for young females, none of the psychosocial factors were statistically associated with SROH. The odds of sub-optimal oral health were higher in young males living with only one parent than those living with both parents (OR 1.39; 95% CI: 1.05, 1.85).

#### ***6.3.2.9 Association between SES measures and behavioural/ material/ psychosocial factors***

The association between SES measures and behavioural, material and psychosocial factors are presented in Appendix C, Tables S1-12. For both genders, all behavioural factors were significantly associated with SES measures (PCGs' highest level of education, family income, family occupational class and medical card status). Similarly, all four selected material factors (financial difficulties, DEIS school, house ownership and private medical insurance) were associated with SES measures for both young males and females. From the four psychosocial factors studied, three factors were associated with four SES measures with job stress not being associated. The 'job stress' variable was significantly associated with PCG education, family income and medical card status and not with the family occupational class. In addition, the association between PCG parental stressors scale scores and the family occupational class was not significant for young females.

Table 6.18 Crude (Unadjusted) associations between psychosocial factors (PCG depression status, family structure, job stress and PCG mean parental stress scale score) at 13 years of age and young persons' parent-reported oral health (number of teeth with dental fillings) at 17/18 years of age and by gender.

|                                                                            |                              | Total<br>Self-reported oral health |                                                   | Males<br>Self-reported oral health |                                                   | Females<br>Self-reported oral health |                                                   |
|----------------------------------------------------------------------------|------------------------------|------------------------------------|---------------------------------------------------|------------------------------------|---------------------------------------------------|--------------------------------------|---------------------------------------------------|
|                                                                            |                              | Optimal oral<br>health<br>n (%)    | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) | Optimal oral<br>health<br>n (%)    | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) | Optimal oral<br>health<br>n (%)      | Suboptimal oral<br>health<br>OR (95% CI)<br>n (%) |
| PCG depression<br>status<br>(n = 5972<br>M = 3047<br>F = 2925)             | Depressed                    | 617 (92.1)                         | 1.11 (0.78; 1.58)<br>53 (7.9)                     | 314 (89.0)                         | 1.11 (0.77; 1.58)<br>39 (11.0)                    | 304 (95.6)                           | 0.97 (0.55; 1.73)<br>14 (4.4)                     |
|                                                                            | Not depressed<br>(Reference) | 4912 (92.6)                        | 390 (7.4)                                         | 2419 (89.8)                        | 275 (10.2)                                        | 2492 (95.6)                          | 115 (4.4)                                         |
| Family structure<br>(n = 6032<br>M = 3082<br>F = 2951)                     | Single parent family         | 1014 (91.0)                        | <b>1.31 (1.04;<br/>1.66)*</b><br>100 (9.0)        | 462 (87.0)                         | <b>1.39 (1.05;<br/>1.85)*</b><br>69 (13.0)        | 552 (94.7)                           | 1.32 (0.87; 1.99)<br>31 (5.3)                     |
|                                                                            | Couple family<br>(Reference) | 4574 (93.0)                        | 344 (7.0)                                         | 2305 (90.4)                        | 246 (9.6)                                         | 2270 (95.9)                          | 98 (4.1)                                          |
| Job stress<br>(n = 5679<br>M = 2901<br>F = 2777)                           | Stressed                     | 3554 (92.7)                        | 0.96 (0.78; 1.19)<br>278 (7.3)                    | 1725 (90.0)                        | 0.99 (0.77; 1.28)<br>192 (10.0)                   | 1828 (95.5)                          | 0.98 (0.66; 1.44)<br>86 (4.5)                     |
|                                                                            | Not stressed<br>(Reference)  | 1708 (92.5)                        | 139 (7.5)                                         | 885 (89.9)                         | 99 (10.1)                                         | 823 (95.4)                           | 40 (4.6)                                          |
| PCG Parental<br>Stressor scale score<br>(n = 5968<br>M = 3044<br>F = 2924) |                              | 5527 (92.6)                        | <b>1.04 (1.02;<br/>1.06)***</b><br>442 (7.4)      | 2731 (89.7)                        | <b>1.05 (1.03;<br/>1.08)***</b><br>313 (10.3)     | 2796 (95.6)                          | 1.00 (0.96; 1.05)<br>128 (4.4)                    |

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$



#### ***6.3.2.10 Mediation by behavioural/material/psychosocial factors in the association of SES Measures and young persons' self-reported oral health***

For testing the fourth condition of mediation, attenuation of the relationship between SES measures/indicators and young persons' self-reported oral health after controlling for behavioural/material/psychosocial factors, only those pairs of relationships that met the first condition of mediation (significant predictor and outcome relationship) were evaluated. The following two pairs satisfied the first condition of mediation in the unadjusted regression analysis for the association between SES measures and young persons' self-reported oral health:

- 1) PCG education and SROH in young males
- 2) Family income and SROH in young males

The role of explanatory factors in explaining educational and income inequalities in the SROH for young males has been described below.

#### **1) To what extent can PCG education-related inequalities in young males' SROH be explained by behavioural, material and psychosocial factors?**

Table 6.19 shows the multivariate association between PCGs' highest level of education and young males' SROH. In the base model, model 1, the association between PCGs' highest level of education and young males' SROH (after adjustment for wave 1 covariates – 'area of residence', 'the main language spoken at home' and 'PCG's country of birth') was investigated. The odds of sub-optimal health were higher for those in the lowest educational (primary or no formal education) group (OR 2.31; 95% CI: 1.29, 4.13) than those in the highest educational (tertiary level of education) group. Furthermore, to examine the relative contribution of the explanatory factors in explaining the educational disparities in young males' SROH, sets of behavioural (model 2), material (model 3) and psychosocial factors (model 4) were separately added to the base model (model 1) (Table 6.19). The association between PCGs' educational level and young persons' SROH was attenuated by including behavioural, material and psychosocial factors. Adjustment of each set of behavioural, material and psychosocial factors resulted in a reduction of OR for the lowest educational group by

22%, 100% and 56%, respectively. The final model, model 5, shows a large explanation of the educational differences in young males' SROH through the simultaneous inclusion of behavioural, material and psychosocial factors. The addition of all explanatory factors in the model substantially reduced the OR for the lowest educational group from 2.02 (95% CI: 1.10, 3.68) to 1.16 (95% CI: 0.56, 2.39), by approximately 88%. In the final model, toothbrushing frequency (OR<sub>less than once</sub>: 4.67; 95% CI: 3.23, 6.81); OR<sub>once</sub>: 2.05; 95% CI: 1.53, 2.75), dentist visit behaviour (OR<sub>problem visit</sub>: 1.67, 95% CI: 1.19, 2.34), sugary foods intake (OR<sub>more than once</sub>: 1.58, 95% CI: 1.11, 2.23) and private medical insurance (OR 1.57, 95% CI: 1.19, 2.09) were significantly associated with young persons' SROH.

Table 6.19 Association between PCGs' highest educational level and young males' self-reported oral health (self-rated oral health) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for self-rated sub-optimal oral health). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                       |                                   | <b>Model 1 (Crude)</b>   | <b>Model 2</b>                       | <b>Model 3</b>                    | <b>Model 4</b>                    | <b>Model 5</b>                    |
|---------------------------------------|-----------------------------------|--------------------------|--------------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
|                                       |                                   | <b>OR (95% CI)</b>       | <b>OR (95% CI)<br/>[% change]</b>    | <b>OR (95% CI)<br/>[% change]</b> | <b>OR (95% CI)<br/>[% change]</b> | <b>OR (95% CI)<br/>[% change]</b> |
| <b>PCG highest level of education</b> | None or primary                   | <b>2.31 (1.29; 4.13)</b> | <b>2.02 (1.10; 3.68)<br/>[22.14]</b> | 0.95 (0.46; 1.97)<br>[100.00]     | 1.57 (0.78; 3.15)<br>[56.49]      | 1.16 (0.56; 2.39)<br>[87.79]      |
|                                       | Secondary                         | 1.33 (0.98; 1.81)        | 1.14 (0.83; 1.58)<br>[57.58]         | 1.00 (0.72; 1.39)<br>[100.00]     | 1.29 (0.94; 1.78)<br>[12.12]      | 0.92 (0.65; 1.31)<br>[100.00]     |
|                                       | Tertiary (Reference)              | 1                        | 1                                    | 1                                 | 1                                 | 1                                 |
| <b>Behavioural factors</b>            | <b>Toothbrushing frequency</b>    |                          |                                      |                                   |                                   |                                   |
|                                       | Less than once /Rarely/Never      |                          | <b>4.69 (3.28; 6.69)</b>             |                                   |                                   | <b>4.67 (3.23; 6.81)</b>          |
|                                       | Once                              |                          | <b>2.01 (1.53; 2.65)</b>             |                                   |                                   | <b>2.05 (1.53; 2.75)</b>          |
|                                       | Twice/More than twice (Reference) |                          | 1                                    |                                   |                                   | 1                                 |
|                                       | <b>Dentist visit behaviour</b>    |                          |                                      |                                   |                                   |                                   |
|                                       | Problem/Never                     |                          | <b>1.91 (1.40; 2.60)</b>             |                                   |                                   | <b>1.67 (1.19; 2.34)</b>          |
|                                       | Occasional visit                  |                          | 0.75 (0.52; 1.07)                    |                                   |                                   | 0.73 (0.50; 1.07)                 |
|                                       | At least a year (Reference)       |                          | 1                                    |                                   |                                   | 1                                 |
|                                       | <b>Sugary drinks intake</b>       |                          |                                      |                                   |                                   |                                   |
|                                       | More than once a day              |                          | 1.16 (0.83; 1.62)                    |                                   |                                   | NA                                |
|                                       | Once a day                        |                          | 1.06 (0.79; 1.41)                    |                                   |                                   | NA                                |
|                                       | Not at all (Reference)            |                          | 1                                    |                                   |                                   | 1                                 |
|                                       | <b>Sugary foods intake</b>        |                          |                                      |                                   |                                   |                                   |
|                                       | More than once a day              |                          | 1.34 (0.96; 1.89)                    |                                   |                                   | <b>1.58 (1.11; 2.23)</b>          |
|                                       | Once a day                        |                          | 0.71 (0.53; 0.95)                    |                                   |                                   | 0.84 (0.61; 1.16)                 |

Table 6.19 Continued...

| <i><b>Behavioural factors</b></i>  | <b>Sugary foods intake</b>               | <b>OR (95% CI)</b> | <b>OR (95% CI) [% change]</b> | <b>OR (95% CI) [% change]</b> | <b>OR (95% CI) [% change]</b> | <b>OR (95% CI) [% change]</b> |
|------------------------------------|------------------------------------------|--------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                                    | Not at all (Reference)                   |                    | 1                             |                               |                               | 1                             |
| <i><b>Material factors</b></i>     | <b>Financial difficulties</b>            |                    |                               |                               |                               |                               |
|                                    | With difficulty                          |                    | 1.04 (0.79; 1.37)             |                               |                               | NA                            |
|                                    | No difficulty (Reference)                |                    | 1                             |                               |                               |                               |
|                                    | <b>DEIS school</b>                       |                    |                               |                               |                               |                               |
|                                    | Yes                                      |                    | 1.03 (0.75; 1.42)             |                               |                               | NA                            |
|                                    | No (Reference)                           |                    | 1                             |                               |                               |                               |
|                                    | <b>Homeownership</b>                     |                    |                               |                               |                               |                               |
|                                    | Renters/Rent free /Others                |                    | 1.23 (0.88; 1.72)             |                               |                               | NA                            |
|                                    | Owners (Reference)                       |                    | 1                             |                               |                               |                               |
|                                    | <b>Private medical insurance</b>         |                    |                               |                               |                               |                               |
|                                    | No                                       |                    | <b>1.84 (1.37; 2.46)</b>      |                               |                               | <b>1.57 (1.19; 2.09)</b>      |
|                                    | Yes (Reference)                          |                    | 1                             |                               |                               | 1                             |
| <i><b>Psychosocial factors</b></i> | <b>PCG parental stressor scale score</b> |                    |                               |                               | <b>1.04 (1.02; 1.07)</b>      | 1.03 (1.00; 1.06)             |
|                                    | <b>PCG depression status</b>             |                    |                               |                               | 1                             | 1                             |
|                                    | Depressed                                |                    |                               |                               | 0.88 (0.60; 1.30)             | 0.69 (0.45; 1.07)             |
|                                    | Not depressed (Reference)                |                    |                               |                               | 1                             | 1                             |
|                                    | <b>Family structure</b>                  |                    |                               |                               |                               |                               |
|                                    | Single parent family                     |                    |                               |                               | 1.25 (0.92; 1.70)             | NA                            |
|                                    | Couple family (Reference)                |                    |                               |                               | 1                             |                               |
|                                    | <b>Job stress</b>                        |                    |                               |                               |                               |                               |
|                                    | Stressed                                 |                    |                               |                               | 1.01 (0.78; 1.32)             | NA                            |
|                                    | Not stressed (Reference)                 |                    |                               |                               | 1                             |                               |

**2) To what extent can income-related inequalities in young males' SROH be explained by behavioural, material and psychosocial factors?**

In Table 6.20, model 1 investigated the association between family income quintiles and young males' SROH (after adjusting wave 1 covariates: 'area of residence', 'the main language spoken at home' and 'PCG's country of birth'). Compared with the highest income quintile group, the odds of sub-optimal oral health were higher for those who belonged to the lowest (OR<sub>lowest</sub>: 1.72; 95% CI: 1.16, 2.56) and second income quintile (OR<sub>2nd</sub>: 1.91; 95% CI: 1.29, 2.82) groups. The relative contribution of the explanatory factors in explaining the income disparities in SROH for young males was examined by adding sets of behavioural (model 2), material (model 3) and psychosocial factors (model 4) separately to model 1. The association between family income and young persons' SROH was attenuated by including behavioural, material and psychosocial factors (see Table 6.19). Adjustment of behavioural factors reduced the OR for the 'lowest income quintile' and 'second income quintile' groups by 69% and 49%, respectively. Similarly, the adjustment of material factors reduced the OR by 97% and 80% for the 'lowest income quintile' and 'second income quintile' groups, respectively. Adjustment of behavioural factors led to the loss of statistical significance for the relationship between family income and SROH. In contrast, the reductions in the OR after adjustment of psychosocial factors were small (lowest income quintile: 5% and 'second income quintile: 28%). In the final model, the relationship between family income and SROH lost statistical significance, and the odds of sub-optimal SROH were lower for the lower income groups than the highest income quintile group. In the final model, toothbrushing frequency (OR<sub>less than once</sub>: 4.72; 95% CI: 3.22, 6.90); OR<sub>once</sub>: 2.09; 95% CI: 1.55, 2.81), dentist visit behaviour (OR<sub>problem visit</sub>: 1.48, 95% CI: 1.05, 2.08; OR<sub>occasional</sub>: 0.61; 95% CI: 0.41, 0.92), sugary foods intake (OR<sub>more than once</sub>: 1.62, 95% CI: 1.13, 2.31) and private medical insurance (OR 1.67, 95% CI: 1.22, 2.29) were significantly associated with young males' SROH.

Table 6.20 Association between household/family income and young males' self-reported oral health (self-rated oral health) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for self-rated sub-optimal oral health). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                          |                                   | <b>Model 1 (Crude)</b>                  | <b>Model 2</b>                          | <b>Model 3</b>                          | <b>Model 4</b>                             | <b>Model 5</b>                          |
|------------------------------------------|-----------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|--------------------------------------------|-----------------------------------------|
|                                          |                                   | <b>OR (95% CI)</b><br><b>[% change]</b> | <b>OR (95% CI)</b><br><b>[% change]</b> | <b>OR (95% CI)</b><br><b>[% change]</b> | <b>OR (95% CI)</b><br><b>[% change]</b>    | <b>OR (95% CI)</b><br><b>[% change]</b> |
| <b>Household/Family Income quintiles</b> | Lowest                            | <b>1.72 (1.16; 2.56)</b>                | 1.22 (0.80; 1.86)<br>[69.44]            | 1.02 (0.64; 1.65)<br>[97.22]            | <b>1.68 (1.11; 2.53)</b><br><b>[5.56]</b>  | 0.80 (0.49; 1.28)<br>[100.00]           |
|                                          | 2 <sup>nd</sup>                   | <b>1.91 (1.29; 2.82)</b>                | 1.46 (0.97; 2.20)<br>[49.45]            | 1.18 (0.74; 1.88)<br>[80.22]            | <b>1.65 (1.10; 2.50)</b><br><b>[28.57]</b> | 0.90 (0.56; 1.43)<br>[100.00]           |
|                                          | 3 <sup>rd</sup>                   | 1.25 (0.82; 1.91)                       | 0.94 (0.60; 1.47)<br>[100.00]           | 0.89 (0.55; 1.43)<br>[100.00]           | 1.27 (0.82; 1.97) [-<br>8.00]              | 0.67 (0.41; 1.09)<br>[100.00]           |
|                                          | 4 <sup>th</sup>                   | 1.08 (0.71; 1.63)                       | 0.98 (0.64; 1.50)<br>[100.00]           | 0.85 (0.55; 1.33)<br>[100.00]           | 0.97 (0.63; 1.50)<br>[100.00]              | 0.75 (0.47; 1.19)<br>[100.00]           |
|                                          | Highest (Reference)               | 1                                       | 1                                       | 1                                       | 1                                          | 1                                       |
| <b>Behavioural factors</b>               | <b>Toothbrushing frequency</b>    |                                         |                                         |                                         |                                            |                                         |
|                                          | Less than once/Rarely/Never       |                                         | <b>4.57 (3.18; 6.57)</b>                |                                         |                                            | <b>4.72 (3.22; 6.90)</b>                |
|                                          | Once                              |                                         | <b>2.05 (1.54; 2.72)</b>                |                                         |                                            | <b>2.09 (1.55; 2.81)</b>                |
|                                          | Twice/More than twice (Reference) |                                         | 1                                       |                                         |                                            | 1                                       |
|                                          | <b>Dentist visit behaviour</b>    |                                         |                                         |                                         |                                            |                                         |
|                                          | Problem/Never                     |                                         | <b>1.72 (1.25; 2.36)</b>                |                                         |                                            | <b>1.48 (1.05; 2.08)</b>                |
|                                          | Occasional visit                  |                                         | <b>0.64 (0.43; 0.93)</b>                |                                         |                                            | <b>0.61 (0.41; 0.92)</b>                |
|                                          | At least a year (Reference)       |                                         | 1                                       |                                         |                                            | 1                                       |
|                                          | <b>Sugary drinks intake</b>       |                                         |                                         |                                         |                                            |                                         |
|                                          | More than once a day              |                                         | 1.22 (0.87; 1.72)                       |                                         |                                            | NA                                      |
|                                          | Once a day                        |                                         | 1.13 (0.84; 1.52)                       |                                         |                                            | NA                                      |
|                                          | Not at all (Reference)            |                                         | 1                                       |                                         |                                            |                                         |
|                                          | <b>Sugary foods intake</b>        |                                         |                                         |                                         |                                            |                                         |
|                                          | More than once a day              |                                         | 1.31 (0.92; 1.85)                       |                                         |                                            | <b>1.62 (1.13; 2.31)</b>                |

Table 6.20 Continued...

| <i>Behavioural factors</i>  | <b>Sugary foods intake</b>               | <b>OR (95% CI)<br/>[% change]</b> | <b>OR (95% CI)<br/>[% change]</b> | <b>OR (95% CI)<br/>[% change]</b> | <b>OR (95% CI)<br/>[% change]</b> | <b>OR (95% CI)<br/>[% change]</b> |
|-----------------------------|------------------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
|                             | Once a day                               |                                   | 0.73 (0.54; 1.00)                 |                                   |                                   | 0.89 (0.64; 1.23)                 |
|                             | Not at all (Reference)                   |                                   | 1                                 |                                   |                                   |                                   |
| <b>Material factors</b>     | <b>Financial difficulties</b>            |                                   |                                   |                                   |                                   |                                   |
|                             | With difficulty                          |                                   |                                   | 1.00 (0.74; 1.35)                 |                                   | NA                                |
|                             | No difficulty (Reference)                |                                   |                                   | 1                                 |                                   |                                   |
|                             | <b>DEIS school</b>                       |                                   |                                   |                                   |                                   |                                   |
|                             | Yes                                      |                                   |                                   | 0.97 (0.70; 1.35)                 |                                   | NA                                |
|                             | No (Reference)                           |                                   |                                   | 1                                 |                                   |                                   |
|                             | <b>Homeownership</b>                     |                                   |                                   |                                   |                                   |                                   |
|                             | Renters/Rent free/Others                 |                                   |                                   | 1.22 (0.87; 1.71)                 |                                   | NA                                |
|                             | Owners (Reference)                       |                                   |                                   | 1                                 |                                   |                                   |
|                             | <b>Private medical insurance</b>         |                                   |                                   |                                   |                                   |                                   |
|                             | No                                       |                                   |                                   | <b>1.80 (1.31; 2.47)</b>          |                                   | <b>1.67 (1.22; 2.29)</b>          |
|                             | Yes (Reference)                          |                                   |                                   | 1                                 |                                   | 1                                 |
| <b>Psychosocial factors</b> | <b>PCG Parental Stressor scale score</b> |                                   |                                   |                                   | <b>1.04 (1.01; 1.07)</b>          | 1.03 (1.00; 1.06)                 |
|                             | <b>PCG depression status</b>             |                                   |                                   |                                   | 1                                 | 1                                 |
|                             | Depressed                                |                                   |                                   |                                   | 0.82 (0.55; 1.22)                 | NA                                |
|                             | Not depressed (Reference)                |                                   |                                   |                                   | 1                                 |                                   |
|                             | <b>Family structure</b>                  |                                   |                                   |                                   |                                   |                                   |
|                             | Single parent family                     |                                   |                                   |                                   | 1.19 (0.87; 1.62)                 | NA                                |
|                             | Couple family (Reference)                |                                   |                                   |                                   | 1                                 |                                   |
|                             | <b>Job stress</b>                        |                                   |                                   |                                   |                                   |                                   |
|                             | Stressed                                 |                                   |                                   |                                   | 1.07 (0.82; 1.40)                 | NA                                |
|                             | Not stressed (Reference)                 |                                   |                                   |                                   | 1                                 |                                   |

#### ***6.3.2.11 Mediation by behavioural/material/psychosocial factors in the association of SES Measures and Parent-reported Oral Health***

The mediation of behavioural, material and psychosocial factors in the associations between SES measures and young persons' parent-reported oral health were investigated only for those pairs of relationships which satisfied the first condition of mediation, i.e., a statistically significant association between predictor (SES measures) and outcome (parent-reported oral health) in the unadjusted regression analysis. The following pairs of associations between the predictors and outcome variables were significant and, therefore, evaluated for potential mediation by behavioural, material and psychosocial factors:

- 1) For young females, PCG highest educational level and young persons' parent-reported oral health ('two teeth with dental fillings' and 'three teeth with dental fillings' outcomes).
- 2) For both genders, family income and young persons' parent-reported oral health ('two teeth with dental fillings' and 'three teeth with dental fillings' outcomes).
- 3) For young males, family occupation and young persons' parent-reported oral health ('one tooth with dental fillings' outcome).
- 4) For young females, family occupation and young persons' parent-reported oral health ('two teeth with dental fillings' and 'three teeth with dental fillings' outcomes).
- 5) For young females, medical card status and young persons' parent-reported oral health ('one tooth with dental fillings' outcome).
- 6) For both genders, medical card status and young persons' parent-reported oral health ('two teeth with dental fillings' and 'three teeth with dental fillings' outcomes).

#### **1) To what extent can PCG education-related inequalities in young females' parent-reported oral health be explained by behavioural/material/psychosocial factors?**

In the unadjusted multinomial regression analysis, as shown in Table 6.8, the odds of two parent-reported young persons' oral health outcomes: 'two teeth with dental fillings' and 'three or more teeth with dental fillings' were significantly associated with the PCGs' highest educational level variable. Therefore, further analyses were carried



out to investigate the role of explanatory factors in the educational inequalities for these oral health outcomes (see Tables 6.21 and 6.22).

Table 6.21 presents the odds of having two teeth with dental fillings in young females by PCGs' highest educational level, adjusted for covariates, behavioural factors, material factors and psychosocial factors. In model 1 (adjusted for wave 1 covariates: 'area of residence', 'main language spoken at home' and 'PCG's country of birth'), the PCGs' highest educational level showed a graded relationship with the 'two teeth with dental fillings' outcome. Those in the lowest educational category (primary or none) had 3.34 (95% CI: 1.99, 5.60) higher odds and those in the secondary category had 1.47 (95% CI: 1.12, 1.93) higher odds of having two teeth with dental fillings, compared with the highest educational category (tertiary). For the lowest educational group, the OR decreased by 18% and 2.6% after adjusting for material (model 3) [(OR 3.34 (95% CI: 1.99, 5.60) to OR 2.92 (95% CI: 1.63, 5.24)] and psychosocial factors (model 4) [(OR 3.14 (95% CI: 1.99, 5.60) to OR 3.28 (95% CI: 1.87, 5.76)], respectively. However, the OR for the secondary group increased after adjusting for material (10.6%) and psychosocial (4.3%) factors. The adjustment of behavioural factors (model 2) to model 1 showed an increase in the OR for the lowest educational group [(OR 3.34 (95% CI: 1.99, 5.60) to OR 3.41 (95% CI: 2.01, 5.78)] by 3% and for the secondary group [(OR 1.47 (95% CI: 1.12, 1.93) to OR 1.48 (95% CI: 1.12, 1.95)] by 2%. In the final model (model 5), the simultaneous inclusion of behavioural, material and psychosocial factors increased the OR for both the lowest and secondary education groups. The OR for the lowest educational group increased from OR 3.34 (95% CI: 1.99, 5.60) to 3.88 (95% CI: 2.18, 6.89), showing an increase of 23% and for the secondary group, the OR increased from 1.47 (95% CI: 1.12, 1.93) to 1.68 (95% CI: 1.25, 2.25), an increase of about 45%. In the final model, only the dentist visit behaviour variable was significant. This suggested that the addition of behaviour and psychosocial factors, individually, did not fundamentally attenuate the relationship between PCG educational level and the odds of having two teeth with dental fillings in young females. However, adjusting for material factors decreased the odds of having two teeth with dental fillings by 18% for the lowest educational group.

Table 6.22 presents the odds of having three or more teeth with dental fillings in young females by PCGs' highest educational level, adjusted for covariates, behavioural factors, material factors and psychosocial factors. The odds of having three or more teeth with dental fillings for the lowest educational group (OR 1.91; 95% CI: 1.07, 3.43) were higher than the highest educational level, model 1 (adjusted for wave 1 covariates: 'area of residence', 'main language spoken at home' and 'PCG's country of birth'). Furthermore, after adjusting model 1 for behavioural factors (model 2), the OR for the lowest education group decreased by about 4% and after the inclusion of material factors (model 3), the OR decreased by about 11%. In contrast, with the addition of psychosocial factors to the base model (model 1), the OR for the lowest educational group increased by 22%. Finally, the inclusion of all the sets of behavioural, material and psychosocial factors resulted in a small increase of about 2% in the OR of the lowest education group, model 5. This suggested that the adjustment of psychosocial factors did not attenuate the strength of the association between PCGs' educational level and the 'three or more teeth with dental fillings' outcome. However, behaviour (by 4%) and material factors (by 11%) moderately attenuated the strength of this relationship. In the final model, for young females, toothbrushing frequency, dentist visit behaviour, sugary foods intake and financial difficulties were associated with three or more teeth with dental fillings outcome.

Table 6.21 Association between PCGs' highest educational level and young females' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having two teeth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                       |                                   | <b>Model 1</b>           | <b>Model 2</b>                      | <b>Model 3</b>                      | <b>Model 4</b>                      | <b>Model 5</b>                       |
|---------------------------------------|-----------------------------------|--------------------------|-------------------------------------|-------------------------------------|-------------------------------------|--------------------------------------|
|                                       |                                   | <b>OR (95% CI)</b>       | <b>OR (95% CI)</b><br>[% change]    | <b>OR (95% CI)</b><br>[% change]    | <b>OR (95% CI)</b><br>[% change]    | <b>OR (95% CI)</b><br>[% change]     |
| <b>PCG highest level of education</b> | None or primary                   | <b>3.34 (1.99; 5.60)</b> | <b>3.41 (2.01; 5.78)</b><br>[-2.99] | <b>2.92 (1.63; 5.24)</b><br>[17.95] | <b>3.28 (1.87; 5.76)</b><br>[2.56]  | <b>3.88 (2.18; 6.89)</b><br>[-23.08] |
|                                       | Secondary                         | <b>1.47 (1.12; 1.93)</b> | <b>1.48 (1.12; 1.95)</b><br>[-2.13] | <b>1.52 (1.13; 2.04)</b><br>[-10.6] | <b>1.49 (1.13; 1.97)</b><br>[-4.26] | <b>1.68 (1.25; 2.25)</b><br>[-44.68] |
|                                       | Tertiary (Reference)              | 1                        | 1                                   | 1                                   | 1                                   | 1                                    |
| <b>Behavioural factors</b>            | <b>Toothbrushing frequency</b>    |                          |                                     |                                     |                                     |                                      |
|                                       | Less than once/Rarely/Never       |                          | 1.27 (0.72; 2.23)                   |                                     |                                     | 1.28 (0.69; 2.36)                    |
|                                       | Once                              |                          | 0.97 (0.72; 1.30)                   |                                     |                                     | 0.89 (0.65; 1.22)                    |
|                                       | Twice/More than twice (Reference) |                          | 1                                   |                                     |                                     | 1                                    |
|                                       | <b>Dentist visit behaviour</b>    |                          |                                     |                                     |                                     |                                      |
|                                       | Problem/Never                     |                          | <b>0.51 (0.37; 0.72)</b>            |                                     |                                     | <b>0.49 (0.34; 0.70)</b>             |
|                                       | Occasional visit                  |                          | 0.90 (0.69; 1.17)                   |                                     |                                     | 0.87 (0.66; 1.14)                    |
|                                       | At least a year (Reference)       |                          | 1                                   |                                     |                                     | 1                                    |
|                                       | <b>Sugary drinks intake</b>       |                          |                                     |                                     |                                     |                                      |
|                                       | More than once a day              |                          | 1.09 (0.80; 1.47)                   |                                     |                                     | NA                                   |
|                                       | Once a day                        |                          | <b>1.51 (1.19; 1.92)</b>            |                                     |                                     | NA                                   |
|                                       | Not at all (Reference)            |                          | 1                                   |                                     |                                     |                                      |
|                                       | <b>Sugary foods intake</b>        |                          |                                     |                                     |                                     |                                      |
|                                       | More than once a day              |                          | 0.98 (0.72; 1.35)                   |                                     |                                     | 0.86 (0.62; 1.19)                    |
|                                       | Once a day                        |                          | 1.26 (0.99; 1.59)                   |                                     |                                     | 1.23 (0.96; 1.57)                    |
|                                       | Not at all (Reference)            |                          | 1                                   |                                     |                                     | 1                                    |

Table 6.21 Continued...

|                             |                                                 | OR (95% CI) | OR (95% CI) | OR (95% CI)       | OR (95% CI)              | OR (95% CI)              |
|-----------------------------|-------------------------------------------------|-------------|-------------|-------------------|--------------------------|--------------------------|
| <b>Material factors</b>     | <b>Financial difficulties</b>                   |             |             |                   |                          |                          |
|                             | With difficulty                                 |             |             | 1.04 (0.82; 1.31) |                          | 1.09 (0.87; 1.37)        |
|                             | No difficulty (Reference)                       |             |             | 1                 |                          | 1                        |
|                             | <b>DEIS school</b>                              |             |             |                   |                          |                          |
|                             | Yes                                             |             |             | 0.96 (0.72; 1.26) |                          | NA                       |
|                             | No (Reference)                                  |             |             | 1                 |                          |                          |
|                             | <b>Homeownership</b>                            |             |             |                   |                          |                          |
|                             | Renters/Rent free/Others                        |             |             | 1.27 (0.96; 1.68) |                          | NA                       |
|                             | Owners (Reference)                              |             |             | 1                 |                          |                          |
|                             | <b>Private medical insurance</b>                |             |             |                   |                          |                          |
|                             | No                                              |             |             | 1.04 (0.82; 1.33) |                          |                          |
|                             | Yes (Reference)                                 |             |             | 1                 |                          |                          |
| <b>Psychosocial factors</b> | <b>PCGs' mean parental stressor scale score</b> |             |             |                   | <b>1.04 (1.01; 1.06)</b> | <b>1.05 (1.02; 1.08)</b> |
|                             | <b>PCG depression status</b>                    |             |             |                   |                          |                          |
|                             | Depressed                                       |             |             |                   | 0.86 (0.60; 1.21)        | NA                       |
|                             | Not depressed (Reference)                       |             |             |                   | 1                        |                          |
|                             | <b>Family structure</b>                         |             |             |                   |                          |                          |
|                             | Single parent family                            |             |             |                   | 1.14 (0.87; 1.49)        | NA                       |
|                             | Couple family (Reference)                       |             |             |                   | 1                        |                          |
|                             | <b>Job stress</b>                               |             |             |                   |                          |                          |
|                             | Stressed                                        |             |             |                   | 0.95 (0.75; 1.19)        | 0.91 (0.72; 1.15)        |
|                             | Not stressed (Reference)                        |             |             |                   | 1                        | 1                        |

Table 6.22 Association between PCGs' highest educational level and young females' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having three or more teeth with dental fillings). ). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                         |                                   | Model 1                  | Model 2                            | Model 3                      | Model 4                              | Model 5                             |
|-----------------------------------------|-----------------------------------|--------------------------|------------------------------------|------------------------------|--------------------------------------|-------------------------------------|
|                                         |                                   | OR (95% CI)              | OR (95% CI)<br>[% change]          | OR (95% CI)<br>[% change]    | OR (95% CI)<br>[% change]            | OR (95% CI)<br>[% change]           |
| <b>PCGs' highest level of education</b> | None/primary                      | <b>1.91 (1.07; 3.43)</b> | <b>1.87 (1.03; 3.40)</b><br>[4.40] | 1.81 (0.97; 3.38)<br>[10.99] | <b>2.11 (1.14; 3.89)</b><br>[-21.98] | <b>1.93 (1.03; 3.60)</b><br>[-2.20] |
|                                         | Secondary                         | 1.28 (0.98; 1.67)        | 1.23 (0.94; 1.62)<br>[17.86]       | 1.15 (0.86; 1.53)<br>[46.43] | 1.22 (0.93; 1.61)<br>[21.43]         | 1.21 (0.91; 1.61)<br>[25.00]        |
|                                         | Tertiary (Reference)              | 1                        | 1                                  | 1                            | 1                                    | 1                                   |
| <b>Behavioural factors</b>              | <b>Toothbrushing frequency</b>    |                          |                                    |                              |                                      |                                     |
|                                         | Less than once/Rarely/Never       |                          | <b>2.43 (1.49; 3.98)</b>           |                              |                                      | <b>2.32 (1.35; 4.00)</b>            |
|                                         | Once                              |                          | <b>1.54 (1.18; 2.02)</b>           |                              |                                      | <b>1.45 (1.09; 1.95)</b>            |
|                                         | Twice/More than twice (Reference) |                          | 1                                  |                              |                                      | 1                                   |
|                                         | <b>Dentist visit behaviour</b>    |                          |                                    |                              |                                      |                                     |
|                                         | Problem/Never                     |                          | <b>0.56 (0.40; 0.79)</b>           |                              |                                      | <b>0.56 (0.39; 0.80)</b>            |
|                                         | Occasional visit                  |                          | 0.83 (0.64; 1.09)                  |                              |                                      | 0.75 (0.56; 1.01)                   |
|                                         | At least a year (Reference)       |                          | 1                                  |                              |                                      | 1                                   |
|                                         | <b>Sugary drinks intake</b>       |                          |                                    |                              |                                      |                                     |
|                                         | More than once a day              |                          | 1.10 (0.82; 1.48)                  |                              |                                      | NA                                  |
|                                         | Once a day                        |                          | 1.13 (0.87; 1.46)                  |                              |                                      | NA                                  |
|                                         | Not at all (Reference)            |                          | 1                                  |                              |                                      |                                     |
|                                         | <b>Sugary foods intake</b>        |                          |                                    |                              |                                      |                                     |
|                                         | More than once a day              |                          | <b>1.59 (1.18; 2.14)</b>           |                              |                                      | <b>1.56 (1.14; 2.14)</b>            |
|                                         | Once a day                        |                          | 1.20 (0.94; 1.54)                  |                              |                                      | 1.25 (0.96; 1.63)                   |
|                                         | Not at all (Reference)            |                          | 1                                  |                              |                                      | 1                                   |

Table 6.22 Continued...

|                             |                                               | OR (95% CI) | OR (95% CI) | OR (95% CI)              | OR (95% CI)       | OR (95% CI)              |
|-----------------------------|-----------------------------------------------|-------------|-------------|--------------------------|-------------------|--------------------------|
| <b>Material factors</b>     | <b>Financial difficulties</b>                 |             |             |                          |                   |                          |
|                             | With difficulty                               |             |             | <b>1.45 (1.14; 1.85)</b> |                   | <b>1.46 (1.15; 1.86)</b> |
|                             | No difficulty (Reference)                     |             |             | 1                        |                   | 1                        |
|                             | <b>DEIS school</b>                            |             |             |                          |                   |                          |
|                             | Yes                                           |             |             | 0.81 (0.60; 1.09)        |                   | NA                       |
|                             | No (Reference)                                |             |             | 1                        |                   |                          |
|                             | <b>Homeownership</b>                          |             |             |                          |                   |                          |
|                             | Renters/Rent free/Others                      |             |             | 1.30 (0.98; 1.73)        |                   | NA                       |
|                             | Owners (Reference)                            |             |             | 1                        |                   |                          |
|                             | <b>Private medical insurance</b>              |             |             |                          |                   |                          |
|                             | No                                            |             |             | 1.06 (0.82; 1.36)        |                   | NA                       |
|                             | Yes (Reference)                               |             |             | 1                        |                   |                          |
| <b>Psychosocial factors</b> | <b>PCG mean parental Stressor scale score</b> |             |             |                          | 1.00 (0.97; 1.03) | 1.00 (0.97; 1.03)        |
|                             | <b>PCG depression status</b>                  |             |             |                          |                   |                          |
|                             | Depressed                                     |             |             |                          | 1.40 (1.00; 1.95) | NA                       |
|                             | Not depressed (Reference)                     |             |             |                          |                   |                          |
|                             | <b>Family structure</b>                       |             |             |                          |                   |                          |
|                             | Single parent family                          |             |             |                          | 1.14 (0.86; 1.49) | NA                       |
|                             | Couple family (Reference)                     |             |             |                          | 1                 |                          |
|                             | <b>Job stress</b>                             |             |             |                          |                   |                          |
|                             | Stressed                                      |             |             |                          | 0.92 (0.73; 1.16) | 0.91 (0.71; 1.16)        |
|                             | Not stressed (Reference)                      |             |             |                          | 1                 |                          |

**2) To what extent can family income-related inequalities in young persons' parent-reported oral health be explained by behavioural/material/psychosocial factors?**

The associations between family income and the 'two teeth with dental fillings' outcome for both young males and females are shown in Table 6.23. For young males, the odds of having two teeth with dental fillings were higher for the lowest income group (OR 1.82; 95% CI: 1.30, 2.55) than the highest income group, model 1 (adjusted for covariates). There was minimal (an increase of 1% in OR) in the odds of having two teeth with dental fillings for the lowest income group after the inclusion of behaviour factors (model 2) to model 1, which suggested that for young males, behavioural factors had no role in explaining the relationship between the lowest income group and the 'two teeth with dental fillings' oral health outcome. However, adjustment for the material (model 3) and psychosocial factors (model 4) to model 1 resulted in a reduction of OR for the lowest income group by 27% and 29%, respectively. The final model (model 5) showed a moderate explanation of the income differences in having two teeth with dental fillings by 21% for the lowest income group. Therefore, for young males, adjustment of material and psychosocial factors moderately reduced the strengths of the association between the lowest family income and the 'two teeth with dental fillings' outcome. The adjustment of behaviour factors did not reduce the strength of this association. This suggests a potential mediation of material and psychosocial factors in the income-related disparities in young persons' 'two teeth with dental fillings' outcome. In model 5, toothbrushing frequency, dentist visit and family structure were significantly associated with having two teeth with dental fillings.

For young females, family income showed a graded relationship with the 'two teeth with dental fillings' oral health outcome after adjustment of covariates in Model 1 (see Table 6.23). Compared with the highest income group, there was a 1.62, 1.64 and 1.78-fold increase in the odds of having two teeth with dental fillings in the 3<sup>rd</sup>, 2<sup>nd</sup> and lowest income group, respectively (OR<sub>third income quintile</sub>: 1.62; 95% CI: 1.16, 2.29; OR<sub>second income quintile</sub>: 1.64; 95% CI: 1.17, 2.31; OR<sub>lowest income quintile</sub>: 1.78; 95% CI: 1.26, 2.52). The inclusion of behavioural factors (model 2) to model 1 resulted in an increase of 13%, 8% and 13% in the ORs for the 3<sup>rd</sup>, 2<sup>nd</sup> and lowest income groups, respectively.

Similarly, the adjustment of material factors (model 3) resulted in an increase in the ORs of the lowest three income groups (27%, 14% and 11% for the 3<sup>rd</sup>, 2<sup>nd</sup> and lowest income groups, respectively). In contrast, the ORs for the three lowest income groups were slightly reduced with the addition of psychosocial factors (model 4) to model 1 (3%, 2% and 3% for the 3<sup>rd</sup>, 2<sup>nd</sup> and lowest income quintile groups, respectively). In the final model, the addition of all explanatory factors together resulted in an approximately 50% increase in the ORs for the lowest three income groups, model 5. These findings suggested that the adjustment of behavioural, material and psychosocial factors, individually or simultaneously, did not reduce the strength of association between family income and the 'two teeth with dental fillings' outcome in young females. In the final model (model 5), two behaviour factors (dentist visit behaviour and sugary drinks intake) and one psychosocial factor (parental stressor scale scores) were significantly associated with the 'two teeth with dental fillings' outcome for young females.

Table 6.24 shows the associations between family income and the 'three or more teeth with dental fillings' outcome for both young males and females. Model 1 represents the association between family income and the dental fillings outcome adjusted for covariates. For young males, the odds of having three or more teeth with dental fillings were higher for the lowest income group (OR 1.58; 95% CI: 1.11, 2.25) than the highest income group, model 1. There was a slight increase in the OR, from 1.58 (95% CI: 1.11, 2.25) to 1.60 (95% CI: 1.11, 2.30) for the lowest income group after the inclusion of behavioural factors (model 2) to model 1. In contrast, the OR for the lowest income group reduced after the adjustment for material (by 55%), model 3 and psychosocial factors (by 10%), model 4. The final model (model 5) showed a more than 50% reduction in the OR of the lowest-income group. However, with the inclusion of material (model 3) and all factors simultaneously (model 5) to the base model (model 1), the relationship between the lowest income quintile and the 'three or more teeth with dental fillings' outcome lost its statistical significance (model 3: OR 1.26, 95% CI: 0.83, 1.92; model 5: OR 1.25, 95% CI: 0.83, 1.88). Therefore, the adjustment of behavioural factors did not attenuate the strength of the association between family income and the 'three or more teeth with dental fillings' outcome, and the material



and psychosocial factors had a role in explaining income-related inequalities in the 'three or more teeth with dental filling' oral health outcome in young males. In model 5, only two behavioural factors (daily toothbrushing frequency and dentist visit behaviour) were significantly associated with the 'three or more teeth with dental fillings' oral health outcome in young males.

For young females, in model 1, the 3<sup>rd</sup> and lowest income groups had statistically significant OR, and compared with the highest income group, there was a 1.42 and 1.89-fold increase in the odds of having three or more teeth with dental fillings in the 3<sup>rd</sup> and lowest income group, respectively (OR<sub>third income quintile</sub>: 1.42; 95% CI: 1.01, 2.01; OR<sub>lowest income quintile</sub>: 1.89; 95% CI: 1.34, 2.66) (see Table 6.24). The OR for the lowest income group decreased (by 21%), and for the 3<sup>rd</sup> income group increased (by 10%) after adjusting for behaviour factors (model 2). In contrast, the OR for the lowest and 3<sup>rd</sup> income groups decreased by 55% and 43%, respectively, after adjusting for material factors (model 3). However, the relationships were not statistically significant. The inclusion of psychosocial factors (model 4) to the base model (model 1) resulted in a reduction of 26% in the OR for the lowest-income group (OR<sub>lowest income quintile</sub>: 1.66; 95% CI: 1.15, 2.39). This suggested that all three sets of factors could help explain income-related differences in the 'three or more teeth oral health outcome' in young females, and material factors had the maximum effect. The final model (model 5) showed a 43% reduction in the OR of the lowest-income group, but the relationship was not significant (OR<sub>lowest income quintile</sub>: 1.50; 95% CI: 1.00, 2.23). In contrast, an increase of 19% in the OR for the 3<sup>rd</sup> income group was observed in the final model (OR<sub>third income quintile</sub>: 1.50; 95% CI: 1.02, 2.20). In model 5, three behavioural factors (daily toothbrushing frequency, dentist visit behaviour and sugary foods intake) and one material factor (financial difficulties) were significantly associated with the 'three or more teeth with dental fillings' oral health outcome in young females.

Table 6.23 Association between household/family income and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having two teeth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                   |                     | <b>Model 1</b>           | <b>Model 2</b>                       | <b>Model 3</b>                       | <b>Model 4</b>                      | <b>Model 5</b>                       |
|-----------------------------------|---------------------|--------------------------|--------------------------------------|--------------------------------------|-------------------------------------|--------------------------------------|
|                                   |                     | <b>OR (95% CI)</b>       | <b>OR (95% CI)<br/>[% change]</b>    | <b>OR (95% CI)<br/>[% change]</b>    | <b>OR (95% CI)<br/>[% change]</b>   | <b>OR (95% CI)<br/>[% change]</b>    |
| <b>Family income in quintiles</b> | <b>Males</b>        |                          |                                      |                                      |                                     |                                      |
|                                   | Lowest              | <b>1.82 (1.30; 2.55)</b> | <b>1.83 (1.29; 2.58)</b><br>[-1.22]  | <b>1.60 (1.07; 2.38)</b><br>[26.83]  | <b>1.58 (1.12; 2.24)</b><br>[29.27] | <b>1.65 (1.12; 2.42)</b><br>[20.73]  |
|                                   | 2 <sup>nd</sup>     | 1.13 (0.80, 1.60)        | 1.13 (0.79; 1.62)<br>[0.00]          | 1.00 (0.66; 1.49)<br>[100.00]        | 0.94 (0.65; 1.36)<br>[100.00]       | 0.97 (0.65; 1.45)<br>[100.00]        |
|                                   | 3 <sup>rd</sup>     | 1.34 (0.94; 1.90)        | 1.26 (0.88; 1.80)<br>[23.53]         | 1.18 (0.80; 1.74)<br>[47.06]         | 1.17 (0.82; 1.68)<br>[50.00]        | 1.12 (0.77; 1.63)<br>[64.71]         |
|                                   | 4 <sup>th</sup>     | 1.25 (0.89; 1.76)        | 1.27 (0.90; 1.79)<br>[-8.00]         | 1.17 (0.82; 1.66)<br>[32.00]         | 1.12 (0.79; 1.59)<br>[52.00]        | 1.13 (0.79; 1.62)<br>[48.00]         |
|                                   | Highest (Reference) | 1                        | 1                                    | 1                                    | 1                                   | 1                                    |
|                                   | <b>Females</b>      |                          |                                      |                                      |                                     |                                      |
|                                   | Lowest              | <b>1.78 (1.26; 2.52)</b> | <b>1.88 (1.32; 2.69)</b><br>[-12.82] | <b>1.87 (1.23; 2.84)</b><br>[-11.54] | <b>1.76 (1.22; 2.53)</b><br>[2.56]  | <b>2.16 (1.45; 3.23)</b><br>[-48.72] |
|                                   | 2 <sup>nd</sup>     | <b>1.64 (1.17; 2.31)</b> | <b>1.69 (1.19; 2.40)</b><br>[-7.81]  | <b>1.73 (1.16; 2.59)</b><br>[-14.06] | <b>1.63 (1.14; 2.33)</b><br>[1.56]  | <b>1.96 (1.32; 2.90)</b><br>[-50.00] |
|                                   | 3 <sup>rd</sup>     | <b>1.62 (1.16; 2.29)</b> | <b>1.70 (1.20; 2.42)</b><br>[-12.90] | <b>1.79 (1.23; 2.62)</b><br>[-27.42] | <b>1.60 (1.12; 2.27)</b><br>[3.23]  | <b>1.97 (1.35; 2.87)</b><br>[-56.45] |
|                                   | 4 <sup>th</sup>     | 0.96 (0.66; 1.39)        | 0.97 (0.66; 1.41)<br>[25.00]         | 1.04 (0.70; 1.54)<br>[100.00]        | 0.95 (0.65; 1.40)<br>[-25.00]       | 1.07 (0.71; 1.59)<br>[100.00]        |
|                                   | Highest (Reference) | 1                        | 1                                    | 1                                    | 1                                   | 1                                    |

Table 6.23 Continued...

|                                |                                   | OR (95% CI) | OR (95% CI)              | OR (95% CI) | OR (95% CI) | OR (95% CI)              |
|--------------------------------|-----------------------------------|-------------|--------------------------|-------------|-------------|--------------------------|
| <b>Behavioural factors</b>     |                                   |             |                          |             |             |                          |
| <b>Daily Toothbrushing</b>     | <b>Males</b>                      |             |                          |             |             |                          |
|                                | Less than once/Rarely/Never       |             | 0.89 (0.58; 1.37)        |             |             | 0.81 (0.51; 1.27)        |
|                                | Once                              |             | <b>1.36 (1.07; 1.73)</b> |             |             | <b>1.31 (1.02; 1.68)</b> |
|                                | Twice/More than twice (Reference) |             | 1                        |             |             | 1                        |
|                                | <b>Females</b>                    |             |                          |             |             |                          |
|                                | Less than once/Rarely/Never       |             | 1.29 (0.73; 2.29)        |             |             | 1.23 (0.66; 2.28)        |
|                                | Once                              |             | 0.89 (0.66; 1.21)        |             |             | 0.82 (0.59; 1.14)        |
|                                | Twice/More than twice (Reference) |             | 1                        |             |             | 1                        |
|                                | <b>Males</b>                      |             |                          |             |             |                          |
|                                | Problem/Never                     |             | <b>0.71 (0.51; 0.98)</b> |             |             | <b>0.68 (0.48; 0.96)</b> |
| <b>Dentist visit behaviour</b> | Occasional visit                  |             | 0.81 (0.61; 1.07)        |             |             | 0.80 (0.59; 1.07)        |
|                                | At least a year (Reference)       |             | 1                        |             |             | 1                        |
|                                | <b>Females</b>                    |             |                          |             |             |                          |
|                                | Problem/Never                     |             | <b>0.56 (0.40; 0.80)</b> |             |             | <b>0.53 (0.36; 0.76)</b> |
|                                | Occasional visit                  |             | 0.88 (0.67; 1.15)        |             |             | 0.84 (0.63; 1.11)        |
|                                | At least a year (Reference)       |             | 1                        |             |             | 1                        |
|                                | <b>Males</b>                      |             |                          |             |             |                          |
|                                | More than once a day              |             | 0.93 (0.69; 1.27)        |             |             | NA                       |
|                                | Once a day                        |             | 1.23 (0.97; 1.57)        |             |             | NA                       |
|                                | Not at all (Reference)            |             | 1                        |             |             |                          |
| <b>Sugary drinks intake</b>    | <b>Females</b>                    |             |                          |             |             |                          |
|                                | More than once a day              |             | 0.96 (0.70; 1.32)        |             |             | 0.84 (0.59; 1.19)        |
|                                | Once a day                        |             | <b>1.50 (1.17; 1.92)</b> |             |             | <b>1.43 (1.10; 1.86)</b> |
|                                | Not at all (Reference)            |             | 1                        |             |             | 1                        |

Table 6.23 Continued...

| Behavioural factors       |                           | OR (95% CI) | OR (95% CI)              | OR (95% CI)              | OR (95% CI) | OR (95% CI)       |
|---------------------------|---------------------------|-------------|--------------------------|--------------------------|-------------|-------------------|
| Sugary foods intake       | <b>Males</b>              |             |                          |                          |             |                   |
|                           | More than once a day      |             | <b>1.42 (1.04; 1.93)</b> |                          |             | NA                |
|                           | Once a day                |             | 0.95 (0.74; 1.23)        |                          |             | NA                |
|                           | Not at all (Reference)    |             | 1                        |                          |             |                   |
|                           | <b>Females</b>            |             |                          |                          |             |                   |
|                           | More than once a day      |             | 1.01 (0.73; 1.40)        |                          |             | 0.90 (0.64; 1.28) |
|                           | Once a day                |             | <b>1.27 (1.00; 1.63)</b> |                          |             | 1.22 (0.95; 1.58) |
|                           | Not at all (Reference)    |             | 1                        |                          |             | 1                 |
| <b>Material factors</b>   |                           |             |                          |                          |             |                   |
| Financial difficulties    | <b>Males</b>              |             |                          |                          |             |                   |
|                           | With difficulty           |             |                          | 0.79 (0.62; 1.02)        |             | 0.78 (0.61; 1.01) |
|                           | No difficulty (Reference) |             |                          | 1                        |             | 1                 |
|                           | <b>Females</b>            |             |                          |                          |             |                   |
| DEIS school               | With difficulty           |             |                          | 0.91 (0.71; 1.17)        |             | 0.89 (0.69; 1.16) |
|                           | No difficulty (Reference) |             |                          | 1                        |             | 1                 |
|                           | <b>Males</b>              |             |                          |                          |             |                   |
|                           | Yes                       |             |                          | <b>1.31 (1.00; 1.73)</b> |             | 1.25 (0.94; 1.66) |
| Homeownership             | No (Reference)            |             |                          | 1                        |             | 1                 |
|                           | <b>Females</b>            |             |                          |                          |             |                   |
|                           | Yes                       |             |                          | 0.95 (0.71; 1.26)        |             | NA                |
|                           | No (Reference)            |             |                          | 1                        |             |                   |
| Private medical insurance | <b>Males</b>              |             |                          |                          |             |                   |
|                           | Renters/Rent free/Others  |             |                          | 1.33 (0.98; 1.81)        |             | 1.11 (0.80; 1.53) |
|                           | Owners (Reference)        |             |                          | 1                        |             |                   |
|                           | <b>Females</b>            |             |                          |                          |             |                   |
| Private medical insurance | Renters/Rent free/Others  |             |                          | 1.15 (0.87; 1.54)        |             | NA                |
|                           | Owners (Reference)        |             |                          | 1                        |             |                   |
|                           | <b>Males</b>              |             |                          |                          |             |                   |
|                           | No                        |             |                          | 1.08 (0.83; 1.41)        |             | NA                |

Table 6.23 Continued...

|                                   |                           | OR (95% CI) | OR (95% CI) | OR (95% CI)       | OR (95% CI)              | OR (95% CI)              |
|-----------------------------------|---------------------------|-------------|-------------|-------------------|--------------------------|--------------------------|
| Private medical insurance         | Yes (Reference)           |             |             | 1                 |                          |                          |
|                                   | <b>Females</b>            |             |             |                   |                          |                          |
|                                   | No                        |             |             | 0.97 (0.75; 1.26) |                          | NA                       |
|                                   | Yes (Reference)           |             |             | 1                 |                          |                          |
| Psychosocial factors              |                           |             |             |                   |                          |                          |
| PCG Parental Stressor scale score | <b>Males</b>              |             |             |                   | 1.01 (0.98; 1.04)        | NA                       |
|                                   | <b>Females</b>            |             |             |                   | 1.03 (1.00; 1.06)        | <b>1.04 (1.01; 1.07)</b> |
| PCG depression status             | <b>Males</b>              |             |             |                   |                          |                          |
|                                   | Depressed                 |             |             |                   | 0.93 (0.66; 1.31)        | NA                       |
|                                   | Not depressed (Reference) |             |             |                   | 1                        |                          |
|                                   | <b>Females</b>            |             |             |                   |                          |                          |
| Family structure                  | Depressed                 |             |             |                   | 0.90 (0.63; 1.29)        | NA                       |
|                                   | Not depressed (Reference) |             |             |                   | 1                        |                          |
|                                   | <b>Males</b>              |             |             |                   |                          |                          |
|                                   | Single parent family      |             |             |                   | <b>1.83 (1.40; 2.40)</b> | <b>1.88 (1.39; 2.52)</b> |
| Job stress                        | Couple family (Reference) |             |             |                   | 1                        | 1                        |
|                                   | <b>Females</b>            |             |             |                   |                          |                          |
|                                   | Single parent family      |             |             |                   | 1.04 (0.79; 1.37)        | NA                       |
|                                   | Couple family (Reference) |             |             |                   | 1                        |                          |
|                                   | <b>Males</b>              |             |             |                   |                          |                          |
|                                   | Stressed                  |             |             |                   | 0.86 (0.68; 1.08)        | NA                       |
|                                   | Not stressed (Reference)  |             |             |                   | 1                        |                          |
|                                   | <b>Females</b>            |             |             |                   |                          |                          |
|                                   | Stressed                  |             |             |                   | 1.03 (0.81; 1.30)        | 0.98 (0.77; 1.25)        |
|                                   | Not stressed (Reference)  |             |             |                   | 1                        | 1                        |

Table 6.24 Association between household/family income and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having three or more teeth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                            |                     | Model 1                  | Model 2                             | Model 3                       | Model 4                             | Model 5                              |
|----------------------------|---------------------|--------------------------|-------------------------------------|-------------------------------|-------------------------------------|--------------------------------------|
|                            |                     | OR (95% CI)              | OR (95% CI)<br>[% change]           | OR (95% CI)<br>[% change]     | OR (95% CI)<br>[% change]           | OR (95% CI)<br>[% change]            |
| Family income in quintiles | <b>Males</b>        |                          |                                     |                               |                                     |                                      |
|                            | Lowest              | <b>1.58 (1.11; 2.25)</b> | <b>1.60 (1.11; 2.30)</b><br>[-3.45] | 1.26 (0.83; 1.92)<br>[55.17]  | <b>1.52 (1.05; 2.21)</b><br>[10.34] | 1.25 (0.83; 1.88)<br>[56.90]         |
|                            | 2 <sup>nd</sup>     | 1.04 (0.72; 1.50)        | 1.07 (0.73; 1.56)<br>[-75.00]       | 0.88 (0.57; 1.34)<br>[100.00] | 1.00 (0.68; 1.47)<br>[100.00]       | 0.89 (0.58; 1.35)<br>[100.00]        |
|                            | 3 <sup>rd</sup>     | 1.31 (0.91; 1.87)        | 1.32 (0.91; 1.90)<br>[-3.23]        | 1.22 (0.82; 1.82)<br>[29.03]  | 1.29 (0.88; 1.88)<br>[6.45]         | 1.18 (0.80; 1.75)<br>[41.94]         |
|                            | 4 <sup>th</sup>     | 1.37 (0.97; 1.94)        | 1.28 (0.89; 1.82)<br>[24.32]        | 1.32 (0.91; 1.90)<br>[13.51]  | 1.42 (0.99; 2.03)<br>[-13.51]       | 1.16 (0.80; 1.69)<br>[56.76]         |
|                            | Highest (Reference) | 1                        | 1                                   | 1                             | 1                                   | 1                                    |
|                            | <b>Females</b>      |                          |                                     |                               |                                     |                                      |
|                            | Lowest              | <b>1.89 (1.34; 2.66)</b> | <b>1.70 (1.20; 2.43)</b><br>[21.35] | 1.40 (0.93; 2.13)<br>[55.06]  | <b>1.66 (1.15; 2.39)</b><br>[25.84] | 1.50 (1.00; 2.23)<br>[43.82]         |
|                            | 2 <sup>nd</sup>     | 0.97 (0.68; 1.41)        | 0.96 (0.66; 1.40)<br>[-33.33]       | 0.76 (0.49; 1.17)<br>[100.00] | 0.93 (0.63; 1.37)<br>[100.00]       | 0.84 (0.55; 1.29)<br>[100.00]        |
|                            | 3 <sup>rd</sup>     | <b>1.42 (1.01; 2.01)</b> | <b>1.46 (1.02; 2.08)</b><br>[-9.52] | 1.24 (0.85; 1.82)<br>[42.86]  | 1.42 (0.99; 2.03)<br>[0.00]         | <b>1.50 (1.02; 2.20)</b><br>[-19.05] |
|                            | 4 <sup>th</sup>     | 1.09 (0.76; 1.56)        | 1.04 (0.72; 1.51)<br>[55.56]        | 0.94 (0.64; 1.38)<br>[100.00] | 1.00 (0.69; 1.47)<br>[100.00]       | 0.96 (0.64; 1.42)<br>[100.00]        |
|                            | Highest (Reference) | 1                        | 1                                   | 1                             | 1                                   | 1                                    |

Table 6.24 Continued...

| Behavioural factors           |                                   | OR (95% CI) | OR (95% CI)              | OR (95% CI) | OR (95% CI) | OR (95% CI)              |
|-------------------------------|-----------------------------------|-------------|--------------------------|-------------|-------------|--------------------------|
| Daily Toothbrushing frequency | <b>Males</b>                      |             |                          |             |             |                          |
|                               | Less than once/Rarely/Never       |             | 1.29 (0.85; 1.94)        |             |             | 1.33 (0.87; 2.02)        |
|                               | Once                              |             | <b>1.34 (1.04; 1.72)</b> |             |             | <b>1.31 (1.01; 1.70)</b> |
|                               | Twice/More than twice (Reference) |             |                          |             |             |                          |
|                               | <b>Females</b>                    |             |                          |             |             |                          |
|                               | Less than once/Rarely/Never       |             | <b>2.55 (1.54; 4.21)</b> |             |             | <b>2.23 (1.28; 3.87)</b> |
|                               | Once                              |             | <b>1.45 (1.09; 1.92)</b> |             |             | <b>1.41 (1.04; 1.91)</b> |
|                               | Twice/More than twice (Reference) |             |                          |             |             |                          |
| Dentist visit behaviour       | <b>Males</b>                      |             |                          |             |             |                          |
|                               | Problem/Never                     |             | <b>0.64 (0.45; 0.90)</b> |             |             | <b>0.65 (0.45; 0.92)</b> |
|                               | Occasional visit                  |             | 0.79 (0.59; 1.06)        |             |             | 0.81 (0.60; 1.09)        |
|                               | At least a year (Reference)       |             |                          |             |             |                          |
|                               | <b>Females</b>                    |             |                          |             |             |                          |
|                               | Problem/Never                     |             | <b>0.63 (0.45; 0.90)</b> |             |             | <b>0.64 (0.44; 0.93)</b> |
|                               | Occasional visit                  |             | 0.83 (0.62; 1.09)        |             |             | 0.75 (0.55; 1.01)        |
|                               | At least a year (Reference)       |             |                          |             |             |                          |
| Sugary drinks intake          | <b>Males</b>                      |             |                          |             |             |                          |
|                               | More than once a day              |             | 1.07 (0.78; 1.47)        |             |             | NA                       |
|                               | Once a day                        |             | <b>1.30 (1.01; 1.67)</b> |             |             | NA                       |
|                               | Not at all (Reference)            |             |                          |             |             |                          |
|                               | <b>Females</b>                    |             |                          |             |             |                          |
|                               | More than once a day              |             | 1.11 (0.82; 1.51)        |             |             | 1.05 (0.76; 1.47)        |
|                               | Once a day                        |             | 1.06 (0.81; 1.39)        |             |             | 1.00 (0.75; 1.33)        |
|                               | Not at all (Reference)            |             |                          |             |             |                          |
| Sugary foods intake           | <b>Males</b>                      |             |                          |             |             |                          |
|                               | More than once a day              |             | 1.07 (0.76; 1.49)        |             |             | NA                       |
|                               | Once a day                        |             | 0.95 (0.73; 1.23)        |             |             | NA                       |
|                               | Not at all (Reference)            |             |                          |             |             |                          |

Table 6.24 Continued...

| Behavioural factors                        |                           | OR (95% CI) | OR (95% CI)              | OR (95% CI)              | OR (95% CI) | OR (95% CI)              |
|--------------------------------------------|---------------------------|-------------|--------------------------|--------------------------|-------------|--------------------------|
| Sugary foods intake                        | <b>Females</b>            |             |                          |                          |             |                          |
|                                            | More than once a day      |             | <b>1.55 (1.14; 2.12)</b> |                          |             | <b>1.47 (1.05; 2.05)</b> |
|                                            | Once a day                |             | 1.22 (0.94; 1.58)        |                          |             | 1.23 (0.93; 1.61)        |
|                                            | Not at all (Reference)    |             |                          |                          |             |                          |
| Material factors<br>Financial difficulties | <b>Males</b>              |             |                          |                          |             |                          |
|                                            | With difficulty           |             |                          | 1.22 (0.94; 1.58)        |             | 1.21 (0.93; 1.58)        |
|                                            | No difficulty (Reference) |             |                          |                          |             |                          |
|                                            | <b>Females</b>            |             |                          |                          |             |                          |
|                                            | With difficulty           |             |                          | <b>1.39 (1.07; 1.81)</b> |             | <b>1.36 (1.03; 1.79)</b> |
|                                            | No difficulty (Reference) |             |                          |                          |             |                          |
| DEIS school                                | <b>Males</b>              |             |                          |                          |             |                          |
|                                            | Yes                       |             |                          | 1.22 (0.91; 1.62)        |             | 1.22 (0.90; 1.64)        |
|                                            | No (Reference)            |             |                          |                          |             |                          |
|                                            | <b>Females</b>            |             |                          |                          |             |                          |
| Homeownership                              | Yes                       |             |                          | 0.87 (0.64; 1.17)        |             | NA                       |
|                                            | No (Reference)            |             |                          |                          |             |                          |
|                                            | <b>Males</b>              |             |                          |                          |             |                          |
|                                            | Renters/Rent free/Others  |             |                          | 1.30 (0.94; 1.80)        |             | 1.01 (0.71; 1.43)        |
|                                            | Owners (Reference)        |             |                          |                          |             |                          |
|                                            | <b>Females</b>            |             |                          |                          |             |                          |
| Private medical insurance                  | Renters/Rent free/Others  |             |                          | 1.25 (0.93; 1.68)        |             | NA                       |
|                                            | Owners (Reference)        |             |                          |                          |             |                          |
|                                            | <b>Males</b>              |             |                          |                          |             |                          |
|                                            | No                        |             |                          | 1.04 (0.79; 1.36)        |             | NA                       |
|                                            | Yes (Reference)           |             |                          |                          |             |                          |
|                                            | <b>Females</b>            |             |                          |                          |             |                          |
|                                            | No                        |             |                          | 1.08 (0.83; 1.42)        |             | NA                       |
|                                            | Yes (Reference)           |             |                          |                          |             |                          |



Table 6.24 Continued...

| Psychosocial factors              |                           | OR (95% CI) | OR (95% CI) | OR (95% CI) | OR (95% CI)              | OR (95% CI)       |
|-----------------------------------|---------------------------|-------------|-------------|-------------|--------------------------|-------------------|
| PCG Parental Stressor scale score | <b>Males</b>              |             |             |             | 1.04 (1.02; 1.07)        | NA                |
|                                   | <b>Females</b>            |             |             |             | 1.00 (0.97; 1.03)        | 1.00 (0.96; 1.03) |
| PCG depression status             | <b>Males</b>              |             |             |             |                          |                   |
|                                   | Depressed                 |             |             |             | 1.07 (0.76; 1.50)        | NA                |
|                                   | Not depressed (Reference) |             |             |             |                          |                   |
| <b>Females</b>                    |                           |             |             |             |                          |                   |
|                                   | Depressed                 |             |             |             | 1.38 (0.97; 1.95)        | NA                |
|                                   | Not depressed (Reference) |             |             |             |                          |                   |
| <b>Males</b>                      |                           |             |             |             |                          |                   |
|                                   | Single parent family      |             |             |             | <b>1.47 (1.10; 1.97)</b> | 1.31 (0.94; 1.81) |
|                                   | Couple family (Reference) |             |             |             |                          |                   |
| <b>Females</b>                    |                           |             |             |             |                          |                   |
|                                   | Single parent family      |             |             |             | 1.06 (0.79; 1.42)        | NA                |
|                                   | Couple family (Reference) |             |             |             |                          |                   |
| <b>Males</b>                      |                           |             |             |             |                          |                   |
|                                   | Stressed                  |             |             |             | <b>0.75 (0.60; 0.95)</b> | NA                |
|                                   | Not stressed (Reference)  |             |             |             |                          |                   |
| <b>Females</b>                    |                           |             |             |             |                          |                   |
|                                   | Stressed                  |             |             |             | 1.03 (0.81; 1.32)        | 1.00 (0.78; 1.29) |
|                                   | Not stressed (Reference)  |             |             |             |                          |                   |

### **3) To what extent can occupational inequalities in young persons' parent reported oral health be explained by behavioural, material and psychosocial factors?**

The associations between young persons' parent reported oral health and family occupational class after adjustment for covariates (model 1), behavioural factors (model 2), material factors (model 3), psychosocial factors (model 4) and all factors combined (model 5) are presented in Table 6.25, 6.26 and 6.27.

Associations between the 'one tooth with dental fillings' outcome and family occupational class for young males have been presented in Table 6.25. For young males, after adjusting for covariates (area of residence, main language spoken at home and PCG country of birth), the odds of having one tooth with dental fillings were lower for the lowest occupational class (semi-skilled/unskilled manual) (OR 0.57; 95% CI: 0.38, 0.86) than the highest occupational group (professional managers). The OR for the lowest occupational class increased by approximately, 12%, 44% and 9% after adjusting for behavioural, material and psychosocial factors, respectively, in model 2, model 3 and model 4. The total reduction in the OR for the lowest occupational class after the simultaneous inclusion of all factors to model 1 resulted in an increase of 37% in the OR for the lowest occupational class. However, the relationships between the lowest occupational group and one tooth with dental fillings outcome were significant only in models 1, 2 and 4, suggesting the role of all three sets of factors in explaining occupation-related differences in the 'one tooth with dental fillings' outcome in young males.

Table 6.26 summarised the associations between family occupational class and the 'two teeth with dental fillings' oral health outcome for young females. There was a 1.74-fold increase in the odds of having two teeth with dental fillings for those who belonged to the lowest occupational family class (semi-skilled/unskilled manual) than the highest occupational class (professional managers) individuals. With the inclusion of behavioural factors (model 2), a slight increase in the OR (from 1.74 (95% CI: 1.29, 2.36) to 1.77 (95% CI: 1.30, 2.41)) was observed for the lowest occupational group. However, adjusting for material and psychosocial factors, in model 3 and model 4, respectively, reduced the OR for the lowest occupational class by 31% and 12%,

suggesting a potential mediation of material and psychosocial factors in the family occupational class and two teeth with dental fillings outcome relationship in young females. In the full model, model 5, the reduction in the OR for the lowest occupation group was approximately 24%. The dentist visit, sugary drinks and homeownership were significantly associated with the 'two teeth with dental fillings' oral health outcome in the final model for young females.

Table 6.27 shows the relationship between the 'three or more teeth with dental fillings' oral health outcome and family social class for young females. To examine the relative contribution of the explanatory factors, sets of behavioural (model 2), material (model 3) and psychosocial (model 4) were added separately to the reference model (model 1). For young females, in the reference model, model 1, the family occupation showed a graded relationship with the dental fillings outcome. Compared with the reference occupational group (professional managers), the odds of having three or more teeth with dental fillings increased among young females with a skilled manual occupational family background to 1.39 and to 1.70 for the lowest occupational group (semi-skilled/unskilled manual) ( $OR_{\text{skilled manual}}: 1.39; 95\% \text{ CI: } 1.10, 1.77$ ; and  $OR_{\text{unskilled}}: 1.70; 95\% \text{ CI: } 1.24, 2.33$ ). The association between family occupational class and the 'three or more teeth with dental fillings' outcome was attenuated by the inclusion of behavioural factors (model 1), material factors (model 2) and psychosocial factors (model 4). After adjusting for behavioural, material and psychosocial factors, respectively, the ORs for the lowest occupational family class reduced by approximately, 13%, 50% and 20% and the ORs for the second lowest group reduced by 20%, 26% and 18%. The final model (model 5) showed a large explanation of the occupational differences in the 'three or more teeth with dental fillings' outcome by 59% for the lowest family occupational group and 51% for the non-manual/skilled manual group. In this model, for young females, toothbrushing frequency, dentist visit behaviours, sugary foods intake, financial difficulties and job stress were significantly associated with the oral health outcome of having three or more teeth with dental fillings.

Table 6.25 Association between family occupational class and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having one tooth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                            |                                   | Model 1                  | Model 2                             | Model 3                      | Model 4                            | Model 5                      |
|----------------------------|-----------------------------------|--------------------------|-------------------------------------|------------------------------|------------------------------------|------------------------------|
|                            |                                   | OR (95% CI)              | OR (95% CI)<br>[% change]           | OR (95% CI)<br>[% change]    | OR (95% CI)<br>[% change]          | OR (95% CI)<br>[% change]    |
| <b>Family Social Class</b> | Semi-skilled/ Unskilled manual    | <b>0.57 (0.38; 0.86)</b> | <b>0.62 (0.41; 0.93)</b><br>[11.63] | 0.76 (0.49; 1.19)<br>[44.19] | <b>0.61 (0.39; 0.95)</b><br>[9.30] | 0.73 (0.46; 1.14)<br>[37.21] |
|                            | Other non-manual/ Skilled manual  | 0.86 (0.67; 1.09)        | 0.87 (0.68; 1.11)<br>[7.14]         | 0.95 (0.72; 1.24)<br>[64.29] | 0.89 (0.69; 1.15)<br>[21.43]       | 0.94 (0.72; 1.22)<br>[57.14] |
|                            | Professional managers (Reference) | 1                        | 1                                   | 1                            | 1                                  | 1                            |
| <b>Behaviour factors</b>   | <b>Daily Toothbrushing</b>        |                          |                                     |                              |                                    |                              |
|                            | Less than once/Rarely/Never       |                          | 0.91 (0.56; 1.48)                   |                              |                                    | NA                           |
|                            | Once                              |                          | 0.93 (0.71; 1.22)                   |                              |                                    | NA                           |
|                            | Twice/More than twice (Reference) |                          |                                     |                              |                                    |                              |
|                            | <b>Dentist visit behaviour</b>    |                          |                                     |                              |                                    |                              |
|                            | Problem/Never                     |                          | 0.88 (0.62; 1.24)                   |                              |                                    | 0.90 (0.62; 1.29)            |
|                            | Occasional visit                  |                          | 0.86 (0.64; 1.16)                   |                              |                                    | 0.92 (0.68; 1.25)            |
|                            | At least a year (Reference)       |                          |                                     |                              |                                    |                              |
|                            | <b>Sugary drinks intake</b>       |                          |                                     |                              |                                    |                              |
|                            | More than once a day              |                          | <b>0.59 (0.42; 0.83)</b>            |                              |                                    | <b>0.61 (0.42; 0.87)</b>     |
|                            | Once a day                        |                          | 0.79 (0.61; 1.03)                   |                              |                                    | 0.84 (0.64; 1.10)            |
|                            | Not at all (Reference)            |                          |                                     |                              |                                    |                              |
|                            | <b>Sugary foods intake</b>        |                          |                                     |                              |                                    |                              |
|                            | More than once a day              |                          | 1.35 (0.95; 1.91)                   |                              |                                    | 1.20 (0.83; 1.73)            |
|                            | Once a day                        |                          | 1.22 (0.93; 1.60)                   |                              |                                    | 1.15 (0.87; 0.52)            |
|                            | Not at all (Reference)            |                          |                                     |                              |                                    |                              |

Table 6.25 Continued...

|                             |                                          | OR (95% CI) | OR (95% CI) | OR (95% CI)       | OR (95% CI)              | OR (95% CI)       |
|-----------------------------|------------------------------------------|-------------|-------------|-------------------|--------------------------|-------------------|
| <b>Material factors</b>     | <b>Financial difficulties</b>            |             |             |                   |                          |                   |
|                             | With difficulty                          |             |             | 0.91 (0.71; 1.16) |                          | 0.93 (0.73; 1.18) |
|                             | No difficulty (Reference)                |             |             |                   |                          |                   |
|                             | <b>DEIS school</b>                       |             |             |                   |                          |                   |
|                             | Yes                                      |             |             | 0.75 (0.52; 1.08) |                          | NA                |
|                             | No (Reference)                           |             |             |                   |                          |                   |
|                             | <b>Homeownership</b>                     |             |             |                   |                          |                   |
|                             | Renters/Rent free/Others                 |             |             | 0.51 (0.31; 0.83) |                          | 0.52 (0.31; 0.85) |
|                             | Owners (Reference)                       |             |             |                   |                          |                   |
|                             | <b>Private medical insurance</b>         |             |             |                   |                          |                   |
|                             | No                                       |             |             | 1.00 (0.77; 1.32) |                          | NA                |
|                             | Yes (Reference)                          |             |             |                   |                          |                   |
| <b>Psychosocial factors</b> | <b>PCG Parental Stressor scale score</b> |             |             |                   | 1.01 (0.98; 1.04)        | NA                |
|                             | <b>PCG depression status</b>             |             |             |                   |                          |                   |
|                             | Depressed                                |             |             |                   | 0.67 (0.43; 1.03)        | NA                |
|                             | Not depressed (Reference)                |             |             |                   |                          |                   |
|                             | <b>Family structure</b>                  |             |             |                   |                          |                   |
|                             | Single parent family                     |             |             |                   | 0.98 (0.66; 1.46)        | 1.19 (0.79; 1.79) |
|                             | Couple family (Reference)                |             |             |                   |                          |                   |
|                             | <b>Job stress</b>                        |             |             |                   |                          |                   |
|                             | Stressed                                 |             |             |                   | <b>0.77 (0.61; 0.99)</b> | 0.81 (0.63; 1.03) |
|                             | Not stressed (Reference)                 |             |             |                   |                          |                   |

Table 6.26 Association between family occupational class and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having two teeth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                  |                                   | Model 1                  | Model 2                             | Model 3                             | Model 4                             | Model 5                             |
|----------------------------------|-----------------------------------|--------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
|                                  |                                   | OR (95% CI)              | OR (95% CI)<br>[% change]           | OR (95% CI)<br>[% change]           | OR (95% CI)<br>[% change]           | OR (95% CI)<br>[% change]           |
| <b>Family occupational class</b> | Semi-skilled/ Unskilled manual    | <b>1.74 (1.29; 2.36)</b> | <b>1.77 (1.30; 2.41)</b><br>[-4.05] | <b>1.51 (1.07; 2.12)</b><br>[31.08] | <b>1.65 (1.21; 2.26)</b><br>[12.16] | <b>1.56 (1.12; 2.18)</b><br>[24.32] |
|                                  | Other non-manual/ Skilled manual  | 1.19 (0.94; 1.50)        | 1.17 (0.92; 1.49)<br>[10.53]        | 1.14 (0.88; 1.49)<br>[26.32]        | 1.17 (0.91; 1.49)<br>[10.53]        | 1.17 (0.90; 1.52)<br>[10.53]        |
|                                  | Professional managers (Reference) | 1                        | 1                                   | 1                                   | 1                                   | 1                                   |
| <b>Behaviour factors</b>         | <b>Toothbrushing frequency</b>    |                          |                                     |                                     |                                     |                                     |
|                                  | Less than once/Rarely/Never       |                          | 1.25 (0.64; 2.42)                   |                                     |                                     | 1.02 (0.51; 2.07)                   |
|                                  | Once                              |                          | 0.92 (0.68; 1.25)                   |                                     |                                     | 0.87 (0.62; 1.20)                   |
|                                  | Twice/More than twice (Reference) |                          | 1                                   |                                     |                                     | 1                                   |
|                                  | <b>Dentist visit behaviour</b>    |                          |                                     |                                     |                                     |                                     |
|                                  | Problem/Never                     |                          | <b>0.66 (0.46; 0.94)</b>            |                                     |                                     | <b>0.57 (0.39; 0.84)</b>            |
|                                  | Occasional visit                  |                          | 0.85 (0.65; 1.12)                   |                                     |                                     | 0.80 (0.60; 1.08)                   |
|                                  | At least a year (Reference)       |                          | 1                                   |                                     |                                     | 1                                   |
|                                  | <b>Sugary drinks intake</b>       |                          |                                     |                                     |                                     |                                     |
|                                  | More than once a day              |                          | 1.24 (0.89; 1.72)                   |                                     |                                     | 1.07 (0.75; 1.53)                   |
|                                  | Once a day                        |                          | <b>1.60 (1.25; 2.06)</b>            |                                     |                                     | <b>1.47 (1.13; 1.92)</b>            |
|                                  | Not at all (Reference)            |                          | 1                                   |                                     |                                     | 1                                   |
|                                  | <b>Sugary foods intake</b>        |                          |                                     |                                     |                                     |                                     |
|                                  | More than once a day              |                          | 0.93 (0.67; 1.30)                   |                                     |                                     | 0.80 (0.56; 1.15)                   |
|                                  | Once a day                        |                          | 1.18 (0.92; 1.51)                   |                                     |                                     | 1.08 (0.83; 1.40)                   |
|                                  | Not at all (Reference)            |                          | 1                                   |                                     |                                     | 1                                   |

Table 6.26 Continued...

|                             |                                               | OR (95% CI) | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] |
|-----------------------------|-----------------------------------------------|-------------|---------------------------|---------------------------|---------------------------|---------------------------|
| <b>Material factors</b>     | <b>Financial difficulties</b>                 |             |                           |                           |                           |                           |
|                             | With difficulty                               |             |                           | 1.20 (0.94; 1.52)         |                           | 1.18 (0.93; 1.51)         |
|                             | No difficulty (Reference)                     |             |                           | 1                         |                           | 1                         |
|                             | <b>DEIS school</b>                            |             |                           |                           |                           |                           |
|                             | Yes                                           |             |                           | 1.06 (0.79; 1.42)         |                           | NA                        |
|                             | No (Reference)                                |             |                           | 1                         |                           |                           |
|                             | <b>Homeownership</b>                          |             |                           |                           |                           |                           |
|                             | Renters/Rent free/Others                      |             |                           | <b>1.61 (1.18; 2.19)</b>  |                           | <b>1.59 (1.16; 2.16)</b>  |
|                             | Owners (Reference)                            |             |                           |                           |                           |                           |
|                             | <b>Private medical insurance</b>              |             |                           |                           |                           |                           |
|                             | No                                            |             |                           | 0.95 (0.73; 1.23)         |                           | NA                        |
|                             | Yes (Reference)                               |             |                           | 1                         |                           |                           |
| <b>Psychosocial factors</b> | <b>PCG mean parental stressor scale score</b> |             |                           |                           | 1.02 (1.00; 1.05)         | 1.03 (1.00; 1.06)         |
|                             | <b>PCG depression status</b>                  |             |                           |                           | 1                         | 1                         |
|                             | Depressed                                     |             |                           |                           | 1.04 (0.71; 1.52)         | NA                        |
|                             | Not depressed (Reference)                     |             |                           |                           | 1                         |                           |
|                             | <b>Family structure</b>                       |             |                           |                           |                           |                           |
|                             | Single parent family                          |             |                           |                           | <b>1.45 (1.07; 1.98)</b>  | NA                        |
|                             | Couple family (Reference)                     |             |                           |                           | 1                         |                           |
|                             | <b>PCG job stress</b>                         |             |                           |                           |                           |                           |
|                             | Stressed                                      |             |                           |                           | 1.01 (0.79; 1.28)         | NA                        |
|                             | Not stressed (Reference)                      |             |                           |                           | 1                         |                           |

Table 6.27 Association between family occupational class and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having three teeth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                           |                                   | Model 1           | Model 2                      | Model 3                      | Model 4                      | Model 5                      |
|---------------------------|-----------------------------------|-------------------|------------------------------|------------------------------|------------------------------|------------------------------|
|                           |                                   | OR (95% CI)       | OR (95% CI)<br>[% change]    | OR (95% CI)<br>[% change]    | OR (95% CI)<br>[% change]    | OR (95% CI)<br>[% change]    |
| Family occupational class | Semi-skilled/ Unskilled manual    | 1.70 (1.24; 2.33) | 1.61 (1.16; 2.24)<br>[12.86] | 1.35 (0.94; 1.95)<br>[50.00] | 1.56 (1.11; 2.19)<br>[20.00] | 1.29 (0.90; 1.86)<br>[58.57] |
|                           | Other non-manual/ Skilled manual  | 1.39 (1.10; 1.77) | 1.31 (1.02; 1.67)<br>[20.51] | 1.29 (0.99; 1.70)<br>[25.64] | 1.32 (1.03; 1.70)<br>[17.95] | 1.19 (0.91; 1.55)<br>[51.28] |
|                           | Professional managers (Reference) | 1                 | 1                            | 1                            | 1                            | 1                            |
| Behavioural factors       | <b>Toothbrushing frequency</b>    |                   |                              |                              |                              |                              |
|                           | Less than once/Rarely/Never       |                   | 2.83 (1.61; 4.97)            |                              |                              | 2.43 (1.33; 4.43)            |
|                           | Once                              |                   | 1.39 (1.04; 1.86)            |                              |                              | 1.39 (1.02; 1.90)            |
|                           | Twice/More than twice (Reference) |                   |                              |                              |                              |                              |
|                           | <b>Dentist visit behaviour</b>    |                   |                              |                              |                              |                              |
|                           | Problem/Never                     |                   | 0.67 (0.47; 0.97)            |                              |                              | 0.67 (0.45; 0.99)            |
|                           | Occasional visit                  |                   | 0.85 (0.64; 1.13)            |                              |                              | 0.78 (0.58; 1.06)            |
|                           | At least a year (Reference)       |                   |                              |                              |                              |                              |
|                           | <b>Sugary drinks intake</b>       |                   |                              |                              |                              |                              |
|                           | More than once a day              |                   | 1.21 (0.88; 1.67)            |                              |                              | 1.07 (0.75; 1.52)            |
|                           | Once a day                        |                   | 1.08 (0.82; 1.42)            |                              |                              | 0.97 (0.72; 1.30)            |
|                           | Not at all (Reference)            |                   |                              |                              |                              |                              |
|                           | <b>Sugary foods intake</b>        |                   |                              |                              |                              |                              |
|                           | More than once a day              |                   | 1.55 (1.12; 2.15)            |                              |                              | 1.48 (1.04; 2.11)            |
|                           | Once a day                        |                   | 1.25 (0.96; 1.62)            |                              |                              | 1.23 (0.93; 1.63)            |
|                           | Not at all (Reference)            |                   |                              |                              |                              |                              |



Table 6.27 Continued...

|                             |                                               | OR (95% CI) | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] |
|-----------------------------|-----------------------------------------------|-------------|---------------------------|---------------------------|---------------------------|---------------------------|
| <b>Material factors</b>     | <b>Financial difficulties</b>                 |             |                           |                           |                           |                           |
|                             | With difficulty                               |             |                           | <b>1.58 (1.22; 2.03)</b>  |                           | <b>1.54 (1.19; 1.99)</b>  |
|                             | No difficulty (Reference)                     |             |                           |                           |                           |                           |
|                             | <b>DEIS school</b>                            |             |                           |                           |                           |                           |
|                             | Yes                                           |             |                           | 0.84 (0.61; 1.15)         |                           | NA                        |
|                             | No (Reference)                                |             |                           |                           |                           |                           |
|                             | <b>Homeownership</b>                          |             |                           |                           |                           |                           |
|                             | Renters/Rent free/Others                      |             |                           | 1.21 (0.87; 1.69)         |                           | 1.23 (0.88; 1.73)         |
|                             | Owners (Reference)                            |             |                           |                           |                           |                           |
|                             | <b>Private medical insurance</b>              |             |                           |                           |                           |                           |
|                             | No                                            |             |                           | 0.99 (0.76; 1.29)         |                           | NA                        |
|                             | Yes (Reference)                               |             |                           |                           |                           |                           |
| <b>Psychosocial factors</b> | <b>PCG mean parental stressor scale score</b> |             |                           |                           | 0.99 (0.96; 1.02)         | 0.98 (0.95; 1.01)         |
|                             | <b>PCG depression status</b>                  |             |                           |                           |                           |                           |
|                             | Depressed                                     |             |                           |                           | <b>1.47 (1.01; 2.15)</b>  | NA                        |
|                             | Not depressed (Reference)                     |             |                           |                           |                           |                           |
|                             | <b>Family structure</b>                       |             |                           |                           |                           |                           |
|                             | Single parent family                          |             |                           |                           | 0.87 (0.60; 1.26)         | NA                        |
|                             | Couple family (Reference)                     |             |                           |                           |                           |                           |
|                             | <b>PCG job stress</b>                         |             |                           |                           |                           |                           |
|                             | Stressed                                      |             |                           |                           | 1.06 (0.82; 1.37)         | NA                        |
|                             | Not stressed (Reference)                      |             |                           |                           |                           |                           |

#### **4) To what extent can Medical Card inequalities in the dental fillings outcomes be explained by behavioural, material and psychosocial factors?**

Tables 6.28, 6.29 and 6.30 present the associations between the three parent-reported young persons' oral health outcomes ('one tooth with dental fillings', 'two teeth with dental fillings' and 'three or more teeth with dental fillings') and study participants medical card status after adjustment for covariates (model 1), behavioural factors (model 2), material factors (model 3), psychosocial factors (model 4) and all factors together (model 5).

Associations between the 'one tooth with dental fillings' outcome and medical card status for young females have been presented in Table 6.28. In model 1, the odds of having one tooth with dental fillings were higher for those with a full medical card (OR 1.36, 95% CI: 1.09, 1.70) than those who did not have one. There was a small reduction (~6%) in the ORs after the inclusion of behavioural (model 2) and psychosocial factors (model 3) in the reference model (model 1). However, an increase in the ORs was observed after adjusting for material factors (model 3) from 1.36 (95% CI: 1.09, 1.70) to 1.57 (95% CI: 1.15, 2.13). Similarly, the OR increased after simultaneously adjusting all explanatory factors (model 5). This suggested a minor role of behavioural and psychosocial factors in explaining medical card-related inequalities in the 'one tooth with dental fillings' outcome in young females. In the final model, dentist visit behaviours, financial difficulties and PCG job stress were significantly associated with having one tooth with dental fillings in young females.

Table 6.29 presents the associations between medical card status and the 'two teeth with dental fillings' oral health outcome for both young males and females. For young males, there was a 1.65-fold increase in the odds of having two teeth with dental fillings for those who had a full medical card than those without a medical card. With the addition of behavioural factors to the reference model (model 2), OR remained almost the same (from 1.65 (95% CI: 1.34, 2.05) to 1.66 (95% CI: 1.34, 2.07)) for the 'full medical card' group. Similarly, the OR for the 'full medical card' group increased by 11% after the inclusion of material factors (model 3) in the reference model.

However, there was a 37% reduction in the OR for the ‘full medical card’ group after adjusting for psychosocial factors (model 4) in model 1. Therefore, there was a potential mediation of psychosocial factors in the relationship between medical card status and the ‘two teeth with dental fillings’ outcome in young males. Including all behavioural, material and psychosocial factors in the reference model resulted in a 28% reduction in the OR of the ‘full medical card’ group, model 5. In the final model (model 5), the dentist visit behaviour, sugary foods and family structure were significantly associated with the ‘two teeth with dental fillings’ outcome in young males. For young females, in the reference model (adjusted for wave 1 covariates), the odds of having two teeth with dental fillings were higher for those who had a medical card (OR 1.41, 95% CI: 1.14, 1.74) than the ‘no medical card’ group, model 1. The OR for the medical card holders increased, remained unchanged, and reduced, respectively, after separately adding behavioural (model 2), psychosocial (model 4) and material factors (model 3) to the reference model. Therefore, only material factors potentially mediated the medical card status and the ‘two teeth with dental fillings’ outcome in young females. In the final model, an overall increase of 39% in OR for the medical card holders was noted after adding all explanatory factors together to the reference model. In this model, only two factors, dentist visit behaviour and PCG parental stressor scale scores, were found to be significantly associated with the ‘two teeth with dental fillings’ oral health outcome.

Table 6.30 presents the relationship between the ‘three or more teeth with dental fillings’ outcome and medical card status for both genders. In the reference model (model 1), the associations between the main explanatory variable (medical card status) and the ‘three or more two with dental fillings’ outcome were statistically significant for both genders. For both genders, the odds of having three or more teeth with dental fillings were higher for the full medical group (OR<sub>males</sub>: 1.44, 95% CI: 1.16, 1.79 and OR<sub>females</sub>: 1.62, 95% CI: 1.59, 1.97) than the no medical card group. Adding behavioural factors to the reference model resulted in small reductions in the OR for the ‘full medical card’ group (young males ~ 2% and young females ~ 5%). Similarly, the adjustment of psychosocial factors (model 4) reduced the OR for the full medical

card group by 23 to 24% (young males = 23% and young females = 24%). However, including material factors in the reference model reduced the OR for the full medical card group four times more in young females than young males (young males ~ 11% and young females ~ 50%). Finally, the OR reductions for young males and females after adjusting all 12 explanatory factors in the full model were almost the same (young males ~ 32% and young females ~ 34%). In the final model (model 5), for young females, the relationship between the full medical card group and the 'three or more dental fillings outcome' was statistically significant. In the full model, the associations between the 'three or more teeth with dental fillings' outcome and behaviour factors (both genders: toothbrushing frequency and dentist visit behaviours; young males: sugary drinks intake; young females: sugary foods intake) were significant for both genders. In addition, financial difficulties in families of young female showed significant associations with the 'three or more teeth with dental fillings' outcome.

Table 6.28 Association between medical card status and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having one tooth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                         |                                   | Model 1           | Model 2                     | Model 3                       | Model 4                       | Model 5                       |
|-----------------------------------------|-----------------------------------|-------------------|-----------------------------|-------------------------------|-------------------------------|-------------------------------|
|                                         |                                   | OR (95% CI)       | OR (95% CI)<br>[% change]   | OR (95% CI)<br>[% change]     | OR (95% CI)<br>[% change]     | OR (95% CI)<br>[% change]     |
| Study participants' medical card status | Yes, full card                    | 1.36 (1.09; 1.70) | 1.34 (1.07; 1.72)<br>[5.56] | 1.57 (1.15; 2.13)<br>[-58.33] | 1.34 (1.04; 1.72)<br>[5.56]   | 1.57 (1.21; 2.03)<br>[-58.33] |
|                                         | Yes, doctor only card             | 1.23 (0.60; 2.53) | 1.23 (0.60; 2.55)<br>[0.00] | 1.42 (0.68; 2.99)<br>[-82.61] | 1.31 (0.63; 2.72)<br>[-34.78] | 1.44 (0.69; 3.00)<br>[-91.30] |
|                                         | Not covered (Reference)           | 1                 | 1                           | 1                             | 1                             | 1                             |
| Behavioural factors                     | <b>Toothbrushing frequency</b>    |                   |                             |                               |                               |                               |
|                                         | Less than once/Rarely/Never       |                   | 0.34 (0.13; 0.88)           |                               |                               | 0.45 (0.17; 1.20)             |
|                                         | Once                              |                   | 1.31 (0.99; 1.74)           |                               |                               | 1.35 (1.00; 1.81)             |
|                                         | Twice/More than twice (Reference) |                   |                             |                               |                               |                               |
|                                         | <b>Dentist visit behaviour</b>    |                   |                             |                               |                               |                               |
|                                         | Problem/Never                     |                   | 1.05 (0.78; 1.42)           |                               |                               | 1.12 (0.82; 1.53)             |
|                                         | Occasional visit                  |                   | 0.78 (0.58; 1.05)           |                               |                               | <b>0.71 (0.52; 0.98)</b>      |
|                                         | At least a year (Reference)       |                   |                             |                               |                               |                               |
|                                         | <b>Sugary drinks intake</b>       |                   |                             |                               |                               |                               |
|                                         | More than once a day              |                   | 1.03 (0.75; 1.42)           |                               |                               | NA                            |
|                                         | Once a day                        |                   | 1.24 (0.95; 1.60)           |                               |                               | NA                            |
|                                         | Not at all (Reference)            |                   |                             |                               |                               |                               |
|                                         | <b>Sugary foods intake</b>        |                   |                             |                               |                               |                               |
|                                         | More than once a day              |                   | 0.97 (0.70; 1.32)           |                               |                               | 0.97 (0.70; 1.35)             |
|                                         | Once a day                        |                   | 0.91 (0.71; 1.16)           |                               |                               | 0.90 (0.70; 1.16)             |
|                                         | Not at all (Reference)            |                   |                             |                               |                               |                               |

Table 6.28 Continued...

|                             |                                               | OR (95% CI) | OR (95% CI) | OR (95% CI)       | OR (95% CI)              | OR (95% CI)              |
|-----------------------------|-----------------------------------------------|-------------|-------------|-------------------|--------------------------|--------------------------|
| <b>Material factors</b>     | <b>Financial difficulties</b>                 |             |             |                   |                          |                          |
|                             | With difficulty                               |             |             | 0.78 (0.61; 1.00) |                          | <b>0.74 (0.58; 0.96)</b> |
|                             | No difficulty (Reference)                     |             |             |                   |                          |                          |
|                             | <b>DEIS school</b>                            |             |             |                   |                          |                          |
|                             | Yes                                           |             |             | 0.82 (0.61; 1.12) |                          | NA                       |
|                             | No (Reference)                                |             |             |                   |                          |                          |
|                             | <b>Homeownership</b>                          |             |             |                   |                          |                          |
|                             | Renters/Rent free/Others                      |             |             | 1.16 (0.84; 1.59) |                          | NA                       |
|                             | Owners (Reference)                            |             |             |                   |                          |                          |
|                             | <b>Private medical insurance</b>              |             |             |                   |                          |                          |
|                             | No                                            |             |             | 0.91 (0.68; 1.20) |                          | NA                       |
|                             | Yes (Reference)                               |             |             |                   |                          |                          |
| <b>Psychosocial factors</b> | <b>PCG mean parental stressor scale score</b> |             |             |                   | 1.00 (0.97; 1.03)        | 0.99 (0.96; 1.03)        |
|                             | <b>PCG depression status</b>                  |             |             |                   |                          |                          |
|                             | Depressed                                     |             |             |                   | 0.91 (0.63; 1.33)        | NA                       |
|                             | Not depressed (Reference)                     |             |             |                   |                          |                          |
|                             | <b>Family structure</b>                       |             |             |                   |                          |                          |
|                             | Single parent family                          |             |             |                   | 1.10 (0.81; 1.48)        | NA                       |
|                             | Couple family (Reference)                     |             |             |                   |                          |                          |
|                             | <b>PCG job stress</b>                         |             |             |                   |                          |                          |
|                             | Stressed                                      |             |             |                   | <b>0.69 (0.55; 0.88)</b> | <b>0.71 (0.56; 0.90)</b> |
|                             | Not stressed (Reference)                      |             |             |                   |                          |                          |

Table 6.29 Association between family medical card status and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having two teeth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                                        |                                   | <b>Model 1</b>           | <b>Model 2</b>                        | <b>Model 3</b>                        | <b>Model 4</b>                       | <b>Model 5</b>                        |
|--------------------------------------------------------|-----------------------------------|--------------------------|---------------------------------------|---------------------------------------|--------------------------------------|---------------------------------------|
|                                                        |                                   | <b>OR (95% CI)</b>       | <b>OR (95% CI)<br/>[% change]</b>     | <b>OR (95% CI)<br/>[% change]</b>     | <b>OR (95% CI)<br/>[% change]</b>    | <b>OR (95% CI)<br/>[% change]</b>     |
| <b>Study participants' medical card status</b>         | <b>Males</b>                      |                          |                                       |                                       |                                      |                                       |
|                                                        | Yes, full card                    | <b>1.65 (1.34; 2.05)</b> | <b>1.66 (1.34; 2.07)<br/>[-1.54]</b>  | <b>1.72 (1.29; 2.30)<br/>[-10.77]</b> | <b>1.41 (1.11; 1.80)<br/>[36.92]</b> | <b>1.47 (1.13; 1.93)<br/>[27.69]</b>  |
|                                                        | Yes, doctor only card             | 0.60 (0.26; 1.40)        | 0.61 (0.26; 1.42)<br>[2.50]           | 0.61 (0.26; 1.43)<br>[2.50]           | 0.54 (0.23; 1.28)<br>[-15.00]        | 0.60 (0.25; 1.40)<br>[0.00]           |
|                                                        | Not covered (Reference)           | 1                        | 1                                     | 1                                     | 1                                    | 1                                     |
|                                                        | <b>Females</b>                    |                          |                                       |                                       |                                      |                                       |
|                                                        | Yes, full card                    | <b>1.41 (1.14; 1.74)</b> | <b>1.49 (1.20; 1.86)<br/>[-19.51]</b> | 1.26 (0.95; 1.67)<br>[36.59]          | <b>1.41 (1.11; 1.78)<br/>[0.00]</b>  | <b>1.57 (1.23; 1.99)<br/>[-39.02]</b> |
|                                                        | Yes, doctor only card             | 1.43 (0.75; 2.73)        | 1.55 (0.80; 2.98)<br>[-27.91]         | 1.26 (0.64; 2.51)<br>[39.53]          | 1.37 (0.70; 2.68)<br>[13.95]         | 1.57 (0.79; 3.11)<br>[-32.56]         |
|                                                        | Not covered (Reference)           | 1                        | 1                                     | 1                                     | 1                                    | 1                                     |
| <b>Behavioural factors<br/>Toothbrushing frequency</b> | <b>Males</b>                      |                          |                                       |                                       |                                      |                                       |
|                                                        | Less than once/Rarely/Never       |                          | 0.88 (0.58; 1.33)                     |                                       |                                      | 0.75 (0.48; 1.18)                     |
|                                                        | Once                              |                          | <b>1.30 (1.03; 1.65)</b>              |                                       |                                      | 1.22 (0.95; 1.56)                     |
|                                                        | Twice/More than twice (Reference) |                          |                                       |                                       |                                      |                                       |
|                                                        | <b>Females</b>                    |                          |                                       |                                       |                                      |                                       |
|                                                        | Less than once/Rarely/Never       |                          | 1.21 (0.68; 2.13)                     |                                       |                                      | 1.26 (0.68; 2.32)                     |
|                                                        | Once                              |                          | 0.96 (0.71; 1.28)                     |                                       |                                      | 0.89 (0.65; 1.21)                     |
|                                                        | Twice/More than twice (Reference) |                          |                                       |                                       |                                      |                                       |

Table 6.29 Continued...

| Behavioural factors     |                             | OR (95% CI) | OR (95% CI)              | OR (95% CI)              | OR (95% CI) | OR (95% CI)              |
|-------------------------|-----------------------------|-------------|--------------------------|--------------------------|-------------|--------------------------|
| Dentist visit behaviour | <b>Males</b>                |             |                          |                          |             |                          |
|                         | Problem/Never               |             | <b>0.65 (0.47; 0.90)</b> |                          |             | <b>0.65 (0.46; 0.92)</b> |
|                         | Occasional visit            |             | 0.83 (0.63; 1.09)        |                          |             | 0.81 (0.61; 1.08)        |
|                         | At least a year (Reference) |             |                          |                          |             |                          |
|                         | <b>Females</b>              |             |                          |                          |             |                          |
|                         | Problem/Never               |             | <b>0.50 (0.36; 0.71)</b> |                          |             | <b>0.48 (0.33; 0.68)</b> |
|                         | Occasional visit            |             | 0.89 (0.69; 1.16)        |                          |             | 0.84 (0.64; 1.11)        |
|                         | At least a year (Reference) |             |                          |                          |             |                          |
| Sugary drinks intake    | <b>Males</b>                |             |                          |                          |             |                          |
|                         | More than once a day        |             | 0.93 (0.69; 1.25)        |                          |             | 0.94 (0.70; 1.28)        |
|                         | Once a day                  |             | 1.21 (0.96; 1.54)        |                          |             | 1.19 (0.93; 1.53)        |
|                         | Not at all (Reference)      |             |                          |                          |             |                          |
|                         | <b>Females</b>              |             |                          |                          |             |                          |
|                         | More than once a day        |             | 1.06 (0.74; 1.44)        |                          |             | NA                       |
|                         | Once a day                  |             | <b>1.52 (1.19; 1.93)</b> |                          |             | NA                       |
|                         | Not at all (Reference)      |             |                          |                          |             |                          |
| Sugary foods intake     | <b>Males</b>                |             |                          |                          |             |                          |
|                         | More than once a day        |             | <b>1.57 (1.16; 2.11)</b> |                          |             | <b>1.59 (1.16; 2.17)</b> |
|                         | Once a day                  |             | 0.93 (0.73; 1.20)        |                          |             | 0.96 (0.74; 1.25)        |
|                         | Not at all (Reference)      |             |                          |                          |             |                          |
|                         | <b>Females</b>              |             |                          |                          |             |                          |
|                         | More than once a day        |             | 0.99 (0.72; 1.35)        |                          |             | 0.88 (0.64; 1.22)        |
|                         | Once a day                  |             | <b>1.28 (1.02; 1.62)</b> |                          |             | 1.26 (0.98; 1.60)        |
|                         | Not at all (Reference)      |             |                          |                          |             |                          |
| Material factors        | <b>Males</b>                |             |                          |                          |             |                          |
|                         | Financial difficulties      |             |                          | <b>0.76 (0.60; 0.96)</b> |             | 0.79 (0.63; 1.00)        |
|                         | No difficulty (Reference)   |             |                          |                          |             |                          |



Table 6.29 Continued...

| <b>Material factors</b>                  |                           | <b>OR (95% CI)</b> | <b>OR (95% CI)</b> | <b>OR (95% CI)</b> | <b>OR (95% CI)</b>       | <b>OR (95% CI)</b>       |
|------------------------------------------|---------------------------|--------------------|--------------------|--------------------|--------------------------|--------------------------|
| <b>Financial difficulties</b>            | <b>Females</b>            |                    |                    |                    |                          |                          |
|                                          | With difficulty           |                    |                    | 1.03 (0.82; 1.31)  |                          | 1.03 (0.81; 1.30)        |
|                                          | No difficulty (Reference) |                    |                    |                    |                          |                          |
| <b>DEIS school</b>                       | <b>Males</b>              |                    |                    |                    |                          |                          |
|                                          | Yes                       |                    |                    | 1.26 (0.96; 1.66)  |                          | NA                       |
|                                          | No (Reference)            |                    |                    |                    |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                    |                          |                          |
|                                          | Yes                       |                    |                    | 1.02 (0.77; 1.34)  |                          | NA                       |
|                                          | No (Reference)            |                    |                    |                    |                          |                          |
| <b>Homeownership</b>                     | <b>Males</b>              |                    |                    |                    |                          |                          |
|                                          | Renters/Rent free/Others  |                    |                    | 1.21 (0.88; 1.65)  |                          | 1.06 (0.77; 1.46)        |
|                                          | Owners (Reference)        |                    |                    |                    |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                    |                          |                          |
|                                          | Renters/Rent free/Others  |                    |                    | 1.22 (0.92; 1.64)  |                          | NA                       |
|                                          | Owners (Reference)        |                    |                    |                    |                          |                          |
| <b>Private medical insurance</b>         | <b>Males</b>              |                    |                    |                    |                          |                          |
|                                          | No                        |                    |                    | 0.87 (0.66; 1.14)  |                          | NA                       |
|                                          | Yes (Reference)           |                    |                    |                    |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                    |                          |                          |
|                                          | No                        |                    |                    | 1.05 (0.81; 1.36)  |                          | NA                       |
|                                          | Yes (Reference)           |                    |                    |                    |                          |                          |
| <b>Psychosocial factors</b>              | <b>Males</b>              |                    |                    |                    | 1.00 (0.98; 1.03)        | NA                       |
| <b>PCG Parental Stressor scale score</b> | <b>Females</b>            |                    |                    |                    | <b>1.03 (1.01; 1.06)</b> | <b>1.04 (1.01; 1.07)</b> |
| <b>PCG depression status</b>             | <b>Males</b>              |                    |                    |                    |                          |                          |
|                                          | Depressed                 |                    |                    |                    | 0.89 (0.64; 1.25)        | NA                       |
|                                          | Not depressed (Reference) |                    |                    |                    |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                    |                          |                          |
|                                          | Depressed                 |                    |                    |                    | 0.83 (0.58; 1.18)        | NA                       |
|                                          | Not depressed (Reference) |                    |                    |                    |                          |                          |

Table 6.29 Continued...

| Psychosocial factors |                           | OR (95% CI) | OR (95% CI) | OR (95% CI) | OR (95% CI)              | OR (95% CI)              |
|----------------------|---------------------------|-------------|-------------|-------------|--------------------------|--------------------------|
| Family structure     | <b>Males</b>              |             |             |             |                          |                          |
|                      | Single parent family      |             |             |             | <b>1.65 (1.24; 2.18)</b> | <b>1.73 (1.28; 2.34)</b> |
|                      | Couple family (Reference) |             |             |             |                          |                          |
|                      | <b>Females</b>            |             |             |             |                          |                          |
|                      | Single parent family      |             |             |             | 1.04 (0.78; 1.37)        | NA                       |
|                      | Couple family (Reference) |             |             |             |                          |                          |
|                      | <b>Males</b>              |             |             |             |                          |                          |
|                      | Stressed                  |             |             |             | 0.82 (0.66; 1.03)        | NA                       |
|                      | Not stressed (Reference)  |             |             |             |                          |                          |
|                      | <b>Females</b>            |             |             |             |                          |                          |
|                      | Stressed                  |             |             |             | 0.96 (0.77; 1.21)        | 0.93 (0.74; 1.18)        |
|                      | Not stressed (Reference)  |             |             |             |                          |                          |
|                      |                           |             |             |             |                          |                          |
| Job stress           |                           |             |             |             |                          |                          |

Table 6.30 Association between family medical card status and young persons' parent-reported oral health (number of teeth with dental fillings) adjusted for covariates (wave 1), behavioural factors, material factors and psychosocial factors (logistic regression odds ratios (95% CI) for having three or more teeth with dental fillings). Model 2: Model 1 + behavioural factors; Model 3: Model 1 + material factors; Model 4: Model 1 + Psychosocial factors and Model 5: Model 1 + behavioural factors + material factors + Psychosocial factors. All models were adjusted for the 'area of residence', the 'main language spoken at home' and 'PCGs' country of birth'. OR: Odds Ratio; NA (not applicable) refers to a variable that was excluded from the model using stepwise backward selection.

|                                                    |                                   | Model 1                  | Model 2                             | Model 3                              | Model 4                              | Model 5                              |
|----------------------------------------------------|-----------------------------------|--------------------------|-------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
|                                                    |                                   | OR (95% CI)              | OR (95% CI)<br>[% change]           | OR (95% CI)<br>[% change]            | OR (95% CI)<br>[% change]            | OR (95% CI)<br>[% change]            |
| <b>Study participants' medical card status</b>     | <b>Males</b>                      |                          |                                     |                                      |                                      |                                      |
|                                                    | Yes, full card                    | <b>1.44 (1.16; 1.79)</b> | <b>1.43 (1.14; 1.80)<br/>[2.27]</b> | <b>1.39 (1.04; 1.85)<br/>[11.36]</b> | <b>1.34 (1.05; 1.71)<br/>[22.73]</b> | 1.30 (1.00; 1.70)<br>[31.82]         |
|                                                    | Yes, doctor only card             | 0.48 (0.19; 1.21)        | 0.51 (0.20; 1.28)<br>[5.77]         | 0.44 (0.17; 1.10)<br>[-7.69]         | 0.46 (0.18; 1.16)<br>[-3.85]         | 0.47 (0.18; 1.17)<br>[-1.92]         |
|                                                    | Not covered (Reference)           | 1                        | 1                                   | 1                                    | 1                                    | 1                                    |
|                                                    | <b>Females</b>                    |                          |                                     |                                      |                                      |                                      |
|                                                    | Yes, full card                    | <b>1.62 (1.31; 2.00)</b> | <b>1.59 (1.27; 1.97)<br/>[4.84]</b> | 1.31 (0.98; 1.75)<br>[50.00]         | <b>1.47 (1.16; 1.87)<br/>[24.19]</b> | <b>1.41 (1.10; 1.81)<br/>[33.87]</b> |
|                                                    | Yes, doctor only card             | 1.26 (0.62; 2.54)        | 1.35 (0.66; 0.75)<br>[-34.62]       | 1.12 (0.53; 2.33)<br>[53.85]         | 0.87 (0.38; 1.99)<br>[100.00]        | 0.84 (0.36; 1.98)<br>[100.00]        |
|                                                    | Not covered (Reference)           | 1                        | 1                                   | 1                                    | 1                                    | 1                                    |
| <b>Behavioural factors<br/>Daily Toothbrushing</b> | <b>Males</b>                      |                          |                                     |                                      |                                      |                                      |
|                                                    | Less than once/Rarely/Never       |                          | 1.22 (0.82; 1.82)                   |                                      |                                      | 1.25 (0.83; 1.89)                    |
|                                                    | Once                              |                          | <b>1.39 (1.10; 1.77)</b>            |                                      |                                      | <b>1.31 (1.02; 1.68)</b>             |
|                                                    | Twice/More than twice (Reference) |                          |                                     |                                      |                                      |                                      |
|                                                    | <b>Females</b>                    |                          |                                     |                                      |                                      |                                      |
|                                                    | Less than once/Rarely/Never       |                          | <b>2.29 (1.40; 3.76)</b>            |                                      |                                      | <b>2.20 (1.27; 3.80)</b>             |
|                                                    | Once                              |                          | <b>1.47 (1.13; 1.95)</b>            |                                      |                                      | <b>1.42 (1.06; 1.91)</b>             |
|                                                    | Twice/More than twice (Reference) |                          |                                     |                                      |                                      |                                      |

Table 6.30 Continued...

| Behaviour factors                          |                             | OR (95% CI) | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] | OR (95% CI)<br>[% change] |
|--------------------------------------------|-----------------------------|-------------|---------------------------|---------------------------|---------------------------|---------------------------|
| Dentist visit behaviour                    | <b>Males</b>                |             |                           |                           |                           |                           |
|                                            | Problem/Never               |             | <b>0.59 (0.42; 0.83)</b>  |                           |                           | <b>0.59 (0.42; 0.84)</b>  |
|                                            | Occasional visit            |             | 0.82 (0.62; 1.08)         |                           |                           | 0.78 (0.58; 1.04)         |
|                                            | At least a year (Reference) |             |                           |                           |                           |                           |
|                                            | <b>Females</b>              |             |                           |                           |                           |                           |
|                                            | Problem/Never               |             | <b>0.53 (0.37; 0.74)</b>  |                           |                           | <b>0.55 (0.38; 0.78)</b>  |
|                                            | Occasional visit            |             | 0.82 (0.63; 1.08)         |                           |                           | 0.75 (0.56; 1.00)         |
|                                            | At least a year (Reference) |             |                           |                           |                           |                           |
| Sugary drinks intake                       | <b>Males</b>                |             |                           |                           |                           |                           |
|                                            | More than once a day        |             | 0.96 (0.70; 1.30)         |                           |                           | 0.81 (0.58; 1.12)         |
|                                            | Once a day                  |             | <b>1.33 (1.05; 1.69)</b>  |                           |                           | <b>1.36 (1.06; 1.74)</b>  |
|                                            | Not at all (Reference)      |             |                           |                           |                           |                           |
|                                            | <b>Females</b>              |             |                           |                           |                           |                           |
|                                            | More than once a day        |             | 1.02 (0.75; 1.37)         |                           |                           | NA                        |
|                                            | Once a day                  |             | 1.10 (0.85; 1.42)         |                           |                           | NA                        |
|                                            | Not at all (Reference)      |             |                           |                           |                           |                           |
| Sugary foods intake                        | <b>Males</b>                |             |                           |                           |                           |                           |
|                                            | More than once a day        |             | 1.13 (0.82; 1.55)         |                           |                           | 1.11 (0.80; 1.54)         |
|                                            | Once a day                  |             | 0.87 (0.68; 1.12)         |                           |                           | 0.85 (0.66; 1.10)         |
|                                            | Not at all (Reference)      |             |                           |                           |                           |                           |
|                                            | <b>Females</b>              |             |                           |                           |                           |                           |
|                                            | More than once a day        |             | <b>1.59 (1.18; 2.14)</b>  |                           |                           | <b>1.56 (1.14; 2.14)</b>  |
|                                            | Once a day                  |             | 1.22 (0.95; 1.57)         |                           |                           | 1.27 (0.97; 1.65)         |
|                                            | Not at all (Reference)      |             |                           |                           |                           |                           |
| Material factors<br>Financial difficulties | <b>Males</b>                |             |                           |                           |                           |                           |
|                                            | With difficulty             |             |                           | 1.22 (0.96; 1.55)         |                           | 1.24 (0.98; 1.58)         |
|                                            | No difficulty (Reference)   |             |                           |                           |                           |                           |

Table 6.30 Continued...

| <b>Material factors</b>                  |                           | <b>OR (95% CI)</b> | <b>OR (95% CI)</b> | <b>OR (95% CI)</b>       | <b>OR (95% CI)</b>       | <b>OR (95% CI)</b>       |
|------------------------------------------|---------------------------|--------------------|--------------------|--------------------------|--------------------------|--------------------------|
| <b>Financial difficulties</b>            | <b>Females</b>            |                    |                    |                          |                          |                          |
|                                          | With difficulty           |                    |                    | <b>1.41 (1.10; 1.80)</b> |                          | <b>1.36 (1.06; 1.75)</b> |
|                                          | No difficulty (Reference) |                    |                    |                          |                          |                          |
| <b>DEIS school</b>                       | <b>Males</b>              |                    |                    |                          |                          |                          |
|                                          | Yes                       |                    |                    | 1.18 (0.90; 1.56)        |                          | NA                       |
|                                          | No (Reference)            |                    |                    |                          |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                          |                          |                          |
|                                          | Yes                       |                    |                    | 0.82 (0.61; 1.10)        |                          | NA                       |
|                                          | No (Reference)            |                    |                    |                          |                          |                          |
| <b>Homeownership</b>                     | <b>Males</b>              |                    |                    |                          |                          |                          |
|                                          | Renters/Rent free/Others  |                    |                    | 1.20 (0.87; 1.65)        |                          | 0.98 (0.70; 1.37)        |
|                                          | Owners (Reference)        |                    |                    |                          |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                          |                          |                          |
|                                          | Renters/Rent free/Others  |                    |                    | 1.22 (0.91; 1.64)        |                          | NA                       |
|                                          | Owners (Reference)        |                    |                    |                          |                          |                          |
| <b>Private medical insurance</b>         | <b>Males</b>              |                    |                    |                          |                          |                          |
|                                          | No                        |                    |                    | 0.84 (0.64; 1.10)        |                          | NA                       |
|                                          | Yes (Reference)           |                    |                    |                          |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                          |                          |                          |
|                                          | No                        |                    |                    | 0.99 (0.76; 1.30)        |                          | NA                       |
|                                          | Yes (Reference)           |                    |                    |                          |                          |                          |
| <b>Psychosocial factors</b>              | <b>Males</b>              |                    |                    |                          | <b>1.04 (1.02; 1.07)</b> | NA                       |
| <b>PCG Parental Stressor scale score</b> | <b>Females</b>            |                    |                    |                          | 1.00 (0.97; 1.03)        | 0.99 (0.96; 1.02)        |
| <b>PCG depression status</b>             | <b>Males</b>              |                    |                    |                          |                          |                          |
|                                          | Depressed                 |                    |                    |                          | 1.01 (0.72; 1.40)        | NA                       |
|                                          | Not depressed (Reference) |                    |                    |                          |                          |                          |
|                                          | <b>Females</b>            |                    |                    |                          |                          |                          |
|                                          | Depressed                 |                    |                    |                          | 1.33 (0.95; 1.85)        | NA                       |
|                                          | Not depressed (Reference) |                    |                    |                          |                          |                          |

Table 6.30 Continued...

| Psychosocial factors |                           | OR (95% CI) | OR (95% CI) | OR (95% CI) | OR (95% CI)              | OR (95% CI)       |
|----------------------|---------------------------|-------------|-------------|-------------|--------------------------|-------------------|
| Family structure     | <b>Males</b>              |             |             |             |                          |                   |
|                      | Single parent family      |             |             |             | 1.29 (0.96; 1.73)        | 1.19 (0.86; 1.65) |
|                      | Couple family (Reference) |             |             |             |                          |                   |
|                      | <b>Females</b>            |             |             |             |                          |                   |
|                      | Single parent family      |             |             |             | 1.00 (0.74; 1.33)        | NA                |
|                      | Couple family (Reference) |             |             |             |                          |                   |
|                      | <b>Males</b>              |             |             |             |                          |                   |
|                      | Stressed                  |             |             |             | <b>0.72 (0.58; 0.90)</b> | NA                |
|                      | Not stressed (Reference)  |             |             |             |                          |                   |
|                      | <b>Females</b>            |             |             |             |                          |                   |
|                      | Stressed                  |             |             |             | 0.93 (0.73; 1.17)        | 0.92 (0.72; 1.17) |
|                      | Not stressed (Reference)  |             |             |             |                          |                   |
| Job stress           |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |
|                      |                           |             |             |             |                          |                   |

## 6.4 Discussion

### **The main findings of the study and comparison with previous literature**

This is the first comprehensive analysis of socioeconomic oral health inequalities in Irish adolescents using nationally representative longitudinal data. Principal findings included: Socioeconomic disparities in Irish adolescents' self-rated oral health (SROH) and parent-reported oral health (number of teeth with dental fillings). Young persons with a lower SES background at 13 years of age reported poorer self and parent-reported oral health at 17 years of age than their peers with a higher socioeconomic background. These findings are similar to those previously reported for adolescents (Perera and Ekanayake, 2010; Telford, Coulter and Murray, 2011; Ravaghi *et al.*, 2012; Silva, Mattos and Carmo, 2018; Nascimento *et al.*, 2021), children (Skafida and Chambers, 2018; Fleitas Alfonzo, Bentley and Singh, 2022; Matsuyama, Fujiwara and Aida, 2023) and adults (Sanders, Spencer and Slade, 2006; Sabbah *et al.*, 2009; Bernabé, Humphris and Freeman, 2017; Duijster *et al.*, 2017). Similar findings from previous national children's oral health surveys showed that family occupational class and medical card-related oral health inequalities exist in Irish adolescents (O'Mullane *et al.*, 1986; Whelton *et al.*, 2006).

Similar to results in other countries we found that females had better SROH and more positive oral health behaviours (Tada and Hanada, 2004; Mamai-Homata, Koletsis-Kounari and Margaritis, 2016; Su *et al.*, 2022). The gender differences in self-perceived oral health and health behaviours may be attributed to the belief that generally, with increasing age, females actively seek oral health knowledge, adopt health-promoting behaviours, tend to exhibit more self-evaluative concerns and care more about their body and behaviours, which promotes their oral health status (Östberg *et al.*, 2003; Sfeatcu *et al.*, 2022; Su *et al.*, 2022). In addition, we observed that associations between the selected SES indicators and oral health outcomes varied according to the SES indicator used and the oral health outcome considered. This is supported by previous studies which have found that different socioeconomic measures reflect different domains of the multi-dimensional construct of social position and, therefore,

these measures are not interchangeable and have varying relationships with health outcomes (Adler and Newman, 2002; Shavers, 2007).

While the results of our analysis provides supporting evidence that behaviour, material and psychosocial factors are important factors contributing to socioeconomic disparities in young males' SROH, material factors contributed most to the explanation of parental education and family income-related SROH inequalities. Socioeconomic disparities in young persons' parent reported oral health were partially explained by material factors, while behavioural and psychosocial factors played no role in accounting for these disparities. Unfortunately, it was difficult to compare these results as no previous longitudinal study had investigated the role of behaviour, material and psychosocial factors in explaining self and parent-reported oral health inequalities in adolescents. However, one study in the USA concluded that adjusting for health-influencing behaviours, genetics and biology and dental care partially accounted for socioeconomic disparities in oral health in Californian adolescents (Telford, Coulter and Murray, 2011). Perera and Ekanayake reported that 3% of the variations in the self-reported oral health in Sri Lankan adolescents were explained by household income, ethnicity and gender, and the addition of the 'use of dental service' and 'toothbrushing frequency' variables only increased the Pseudo  $R^2$  (proportion of variance in outcome variable explained by predictors) from 3% to 4% (Perera and Ekanayake, 2008). Polk et al. reported that selected oral health behaviours (toothbrushing, flossing and dental utilisation) and preventive interventions (fluoridated water, fluoridated toothpaste and fluoride drops) did not account for socioeconomic disparities in caries experience (i.e., DMFT) in Pennsylvanian adolescents (2010). Similarly, Ravaghi et al. concluded that behavioural (toothbrushing frequency, dental flossing and dentist visits) and psychological factors (self-esteem, depression and anxiety) explained only a small portion of the relationships between SES indicators and self-reported oral health outcomes among Iranian adolescents (2012).



Evidence from comparable studies in adults is inconclusive; some studies reported little or no role for behavioural factors, while others suggest a substantial role in explaining socioeconomic oral health inequalities. One Australian study concluded that behavioural factors accounted for little, if any, of the social gradient in oral health outcomes (Sanders, Spencer and Slade, 2006). Similarly, results from two longitudinal studies suggested no mediation of health behaviours in the association between SES and caries experience (Sabbah *et al.*, 2014; Mariëlle *et al.*, 2021).

It was reported that differences in oral health outcomes among the social groups were explained by lifestyle factors such as daily smoking, daily snuffing, diet with less fruit and vegetables, high alcohol consumption and physical inactivity. Approximately two-thirds of the differences were related to lifestyle choices and refraining from seeking dental treatments (Wamala, Merlo and Boström, 2006). The authors concluded that insufficient access to dental care services was a stronger explanation, compared to lifestyle factors, for poor oral health among socially disadvantaged Swedish adults (Wamala, Merlo and Boström, 2006). It should be noted that we could not investigate the effect of insufficient access to dental care services on young persons' oral health status because of the very low response numbers for that survey measure. A similar study based on Swedish and Norwegian adults observed that oral health behaviours attenuated education-related gradient in both cohorts (Åström, Lie and Özkaya, 2021). Studies of American adults reported that health behaviours attenuated but did not eliminate the income and educational disparities in self-reported and clinically examined oral health outcomes (Sabbah *et al.*, 2009; Stein, Cunha-Cruz and Hugo, 2021). For Dutch adults, it was found that behavioural factors accounted for most of the educational and income-related disparities in oral health outcomes (Duijster *et al.*, 2017). Bernabe *et al.* have also reported that dental health behaviours accounted for a significant portion of educational and income-related oral health differences in British adults (2017). The substantial role of behavioural factors in explaining oral health inequalities was also confirmed by a South Korean study of adults aged 19-54 years (Novrinda *et al.*, 2019).

The material factors had a substantial role in explaining socioeconomic differences in self-reported general health among children, adolescents and adults (Floor, Frank and Johan, 2005; Richter, Moor and Lenthe, 2012; Hiyoshi *et al.*, 2014; Oosterhoff *et al.*, 2019).

Although the number of teeth with dental fillings and SROH are valid measures of an individual's clinical oral health, they measure different aspects of oral health (Locker and Jokovic, 1996; Östberg *et al.*, 2003; Duijster *et al.*, 2017). SROH, is a subjective measure of current oral health status and could reflect current pain or functional limitations (Östberg *et al.*, 2003). Parent-reported number of teeth with dental fillings may indicate previous dental decay or trauma and could be influenced by PCG's beliefs, dental services affordability and availability (Matsuyama, Fujiwara and Aida, 2023). Therefore, the contribution of explanatory factors in explaining socioeconomic disparities differed depending on the oral health outcome studied. For example, we found that the odds of sub-optimal SROH were higher, and the odds of having two or more teeth with fillings were lower for those who never or only visited the dentist for a problem than those who were visiting the dentist annually.

### **Strengths and limitations**

Strengths of this study included: a large nationally representative sample of Irish children and adolescents. The sample size provided sufficient power for separate analyses for young males and females. The longitudinal nature of the study and use of wide range of factors to investigate potential pathways to explain socioeconomic inequalities in adolescents' oral health.

The findings should be interpreted cautiously as there are some methodological considerations and limitations. The main study limitation relates to the parent-reported oral health outcome. The number of fillings the study participants had could be influenced by parental beliefs, dental services affordability and availability (Matsuyama, Fujiwara and Aida, 2023). The number of dental fillings (assumed largely due to dental caries) may also vary according to lifetime fluoride exposure (Sheiham and James, 2014a). The 'area of residence' variable was used as a proxy for the

community water fluoridation (CWF) status. About 71% of the Irish population is supplied with fluoridated water (James *et al.*, 2021). In RoI, urban areas are supplied with fluoridated while rural and dense populated areas are non-fluoridated (Comber *et al.*, 2011). It was assumed that most participants used fluoridated toothpaste. By 2002, there was an almost universal use of fluoridated toothpaste in Ireland (more than 95% of toothpastes sold in Ireland were fluoridated) (Whelton *et al.*, 2006). Furthermore, the persistence of oral health inequalities after adjustment of behavioural, material and psychosocial factors suggests other explanatory factors that have not been investigated. For example, factors such as life events, oral health beliefs, dental anxiety, cultural values and health-related support (Broadbent, Thomson and Poulton, 2006; Heilmann, Tsakos and Watt, 2015; Bernabé, Humphris and Freeman, 2017). While the results suggest a temporal relationship between explanatory factors and oral health outcomes, it cannot be said with certainty that the exposure preceded the outcome, as the exact timing of the events was unknown. An inherent limitation in secondary analysis of population-based data is that the data are not collected to address a particular research question (Ikeda, 2016).

The validity of self-reported measures used in the GUI surveys was unclear and may be prone to recall, reporting and social desirability bias (Nederhof, 1985; Watson *et al.*, 2014). The addition of clinical assessments to an individual's subjective perception would probably provide a more comprehensive basis for the monitoring of oral health in children and adolescents (Östberg *et al.*, 2003). The current study used single time point data for time-varying explanatory factors, for example, sugar consumption, income and fluoride exposure rather than repeated measures (Celeste, 2020). Lastly, the material deprivation measures used in the study should be interpreted in the context of the timing of "The Great Recession". The year of data collection for wave 2, when the children were 13 years old, between August 2011 and March 2012, corresponded to the deepest point of the recession (Watson *et al.*, 2014).

### **Policy implications of the findings**

The main aim of the national oral health policy of Ireland is to enable every person in Ireland to achieve their personal best oral health, and a key indicator of policy evaluation will be oral health related quality of life (Department of Health Ireland, 2019). In the present study, while behavioural factors had no, or a minor role, in explaining socioeconomic oral health inequalities, unhealthy oral health behaviours during early life years were important predictors of parent/self-reported poor oral health in Irish adolescents. Behaviour factors are modifiable risk factors for dental diseases (Watt and Sheiham, 2012). Therefore, national oral health policies should target behavioural factors to improve population oral health. In our analysis, socioeconomic inequalities in oral health were mainly explained by material factors. Interventions are needed to enhance the material circumstances of families with a lower SES (Floor, Frank and Johan, 2005; Richter, Moor and Lenthe, 2012; Hiyoshi *et al.*, 2014; Oosterhoff *et al.*, 2019).

### **Future recommendations**

In agreement with previous publications, the following are the recommendations for future research (Locker, Clarke and Payne, 2000; Locker, 2000; Sisson, 2007; Ravaghi *et al.*, 2012; Singh *et al.*, 2016; Duijster *et al.*, 2017; Nascimento *et al.*, 2021; Tsakos, Watt and Guarnizo-Herreño, 2023):

- 1) Investigating the possible interaction between area-based and individual measures of SES in determining oral health outcomes in adolescents.
- 2) Identify the role of structural and commercial determinants of health in shaping oral health inequalities at different levels and time periods, using a qualitative and/or mixed methods approach.
- 3) Using a life-course approach to explain oral health inequalities in longitudinal studies.
- 4) Studying potential barriers and facilitators of healthy oral health behaviours using interacting factors and intersectionality frameworks.

- 5) Linking administrative data with longitudinal survey data for creating a study cohort for initial evaluation of complex public health interventions.
- 6) Including all gender identifications for a better overview of the oral health inequalities in populations.

## **Conclusion**

The present study provides evidence of socioeconomic inequalities in Irish adolescents' parental and self-reported oral health. Information on potential pathways by which oral health inequalities in adolescents develop could help design of effective interventions. Behavioural, material and psychosocial factors showed a socioeconomic gradient and partially accounted for socioeconomic disparities in oral health. In the context of Ireland, given that CWF has significantly reduced oral health inequalities, our results indicate that interventions to improve the suboptimal material circumstances of families may contribute to further reductions.

## **CHAPTER 7**

### **7. General Discussion**

This analysis had four objectives:

- 1) To review all children's dental health surveys at National, Regional and County-levels conducted in the Republic of Ireland from 1950 to 2021 and describe trends in dental caries prevalence. A secondary objective was to compare the dental caries experience of children living in areas with and without Community Water Fluoridation (CWF).
- 2) To evaluate the harmonisation potential of oral health-related questionnaires from selected nationally representative birth/child cohort surveys in high-income countries.
- 3) To demonstrate the development of an analytical, interactive dashboard for researchers using oral health-related data from three Irish national child surveys.
- 4) To study the association between family socioeconomic status at 13 years of age and the young person's (parent and self-reported) dental health at 17/18 years of age. In addition, the role of behavioural, material and psychosocial factors in explaining socioeconomic inequalities in young persons' oral health was investigated.

Thus, according to the above objectives, the findings of this thesis have been discussed in the following sections.

**Objective 1:** *To review all children's dental health surveys at National, Regional and County-levels conducted in the Republic of Ireland from 1950 to 2021 and describe trends in dental caries prevalence. The secondary objective was to compare the dental caries experience of children living in areas with and without CWF.*

A systematic review was conducted to summarise dental caries trends among Irish children over the last seven decades at national, regional and county levels (Chapter 3). There were substantial reductions in dental caries levels in Irish children's primary

and permanent dentitions over the last seven decades. The last Children's National Oral Health Survey was undertaken in 2002. Therefore, children's caries levels in Ireland could not be compared with other countries after this date due to the lack of national dental caries prevalence data. However, Dublin County oral health data was used as a proxy for national figures as approximately one-third of the Irish population resides in County Dublin. Between 2010 and 2021, the mean DMFT scores for 12-year-olds living in Dublin County (0.6) were lower than those living in Italy (1.2), Spain (0.79), Belgium (0.9), Sweden (0.7), the United Kingdom (0.74), Portugal (1.2), Switzerland (0.9), Finland (1.1), New Zealand (1.12) and Norway (0.98). However, the mean DMFT levels were higher than those in Denmark (0.5) and Germany (0.5). The comparability of the national data for DMFT scores among the 12-year-olds may have been affected by variations in sampling techniques, diagnostic criteria, and methods to train and calibrate examiners employed during the national oral health surveys among the European countries (Patel *et al.*, 2016).

The observed reductions in dental caries were greater among children living in areas with Community Water Fluoridation. The trends presented in this review suggested that CWF has been an effective public health measure for reducing dental caries levels in children. The present study results were consistent with the results of previously published systematic reviews of the effectiveness of CWF (McDonagh *et al.*, 2000; Iheozor-Ejiofor *et al.*, 2015; Belotti and Frazão, 2021). The use of fluoridated toothpastes in early childhood and increased frequency of toothbrushing has most likely contributed to the reduction in caries severity in children both with and without CWF (O'Mullane, Clarkson and Parnell, 2018; James *et al.*, 2021; Whelton *et al.*, 2006). In addition, the reduction in dental caries prevalence among children living without CWF has also been attributed to the benefits of fluoride obtained from consuming foods and drinks processed using fluoridated water (the "halo effect") (Whelton *et al.*, 2006). Fluoride from other sources, such as fluoridated mouth rinses, fluoride tablets and professional applications such as fluoride solutions, varnishes and gels may also have contributed to this decline.



This study also highlighted the lack of data relating dental caries and known risk factors in the Irish population such as dietary behaviours, and socioeconomic status of families. In the RoI, dental health surveys at regional and county levels were generally descriptive and compared the dental caries levels between fluoridated and non-fluoridated groups. Therefore, this study could not investigate potential confounding variables ) while comparing caries levels among those with CWF and those without CWF. Longitudinal studies investigating risk factors for dental caries are needed to assist in developing effective interventions targeting further reductions in dental caries levels among Irish children.

Furthermore, this study contacted two survey authors of the most recent National Children's Oral Health Surveys to investigate the effect of changes in caries diagnostic criteria over the past decades on caries trends. It was confirmed that caries-free children may have been under-reported in the 2002 survey compared with the 1960s and 1984 surveys due to the change in the diagnostic threshold of 3C (cavity into dentine) during the 1960s and 1984 surveys to 3VC (non-cavitated lesions into dentine and above) during the 2002 survey. A major limitation of the Irish oral health surveys, highlighted in the present review, is the absence of inclusion of variance or standard deviation for most of the included surveys. Thus, it was not possible to conduct a meta-analysis of the data

**Recommendations:**

- 1) National oral health surveys should be conducted at regular intervals to monitor dental caries prevalence and incidence.
- 2) An international consensus of protocols should be formulated for standardisation of epidemiological surveys of dental caries in children.
- 3) Data related to known risk factors associated with dental diseases such as, dietary intake of high sugar foods and socioeconomic status should also be collected.
- 4) Survey developers should follow a common risk factor approach when designing future surveys to facilitate investigation of dental and general health relationships.

**Objective 2:** *To evaluate the harmonisation potential of oral health-related questionnaire data from selected nationally representative birth/child cohort surveys in high-income countries.*

A major challenge for longitudinal and cross-national oral health research is the inconsistency of survey questionnaires (intended for measuring the same construct). This section evaluated the quality and comparability of oral health-related questionnaire data from seven nationally representative birth/child cohort surveys (a total of 50 survey waves). A framework was developed for reviewing, collating and comparing study-specific questionnaire data across and within cohort surveys. In addition, a DataSchema was developed to demonstrate how data harmonisation can be used to improve the comparability of oral health-related variables both within and across survey datasets.

For each cohort survey, the DataSchema variables that could be generated ranged between 26% and 76%. The Millennium Cohort Study (MCS) survey scored low at 26%, mainly due to the non-availability of oral health-related questionnaires. The LSAC surveys scored highly, between 71 and 76%, due to consistent and comprehensive coverage of oral health-related questions across the survey waves. The Growing Up in Ireland (GUI) infant survey scored approximately 50%, while the GUI child survey scored about 45%. In addition, the harmonisation potential for the global self-rated oral health measure, a commonly used measure to study subjective oral health status in population surveys, was 8% compared to 88% for a comparable general health measure. This finding highlights the prevailing indifference towards measuring population oral health in national longitudinal studies.

Variations in survey questionnaires across cohort surveys may be partially due to regional and language variations and within survey variations could arise due to adjustments to comply with maturing cohorts (Bath, Deeg and Poppelaars, 2010; Fortier *et al.*, 2019). However, the absence of internationally accepted standardised oral health-related questionnaires may also be a contributing factor (Taylor *et al.*,

2023). In the absence of standardised formats for data collection, longitudinal studies will continue to gather inaccurate or unusable data (Joda *et al.*, 2019).

Another objective of this section was to identify coverage gaps in survey questionnaires which may facilitate designing questionnaires for future surveys and help data users understand and interpret the consistency of available data. The coverage gaps were discussed for individual constructs as outlined in the following section.

For the dental injury construct, questions related to dental injury extent, dentition type, number of teeth injured, and number of untreated dental injuries would be useful. Common causes of dental injuries in preschool children are falls, predominantly collisions during contact sports for young school-going children and assaults and traffic accidents for adolescents and young adults (Andersson, 2013). Other less frequently associated factors with dental injuries in children include the physical and environmental characteristics of their houses, schools and neighbourhoods (Malikaew, Watt and Sheiham, 2003). Therefore, survey items reporting the cause, location and treatment of dental injuries could provide evidence for planning interventions to reduce the prevalence of dental injuries.

Similarly, for the dental problems construct, apart from dental caries/fillings no data were available in relation to other common dental issues such as periodontal disease, , malocclusion, dental fluorosis xerostomia and orofacial pain. Furthermore, cohort surveys should consider collecting information about the utilisation of preventive dental services e.g., fluoride varnish or fissure sealants and the type of anaesthesia (local or general anaesthesia) used during dental procedures. This information could provide a better understanding of the extent of dental resource utilisation in the community. In addition, the information about complex dental procedures such as root canal treatments, veneers and crowns would be informative. Adolescents and younger adults may be asked about the impact of oral health conditions on their social and emotional lives.

Studies have reported the use of fluoridated toothpaste in children before 2 years of age, a practice associated with an increased risk of dental fluorosis in 8-year-olds (O'Mullane, Clarkson and Parnell, 2018). Survey items to record the 'age when starting toothpaste use' and 'type of toothpaste used' could be considered for countries with mandatory community water fluoridation, such as Ireland, Australia, and New Zealand.

Future surveys could also consider adding 'the use of dental floss or interdental brushes' to the toothbrushing construct. The risk of gingivitis, plaque, or both were lower in individuals using floss or interdental brushes in addition to toothbrushing than those who preferred toothbrushing alone (Worthington *et al.*, 2019). No information was collected about the age and purpose of the first dentist visit. The first dentist visit should occur before the child is one year old (American Association of Pediatric Dentistry, 2022). The major benefits of an early dental visit include the opportunity to provide tailored oral health education, perform a caries risk assessment, and institute preventive dental care (Duane *et al.*, 2017; American Association of Pediatric Dentistry, 2022).

Most surveys, did not use items to record the study child's dental anxiety/fear. Dentally anxious patients are be less willing to seek dental care and, hence, not obtain the benefits of preventive dental treatments provided at routine dental visits (Crego *et al.*, 2014). Some studies have found that parents tend to bring their child to a dentist only when there was a dental problem because of financial constraints and lack of available services in the community (Mofidi, Rozier and King, 2002; Kelly *et al.*, 2005; Farlina and Maharani, 2018). Therefore, information, about study participants' reasons for dentist visits would give a better understanding of difficulties with access to dental care. Policymakers may use this information in the provision and implementation of required dental services in the community.

The daily intake of foods and drinks varies for most individuals, and a single 24-hour recall method is insufficient to represent an individual's habitual consumption

(Thompson and Subar, 2017). Repeated 24-hour recalls or multiple recalls conducted over several days are more reflective of habitual consumption (Hartman *et al.*, 1990; Ma *et al.*, 2009). Cohort surveys should consider using multiple 24-hour recalls. Higher reproducibility is guaranteed with four or five recalls compared to repeating the recall only twice or thrice (Rankin *et al.*, 2012).

**Recommendations:**

- 1) Improved survey design and validation could simplify data harmonisation and inter-linkable data standards.
- 2) Data harmonisation should be transparent, rigorous, and well-documented to ensure validity.
- 3) Harmonisation should be avoided for non-comparable data derived from different data collection methods as it will lead to bias.

**Objective 3:** *To demonstrate the development and usefulness of an analytical, interactive dashboard for researchers using oral health-related data from three Irish national child surveys.*

This section illustrated the development of an interactive dashboard for oral health-related data. Dashboards facilitate exploratory analysis of survey data without requiring multiple plots and tables and sharing of extensive documentation. Our developed protocol demonstrate a number of advantages to this type of data visualisation, including easy and interactive communication of descriptive statistics, data-driven hypothesis generation, faster dissemination of results, computational reproducibility, and accessibility across multiple devices with potential for interactive learning.

Observation of longitudinal changes within cohort survey participants and inter-survey comparisons of similar variables can provide useful insights into age or cohort changes occurring in developing children. For example, for nationally representative surveys, changes in oral health behaviours (such as toothbrushing frequency and use

of dental services) among children and adolescents over the years may provide evidence for the evaluation of existing oral health policies. Moreover, the evidence can also be used for developing and implementing interventions to improve the population's oral health. Dashboards integrated with AI-based technologies may prove to be an indispensable tool for predicting future response rates and study-specific outcomes (Golafshar *et al.*, 2021). Using automated alerts in dashboards to help identify non-response rates for individual survey items may help the management of non-response and participant attrition for future survey waves (Murphy *et al.*, 2019; Okpara *et al.*, 2022). Another useful feature is that the dashboard can be displayed on multiple devices, including tablets and mobile phones. This increases convenience, portability, efficiency, and productivity and, therefore, enhances user experience.

It is important to note that using R to build dashboards is free, however, for building complex visualisations more advanced knowledge of R is required, which may be a time investment. Other commercial softwares for dashboard development, such as Tableau (Beard and Aghassibake, 2021), Google Cloud Business Intelligence, and Microsoft Power Business Intelligence (Lachev and Price, 2015) are highly customisable with drill down features, allowing researchers to suit the specific needs of presenting results to a larger population (Barnum *et al.*, 2019).

Data literacy should be a core competence in dental curricula (Schwendicke and Krois, 2022). Lowndes *et al.*, identified exposure (knowing the specific tools required) and confidence (to develop the skills to use these tools) as the main barriers to engagement of researchers with open science tools (2017). While a basic knowledge of R is sufficient for data preparation and dashboard development the learning curve for this more complex skillset is steep.

**Recommendations:**

- 1) Given the exponential growth of digital data, dental researchers must be prepared for a more data-driven approach, whether utilising novel or more traditional surveillance data (Höhle, 2017; Joda *et al.*, 2019).
- 2) Strategies to improve the uptake of dashboards and training for both researchers and end-users to achieve any real beneficial outcomes (Helminski *et al.*, 2022).
- 3) Introduction of version control systems (Git/GitHub) and literate programming (R Markdown) in the dental undergraduate curriculum.

**Objective 4:** *To study the association between the family socioeconomic status at 13 years of age and the young person's (parent and self-reported) dental health at 17/18 years of age. In addition, the role of behavioural, material and psychosocial factors in explaining socioeconomic inequalities in young persons' oral health was investigated.*

This section identified socioeconomic disparities in Irish adolescents' self-rated oral health (SROH) and parent-reported oral health (number of teeth with dental fillings). Young persons with a lower socioeconomic background at 13 years of age reported poorer self and parent-reported oral health at 17 years of age than their peers from higher socioeconomic backgrounds. These findings were similar to those previously reported for adolescents (Perera and Ekanayake, 2010; Telford, Coulter and Murray, 2011; Ravaghi *et al.*, 2012; Silva, Mattos and Carmo, 2018; Nascimento *et al.*, 2021), children (Skafida and Chambers, 2018; Fleitas Alfonzo, Bentley and Singh, 2022; Matsuyama, Fujiwara and Aida, 2023) and adults (Sanders, Spencer and Slade, 2006; Sabbah *et al.*, 2009; Bernabé, Humphris and Freeman, 2017; Duijster *et al.*, 2017). Similarly, previous Irish national children's oral health surveys reported that family occupational class and medical card-related oral health inequalities in Irish adolescents (O'Mullane *et al.*, 1986; Whelton *et al.*, 2006).

We found that behaviour, material and psychosocial factors were all important factors contributing to the explanation of socioeconomic disparities in young males' SROH, material factors contributed most to the explanation of parental education and family

income-related SROH inequalities. Socioeconomic disparities in young persons' parent report oral health were partially explained by material factors, while behavioural and psychosocial factors played no role in accounting for these disparities. Unfortunately, it was difficult to compare these results as no previous longitudinal study had investigated the role of behaviour, material and psychosocial factors in explaining self and parent-reported oral health inequalities in adolescents. However, our study results were similar to those reported for adolescents in cross-sectional studies (Perera and Ekanayake, 2008; Polk, Weyant and Manz, 2010; Ravaghi *et al.*, 2012). Evidence from comparable studies in adults is inconclusive; some studies reported little or no role for behavioural factors, while others suggest a substantial role in explaining socioeconomic oral health inequalities. Our study results were in agreement with the general health literature, material factors had a substantial role in explaining socioeconomic differences in self-reported general health among children, adolescents and adults (Floor, Frank and Johan, 2005; Richter, Moor and Lenthe, 2012; Hiyoshi *et al.*, 2014; Oosterhoff *et al.*, 2019).

Number of teeth with dental fillings and SROH are valid measures of an individual's clinical oral health but they measure different aspects of oral health (Locker and Jokovic, 1996; Östberg *et al.*, 2003; Duijster *et al.*, 2017). SROH, self-reported by the study participants, is a subjective measure of their current oral health status and could reflect current pain or functional limitations (Östberg *et al.*, 2003). Parent-reported number of teeth with dental fillings could indicate past dental decay or dental trauma. This outcome could be influenced by PCG's beliefs, dietary behaviours, life time fluoride exposure and dental services affordability and availability (Matsuyama, Fujiwara and Aida, 2023). Therefore, the contribution of explanatory factors in explaining socioeconomic disparities differed depending on the oral health outcome studied. The validity of self-reported measures was unclear in the GUI surveys and may be prone to reporting, recall and social desirability bias (Nederhof, 1985; Watson *et al.*, 2014).



The ability to link data held within administrative systems to the data collected by cohort studies such as, GUI offers a unique ability to enhance the analytical potential of both forms of data. This practice allows the researchers to combine the detailed administrative data to the rich and varied data collected by longitudinal surveys (Connelly *et al.*, 2016). Data linkage can help the cross-validation of self-reported and administrative data and facilitates addressing issues of missing data and sampling biases (Fortin *et al.*, 2017). Moreover, data linking can also reduce the study participants' data collection load in certain survey areas (Gilbert *et al.*, 2017). However, as different data sources have specific access requirements and restrictions, data linkage generally have legal, ethical and social challenges (O'Neill *et al.*, 2019). Providing information to the survey participants and obtaining their consent for use of their data beyond the primary study could be considered at the start of the survey.

### **Recommendations**

- 1) Using a life-course approach to explain oral health inequalities in longitudinal studies.
- 2) Linking administrative data with longitudinal survey data.

### **Conclusion**

This thesis presented a detailed study on the oral health of Irish children and adolescents over the last seven decades with an emphasis on using parent/self-reported oral health and key risk indicators data available in national birth and child cohort surveys. Reductions in dental caries levels among Irish children and adolescents from the 1960s to 2002 were highlighted following a were systematic review with greater reductions among those with fluoridated drinking water supplies. The findings presented in this research highlight the issue of inconsistencies in cohort survey questionnaires across countries and within waves of a single cohort . This is one of the main challenges of undertaking longitudinal and cross-national oral health research. We also highlighted the potential use of data harmonisation to reduce variable heterogeneity across and within surveys. Our analysis also illustrated the use of open-source technologies such as R shiny dashboards for interactive analysis of cohort

survey datasets. Finally, by analysing data from the first three waves of the GUI child cohort surveys, this research highlighted the socioeconomic disparities in young Irish persons' self and parent-reported oral health which are partially explained by the material circumstances of their families. Irish adolescents belonging to lower social groups had a greater risk of poor oral health than those belonging to higher social groups.

## **BIBLIOGRAPHY**

Adhikari, K., Patten, S. B., Patel, A. B., Premji, S., Tough, S., Letourneau, N., Giesbrecht, G. and Metcalfe, A. (2021) 'Data harmonization and data pooling from cohort studies: a practical approach for data management', *International Journal of Population Data Science*, 6(1), pp. 1-15.

Adler, N. E. and Newman, K. (2002) 'Socioeconomic disparities In health: pathways and policies', *Health Affairs*, 21(2), pp. 60-76.

Agostoni, C., Berni Canani, R., Fairweather Tait, S., Heinonen, M., Korhonen, H., La Vieille, S., Marchelli, R., Martin, A., Naska, A. and Neuhäuser Berthold, M. (2014) 'Scientific opinion on the essential composition of infant and follow-on formulae. EFSA panel on dietetic products, nutrition and allergies (NDA)', *EFSA Journal* 12(7), pp. 1-106.

Aida, J., Matsuyama, Y., Tabuchi, T., Komazaki, Y., Tsuboya, T., Kato, T., Osaka, K. and Fujiwara, T. (2017) 'Trajectory of social inequalities in the treatment of dental caries among preschool children in Japan', *Community Dentistry and Oral Epidemiology*, 45(5), pp. 407-412.

Aimutis, W. R. (2004) 'Bioactive properties of milk proteins with particular focus on anticariogenesis', *The Journal of Nutrition*, 134(4), pp. 989S-995S.

Akinkugbe, A. A., Sharma, S., Ohrbach, R., Slade, G. D. and Poole, C. (2016) 'Directed acyclic graphs for oral disease research', *Journal of Dental Research*, 95(8), pp. 853-859.

Al Hasan, S. M., Saulam, J., Kanda, K. and Hirao, T. (2019) 'Temporal trends in apparent food consumption in Bangladesh: a joinpoint regression analysis of FAO's food balance sheet data from 1961 to 2013', *Nutrients*, 11(8), pp. 1-19.

Al-Ghutaimel, H., Riba, H., Al-Kahtani, S. and Al-Duhaimi, S. (2014) 'Common periodontal diseases of children and adolescents', *International Journal of Dentistry*, 2014, pp. 1-7.

American Association of Pediatric Dentistry (2022) *Periodicity of examination, preventive dental services, anticipatory guidance/counselling, and oral treatment for infants, children, and adolescents*. Available at: <https://www.aapd.org/research/oral-health-policies--recommendations/periodicity-of-examination-preventive-dental-services-anticipatory-guidance-counseling-and-oral-treatment-for-infants-children-and-adolescents/> (Accessed: 09/09/2022).

Andersson, L. (2013) 'Epidemiology of traumatic dental injuries', *Journal of Endodontics*, 39(3), pp. S2-S5.

Antunes, J. L. F. and Narvai, P. C. (2010) 'Dental health policies in Brazil and their impact on health inequalities', *Rev Saúde Pública*, 44(2), pp. 360-365.

- Arany, S., Kopycka-Kedzierawski, D. T., Caprio, T. V. and Watson, G. E. (2021) 'Anticholinergic medication: related dry mouth and effects on the salivary glands', *Oral Surgery Oral Medicine Oral Pathology Oral Radiology*, 132(6), pp. 662-670.
- Asaka, Y., Sekine, M., Yamada, M., Tatsuse, T. and Sano, M. (2020) 'Association of short sleep duration and long media use with caries in school children', *Pediatrics International*, 62(2), pp. 214-220.
- Åstrøm, A. N., Lie, S. A. and Özkaya, F. (2021) 'Influences of behaviour and attitude on education related inequality in tooth loss: findings from Norway and Sweden over 5 years of follow- up', *Acta Odontologica Scandinavica*, 79(2), pp. 81-88.
- Atkin, A. J., Biddle, S. J. H., Broyles, S. T., Chinapaw, M., Ekelund, U., Esliger, D. W., Hansen, B. H., Kriemler, S., Puder, J. J., Sherar, L. B. and Van Sluijs, E. M. F. (2017) 'Harmonising data on the correlates of physical activity and sedentary behaviour in young people: methods and lessons learnt from the international children's accelerometry database (ICAD)', *International Journal of Behavioral Nutrition and Physical Activity*, 14(1), pp. 1-12.
- Baeza, M., Morales, A., Cisterna, C., Cavalla, F., Jara, G., Isamitt, Y., Pino, P. and Gamonal, J. (2020) 'Effect of periodontal treatment in patients with periodontitis and diabetes: systematic review and meta-analysis', *Journal of Applied Oral Science*, 28, pp. 1-13.
- Baghla, K., Muirhead, V., Moynihan, P., Weston-Price, S. and Pine, C. (2018) 'Free sugars consumption around bedtime and dental caries in children: a systematic review', *JDR Clinical & Translational Research*, 3(2), pp. 118-129.
- Bagramian, R. A., Garcia-Godoy, F. and Volpe, A. R. (2009) 'The global increase in dental caries. A pending public health crisis', *American Journal of Dentistry*, 22(1), pp. 3-8.
- Barnum, T., Vaez, K., Cesarone, D. and Yingling, C. (2019) 'Your data looks good on a dashboard', *Online Journal of Nursing Informatics* 23(3), pp. 1-4.
- Baron, R. M. and Kenny, D. A. (1986) 'The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations', *Journal of Personality and Social Psychology*, 51(6), pp. 1173-1182.
- Bartley, M. (2017) *Health Inequality: An Introduction to Concepts, Theories and Methods*. 2nd edn. Cambridge, UK ; Malden, MA, USA Polity Press.
- Bastos, J. L., Peres, M. A., Peres, K. G., Araujo, C. L. P. and Menezes, A. M. B. (2008) 'Toothache prevalence and associated factors: a life course study from birth to age 12 yr', *European Journal of Oral Sciences*, 116(5), pp. 458-466.

Bath, P. A., Deeg, D. and Poppelaars, J. (2010) 'The harmonisation of longitudinal data: a case study using data from cohort studies in the Netherlands and the United Kingdom', *Ageing and Society*, 30(8), pp. 1419-1437.

Bauermeister, S., Phatak, M., Sparks, K., Sargent, L., Griswold, M., McHugh, C., Nalls, M., Young, S., Bauermeister, J., Elliott, P., Steptoe, A., Porteous, D., Dufouil, C. and Gallacher, J. (2023) 'Evaluating the harmonisation potential of diverse cohort datasets', *European Journal of Epidemiology*, 38(6), pp. 605-615.

Baumgartner, C. S., Wang, N. J. and Wigen, T. I. (2022) 'Oral health behaviours in 12-year-olds. Association with caries and characteristics of the children?', *Acta Odontologica Scandinavica*, 80(1), pp. 15-20.

Beard, L. and Aghassibake, N. (2021) 'Tableau (version 2020.3)', *Journal of the Medical Library Association: JMLA*, 109(1), pp. 159.

Beck, J. D. (1998) 'Risk revisited', *Community Dentistry and Oral Epidemiology*, 26(4), pp. 220-225.

Behrman, J. R. and Deolalikar, A. B. (1988) 'Chapter 14 Health and nutrition', in Chenery, H. and Srinivasan, T.N. (eds.) *Handbook of Development Economics*: Elsevier, pp. 631-711.

Beil, H., Rozier, R. G., Preisser, J. S., Stearns, S. C. and Lee, J. Y. (2014) 'Effects of early dental office visits on dental caries experience', *American Journal of Public Health*, 104(10), pp. 1979-1985.

Belotti, L. and Frazão, P. (2021) 'Effectiveness of water fluoridation in an upper-middle-income country: a systematic review and meta-analysis', *International Journal of Paediatric Dentistry*, 32(4), pp. 503-513.

Benson, P. E., Parkin, N., Dyer, F., Millett, D. T. and Germain, P. (2019) 'Fluorides for preventing early tooth decay (demineralised lesions) during fixed brace treatment', *Cochrane Database of Systematic Reviews*, 2019(11), pp. 1-68.

Bergeron, J., Massicotte, R., Atkinson, S., Bocking, A., Fraser, W. and Fortier, I. (2020) 'Cohort profile: research advancement through cohort cataloguing and harmonization (ReACH)', *International Journal of Epidemiology*, 50(2), pp. 396-397.

Bernabé, E., Humphris, G. and Freeman, R. (2017) 'The social gradient in oral health: is there a role for dental anxiety?', *Community Dentistry and Oral Epidemiology*, 45(4), pp. 348-355.

Bernabe, E., Vehkalahti, M. M., Sheiham, A., Lundqvist, A. and Suominen, A. L. (2016) 'The shape of the dose-response relationship between sugars and caries in adults', *Journal of Dental Research*, 95(2), pp. 167-72.

- Bingham, S. (1997) 'Validation of dietary assessment methods in the UK arm of EPIC using weighed records, and 24-hour urinary nitrogen and potassium and serum vitamin C and carotenoids as biomarkers', *International Journal of Epidemiology*, 26(1(Suppl. 1)), pp. S137-S151.
- Bingham, S. A. (1987) 'The dietary assessment of individuals; methods, accuracy, new techniques and recommendation', *Nutrition Abstracts and Reviews (Series A)*, 57, pp. 705-742.
- Bingham, S. A. (1991) 'Limitations of the various methods for collecting dietary intake data', *Annals of Nutrition and Metabolism*, 35(3), pp. 117-127.
- Birch, L., Savage, J. S. and Ventura, A. (2007) 'Influences on the development of children's eating behaviours: from infancy to adolescence', *Canadian Journal of Dietetic Practice and Research*, 68(1), pp. S1-S56.
- Björck, I., Asp, N. G., Birkhed, D., Eliasson, A. C., Sjöberg, L. B. and Lundquist, I. (1984) 'Effects of processing on starch availability *In vitro* and *In vivo*. II. Drum-drying of wheat flour', *Journal of Cereal Science*, 2(3), pp. 165-178.
- Boeira, G. F., Correa, M. B., Peres, K. G., Peres, M. A., Santos, I. S., Matijasevich, A., Barros, A. J. D. and Demarco, F. F. (2012) 'Caries is the main cause for dental pain in childhood: findings from a birth cohort', *Caries Research*, 46(5), pp. 488-495.
- Boettiger, C. (2015) 'An introduction to Docker for reproducible research', *ACM SIGOPS Operating Systems Review*, 49(1), pp. 71-79.
- Bolin, A. K., Bolin, A., Jansson, L. and Calltorp, J. (1997) 'Children's dental health in Europe', *Swedish Dental Journal*, 21(1), pp. 25-40.
- Booth, A., Clarke, M., Dooley, G., Ghera, D., Moher, D., Petticrew, M. and Stewart, L. (2012) 'The nuts and bolts of PROSPERO: an international prospective register of systematic reviews', *Systematic Reviews*, 1(1), pp. 1-8.
- Botelho, J., Machado, V., Proença, L., Delgado, A. S. and Mendes, J. J. (2020) 'Vitamin D deficiency and oral health: a comprehensive review', *Nutrients*, 12(5), pp. 1-16.
- Bowen, W. H. (2013) 'The Stephan Curve revisited', *Odontology*, 101(1), pp. 2-8.
- Bradshaw, D. J. and Lynch, R. J. M. (2013) 'Diet and the microbial aetiology of dental caries: new paradigms', *International Dental Journal*, 63 Suppl 2, pp. 64-72.
- Bradshaw, J., Hoelscher, P. and Richardson, D. (2006) 'An index of child well-being in the European Union', *Social Indicators Research*, 80(1), pp. 133-177.
- Braveman, P. A., Cubbin, C., Egerter, S., Chideya, S., Marchi, K. S., Metzler, M. and Posner, S. (2005) 'Socioeconomic status in health research: one size does not fit all', *Jama*, 294(22), pp. 2879-2888.

Bresson, J., Flynn, A., Heinonen, M., Hulshof, K., Korhonen, H., Lagiou, P., Løvik, M., Marchelli, R., Martin, A. and Moseley, B. (2009) 'Review of labelling reference intake values—Scientific Opinion of the Panel on Dietetic Products, Nutrition and Allergies on a request from the Commission related to the review of labelling reference intake values for selected nutritional elements', *European Food Safety Authority Journal*, 1008, pp. 1-14.

Broadbent, J. M., Thomson, W. M., Boyens, J. V. and Poulton, R. (2011) 'Dental plaque and oral health during the first 32 years of life', *The Journal of the American Dental Association*, 142(4), pp. 415-426.

Broadbent, J. M., Thomson, W. M. and Poulton, R. (2006) 'Oral health beliefs in adolescence and oral health in young adulthood', *Journal of Dental Research*, 85(4), pp. 339-343.

Broadbent, J. M., Zeng, J., Foster Page, L. A., Baker, S. R., Ramrakha, S. and Thomson, W. M. (2016) 'Oral health—related beliefs, behaviors, and outcomes through the life course', *Journal of Dental Research*, 95(7), pp. 808-813.

Bronfenbrenner, U. and Morris, P. A. (2007) 'The bioecological model of human development', in Damon, W. and Lerner, R.M. (eds.) *Handbook of Child Psychology: Theoretical Models of Human Development*: John Wiley & Sons, Inc., pp. 793–828.

Brown, P., Guy, M. and Broad, J. (2005) 'Individual socio-economic status, community socio-economic status and stroke in New Zealand: a case control study', *Social Science & Medicine*, 61(6), pp. 1174-88.

Brownson, R. C., Fielding, J. E. and Maylahn, C. M. (2009) 'Evidence-based public health: a fundamental concept for public health practice', *Annual Review of Public Health*, 30(1), pp. 175-201.

Brustad, M., Skeie, G., Braaten, T., Slimani, N. and Lund, E. (2003) 'Comparison of telephone vs face-to-face interviews in the assessment of dietary intake by the 24 h recall EPIC SOFT program--the Norwegian calibration study', *European Journal of Clinical Nutrition*, 57(1), pp. 107-113.

Burke, B. S. (1947) 'The dietary history as a tool in research', *Journal of the American Dietetic Association*, 23(12), pp. 1041-1042.

Burns, C., Cook, K. and Mavoa, H. (2013) 'Role of expendable income and price in food choice by low income families', *Appetite*, 71, pp. 209-217.

Burt, B. A. (1997) 'How useful are cross-sectional data from surveys of dental caries?', *Community Dentistry and Oral Epidemiology*, 25(1), pp. 36-41.

Burt, B. A. (2005) 'Concepts of risk in dental public health', *Community Dentistry and Oral Epidemiology*, 33(4), pp. 240-247.



Burt, B. A. and Pai, S. (2001) 'Sugar consumption and caries risk: a systematic review', *Journal of Dental Education*, 65(10), pp. 1017-1023.

Cantwell, M. M., Millen, A. E., Carroll, R., Mittl, B. L., Hermansen, S., Brinton, L. A. and Potischman, N. (2006) 'A debriefing session with a nutritionist can improve dietary assessment using food diaries', *The Journal of Nutrition*, 136(2), pp. 440-445.

Casamassimo, P. S., Lee, J. Y., Marazita, M. L., Milgrom, P., Chi, D. L. and Divaris, K. (2014) 'Improving children's oral health: an interdisciplinary research framework', *Journal of Dental Research*, 93(10), pp. 938-942.

Caufield, P. W. and Griffen, A. L. (2000) 'Dental caries: an infectious and transmissible disease', *Pediatric Clinics of North America*, 47(5), pp. 1001-1019.

Caufield, P. W., Schön, C. N., Saraithong, P., Li, Y. and Argimón, S. (2015) 'Oral Lactobacilli and dental caries', *Journal of Dental Research*, 94(9\_suppl), pp. 110S-118S.

Celeste, R. K. (2020) 'Bias in population oral health research: longitudinal studies', *Community Dental Health*, 37(1), pp. 90-95.

Centers for Disease Control and Prevention (2018) *Water fluoridation data & statistics*. Atlanta, USA: U.S. Department of Health & Human Services. Available at: <https://www.cdc.gov/fluoridation/statistics/index.htm> (Accessed: 15/05/2023).

Central Statistics Office (2024) *Census 2022, preliminary actual and percentage change in population 2016-2022*. Ireland: Central Statistics Office. Available at: <https://data.cso.ie/> (Accessed: 09/02/2024).

Cesarino Gomes, M., Clementino, M., Tassia, C., De, A., Pinto, S., Maria, E., Costa, M., Martins, C., Granville-Garcia, A., Garcia, G. and Paiva, S. (2015) 'Parental perceptions of oral health status in preschool children and associated factors', *Brazilian Dental Journal*, 36, pp. 428-434.

Chang, W., Cheng, J., JJ, A., Sievert, C., Schloerke, B., Xie, Y., Allen, J., McPherson, J., Dipert, A. and Borges, B. (2022) *shiny: web application framework for R*. Available at: <https://shiny.rstudio.com/> (Accessed: 22/07/2022).

Cheng, C. K., Ip, D. K., Cowling, B. J., Ho, L. M., Leung, G. M. and Lau, E. H. (2011) 'Digital dashboard design using multiple data streams for disease surveillance with influenza surveillance as an example', *Journal of Medical Internet Research*, 13(4), pp. 1-9.

Cheng, K. K., Chalmers, I. and Sheldon, T. A. (2007) 'Adding fluoride to water supplies', *BMJ*, 335(7622), pp. 699-702.

Chi, D. L., Luu, M. and Chu, F. (2017) 'A scoping review of epidemiologic risk factors for pediatric obesity: implications for future childhood obesity and dental caries prevention research', *Journal of Public Health Dentistry*, 77 (SI), pp. S8-S31.

Chouchene, F., Masmoudi, F., Baaziz, A., Maatouk, F. and Ghedira, H. (2021) 'Parental stress as a predictor of early childhood caries: a systematic review', *European Archives of Paediatric Dentistry*, 22(2), pp. 111-119.

Chow, K. F. (2017) 'A review of excessive sugar metabolism on oral and general health', *Chinese Journal of Dental Research*, 20(4), pp. 193-198.

Citizens Information Board (2023) *Medical cards*. Dublin. Available at: <https://www.citizensinformation.ie/en/health/medical-cards-and-gp-visit-cards/medical-card/#:~:text=visit%20card%20holders,-,How%20to%20qualify%20for%20a%20medical%20card,without%20a%20means%20test'%20below>. (Accessed: 12/01/2024).

Clarke, M. (2012) 'The digital revolution', in Campbell, R., Pentz, E. and Borthwick, I. (eds.) *Academic and Professional Publishing*: Chandos Publishing, pp. 79-98.

Clarkson, J., McLoughlin, J. and O'Hickey, S. (2003) 'Water fluoridation in Ireland-a success story', *Journal of Dental Research*, 82(5), pp. 334-337.

Clarkson, J. E., Pitts, N. B., Fee, P. A., Goulao, B., Boyers, D., Ramsay, C. R., Floate, R., Braid, H. J., Ord, F. S., Worthington, H. V., van der Pol, M., Young, L., Freeman, R., Gouick, J., Humphris, G. M., Mitchell, F. E., McDonald, A. M., Norrie, J. D. T., Sim, K., Douglas, G. and Ricketts, D. (2021) 'Examining the effectiveness of different dental recall strategies on maintenance of optimum oral health: the INTERVAL dental recalls randomised controlled trial', *British Dental Journal*, 230(4), pp. 236-243.

Clerehugh, V. (2008) 'Periodontal diseases in children and adolescents', *British Dental Journal*, 204(8), pp. 469-471.

Cleveland, W. S. (1993) *Visualizing Data*. New Jersey: Hobart Press.

Cole, T. J. (2000) 'Establishing a standard definition for child overweight and obesity worldwide: international survey', *BMJ*, 320(7244), pp. 1240-1240.

Collins, C. K. and O'Mullane, D. M. (1970) 'Dental caries experience in Cork City schoolchildren aged 4-11 years after 4 1/2 years of fluoridation', *Journal of Irish Dental Association*, 16(5), pp. 130-134.

Comber, H., Deady, S., Montgomery, E. and Gavin, A. (2011) 'Drinking water fluoridation and osteosarcoma incidence on the island of Ireland', *Cancer Causes Control*, 22(6), pp. 919-924.

Concannon, D., Herbst, K. and Manley, E. (2019) 'Developing a data dashboard framework for population health surveillance: widening access to clinical trial findings', *JMIR Formative Research*, 3(2), pp. 1-13.

Connelly, R., Playford, C. J., Gayle, V. and Dibben, C. (2016) 'The role of administrative data in the big data revolution in social science research', *Social Science Research*, 59, pp. 1-12.

Cormann, M. and Dongyu, Q. (2021) *OECD-FAO agricultural outlook 2021–2030*, Paris: OECD and FAO. Available at: [https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2021-2030\\_19428846-en](https://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2021-2030_19428846-en) (Accessed: 24/04/2023).

Costa, S. M., Martins, C. C., Bonfim Mde, L., Zina, L. G., Paiva, S. M., Pordeus, I. A. and Abreu, M. H. (2012) 'A systematic review of socioeconomic indicators and dental caries in adults', *International Journal of Environmental Research and Public Health*, 9(10), pp. 3540-3574.

Costa, S. M., Martins, C. C., Pinto, M. Q. C., Vasconcelos, M. and Abreu, M. (2018) 'Socioeconomic factors and caries in people between 19 and 60 Years of age: an update of a systematic review and meta-analysis of observational studies', *International Journal of Environmental Research and Public Health*, 15(8), pp. 1-17.

Counihan, D., T. O'Shea\*, M., Guigui, D., Sloan, S., Chzhen, Y., Taylor, L. K. and Symonds, J. E. (2023) *Scoping review to inform the development of a potential new birth cohort for Growing Up in Ireland*, Dublin, Ireland: Growing Up in Ireland. Available at: <https://www.growingup.gov.ie/pubs/230525-GUI-Scoping-Review.pdf> (Accessed: 07/03/2024).

Crall, J. J. and Forrest, C. B. (2018) 'A life course health development perspective on oral health', in Halfon, N., Forrest, C.B., Lerner, R.M. and Faustman, E.M. (eds.) *Handbook of Life Course Health Development*. Cham (CH), pp. 299-320.

Crawford, P. B., Obarzanek, E., Morrison, J. and Sabry, Z. (1994) 'Comparative advantage of 3-day food records over 24-hour recall and 5-day food frequency validated by observation of 9-and 10-year-old girls', *Journal of the American Dietetic Association*, 94(6), pp. 626-630.

Creedon, M. I. and O'Mullane, D. M. (2001) 'Factors affecting caries levels amongst 5-year-old children in County Kerry, Ireland', *Community Dental Health*, 18(2), pp. 72-78.

Crego, A., Carrillo-Díaz, M., Armfield, J. M. and Romero, M. (2014) 'From public mental health to community oral health: the impact of dental anxiety and fear on dental status', *Frontiers in public health*, 2, pp. 16.

Cronin, J., Moore, S., Harding, M., Whelton, H. and Woods, N. (2021) 'A cost-effectiveness analysis of community water fluoridation for schoolchildren', *BMC Oral Health*, 21(1), pp. 1-12.

Crowe, M. (2018) *Diet and other risk indicators associated with dental problems in Irish preschool children* Ph.D thesis, Trinity College Dublin Dublin.

Crowe, M., O' Sullivan, M., Cassetti, O. and O' Sullivan, A. (2017) 'Weight status and dental problems in early childhood: classification tree analysis of a national cohort', *Dentistry Journal*, 5(3), pp. 1-11.

Crowe, M., O'Sullivan, A., McGrath, C., Cassetti, O., Swords, L. and O'Sullivan, M. (2016) 'Early Childhood Dental Problems', *JDR Clinical & Translational Research*, 1(3), pp. 275-284.

Crowe, M., O'Sullivan, M., Cassetti, O. and O'Sullivan, A. (2020) 'Estimation and consumption pattern of free sugar intake in 3-year-old Irish preschool children', *European Journal of Nutrition*, 59(5), pp. 2065-2074.

Cui, L., Li, X., Tian, Y., Bao, J., Wang, L., Xu, D., Zhao, B. and Li, W. (2017) 'Breastfeeding and early childhood caries: a meta-analysis of observational studies', *Asia Pacific Journal of Clinical Nutrition*, 26(5), pp. 867-880.

Cury, J. A., Ricomini-Filho, A. P., Berti, F. L. P. and Tabchoury, C. P. M. (2019) 'Systemic effects (risks) of water fluoridation', *Brazilian Dental Journal*, 30, pp. 421-428.

Curzon, M. E. J. and Hefferren, J. J. (2001) 'Modern methods for assessing the cariogenic and erosive potential of foods', *British Dental Journal*, 191(1), pp. 41-46.

Daher, A., Abreu, M. H. and Costa, L. R. (2015) 'Recognizing preschool children with primary teeth needing dental treatment because of caries-related toothache', *Community Dentistry and Oral Epidemiology*, 43(4), pp. 298-307.

Daly, B., Hobdell, M. H., Sadlier, D. and Jennings, N. (1991) 'The Kilkenny integrated oral health project', *Irish Journal of Medical Science* 160 (Suppl 9), pp. 50-54.

Dao, M. C., Subar, A. F., Warthon-Medina, M., Cade, J. E., Burrows, T., Golley, R. K., Forouhi, N. G., Pearce, M. and Holmes, B. A. (2019) 'Dietary assessment toolkits: an overview', *Public Health Nutrition*, 22(3), pp. 404-418.

Darnton-Hill, I., Nishida, C. and James, W. (2004) 'A life course approach to diet, nutrition and the prevention of chronic diseases', *Public Health Nutrition*, 7(1a), pp. 101-121.

Davison, J., McLaughlin, M. and Giles, M. (2019) 'Factors influencing children's tooth brushing intention: an application of the theory of planned behaviour', *Health Psychology Bulletin*, 3(1), pp. 58-66.

DCEDIY and CSO (2023) *Growing Up in Ireland*. Ireland: Department of Children, Equality, Disability, Integration and Youth (DCEDIY). Available at: <https://www.growingup.gov.ie/about-growing-up-in-ireland/> (Accessed: 07/06/2023).

de Sousa, F. S. O., Dos Santos, A. P. P., Nadanovsky, P., Hujoel, P., Cunha-Cruz, J. and de Oliveira, B. H. (2019) 'Fluoride varnish and dental caries in preschoolers: a systematic review and meta-analysis', *Caries research*, 53(5), pp. 502-513.

Declerck, D., Leroy, R., Martens, L., Lesaffre, E., Garcia-Zattera, M. J., Vanden Broucke, S., Debyser, M. and Hoppenbrouwers, K. (2008) 'Factors associated with prevalence and severity of caries experience in preschool children', *Community Dentistry and Oral Epidemiology*, 36(2), pp. 168-78.

Department of Education (2022) *Minister Foley announces €32 million major expansion of the DEIS programme incorporating 310 new schools*. Dublin, Ireland. Available at: <https://www.gov.ie/en/press-release/71054-minister-foley-announces-32-million-major-expansion-of-the-deis-programme-incorporating-310-new-schools/#:~:text=In%20the%202021%2F22%20academic,programme%20serving%20over%20180%2C000%20students>. (Accessed: 02/09/2023).

Department of Health (DoH) (1962a) *Health (Fluoridation of water supplies) Act, 1960: report on the incidence of dental caries in school children, and on the analysis of public piped water supplies in the health authority areas of Cork, Limerick and Waterford*, Dublin, Ireland. Available at: <https://www.lenus.ie/handle/10147/249858> (Accessed: 09/11/2021).

Department of Health (DoH) (1962b) *Health (Fluoridation of water supplies) Act, 1960: report on the Incidence of Dental Caries in School Children, and on the Analysis of Public Piped Water Supplies, in Dublin, Kildare and Wicklow Health Authority Areas*, Dublin, Ireland. Available at: <https://www.lenus.ie/handle/10147/249833> (Accessed: 09/11/2021).

Department of Health (DoH) (1963) *Health (Fluoridation of Water Supplies Act) 1960: report on the incidence of dental caries in school children and on the analyses of public piped water supplies in the Health Authority areas of Louth, Wexford, Laois and Galway*, Dublin, Ireland (Accessed: 09/11/2021).

Department of Health (DoH) (1964a) *Health (Fluoridation of Water Supplies Act) 1960: report on the incidence of dental caries in school children and on the analyses of public piped water supplies in the Health Authority areas of Kerry, Clare, West-Meath and Offaly*, Dublin, Ireland (Accessed: 09/11/2021).

Department of Health (DoH) (1964b) *Health (Fluoridation of Water Supplies Act) 1960: report on the incidence of dental caries in school children and on the analyses of public piped water supplies in the Health Authority areas of Tipperary (North Riding), Tipperary (South Riding), Kilkenny and Carlow.*, Dublin, Ireland (Accessed: 09/11/2021).

Department of Health (DoH) (1965a) *Health (Fluoridation of Water Supplies Act) 1960: report on the incidence of dental caries in school children and on the analyses of public piped water supplies in the Health Authority areas of Meath, Donegal, Sligo and Mayo.*, Dublin, Ireland (Accessed: 09/11/2021).

Department of Health (DoH) (1965b) *Health (Fluoridation of Water Supplies Act) 1960: report on the incidence of dental caries in school children and on the analyses of public piped water supplies in the Health Authority areas of Roscommon, Longford, Leitrim,*

Cavan and Monaghan, Dublin, Ireland. Available at: <https://www.lenus.ie/handle/10147/237754> (Accessed: 09/11/2021).

Department of Health Ireland (2019) *Smile agus Sláinte – national oral health policy*, Dublin Government of Ireland. Available at: <https://www.gov.ie/en/publication/90687b-smile-agus-slainte-national-oral-health-policy/> (Accessed: 12/02/2022).

DeWalt, D. A. and Hink, A. (2009) 'Health literacy and child health outcomes: a systematic review of the literature', *Pediatrics*, 124(Supplement\_3), pp. S265-S274.

Dhadse, P., Gattani, D. and Mishra, R. (2010) 'The link between periodontal disease and cardiovascular disease: how far we have come in last two decades?', *Journal of Indian Society of Periodontology*, 14(3), pp. 148–154.

Dhar, V. and Bhatnagar, M. (2009) 'Physiology and toxicity of fluoride', *Indian Journal of Dental Research*, 20(3), pp. 350-355.

Dirks, O. B., Houwink, B. and Kwant, G. W. (1961) 'The results of 612 years of artificial fluoridation of drinking water in The Netherlands: The tiel—Culemborg experiment', *Archives of Oral Biology*, 5(3), pp. 284-300.

Dix, A. (2013) 'Introduction to information visualisation', in Agosti, M., Ferro, N., Forner, P., Müller, H. and Santucci, G. (eds.) *Information Retrieval Meets Information Visualization*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 1-27.

Doiron, D., Burton, P., Marcon, Y., Gaye, A., Wolffenbuttel, B. H. R., Perola, M., Stolk, R. P., Foco, L., Minelli, C., Waldenberger, M., Holle, R., Kvaløy, K., Hillege, H. L., Tassé, A.-M., Ferretti, V. and Fortier, I. (2013) 'Data harmonization and federated analysis of population-based studies: the BioSHaRE project', *Emerging Themes in Epidemiology*, 10(1), pp. 1-8.

Downer, M., Blinkhorn, A., Holt, R., Wight, C. and Attwood, D. (1994) 'Dental caries experience and defects of dental enamel among 12-year-old children in north London, Edinburgh, Glasgow and Dublin', *Community Dentistry and Oral Epidemiology*, 22(5 Pt 1), pp. 283-285.

Dror, D. K. and Allen, L. H. (2014) 'Dairy product intake in children and adolescents in developed countries: trends, nutritional contribution, and a review of association with health outcomes', *Nutrition Reviews*, 72(2), pp. 68-81.

Duane, B., McGovern, E., Ni Chaollai, A. and FitzGerald, K. (2017) 'First tooth, first visit, zero cavities: a review of the evidence as it applies to Ireland', *Journal of the Irish Dental Association*, 63(2), pp. 105-111.

Duijster, D., Oude Groeniger, J., van der Heijden, G. J. M. G. and van Lenthe, F. J. (2017) 'Material, behavioural, cultural and psychosocial factors in the explanation of



socioeconomic inequalities in oral health', *European Journal of Public Health*, 28(4), pp. 590-597.

Dusseldorp, E., Kamphuis, M. and Schuller, A. (2015) 'Impact of lifestyle factors on caries experience in three different age groups: 9, 15, and 21-year-olds', *Community Dentistry and Oral Epidemiology*, 43(1), pp. 9-16.

Dye, B. A. (2017) 'The global burden of oral disease: research and public health significance', *Journal of Dental Research*, 96(4), pp. 361-363.

Dye, B. A., Thornton, E. G. and Li, X. (2015) *Dental caries and sealant prevalence in children and adolescents in the United States, 2011–2012*, Hyattsville, MD: National Center for Health Statistics. 191). Available at: <https://www.cdc.gov/nchs/data/databriefs/db191.pdf>.

Eastern Health Board (1994) *Children's dental health in the Eastern Health Board region, 1993: Report of a study conducted by the Dental Department of the Eastern Health Board in collaboration with the Oral Services Research Centre University College Cork.*, Dublin, Ireland: Oral Health Services Research Center. University College Cork. Available at: <http://hdl.handle.net/10147/559275> (Accessed: 07/11/2021).

Eastern Health Board (1997) *Oral health of children in the Eastern Health Board*, Dublin, Ireland: Oral Health Services Research Center. University College Cork. Available at: <http://hdl.handle.net/10147/46223> (Accessed: 03/11/2021).

Echeverria, M. S., Schuch, H. S., Cenci, M. S., Motta, J. V. S., Bertoldi, A. D., Hallal, P. C. and Demarco, F. F. (2022) 'Trajectories of sugar consumption and dental caries in early childhood', *Journal of Dental Research*, 101(6), pp. 1-7.

Ellis, D. A. and Merdian, H. L. (2015) 'Thinking outside the box: developing dynamic data visualizations for psychology with shiny', *Frontiers in Psychology*, 6, pp. 1-6.

Emery, T., Pollock, G. and Scherpenzeel, A. (2019) 'Securing high-quality data on populations: why we need EuroCohort, GGP and SHARE in Europe', *Population & Policy Compact*.

Englyst, H. N. and Hudson, G. J. (1996) 'The classification and measurement of dietary carbohydrates', *Food Chemistry*, 57(1), pp. 15-21.

Erickson, J., Sadeghirad, B., Lytvyn, L., Slavin, J. and Johnston, B. C. (2017) 'The scientific basis of guideline recommendations on sugar intake', *Annals of Internal Medicine*, 166(4), pp. 257-267.

European Parliament and the Council of the European Union, E. (2006) 'Regulation (EC) No. 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods', *Official Journal of the European Union*, L 404 pp. 1-17.

Faber, M., Wenhold, F. A. M., MacIntyre, U. E., Wentzel-Viljoen, E., Steyn, N. P. and Oldewage-Theron, W. H. (2013) 'Presentation and interpretation of food intake data: factors affecting comparability across studies', *Nutrition*, 29(11-12), pp. 1286-92.

Farkas, L. (2017) *Data collection in the field of ethnicity*, Luxembourg: European Union. Available at: [https://commission.europa.eu/system/files/2021-09/data\\_collection\\_in\\_the\\_field\\_of\\_ethnicity.pdf](https://commission.europa.eu/system/files/2021-09/data_collection_in_the_field_of_ethnicity.pdf) (Accessed: 12/01/2024).

Farlina, A. and Maharani, D. A. (2018) 'Barriers of utilisation of dental services among children and adolescent: A systematic review', *Padjadjaran Journal of Dentistry*, 30(3), pp. 149-161.

Farshchi, H. R., Macdonald, I., Madjd, A. and Taylor, M. A. (2017) 'Benefits and Limitations of Traditional Self-Report Instruments', in Schoeller, D.A. and Westerterp-Plantenga, M.S. (eds.) *Advances in the Assessment of Dietary Intake*. Boca Raton: CRC Press, pp. 1-17.

Featherstone, J. D. (2004) 'The continuum of dental caries--evidence for a dynamic disease process', *Journal of dental research*, 83 Spec No C, pp. C39-C42.

Featherstone, J. D. (2008) 'Dental caries: a dynamic disease process', *Australian Dental Journal*, 53(3), pp. 286-291.

Featherstone, J. D. B. (1999) 'Prevention and reversal of dental caries: role of low level fluoride', *Community Dentistry and Oral Epidemiology*, 27(1), pp. 31-40.

Fejerskov, O. (2004) 'Changing paradigms in concepts on dental caries: consequences for oral health care', *Caries Research*, 38(3), pp. 182-191.

Feldens, C. A., Rodrigues, P. H., de Anastácio, G., Vítolo, M. R. and Chaffee, B. W. (2018) 'Feeding frequency in infancy and dental caries in childhood: a prospective cohort study', *International Dental Journal*, 68(2), pp. 113-121.

Ferrazzano, G. F., Cantile, T., Quarto, M., Ingenito, A., Chianese, L. and Addeo, F. (2008) 'Protective effect of yogurt extract on dental enamel demineralization in vitro', *Australian Dental Journal*, 53(4), pp. 314-319.

Feskanich, D., Rimm, E. B., Giovannucci, E. L., Colditz, G. A., Stampfer, M. J., Litin, L. B. and Willett, W. C. (1993) 'Reproducibility and validity of food intake measurements from a semiquantitative food frequency questionnaire', *Journal of the American Dietetic Association*, 93(7), pp. 790-796.

Few, S. (2006) *Information dashboard design: The effective visual communication of data*. O'Reilly Media, Inc.

Fidler Mis, N., Braegger, C., Bronsky, J., Campoy, C., Domellöf, M., Embleton, N. D., Hojsak, I., Hulst, J., Indrio, F., Lapillonne, A., Mihatsch, W., Molgaard, C., Vora, R. and Fewtrell, M. (2017) 'Sugar in infants, children and adolescents: a position paper of the



European Society for Paediatric Gastroenterology, Hepatology and Nutrition Committee on nutrition', *Journal of Pediatric Gastroenterology & Nutrition*, 65(6), pp. 681-696.

Fisher-Owens, S. A., Gansky, S. A., Platt, L. J., Weintraub, J. A., Soobader, M. J., Bramlett, M. D. and Newacheck, P. W. (2007) 'Influences on children's oral health: a conceptual model', *Pediatrics*, 120(3), pp. e510-e520.

Fleitas Alfonso, L., Bentley, R. and Singh, A. (2022) 'Home ownership, income and oral health of children in Australia—a population-based study', *Community Dentistry and Oral Epidemiology*, 50(3), pp. 156-163.

Floor, V. A. v. O., Frank, J. v. L. and Johan, P. M. (2005) 'Material, psychosocial, and behavioural factors in the explanation of educational inequalities in mortality in the Netherlands', *Journal of Epidemiology and Community Health*, 59(3), pp. 214-220.

Flores, M. T., Malmgren, B., Andersson, L., Andreasen, J. O., Bakland, L. K., Barnett, F., Bourguignon, C., DiAngelis, A., Hicks, L., Sigurdsson, A., Trope, M., Tsukiboshi, M. and von Arx, T. (2007) 'Guidelines for the management of traumatic dental injuries. III. Primary teeth', *Dental Traumatology*, 23(4), pp. 196-202.

Food and Agriculture Organization (2018) *Dietary assessment: a resource guide to method selection and application in low resource settings*. 1 edn. Rome, Italy: FAO, p. 1-172.

Food and Agriculture Organization of the United Nations (2022) *FAOSTAT, Food and agriculture data*. Available at: <https://www.fao.org/faostat/en/#data/FBS> (Accessed: 24/09/2022 2022).

Food Safety Authority of Ireland (2011) *Scientific recommendations for healthy eating guidelines in Ireland*, Dublin, Ireland. Available at: <https://www.fsai.ie/> (Accessed: 03/06/2022).

Food Safety Authority of Ireland (2021) *Scientific recommendations for food-based dietary guidelines for older adults in Ireland*, Dublin, Ireland. Available at: <https://www.fsai.ie/> (Accessed: 03/06/2022).

Fortier, I., Burton, P. R., Robson, P. J., Ferretti, V., Little, J., L'Heureux, F., Deschenes, M., Knoppers, B. M., Doiron, D., Keers, J. C., Linksted, P., Harris, J. R., Lachance, G., Boileau, C., Pedersen, N. L., Hamilton, C. M., Hveem, K., Borugian, M. J., Gallagher, R. P., McLaughlin, J., Parker, L., Potter, J. D., Gallacher, J., Kaaks, R., Liu, B., Sprosen, T., Vilain, A., Atkinson, S. A., Rengifo, A., Morton, R., Metspalu, A., Wichmann, H. E., Tremblay, M., Chisholm, R. L., Garcia-Montero, A., Hillege, H., Litton, J. E., Palmer, L. J., Perola, M., Wolffenbuttel, B. H., Peltonen, L. and Hudson, T. J. (2010) 'Quality, quantity and harmony: the DataSHaPER approach to integrating data across bioclinical studies', *International Journal of Epidemiology*, 39(5), pp. 1383-93.

Fortier, I., Doiron, D., Little, J., Ferretti, V., L'Heureux, F., Stolk, R. P., Knoppers, B. M., Hudson, T. J., Burton, P. R. and Initiative, o. b. o. t. I. H. (2011) 'Is rigorous retrospective harmonization possible? Application of the DataSHaPER approach across 53 large studies', *International Journal of Epidemiology*, 40(5), pp. 1314-1328.

Fortier, I., Dragieva, N., Saliba, M., Craig, C. and Robson, P. J. (2019) 'Harmonization of the health and risk factor questionnaire data of the Canadian Partnership for Tomorrow Project: a descriptive analysis', *CMAJ Open*, 7(2), pp. E272-E282.

Fortier, I., Raina, P., Van Den Heuvel, E. R., Griffith, L. E., Craig, C., Saliba, M., Doiron, D., Stolk, R. P., Knoppers, B. M., Ferretti, V., Granda, P. and Burton, P. (2016) 'Maelstrom Research guidelines for rigorous retrospective data harmonization', *International Journal of Epidemiology*, 46(1), pp. 103-115.

Fortier, I., Wey, T. W., Bergeron, J., Pinot De Moira, A., Nybo-Andersen, A.-M., Bishop, T., Murtagh, M. J., Miočević, M., Swertz, M. A., Van Enckevort, E., Marcon, Y., Mayrhofer, M. T., Ornelas, J. P., Sebert, S., Santos, A. C., Rocha, A., Wilson, R. C., Griffith, L. E. and Burton, P. (2023) 'Life course of retrospective harmonization initiatives: key elements to consider', *Journal of Developmental Origins of Health and Disease*, 14(2), pp. 190-198.

Fortin, M., Haggerty, J., Sanche, S. and Almirall, J. (2017) 'Self-reported versus health administrative data: implications for assessing chronic illness burden in populations. A cross-sectional study', *CMAJ Open*, 5(3), pp. e729-e733.

Foster, E. and Bradley, J. (2018) 'Methodological considerations and future insights for 24-hour dietary recall assessment in children', *Nutrition Research*, 51, pp. 1-11.

Gao, X., Hamzah, S. H., Yiu, C. K. Y., McGrath, C. and King, N. M. (2013) 'Dental fear and anxiety in children and adolescents: qualitative study using YouTube', *Journal of Medical Internet Research*, 15(2), pp. 1-11.

Garbarino, J. (1982) *Children and families in the social environment*. New York: Aldine Publishing Company, p. 1-296.

Gasmi Benahmed, A., Gasmi, A., Dadar, M., Arshad, M. and Bjorklund, G. (2021) 'The role of sugar-rich diet and salivary proteins in dental plaque formation and oral health', *Journal of Oral Biosciences*, 63(2), pp. 134-141.

Gavic, L., Tadin, A., Mihanovic, I., Gorseta, K. and Cigic, L. (2018) 'The role of parental anxiety, depression, and psychological stress level on the development of early-childhood caries in children', *International Journal of Paediatric Dentistry*, 28(6), pp. 616-623.

Genco, R. J., Grossi, S. G., Ho, A., Nishimura, F. and Murayama, Y. (2005) 'A proposed model linking inflammation to obesity, diabetes, and periodontal infections', *Journal of Periodontology*, 76, pp. 2075-2084.

Genco, R. J., Ho, A. W., Grossi, S. G., Dunford, R. G. and Tedesco, L. A. (1999) 'Relationship of stress, distress, and inadequate coping behaviors to periodontal disease', *Journal of Periodontology*, 70(7), pp. 711-723.

Giacaman, R. A. (2018) 'Sugars and beyond. The role of sugars and the other nutrients and their potential impact on caries', *Oral Diseases*, 24(7), pp. 1185-1197.

Gibson, R. S. (2005) *Principles of Nutritional Assessment*. Oxford, New York: Oxford University Press.

Gilbert, R., Lafferty, R., Hagger-Johnson, G., Harron, K., Zhang, L.-C., Smith, P., Dibben, C. and Goldstein, H. (2017) 'GUILD: GUIDance for Information about Linking Data sets+', *Journal of Public Health*, 40(1), pp. 191-198.

Glick, M., Williams, D. M., Kleinman, D. V., Vujcic, M., Watt, R. G. and Weyant, R. J. (2016) 'A new definition for oral health developed by the FDI World Dental Federation opens the door to a universal definition of oral health', *British dental journal*, 221(12), pp. 792-793.

Godson, J., Csikar, J. and White, S. (2018) 'Oral health of children in England: a call to action!', *Archives of Disease in Childhood*, 103(1), pp. 5-10.

Golafshar, M. A., Petersen, M., Vargas, C. E., Samadder, N. J., Kunze, K. L., McCormick, N., Watkin, S. A., Maleyeva, D., Cheng, T. W., Vargas, M. and DeWees, T. A. (2021) 'Utilizing open-source platforms to build and deploy interactive patient-reported quality of life tracking tools for monitoring protocol adherence', *Quality of Life Research*, 30(11), pp. 3189-3197.

Goldfeld, S., Francis, K. L., Hoq, M., Do, L., O'Connor, E. and Mensah, F. (2019) 'The impact of policy modifiable factors on inequalities in rates of child dental caries in Australia', *International Journal of Environmental Research and Public Health*, 16(11), pp. 1970.

Gomez, F., Crystal, Y., Ng, M. W., Crall, J. and Featherstone, J. (2010) 'Pediatric dental care: prevention and management protocols based on caries risk assessment', *Journal of the California Dental Association*, 38, pp. 746-761.

Götzfried, F. (2006) 'Legal aspects of fluoride in salt, particularly within the EU', *Schweiz Monatsschr Zahnmed*, 116(4), pp. 371-375.

Republic of Ireland, *Health (Fluoridation of Water Supplies) Act, 1960* (1960).

Republic of Ireland, *Fluoridation of Water Supplies Regulations 2007* (2007).

Grimes, D. A. and Schulz, K. F. (2002) 'Cohort studies: marching towards outcomes', *The Lancet*, 359(9303), pp. 341-345.

Guarnizo-Herreño, C. C., Watt, R. G., Garzón-Orjuela, N. and Tsakos, G. (2019) 'Explaining oral health inequalities in European welfare state regimes: The role of health behaviours', *Community Dentistry and Oral Epidemiology*, 47(1), pp. 40-48.

Gussy, M., Mnatzaganian, G., Dashper, S., Carpenter, L., Calache, H., Mitchell, H., Reynolds, E., Gibbs, L., Hegde, S., Adams, G., Johnson, S., Amezdroz, E. and Christian, B. (2020) 'Identifying predictors of early childhood caries among Australian children using sequential modelling: findings from the VicGen birth cohort study', *Journal of Dentistry*, 93, pp. 1-9.

Gussy, M. G., Waters, E. G., Walsh, O. and Kilpatrick, N. M. (2006) 'Early childhood caries: current evidence for aetiology and prevention', *Journal of Paediatrics and Child Health*, 42(1-2), pp. 37-43.

Gustafsson, B. E., Quensel, C. E., Lanke, L. S., Lundqvist, C., Grahnen, H., Bonow, B. E. and Krasse, B. (1954) 'The Vipeholm dental caries study; the effect of different levels of carbohydrate intake on caries activity in 436 individuals observed for five years', *Acta Odontologica Scandinavica*, 11(3-4), pp. 232-264.

Ha, D., Spencer, A., Moynihan, P., Thomson, W. and Do, L. (2021) 'Excess risk of dental caries from higher free sugars intake combined with low exposure to water fluoridation', *Journal of Dental Research*, 100(11), pp. 1243-1250.

Halfon, N. and Hochstein, M. (2002) 'Life Course Health Development: an integrated framework for developing health, policy, and research', *The Milbank Quarterly*, 80(3), pp. 433-479.

Halvorsrud, K., Lewney, J., Craig, D. and Moynihan, P. J. (2019) 'Effects of starch on oral health: systematic review to inform WHO guideline', *Journal of Dental Research*, 98(1), pp. 46-53.

Hampton, S. E., Anderson, S. S., Bagby, S. C., Gries, C., Han, X., Hart, E. M., Jones, M. B., Lenhardt, W. C., Macdonald, A., Michener, W. K., Mudge, J., Pourmokhtarian, A., Schildhauer, M. P., Woo, K. H. and Zimmerman, N. (2015) 'The Tao of open science for ecology', *Ecosphere*, 6(7), pp. 1-13.

Hancock, S., Zinn, C. and Schofield, G. (2020) 'The consumption of processed sugar-and starch-containing foods, and dental caries: a systematic review', *European Journal of Oral Sciences*, 128(6), pp. 467-475.

Hann, D., Winter, K. and Jacobsen, P. (1999) 'Measurement of depressive symptoms in cancer patients: evaluation of the Center for Epidemiological Studies Depression Scale (CES-D)', *Journal of Psychosomatic Research*, 46(5), pp. 437-443.

Hannigan, A., Villarroel, N., Roura, M., Lemaster, J., Basogomba, A., Bradley, C. and Macfarlane, A. (2020) 'Ethnicity recording in health and social care data collections in Ireland: where and how is it measured and what is it used for?', *International Journal for Equity in Health*, 19(1).

Harding, M. A. and O'Mullane, D. M. (2013) 'Water fluoridation and oral health', *Acta Medica Academica*, 42(2), pp. 131-139.

Harris, R. (1963) 'Biology of the children of Hopewood house, Bowral, Australia. 4. Observations on dental-caries experience extending over five years (1957-61)', *Journal of Dental Research*, 42(6), pp. 1387-1399.

Harris, R., Nicoll, A. D., Adair, P. M. and Pine, C. M. (2004) 'Risk factors for dental caries in young children: a systematic review of the literature', *Community dental health*, 21(1), pp. 71-85.

Hartman, A. M., Brown, C. C., Palmgren, J., Pietinen, P., Verkasalo, M., Myer, D. and Virtamo, J. (1990) 'Variability in nutrient and food intakes among older middle-aged men. Implications for design of epidemiologic and validation studies using food recording', *American Journal of Epidemiology*, 132(5), pp. 999-1012.

Hayden, C., Bowler, J. O., Chambers, S., Freeman, R., Humphris, G., Richards, D. and Cecil, J. E. (2013) 'Obesity and dental caries in children: a systematic review and meta-analysis', *Community Dentistry and Oral Epidemiology*, 41(4), pp. 289-308.

Heilmann, A., Tsakos, G. and Watt, R. G. (2015) 'Oral Health Over the Life Course', in Burton-Jeangros, C., Cullati, S., Sacker, A. and Blane, D. (eds.) *A Life Course Perspective on Health Trajectories and Transitions Life Course Research and Social Policies*. Cham (CH): Springer International Publishing, pp. 39-59.

Helminski, D., Kurlander, J. E., Renji, A. D., Sussman, J. B., Pfeiffer, P. N., Conte, M. L., Gadabu, O. J., Kokaly, A. N., Goldberg, R., Ranusch, A., Damschroder, L. J. and Landis-Lewis, Z. (2022) 'Dashboards in health care settings: protocol for a scoping review', *JMIR Research Protocols*, 11(3), pp. 1-9.

Higgs, S. (2015) 'Social norms and their influence on eating behaviours', *Appetite*, 86, pp. 38-44.

Hirleman, C. E. (2018) *The impact of dental caries on the oral health-related quality of life in children*. Master of Science degree in Dental Public Health in the Graduate College of The University of Iowa., University of Iowa 17/04/2021).

Hiyoshi, A., Fukuda, Y., Shipley, M. J. and Brunner, E. J. (2014) 'Health inequalities in Japan: the role of material, psychosocial, social relational and behavioural factors', *Social Science & Medicine*, 104, pp. 201-209.

Höhle, M. (2017) 'A statistician's perspective on digital epidemiology', *Life Sciences, Society and Policy*, 13(1), pp. 1-4.

Holland, T. J., Whelton, H., O'Mullane, D. M. and Creedon, P. (1995) 'Evaluation of a fortnightly school-based sodium fluoride mouthrinse 4 years following its cessation', *Caries Research*, 29(6), pp. 431-434.

Hong, J., Whelton, H., Douglas, G. and Kang, J. (2018) 'Consumption frequency of added sugars and UK children's dental caries', *Community Dentistry and Oral Epidemiology*, 46(5), pp. 457-464.

Hooley, M., Skouteris, H., Boganin, C., Satur, J. and Kilpatrick, N. (2012a) 'Body mass index and dental caries in children and adolescents: a systematic review of literature published 2004 to 2011', *Systematic Reviews*, 1, pp. 1-26.

Hooley, M., Skouteris, H., Boganin, C., Satur, J. and Kilpatrick, N. (2012b) 'Parental influence and the development of dental caries in children aged 0–6 years: a systematic review of the literature', *Journal of Dentistry*, 40(11), pp. 873-885.

Republic of Ireland, *Health Act, 1947* (1947).

Republic of Ireland, *Health (Eastern Regional Health Authority) Act, 1999* (1999).

Hu, K.-F., Chou, Y.-H., Wen, Y.-H., Hsieh, K.-P., Tsai, J.-H., Yang, P., Yang, Y.-H. and Lin, C.-H. R. (2016) 'Antipsychotic medications and dental caries in newly diagnosed schizophrenia: a nationwide cohort study', *Psychiatry research*, 245, pp. 45-50.

Hu, S., Sim, Y. F., Toh, J. Y., Saw, S. M., Godfrey, K. M., Chong, Y.-S., Yap, F., Lee, Y. S., Shek, L. P.-C., Tan, K. H., Chong, M. F.-F. and Hsu, C.-Y. S. (2019) 'Infant dietary patterns and early childhood caries in a multi-ethnic Asian cohort', *Scientific Reports*, 9(1), pp. 1-8.

Hu, X., Zhang, J., Qiu, Y. and Liu, Z. (2021) 'Periodontal disease and the risk of Alzheimer's disease and mild cognitive impairment: a systematic review and meta-analysis', *Psychogeriatrics*, 21(5), pp. 813-825.

Hugoson, A., Koch, G., Gothberg, C., Helkimo, A. N., Lundin, S. A., Norderyd, O., Sjodin, B. and Sondell, K. (2005) 'Oral health of individuals aged 3-80 years in Jonkoping, Sweden during 30 years (1973-2003). I. Review of findings on dental care habits and knowledge of oral health', *Swedish Dental Journal*, 29(4), pp. 125-138.

Humphrey, L. L., Fu, R., Buckley, D. I., Freeman, M. and Helfand, M. (2008) 'Periodontal disease and coronary heart disease incidence: a systematic review and meta-analysis', *Journal of general internal medicine*, 23(12), pp. 2079-2086.

Iannone, R., Allaire, J. and Borges, B. (2018) *flexdashboard: R markdown format for flexible dashboards*. Available at: <https://pkgs.rstudio.com/flexdashboard/>. <https://github.com/rstudio/flexdashboard/>. (Accessed: 09/05/2022).

Ibrahim, J. G. and Molenberghs, G. (2009) 'Missing data methods in longitudinal studies: a review', *Test*, 18(1), pp. 1-43.

Iheozor-Ejiofor, Z., Worthington, H. V., Walsh, T., O'Malley, L., Clarkson, J. E., Macey, R., Alam, R., Tugwell, P., Welch, V. and Glenny, A.-M. (2015) 'Water fluoridation for

the prevention of dental caries', *Cochrane Database of Systematic Reviews*, (6), pp. 1-261.

Ikeda, N. (2016) 'Secondary data analysis of national surveys in Japan toward improving population health', *Journal of Epidemiology*, 26(3), pp. 106-114.

Institute of Medicine (2005) *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids*. Washington, DC: The National Academies Press.

Irish Oral Health Services Guideline Initiative (2010) *Pit and Fissure Sealants: Evidence-based guidance on the use of sealants for the prevention and management of pit and fissure caries*. Available at: [https://www.dentalhealth.ie/assets/files/pdf/fs\\_guideline\\_online\\_final\\_v\\_2.pdf](https://www.dentalhealth.ie/assets/files/pdf/fs_guideline_online_final_v_2.pdf) (Accessed: 21/09/2021).

Irish Oral Health Services Guideline Initiative, I. (2009) *Strategies to prevent dental caries in children and adolescents: Evidence-based guidance on identifying high caries risk children and developing preventive strategies for high caries risk children in Ireland (Full guideline)*. Available at: [https://www.dentalhealth.ie/assets/files/pdf/full\\_strategies\\_finaleb.pdf](https://www.dentalhealth.ie/assets/files/pdf/full_strategies_finaleb.pdf) (Accessed: 12/01/2021).

Irish Universities Nutrition Alliance, I. (2012) *National Pre-School Nutrition Survey Summary Report June 2012*, Ireland. Available at: [www.iuna.net](http://www.iuna.net) <https://irp-cdn.multiscreensite.com/46a7ad27/files/uploaded/The%20National%20Pre-School%20Nutrition%20Survey%20Summary%20Report%20June%202012.pdf> (Accessed: 02/04/2021).

Irish Universities Nutrition Alliance, I. (2019) *National Children's Food Survey II, Main Report.*, Cork, Ireland. Available at: <https://www.iuna.net/surveyreports> (Accessed: 20/04/2021).

Jabin, Z., Vishnupriya, V., Agarwal, N., Nasim, I., Jain, M. and Sharma, A. (2020) 'Effect of 38% silver diamine fluoride on control of dental caries in primary dentition: a systematic review', *Journal of Family Medicine and Primary Care*, 9(3), pp. 1302-1307.

Jackson, S. L., Vann, W. F., Kotch, J. B., Pahel, B. T. and Lee, J. Y. (2011) 'Impact of poor oral health on children's school attendance and performance', *American Journal of Public Health*, 101(10), pp. 1900-1906.

Jaddoe, V. W. V., Felix, J. F., Andersen, A.-M. N., Charles, M.-A., Chatzi, L., Corpeleijn, E., Donner, N., Elhakeem, A., Eriksson, J. G. and Foong, R. (2020) 'The LifeCycle Project-EU Child Cohort Network: a federated analysis infrastructure and harmonized data of more than 250,000 children and parents', *European Journal of Epidemiology*, 35(7), pp. 709-724.

James, P., Harding, M., Beecher, T., Browne, D., Cronin, M., Guiney, H., O'Mullane, D. and Whelton, H. (2021) 'Impact of reducing water fluoride on dental caries and fluorosis', *Journal of Dental Research*, 100(5), pp. 507-514.

James, P., Harding, M., Beecher, T., Parnell, C., Browne, D., Tuohy, M., Kavanagh, D., O'Mullane, D., Guiney, H., Cronin, M. and Whelton, H. (2018a) 'Fluoride And Caring for Children's Teeth (FACCT): Clinical Fieldwork Protocol', *HRB Open Research*, 1, pp. 1-17.

James, S. L., Abate, D., Abate, K. H., Abay, S. M., Abbafati, C., Abbasi, N. and et al. (2018b) 'Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017', *The Lancet*, 392(10159), pp. 1789-1858.

Jepsen, S., Blanco, J., Buchalla, W., Carvalho, J. C., Dietrich, T., Dorfer, C., Eaton, K. A., Figuero, E., Frencken, J. E., Graziani, F., Higham, S. M., Kocher, T., Maltz, M., Ortiz-Vigon, A., Schmoekel, J., Sculean, A., Tenuta, L. M., van der Veen, M. H. and Machiulskiene, V. (2017) 'Prevention and control of dental caries and periodontal diseases at individual and population level: consensus report of group 3 of joint EFP/ORCA workshop on the boundaries between caries and periodontal diseases', *Journal of Clinical Periodontology*, 44 Suppl 18, pp. S85-S93.

Jevdjevic, M., Listl, S., Beeson, M., Rovers, M. and Matsuyama, Y. (2021) 'Forecasting future dental health expenditures: Development of a framework using data from 32 OECD countries', *Community Dentistry and Oral Epidemiology*, 49(3), pp. 256-266.

Jin, L. J., Lamster, I. B., Greenspan, J. S., Pitts, N. B., Scully, C. and Warnakulasuriya, S. (2016) 'Global burden of oral diseases: emerging concepts, management and interplay with systemic health', *Oral Diseases*, 22(7), pp. 609-619.

Joda, T., Bornstein, M. M., Jung, R. E., Ferrari, M., Waltimo, T. and Zitzmann, N. U. (2020) 'Recent trends and future direction of dental research in the digital era', *International Journal of Environmental Research and Public Health*, 17(6).

Joda, T., Waltimo, T., Pauli-Magnus, C., Probst-Hensch, N. and Zitzmann, N. U. (2018) 'Population-based linkage of Big Data in dental research', *International Journal of Environmental Research and Public Health*, 15(11), pp. 1-5.

Joda, T., Waltimo, T., Probst-Hensch, N., Pauli-Magnus, C. and Zitzmann, N. U. (2019) 'Health Data in Dentistry: An Attempt to Master the Digital Challenge', *Public Health Genomics*, 22(1-2), pp. 1-7.

Johansson, G., Åkesson, A., Berglund, M., Nermell, B. and Vahter, M. (1998) 'Validation with biological markers for food intake of a dietary assessment method used by Swedish women with three different with dietary preferences', *Public Health Nutrition*, 1(3), pp. 199-206.



Johansson, I. (2002) 'Milk and dairy products: possible effects on dental health', *Scandinavian Journal of Nutrition*, 46(3), pp. 119-122.

John, M. T., Sekulić, S., Bekes, K., Al-Harthy, M. H., Michelotti, A., Reissmann, D. R., Nikolovska, J., Sanivarapu, S., Lawal, F. B. and List, T. (2020) 'Why patients visit dentists—a study in all world health organization regions', *Journal of Evidence Based Dental Practice*, 20(3), pp. 1-12.

Johnson, S., Carpenter, L., Amezdroz, E., Dashper, S., Gussy, M., Calache, H., de Silva, A. M. and Waters, E. (2017) 'Cohort Profile: The VicGeneration (VicGen) study: An Australian oral health birth cohort', *International Journal of Epidemiology*, 46(1), pp. 29-30.

Johnston, M. P. (2014) 'Secondary data analysis: a method of which the time has come', *Qualitative and quantitative methods in libraries*, 3(3), pp. 619-626.

Joly, M.-P., Boivin, M., Junker, A., Bocking, A., Kramer, M. S. and Atkinson, S. A. (2012) 'An inventory of Canadian pregnancy and birth cohort studies: research in progress', *BMC Pregnancy and Childbirth*, 12(1), pp. 1-8.

Jordan, A. R., Becker, N., Jöhren, H.-P. and Zimmer, S. (2016) 'Early childhood caries and caries experience in permanent dentition: a 15-year cohort study', *Swiss Dental Journal*, 126(2), pp. 114-119.

Julihn, A., Cunha Soares, F., Hjern, A. and Dahllöf, G. (2021) 'Development level of the country of parental origin on dental caries in children of immigrant parents in Sweden', *Acta Paediatrica*, 110(8), pp. 2405-2414.

Jürgensen, N. and Petersen, P. (2013) 'Promoting oral health of children through schools—Results from a WHO global survey 2012', *Community Dental Health*, 30(4), pp. 204-18.

Kashket, S., Zhang, J. and Van Houte, J. (1996) 'Accumulation of fermentable sugars and metabolic acids in food particles that become entrapped on the dentition', *Journal of Dental Research*, 75(11), pp. 1885-1891.

Kassebaum, N. J., Smith, A. G. C., Bernabe, E., Fleming, T. D., Reynolds, A. E., Vos, T., Murray, C. J. L. and Marcenes, W. (2017) 'Global, regional, and national prevalence, incidence, and disability-adjusted life years for oral conditions for 195 countries, 1990–2015: a systematic analysis for the global burden of diseases, injuries, and risk factors', *Journal of Dental Research*, 96(4), pp. 380-387.

Kazemina, M., Abdi, A., Shohaimi, S., Jalali, R., Vaisi-Raygani, A., Salari, N. and Mohammadi, M. (2020) 'Dental caries in primary and permanent teeth in children's worldwide, 1995 to 2019: a systematic review and meta-analysis', *Head & Face Medicine*, 16(1), pp. 1-21.

Keane, C., Regan, M. and Walsh, B. (2021) 'Failure to take-up public healthcare entitlements: evidence from the Medical Card system in Ireland', *Social Science & Medicine*, 281, pp. 1-9.

Kehoe, L., Buffini, M., McNulty, B. A., Kearney, J. M., Flynn, A. and Walton, J. (2023) 'Food and nutrient intakes and compliance with recommendations in school-aged children in Ireland: findings from the National Children's Food Survey II (2017–2018) and changes since 2003–2004', *British Journal of Nutrition*, 129(11), pp. 2011-24.

Kelly, S. E., Binkley, C. J., Neace, W. P. and Gale, B. S. (2005) 'Barriers to care-seeking for children's oral health among low-income caregivers', *American Journal of Public Health*, 95(8), pp. 1345-1351.

Kirch, W. (2008) 'Oral health behavior', in Kirch, W. (ed.) *Encyclopedia of Public Health*. Dordrecht: Springer Netherlands, pp. 1040-1040.

Kirkevang, L.-L. and Wenzel, A. (2003) 'Risk indicators for apical periodontitis', *Community Dentistry and Oral Epidemiology*, 31(1), pp. 59-67.

Kirkmeyer, S. and Mattes, R. (2000) 'Effects of food attributes on hunger and food intake', *International Journal of Obesity*, 24(9), pp. 1167-1175.

Kirthiga, M., Murugan, M., Saikia, A. and Kirubakaran, R. (2019) 'Risk factors for early childhood caries: a systematic review and meta-analysis of case control and cohort studies', *Pediatric dentistry*, 41(2), pp. 95-112.

Klein, H., Palmer, C. E. and Knutson, J. W. (1938) 'Studies on dental caries: I. Dental status and dental needs of elementary school children', *Public Health Reports (1896-1970)*, 53(19), pp. 751-765.

Knorst, J. K., Sfreddo, C. S., de F. Meira, G., Zanatta, F. B., Vettore, M. V. and Ardenghi, T. M. (2021) 'Socioeconomic status and oral health-related quality of life: a systematic review and meta-analysis', *Community Dentistry and Oral Epidemiology*, 49(2), pp. 95-102.

Kolar, A. S., Patterson, R. E., White, E., Neuhouser, M. L., Frank, L. L., Standley, J., Potter, J. D. and Kristal, A. R. (2005) 'A practical method for collecting 3-day Food Records in a large cohort', *Epidemiology*, 16(4), pp. 579-583.

Kończyńska, M. and Schoene, M. (2018) 'Survey data harmonization and the quality of data documentation in cross-national surveys', in Johnson, T.P., Pennell, B.-E., Stoop, I.A.L. and Dorer, B. (eds.) *Advances in Comparative Survey Methods: Multinational, Multiregional, and Multicultural Contexts (3MC)*: John Wiley & Sons, Inc., pp. 963-984.

Koletzko, B., Baker, S., Cleghorn, G., Neto, U. F., Gopalan, S., Hernell, O., Hock, Q. S., Jirapinyo, P., Lonnerdal, B., Pencharz, P., Pzyrembel, H., Ramirez-Mayans, J., Shamir, R., Turck, D., Yamashiro, Y. and Zong-Yi, D. (2005) 'Global standard for the composition

of infant formula: recommendations of an ESPGHAN coordinated international expert group', *Journal of Pediatric Gastroenterology and Nutrition*, 41(5), pp. 584-599.

Kopp, W. (2019) 'How western diet and lifestyle drive the pandemic of obesity and civilization diseases', *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy*, 12, pp. 2221-2236.

Köster, E. P. (2009) 'Diversity in the determinants of food choice: a psychological perspective', *Food Quality and Preference*, 20(2), pp. 70-82.

Krieger, N. (2001) 'A glossary for social epidemiology', *Journal of Epidemiology & Community Health*, 55(10), pp. 693-700.

Krieger, N. (2008) 'Proximal, distal, and the politics of causation: what's level got to do with it?', *American Journal of Public Health*, 98(2), pp. 221-30.

Kuh, D., Ben-Shlomo, Y., Lynch, J., Hallqvist, J. and Power, C. (2003) 'Life course epidemiology', *Journal of Epidemiology & Community Health*, 57(10), pp. 778-783.

Kumar, C. S. (2015) 'Common risk factor approach: finding common ground for better health outcomes', *International Journal of Contemporary Medical Research*, 4(6), pp. 1367-1370.

Kundu, H., Patthi, B., Singla, A., Jankiram, C., Jain, S. and Singh, K. (2015) 'Dental caries scenario among 5, 12 and 15-year-old children in India-A retrospective analysis', *Journal of Clinical and Diagnostic Research: JCDR*, 9(7), pp. ZE01-ZE05.

Lachev, T. and Price, E. (2015) *Applied microsoft power BI: bring your data to life!*: Prologika Press.

Lagerweij, M. and van Loveren, C. (2020) 'Chapter 7: Sugar and dental Caries', in Zohoori, F. and Duckworth, R. (eds.) *The Impact of Nutrition and Diet on Oral Health: Vol. 28 Monographs in Oral Science*. New York: Karger Medical and Scientific Publishers, pp. 68-76.

Lakerveld, J., Loyen, A., Ling, F. C. M., De Craemer, M., Van Der Ploeg, H. P., O'Gorman, D. J., Carlin, A., Caprinica, L., Kalter, J., Oppert, J.-M., Chastin, S., Cardon, G., Brug, J. and Macdonncha, C. (2017) 'Identifying and sharing data for secondary data analysis of physical activity, sedentary behaviour and their determinants across the life course in Europe: general principles and an example from DEDIPAC', *BMJ Open*, 7(10), pp. 1-10.

Lakshman, R., Elks, C. E. and Ong, K. K. (2012) 'Childhood obesity', *Circulation*, 126(14), pp. 1770-1779.

LaValle, P., Glaros, A., Bohaty, B. and McCunniff, M. (2000) 'The effect of parental stress on the oral health of children', *Journal of Clinical Psychology in Medical Settings*, 7, pp. 197-201.

LaValle, S., Lesser, E., Shockley, R., Hopkins, M. S. and Kruschwitz, N. (2010) 'Big data, analytics and the path from insights to value', *MIT Sloan Management Review*, 52(2), pp. 21-32.

Leary, S. D. and Do, L. G. (2019) 'Changes in oral health behaviours between childhood and adolescence: findings from a UK cohort study', *Community Dentistry and Oral Epidemiology*, 47(5), pp. 367-373.

Lee, J. Y. and Divaris, K. (2014) 'The ethical imperative of addressing oral health disparities: a unifying framework', *Journal of Dental Research*, 93(3), pp. 224-30.

Leech, R. M., Worsley, A., Timperio, A. and McNaughton, S. A. (2015) 'Understanding meal patterns: definitions, methodology and impact on nutrient intake and diet quality', *Nutrition Research Reviews*, 28(1), pp. 1-21.

Lemasney, J., O'Mullane, D. and Coleman, M. (1984) 'Effect of fluoridation on dental health in 5- and 11-year-old Irish schoolchildren', *Community Dentistry and Oral Epidemiology*, 12(4), pp. 218-222.

Leong, P. M., Gussy, M. G., Barrow, S. Y., de Silva-Sanigorski, A. and Waters, E. (2013) 'A systematic review of risk factors during first year of life for early childhood caries', *International Journal of Paediatric Dentistry*, 23(4), pp. 235-250.

Leroy, R., Bogaerts, K., Hoppenbrouwers, K., Martens, L. C. and Declerck, D. (2013) 'Dental attendance in preschool children - a prospective study', *International Journal of Paediatric Dentistry*, 23(2), pp. 84-93.

Levin, K. A. (2006) 'Study design III: Cross-sectional studies', *Evidence-Based Dentistry*, 7(1), pp. 24-25.

Levin, L., Shpigel, I. and Peretz, B. (2013) 'The use of a self-report questionnaire for dental health status assessment: a preliminary study', *British Dental Journal*, 214(5), pp. E15-E15.

Li, K. Y., Okunseri, C. E., McGrath, C. and Wong, M. C. M. (2018) 'Trends in self-reported oral health of US adults: National Health and Nutrition Examination Survey 1999-2014', *Community Dentistry and Oral Epidemiology*, 46(2), pp. 203-211.

Lightowler, H. J. and Davies, G. J. (1998) 'Iodine intake and iodine deficiency in vegans as assessed by the duplicate-portion technique and urinary iodine excretion', *British Journal of Nutrition*, 80(6), pp. 529-535.

Lingstrom, P., van Houte, J. and Kashket, S. (2000) 'Food starches and dental caries', *Critical Reviews in Oral Biology & Medicine*, 11(3), pp. 366-380.

Liska, D., Kelley, M. and Mah, E. (2019) '100% fruit juice and dental health: a systematic review of the literature', *Frontiers in Public Health*, 7, pp. 1-14.

- Listl, S., Galloway, J., Mossey, P. A. and Marcenes, W. (2015) 'Global economic impact of dental diseases', *Journal of Dental Research*, 94(10), pp. 1355-1361.
- Livingstone, M. B. E., Robson, P. J. and Wallace, J. M. W. (2004) 'Issues in dietary intake assessment of children and adolescents', *British Journal of Nutrition*, 92(S2), pp. S213-S222.
- Lock, N. C., Susin, C., Brusius, C. D., Maltz, M. and Alves, L. S. (2019) 'Obesity and dental caries among South Brazilian schoolchildren: a 2.5-year longitudinal study', *Brazilian Oral Research*, 33, pp. 1-9.
- Locker, D. (2000) 'Deprivation and oral health: a review', *Community Dentistry and Oral Epidemiology*, 28(3), pp. 161-169.
- Locker, D., Clarke, M. and Payne, B. (2000) 'Self-perceived oral health status, psychological well-being, and life satisfaction in an older adult population', *Journal of Dental Research*, 79(4), pp. 970-975.
- Locker, D. and Jokovic, A. (1996) 'Using subjective oral health status indicators to screen for dental care needs in older adults', *Community Dentistry and Oral Epidemiology*, 24(6), pp. 398-402.
- Locker, D., Maggiri, J. and Quiñonez, C. (2011) 'Income, dental insurance coverage, and financial barriers to dental care among Canadian adults', *Journal of Public Health Dentistry*, 71(4), pp. 327-334.
- Loginova, J. and Wohland, P. (2020) 'How to create an interactive dashboard using R: the example of the Queensland COVID-19 tracker', *Australian Population Studies*, 4(2), pp. 39-47.
- Lowndes, J. S. S., Best, B. D., Scarborough, C., Afflerbach, J. C., Frazier, M. R., O'Hara, C. C., Jiang, N. and Halpern, B. S. (2017) 'Our path to better science in less time using open data science tools', *Nature Ecology & Evolution*, 1(6), pp. 1-7.
- Luzzi, L., Chrisopoulos, S. and Brennan, D. S. (2014) 'Decline in usually visiting the dentist for a problem in Australia, 1994 to 2010: an age-period-cohort analysis', *Community Dentistry and Oral Epidemiology*, 42(4), pp. 349-357.
- Ma, Y., Olendzki, B. C., Pagoto, S. L., Hurley, T. G., Magner, R. P., Ockene, I. S., Schneider, K. L., Merriam, P. A. and Hébert, J. R. (2009) 'Number of 24-hour diet recalls needed to estimate energy intake', *Annals of Epidemiology*, 19(8), pp. 553-559.
- Maliderou, M., Reeves, S. and Noble, C. (2006) 'The effect of social demographic factors, snack consumption and vending machine use on oral health of children living in London', *British Dental Journal*, 201(7), pp. 441-444.

Malikaew, P., Watt, R. G. and Sheiham, A. (2003) 'Associations between school environments and childhood traumatic dental injuries', *Oral Health and Preventive Dentistry*, 1(4), pp. 255-266.

Malmo University and World Health Organisation (2022) *Oral Health Country/Area Profile Project*. Available at: <https://capp.mau.se/dental-caries/> (Accessed: 09/09/2022).

Mamai-Homata, E., Koletsi-Kounari, H. and Margaritis, V. (2016) 'Gender differences in oral health status and behavior of Greek dental students: a meta-analysis of 1981, 2000, and 2010 data', *Journal of International Society of Preventive and Community Dentistry*, 6(1), pp. 60-8.

Mann, C. (2003) 'Observational research methods. Research design II: cohort, cross sectional, and case-control studies', *Emergency Medicine Journal*, 20(1), pp. 54-60.

Manohar, N., Hayen, A., Scott, J. A., Do, L. G., Bhole, S. and Arora, A. (2021) 'Impact of dietary trajectories on obesity and dental caries in preschool children: findings from the Healthy Smiles Healthy Kids Study', *Nutrients*, 13(7), pp. 1-19.

Mariëlle, Jan, Paula and Annemarie (2021) 'Experiencing financial strain and clinically assessed caries experience in dentate adults aged 25–44 years: an exploration of potential pathways', *Caries Research*, 55(1), pp. 63-72.

Marinho, V. C., Higgins, J., Logan, S. and Sheiham, A. (2003) 'Fluoride toothpastes for preventing dental caries in children and adolescents', *Cochrane Database of Systematic Reviews*, 2016(11), pp. 1-93.

Marmot, M. and Bell, R. (2011) 'Social determinants and dental health', *Advances in Dental Research* 23(2), pp. 201-206.

Marsh, P. D. (2006) 'Dental plaque as a biofilm and a microbial community - implications for health and disease', *BMC Oral Health*, 6 (Suppl 1), pp. 1-7.

Marthaler, T. M. (2004) 'Changes in dental caries 1953–2003', *Caries Research*, 38(3), pp. 173-181.

Marthaler, T. M., Brunelle, J., Downer, M. C., König, K. G., Künzel, G. J., O'Mullane, D. M., Møller, I. J., Von Der Fehr, F. R. and Vrbic, V. (1996) 'The prevalence of dental caries in Europe 1990-1995', *Caries Research*, 30(4), pp. 237-255.

Martínez-Mier, E. A. (2011) 'Fluoride: its metabolism, toxicity, and role in dental health', *Journal of Evidence-Based Complementary & Alternative Medicine*, 17(1), pp. 28-32.

Massey University (2023) *Access to fluoridated drinking-water*. Wellington, New Zealand: Ministry of Health. Available at:

<https://www.ehinz.ac.nz/indicators/water/drinking-water-quality/access-to-fluoridated-drinking-water/> (Accessed: 15/05/2023).

Matsuyama, Y., Fujiwara, T. and Aida, J. (2023) 'Tap water natural fluoride and parent-reported experience of child dental caries in Japan: evidence from a nationwide birth cohort survey', *Community Dentistry and Oral Epidemiology*, 51(6), pp. 1141-1149.

Mayo, C. D., Farzam-Kia, N. and Ghahari, S. (2021) 'Identifying barriers to and facilitators of health service access encountered by individuals with multiple sclerosis', *International Journal of MS Care*, 23(1), pp. 37-44.

McDonagh, M. S., Whiting, P. F., Wilson, P. M., Sutton, A. J., Chestnutt, I., Cooper, J., Misso, K., Bradley, M., Treasure, E. and Kleijnen, J. (2000) 'Systematic review of water fluoridation', *BMJ*, 321(7265), pp. 855-859.

McNamara, E., O'Mahony, D. and Murray, A. (2020) *Design, instrumentation and procedures for cohort '08 of Growing Up in Ireland at 9 years old (wave 5)* [Technical ], Dublin: ESRI/TCD/DCEDIY. Available at: <https://www.esri.ie/publications/design-instrumentation-and-procedures-for-cohort-08-of-growing-up-in-ireland-at-9> (Accessed: 10/07/2021).

McNamara, E., O'Reilly, C., Murray, A., O'Mahony, D., Williams, J., Murphy, D., McClintock, R. and Watson, D. (2021) *Design, instrumentation and procedures for Cohort '98 (child cohort) at wave 4 (20 years of age)*, Dublin: ESRI/TCD/DCEDIYTECHNICAL SERIES NUMBER 2021 - 2). Available at: <https://www.growingup.gov.ie/pubs/20Yr-Design-Report.pdf> (Accessed: 24/09/2022).

Medical Research Council of Ireland (1953) *Dental caries in Ireland*, Dublin, Ireland. Available at: <http://hdl.handle.net/10147/345722> (Accessed: 04/11/2021).

Melnyk, L. J., McCombs, M., Brown, G. G., Raymer, J., Nishioka, M., Buehler, S., Freeman, N. and Michael, L. C. (2012) 'Community duplicate diet methodology: a new tool for estimating dietary exposures to pesticides', *Journal of Environmental Monitoring*, 14(1), pp. 85-93.

Mennella, J. A. (2014) 'Ontogeny of taste preferences: basic biology and implications for health', *The American Journal of Clinical Nutrition*, 99(3), pp. 704S-711S.

Menon, I., Nagarajappa, R., Ramesh, G. and Tak, M. (2013) 'Parental stress as a predictor of early childhood caries among preschool children in India', *International Journal of Paediatric Dentistry*, 23(3), pp. 160-165.

Mid-Western Health Board (1998) *Survey of Oral Health of Children and Adolescents, 1997*, Ireland: Oral Health Services Research Center. University College Cork (Accessed: 12/11/2021).

Mika, A., Mitus-Kenig, M., Zeglen, A., Drapella-Gasior, D., Rutkowska, K. and Josko-Ochojska, J. (2018) 'The child's first dental visit. Age, reasons, oral health status and dental treatment needs among children in Southern Poland', *European Journal of Paediatric Dentistry*, 19(4), pp. 265-270.

Mikkonen, J., Remes, H., Moustgaard, H. and Martikainen, P. (2020) 'Evaluating the role of parental education and adolescent health problems in educational attainment', *Demography*, 57(6), pp. 2245-2267.

Mofidi, M., Rozier, R. G. and King, R. S. (2002) 'Problems with access to dental care for Medicaid-insured children: what caregivers think', *American Journal of Public Health*, 92(1), pp. 53-58.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G. and Group\*, P. (2009) 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement', *Annals of Internal Medicine*, 151(4), pp. 264-269.

Moimaz, S. A., Fadel, C. B., Lolli, L. F., Garbin, C. A., Garbin, A. J. and Saliba, N. A. (2014) 'Social aspects of dental caries in the context of mother-child pairs', *Journal of Applied Oral Science*, 22(1), pp. 73-78.

Mörmann, J. E. and Mühlemann, H. R. (1981) 'Oral starch degradation and its influence on acid production in human dental plaque', *Caries Research*, 15(2), pp. 166-175.

Moskowitz, H. R. (1970) 'Ratio scales of sugar sweetness', *Perception & Psychophysics*, 7(5), pp. 315-320.

Mount, J. and Zumel, N. (2019) *Practical data science with R*. 2nd edn.: Simon and Schuster.

Moynihan, P. (2000) 'Foods and factors that protect against dental caries', *Nutrition Bulletin*, 25(4), pp. 281-286.

Moynihan, P. (2005) 'The interrelationship between diet and oral health', *Proceedings of the Nutrition Society*, 64(4), pp. 571-580.

Moynihan, P. (2016) 'Sugars and dental caries: evidence for setting a recommended threshold for Intake', *Advances in Nutrition*, 7(1), pp. 149-56.

Moynihan, P., Makino, Y., Petersen, P. E. and Ogawa, H. (2018) 'Implications of WHO guideline on sugars for dental health professionals', *Community Dentistry and Oral Epidemiology*, 46(1), pp. 1-7.

Moynihan, P. and Petersen, P. E. (2004) 'Diet, nutrition and the prevention of dental diseases', *Public Health Nutrition*, 7(1A), pp. 201-226.

Moynihan, P., Tanner, L. M., Holmes, R. D., Hillier-Brown, F., Mashayekhi, A., Kelly, S. A. M. and Craig, D. (2019) 'Systematic review of evidence pertaining to factors that



modify risk of early childhood caries', *JDR Clinical & Translational Research*, 4(3), pp. 202-216.

Moynihan, P., Thomason, M., Walls, A., Gray-Donald, K., Morais, J. A., Ghanem, H., Wollin, S., Ellis, J., Steele, J., Lund, J. and Feine, J. (2009) 'Researching the impact of oral health on diet and nutritional status: methodological issues', *Journal of Dentistry*, 37(4), pp. 237-249.

Moynihan, P. J. (2002) 'Dietary advice in dental practice', *British dental journal*, 193(10), pp. 563-568.

Moynihan, P. J. and Kelly, S. A. (2014) 'Effect on Caries of Restricting Sugars Intake: Systematic Review to inform WHO Guidelines', *Journal of Dental Research*, 93(1), pp. 8-18.

Mueller, C. W. and Parcel, T. L. (1981) 'Measures of socioeconomic status: alternatives and recommendations', *Child Development*, 52(1), pp. 13-30.

Munn, Z., Moola, S., Lisy, K., Riitano, D. and Tufanaru, C. (2015) 'Methodological guidance for systematic reviews of observational epidemiological studies reporting prevalence and cumulative incidence data', *JBIM Evidence Implementation*, 13(3), pp. 147-153.

Murphy, J., Duprey, M. A., Chew, R., Biemer, P., Harris, K. M. and Halpern, C. T. (2019) 'Interactive visualization to facilitate monitoring longitudinal survey data and paradata', *RTI Press*.

Murray, A., McCrory, C., Thornton, M., Williams, J., Quail, A., Swords, L., Doyle, E. and Harris, E. (2010) *Growing Up in Ireland: Design, instrumentation and procedures for the Child Cohort (aged 9 years)*, Dublin: ESRI/TCD/DCYA (Child Cohort Technical Report No. 1. Available at: <https://www.growingup.ie/pubs/BKMNEXT255.pdf> (Accessed: 14/01/2021).

Murray, J. J., Vernazza, C. R. and Holmes, R. D. (2015) 'Forty years of national surveys: An overview of children's dental health from 1973-2013', *British Dental Journal*, 219(6), pp. 281-285.

Myatt, L., Roberts, J. M. and Redman, C. W. G. (2017) 'Availability of COLLECT, a database for pregnancy and placental research studies worldwide', *Placenta*, 57, pp. 223-224.

Nascimento, M., Cunha Soares, F., Dahllöf, G., Burgos Souto Maior, G., Kvist, T. and Colares, V. (2021) 'Determinants of self-perceived oral health in adolescents: a cross-sectional study', *International Journal of Paediatric Dentistry*, 31(2), pp. 254-261.

Nascimento, P. C., Castro, M. M. L., Magno, M. B., Almeida, A., Fagundes, N. C. F., Maia, L. C. and Lima, R. R. (2019) 'Association between periodontitis and cognitive impairment in adults: a systematic review', *Frontiers in Neurology* 10, pp. 1-9.

Naska, A., Berg, M.-A., Cuadrado, C., Freisling, H., Gedrich, K., Gregorič, M., Kelleher, C., Leskova, E., Nelson, M., Pace, L., Remaut, A.-M., Rodrigues, S., Sekula, W., Sjöström, M., Trygg, K., Turrini, A., Volatier, J. L., Zajkas, G. and Trichopoulou, A. (2008) 'Food balance sheet and household budget survey dietary data and mortality patterns in Europe', *British Journal of Nutrition*, 102(1), pp. 166-171.

Naska, A., Lagiou, A. and Lagiou, P. (2017) 'Dietary assessment methods in epidemiological research: current state of the art and future prospects', *F1000Research*, 6(F1000 Faculty Rev), pp. 1-8.

Ndanuko, R. N., Tapsell, L. C., Charlton, K. E., Neale, E. P. and Batterham, M. J. (2016) 'Dietary patterns and blood pressure in adults: a systematic review and meta-analysis of randomized controlled trials', *Advances in Nutrition*, 7(1), pp. 76-89.

Nederhof, A. J. (1985) 'Methods of coping with social desirability bias: a review', *European Journal of Social Psychology*, 15(3), pp. 263-280.

Neuhaus, K. W., Ellwood, R., Lussi, A. and Pitts, N. B. (2009) 'Traditional lesion detection aids', *Monographs in Oral Science*, 21, pp. 42-51.

Newbrun, E. (1989) 'Effectiveness of water fluoridation', *Journal of Public Health Dentistry*, 49(5), pp. 279-289.

Ngo, J., Engelen, A., Molag, M., Roesle, J., García-Segovia, P. and Serra-Majem, L. (2009) 'A review of the use of information and communication technologies for dietary assessment', *British Journal of Nutrition*, 101(S2), pp. S102-S112.

Nicolau, B., Thomson, W. M., Steele, J. G. and Allison, P. J. (2007) 'Life-course epidemiology: concepts and theoretical models and its relevance to chronic oral conditions', *Community Dentistry and Oral Epidemiology*, 35(4), pp. 241-249.

North Eastern Health Board (1996) *Children's Dental Health in the North Eastern Health Board Region, 1995*, Ireland: Oral Health Services Research Center. University College Cork (Accessed: 12/11/2021).

North Western Health Board (1998) *Survey of Oral Health of Children and Adolescents, 1997/'98*, Ireland: Oral Health Services Research Center. University College Cork. Available at: <http://hdl.handle.net/10147/559289> (Accessed: 08/11/2021).

Nöthlings, U., Hoffmann, K., Bergmann, M. M. and Boeing, H. (2007) 'Fitting portion sizes in a self-administered food frequency questionnaire', *The Journal of Nutrition*, 137(12), pp. 2781-2786.

Novrinda, H., Han, D. H., Jung-Choi, K. and Ryu, J. I. (2019) 'Neo-Marxian social class inequalities in oral health among the South Korean population', *Community Dentistry and Oral Epidemiology*, 47(2), pp. 162-170.

O'Hickey, S. and Pigott, B. (1981) 'Dental caries experience of Dublin school-children after 5 1/2 years of fluoridation', *Journal of Irish Dental Association*, 27, pp. 78-83.

O'Hickey, S. and Pigott, B. (1983) 'Dental caries experience of Dublin school-children after 10 1/2 years of fluoridation', *Journal of Irish Dental Association*, 29(1), pp. 5-8.

O'Leary-Kelly, S. W. and J. Vokurka, R. (1998) 'The empirical assessment of construct validity', *Journal of Operations Management*, 16(4), pp. 387-405.

O'Mullane, D., Clarkson, J., Holland, T., O'Hickey, S. and Whelton, H. (1988) 'Effectiveness of water fluoridation in the prevention of dental caries in Irish children', *Community Dental Health*, 5(4), pp. 331-344.

O'Mullane, D., Clarkson, J., Holland, T., O'Hickey, S., Whelton, H., Health, M. f. and Cork, U. C. (1986) *Children's Dental Health in Ireland, 1984: A Survey Conducted on behalf of the Minister for Health by University College Cork*, Dublin: Department of Health Ireland. Available at: <http://hdl.handle.net/10147/575361> (Accessed: 10/11/2021).

O'Mullane, D., Clarkson, J. and Parnell, C. (2018) *Report of the working group on the use of fluoride toothpaste in children under six years of age*. Available at: <https://assets.gov.ie/9611/b5b0d7e8830347eca2efa32d599f48d3.pdf> (Accessed: 12/08/2022).

O'Neill, D., Benzeval, M., Boyd, A., Calderwood, L., Cooper, C., Corti, L., Dennison, E., Fitzsimons, E., Goodman, A., Hardy, R., Inskip, H., Molloy, L., Sacker, A., Sudlow, A., Sullivan, A. and Park, A. (2019) 'Data Resource Profile: Cohort and Longitudinal Studies Enhancement Resources (CLOSER)', *International Journal of Epidemiology*, 48(3), pp. 675-676.

Oh, T.-J., Eber, R. and Wang, H.-L. (2002) 'Periodontal diseases in the child and adolescent', *Journal of Clinical Periodontology*, 29(5), pp. 400-410.

Okpara, C., Edokwe, C., Ioannidis, G., Papaioannou, A., Adachi, J. D. and Thabane, L. (2022) 'The reporting and handling of missing data in longitudinal studies of older adults is suboptimal: a methodological survey of geriatric journals', *BMC Medical Research Methodology*, 22(1), pp. 1-9.

Oliver, G. and Wardle, J. (1999) 'Perceived effects of stress on food choice', *Physiology & behavior*, 66(3), pp. 511-515.

Oliver, G., Wardle, J. and Gibson, E. L. (2000) 'Stress and food choice: a laboratory study', *Psychosomatic Medicine*, 62(6), pp. 853-865.

Onyejaka, N. K., Folayan, M. O. and Folaranmi, N. (2016) 'Barriers and facilitators of dental service utilization by children aged 8 to 11 years in Enugu State, Nigeria', *BMC Health Services Research*, 16, pp. 1-9.

Oosterhoff, M., Joore, M. A., Bartelink, N. H. M., Winkens, B., Schayck, O. C. P. and Bosma, H. (2019) 'Longitudinal analysis of health disparities in childhood', *Archives of Disease in Childhood*, 104(8), pp. 781-788.

Opal, S., Garg, S., Jain, J. and Walia, I. (2015) 'Genetic factors affecting dental caries risk', *Australian Dental Journal*, 60(1), pp. 2-11.

Oral Health Services Research Centre. University College Cork (2018) *OHSRC Briefing Document on HRB funded Fluoride and Caring for Children's Teeth study (FACCT)*, Ireland. Available at: <https://assets.gov.ie/9587/a7123c5bd5724ca59b3c7e9a64bae54f.pdf> (Accessed: 24/12/2021).

Ortega, R. M., Pérez-Rodrigo, C. and López-Sobaler, A. M. (2015) 'Dietary assessment methods: dietary records', *Nutricion hospitalaria*, 31(3), pp. 38-45.

Östberg, A.-L., Eriksson, B., Lindblad, U. and Halling, A. (2003) 'Epidemiological dental indices and self-perceived oral health in adolescents: ecological aspects', *Acta Odontologica Scandinavica*, 61(1), pp. 19-24.

Ouzzani, M., Hammady, H., Fedorowicz, Z. and Elmagarmid, A. (2016) 'Rayyan—a web and mobile app for systematic reviews', *Systematic reviews*, 5(1), pp. 1-10.

Pabbla, A., Duijster, D., Grasveld, A., Sekundo, C., Agyemang, C. and Van Der Heijden, G. (2021) 'Oral health status, oral health behaviours and oral health care utilisation among migrants residing in Europe: a systematic review', *Journal of Immigrant and Minority Health*, 23(2), pp. 373-388.

Paisi, M., Kay, E., Bennett, C., Kaimi, I., Witton, R., Nelder, R. and Lapthorne, D. (2019) 'Body mass index and dental caries in young people: a systematic review', *BMC Pediatrics*, 19(1), pp. 1-9.

Paisi, M., Kay, E., Kaimi, I., Witton, R., Nelder, R., Christophi, C. and Lapthorne, D. (2018) 'Obesity and dental caries in young children in Plymouth, United Kingdom: a spatial analysis', *Community Dental Health* 35(1), pp. 58-64.

Palacios, C. (2006) 'The role of nutrients in bone health, from A to Z', *Critical reviews in food science and nutrition*, 46(8), pp. 621-628.

Parnell, C., Whelton, H. and O'Mullane, D. (2009) 'Water fluoridation', *European Archives of Paediatric Dentistry*, 10(3), pp. 141-148.

Patel, R. (2012) *The State of Oral Health in Europe. Report Commissioned by the Platform for Better Oral Health in Europe*. Available at: <http://www.oralhealthplatform.eu/wp-content/uploads/2015/09/Report-the-State-of-Oral-Health-in-Europe.pdf> (Accessed: 11/01/2021).

- Patel, R. N., Eaton, K., Pitts, N., Schulte, A., Pieper, K. and White, S. (2016) 'Variation in methods used to determine national mean DMFT scores for 12-year-old children in European countries', *Community Dental Health*, 33(4), pp. 286-291.
- Pearce, M. S., Unwin, N. C., Parker, L. and Craft, A. W. (2009) 'Cohort Profile: The Newcastle Thousand Families 1947 Birth Cohort', *International Journal of Epidemiology*, 38(4), pp. 932-937.
- Peng, R. D. (2009) 'Reproducible research and biostatistics', *Biostatistics*, 10(3), pp. 405-408.
- Peng, R. D. (2011) 'Reproducible research in computational science', *Science*, 334(6060), pp. 1226-1227.
- Peng, R. D. and Hicks, S. C. (2021) 'Reproducible research: a retrospective', *Annual Review of Public Health*, 42(1), pp. 79-93.
- Perera, I. and Ekanayake, L. (2008) 'Factors influencing perception of oral health among adolescents in Sri Lanka', *International Dental Journal* 58(6), pp. 349-55.
- Perera, I. and Ekanayake, L. (2010) 'Social inequality in perceived oral health among Sri Lankan adolescents', *Community Dental Health*, 27(1), pp. 29-34.
- Peres, K. G., Nascimento, G. G., Gupta, A., Singh, A., Cassiano, L. S. and Rugg-Gunn, A. J. (2022) 'Scoping review of oral health-related birth cohort studies: toward a global consortium', *Journal of Dental Research*, 101(6), pp. 632-646.
- Peres, K. G., Thomson, W. M., Chaffee, B. W., Peres, M. A., Birungi, N., Do, L. G., Feldens, C. A., Fontana, M., Marshall, T. A., Pitiphat, W., Seow, W. K., Wagner, Y., Wong, H. M. and Rugg-Gunn, A. J. (2020a) 'Oral health birth cohort studies: achievements, challenges, and potential', *Journal of Dental Research*, 99(12), pp. 1321-1331.
- Peres, M. A., Daly, B., Guarnizo-Herreño, C. C., Benzian, H. and Watt, R. G. (2020b) 'Oral diseases: a global public health challenge-authors' reply', *The Lancet*, 395(10219), pp. 186-187.
- Peres, M. A., Macpherson, L. M. D., Weyant, R. J., Daly, B., Venturelli, R., Mathur, M. R., Listl, S., Celeste, R. K., Guarnizo-Herreño, C. C., Kearns, C., Benzian, H., Allison, P. and Watt, R. G. (2019) 'Oral diseases: a global public health challenge', *The Lancet*, 394(10194), pp. 249-260.
- Peres, M. A., Peres, K. G., de Barros, A. J. and Victora, C. G. (2007a) 'The relation between family socioeconomic trajectories from childhood to adolescence and dental caries and associated oral behaviours', *Journal of Epidemiology & Community Health*, 61(2), pp. 141-145.

Peres, M. A., Peres, K. G., De Barros, A. J. D. and Victora, C. G. (2007b) 'The relation between family socioeconomic trajectories from childhood to adolescence and dental caries and associated oral behaviours', *Journal of Epidemiology & Community Health*, 61(2), pp. 141-145.

Peruzzo, D. C., Benatti, B. B., Ambrosano, G. M. B., Nogueira-Filho, G. R., Sallum, E. A., Casati, M. Z. and Nociti Jr., F. H. (2007) 'A systematic review of stress and psychological factors as possible risk factors for periodontal disease', *Journal of Periodontology*, 78(8), pp. 1491-1504.

Petersen, P. E. (2003) 'The World Oral Health Report 2003: continuous improvement of oral health in the 21st century - the approach of the WHO Global Oral Health Programme', *Community Dentistry and Oral Epidemiology*, 31(s1), pp. 3-24.

Petersen, P. E. (2005) 'Sociobehavioural risk factors in dental caries—international perspectives', *Community Dentistry and Oral Epidemiology*, 33(4), pp. 274-279.

Petersen, P. E., Bourgeois, D., Ogawa, H., Estupinan-Day, S. and Ndiaye, C. (2005) 'The global burden of oral diseases and risks to oral health', *Bulletin of the World Health Organization*, 83, pp. 661-669.

Petersen, P. E. and Lennon, M. A. (2004) 'Effective use of fluorides for the prevention of dental caries in the 21st century: the WHO approach', *Community Dentistry and Oral Epidemiology*, 32(5), pp. 319-321.

Petersen, P. E. and Ogawa, H. (2016) 'Prevention of dental caries through the use of fluoride—the WHO approach', *Community Dental Health*, 33(2), pp. 66-68.

Petersen, P. E., Ramon, J. B. and World Health Organisation (2013) *Oral Health Surveys: Basic Methods*. 5th edn. France: World Health Organization.

Pitts, N., Chadwick, B. and Anderson, T. (2015) *Children's Dental Health Survey 2013. Report 2: Dental disease and damage in children England, Wales and Northern Island* England: Health & Social Care Information Centre. Available at: <https://files.digital.nhs.uk/publicationimport/pub17xxx/pub17137/cdhs2013-report2-dental-disease.pdf> (Accessed: 22/09/2022).

Pitts, N. B., Evans, D. J. and Pine, C. M. (1997) 'British Association for the Study of Community Dentistry (BASCD) diagnostic criteria for caries prevalence surveys-1996/97', *Community Dental Health*, 14 pp. 6-9.

Polk, D. E., Weyant, R. J. and Manz, M. C. (2010) 'Socioeconomic factors in adolescents' oral health: are they mediated by oral hygiene behaviors or preventive interventions?', *Community Dentistry and Oral Epidemiology*, 38(1), pp. 1-9.

Pollard, J., Kirk, S. F. L. and Cade, J. E. (2002) 'Factors affecting food choice in relation to fruit and vegetable intake: a review', *Nutrition Research Reviews*, 15(2), pp. 373-387.

Popkin, B., Duffey, K. and Gordonlarsen, P. (2005) 'Environmental influences on food choice, physical activity and energy balance', *Physiology & Behavior*, 86(5), pp. 603-613.

Public Health Agency of Canada (2022) *The State of Community Water Fluoridation Across Canada*, Canada: Public Health Agency of Canada Ottawa, ON, Canada. Available at: <https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/healthy-living/community-water-fluoridation-across-canada/community-water-fluoridation-across-canada-eng.pdf> (Accessed: 16/05/2023).

Public Health England (2020) *National Dental Epidemiology Programme for England: Oral health survey of 5-year-olds 2019. A report on the variations in prevalence and severity of dental decay*, London. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/873492/NDEP for England OH Survey 5yr 2019 v1.0.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/873492/NDEP_for_England_OH_Survey_5yr_2019_v1.0.pdf) (Accessed: 08/07/2021).

Public Health England (2021) *National Dental Epidemiology Programme for England: oral health survey of 3-year-old children 2020 A report on the prevalence and severity of dental decay Version 2*: Public Health England. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/987179/NDEP for England OH Survey 3yr 2020 v2.0.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/987179/NDEP_for_England_OH_Survey_3yr_2020_v2.0.pdf) (Accessed: 08/07/2021).

Public Health England and Food Standards Agency (2019) *National Diet and Nutrition Survey, Years 1 to 9 of the Rolling Programme (2008/2009 – 2016/2017): Time trend and income analyses*, London. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/772434/NDNS UK Y1-9 report.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/772434/NDNS_UK_Y1-9_report.pdf) (Accessed: 24/04/2022).

Public Health England, P. (2014) *Dental public health epidemiology programme Oral health survey of three-year-old children 2013 A report on the prevalence and severity of dental decay*. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/773621/Oral health survey of 3 year old children 2013.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/773621/Oral_health_survey_of_3_year_old_children_2013.pdf) (Accessed: 28/01/2021).

Public Health England, P. (2018) *National Dental Epidemiology Programme for England: oral health survey of five-year-old children 2017 A report on the inequalities found in prevalence and severity of dental decay.*, London: Public Health England. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/768368/NDEP for England OH Survey 5yr 2017 Report.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/768368/NDEP_for_England_OH_Survey_5yr_2017_Report.pdf) (Accessed: 08/07/2021).

Public Health England, P. and Department of Health, D. (2017) *Delivering better oral health: an evidence-based toolkit for prevention*



Third edition, London. Available at: [www.gov.uk/phe](http://www.gov.uk/phe) (Accessed: 03/04/2021).

Quail, A., Williams, J., Thornton, M. and Murray, A. (2014) *A summary guide to wave 2 of the child cohort (at 13 years) of Growing Up in Ireland*, Dublin: The Economic and Social Research Institute and Trinity College Dublin. Available at: <https://www.ucd.ie/t4cms/Summary%20guide%20to%20the%20datasets%20-%20Child%20-%20Wave%202.pdf> (Accessed: 12/09/2023).

R Core Team (2022) *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. Available at: <https://www.R-project.org/>.

Rai, N. K. and Tiwari, T. (2018) 'Parental factors influencing the development of early childhood caries in developing nations: a systematic review', *Frontiers in Public Health*, 6, pp. 1-8.

Rangan, A., Allman-Farinelli, M., Donohoe, E. and Gill, T. (2014) 'Misreporting of energy intake in the 2007 Australian Children's Survey: differences in the reporting of food types between plausible, under- and over-reporters of energy intake', *Journal of Human Nutrition and Dietetics: The Official Journal of the British Dietetic Association*, 27(5), pp. 450-458.

Rankin, D., MacIntyre, U., Hanekom, S., Steyn, H. and Wright, H. (2012) 'Reproducibility of two, three, four and five 24-hour recalls in peri-urban African adolescents in the North West province', *South African Journal of Clinical Nutrition*, 25(1), pp. 27-32.

Ravaghi, V., Hill, K., Ryan, R. and Dennes, M. (2015) *Children's Dental Health Survey 2013. Country specific report: Northern Ireland*: Health and Social Care Information Center. Available at: <https://bda.org/news-centre/blog/Documents/CDHS2013-Northern-Ireland-Report.pdf> (Accessed: 25/10/2022).

Ravaghi, V., Rezaee, A., Pallan, M. and Morris, A. J. (2020) 'Childhood obesity and dental caries: an ecological investigation of the shape and moderators of the association', *BMC Oral Health*, 20(1), pp. 1-7.

Ravaghi, V., Underwood, M., Marinho, V. and Eldridge, S. (2012) 'Socioeconomic status and self-reported oral health in Iranian adolescents: the role of selected oral health behaviors and psychological factors', *Journal of Public Health Dentistry*, 72(3), pp. 198-207.

Reisine, S. T. and Psoter, W. (2001) 'Socioeconomic Status and Selected Behavioral Determinants as Risk Factors for Dental Caries', *Journal of Dental Education*, 65(10), pp. 1009-1016.

Reissmann, D. R., John, M. T., Schierz, O., Kriston, L. and Hinz, A. (2013) 'Association between perceived oral and general health', *Journal of Dentistry*, 41(7), pp. 581-589.



Richards, D. (2013) 'Oral diseases affect some 3.9 billion people', *Evidence-Based Dentistry*, 14(2), pp. 35-35.

Richardson, D. and Ali, N. (2014) *An evaluation of international surveys of children*, France: Directorate for Employment, Labour and Social Affairs(146). Available at: <https://www.oecd-ilibrary.org/docserver/5jxzmjrqvntf-en.pdf?expires=1648816747&id=id&accname=guest&checksum=1F24D6DA6BC27732DF95868D4C7C844B> (Accessed: 27/06/2022).

Richter, M., Erhart, M., Vereecken, C. A., Zambon, A., Boyce, W. and Gabhainn, S. N. (2009) 'The role of behavioural factors in explaining socio-economic differences in adolescent health: A multilevel study in 33 countries', *Social Science & Medicine*, 69(3), pp. 396-403.

Richter, M., Moor, I. and Lenthe, F. J. v. (2012) 'Explaining socioeconomic differences in adolescent self-rated health: the contribution of material, psychosocial and behavioural factors', *Journal of Epidemiology and Community Health*, 66(8), pp. 691-697.

Righolt, A. J., Jevdjevic, M., Marcenes, W. and Listl, S. (2018) 'Global-, Regional-, and Country-level economic impacts of dental diseases in 2015', *Journal of Dental Research*, 97(5), pp. 501-507.

Ripa, L. W. (1993) 'A half-century of community water fluoridation in the United States: review and commentary', *Journal of Public Health Dentistry*, 53(1), pp. 17-44.

Robinson, P. G., Nadanovsky, P. and Sheiham, A. (1998) 'Can questionnaires replace clinical surveys to assess dental treatment needs of adults?', *Journal of Public Health Dentistry*, 58(3), pp. 250-253.

Rolland, B., Reid, S., Stelling, D., Warnick, G., Thornquist, M., Feng, Z. and Potter, J. D. (2015) 'Toward rigorous data harmonization in cancer epidemiology research: one approach', *American Journal of Epidemiology*, 182(12), pp. 1033-1038.

Royal College of Surgeons of England. Faculty of Dental Surgery (2019) *Position Statement, Children's oral health*, London. Available at: <https://www.rcseng.ac.uk/news-and-events/media-centre/press-releases/dental-decay-hosp-admissions/> (Accessed: 29/01/2021).

Rozin, P. (2006) 'The integration of biological, social, cultural and psychological influences on food choice', in Shepherd, R. and Raats, M. (eds.) *The Psychology of Food Choice Frontiers in Nutritional Science*. Wallingford, Oxfordshire, UK: CABI in association with the Nutrition Society, pp. 19-39.

RStudio Team (2022) *RStudio: Integrated Development Environment for R*. Boston, MA: RStudio, PBC. Available at: <http://www.rstudio.com/>.

Rugg-Gunn, A. J., Spencer, A. J., Whelton, H. P., Jones, C., Beal, J. F., Castle, P., Cooney, P. V., Johnson, J., Kelly, M. P., Lennon, M. A., McGinley, J., O'Mullane, D., Sgan-Cohen, H. D., Sharma, P. P., Thomson, W. M., Woodward, S. M. and Zusman, S. P. (2016) 'Critique of the review of 'Water fluoridation for the prevention of dental caries' published by the Cochrane Collaboration in 2015', *British Dental Journal*, 220(7), pp. 335-340.

Russell, S. L., Ickovics, J. R. and Yaffee, R. A. (2010) 'Parity & untreated dental caries in US women', *Journal of Dental Research*, 89(10), pp. 1091-1096.

Rutishauser, I. H. (2005) 'Dietary intake measurements', *Public Health Nutrition*, 8(7a), pp. 1100-1107.

Sabbah, W., Suominen, A. L., Vehkalahti, M. M., Aromaa, A. and Bernabé, E. (2014) 'The role of behaviour in inequality in increments of dental caries among Finnish adults', *Caries Research*, 49(1), pp. 34-40.

Sabbah, W., Tsakos, G., Sheiham, A. and Watt, R. G. (2009) 'The role of health-related behaviors in the socioeconomic disparities in oral health', *Social Science & Medicine*, 68(2), pp. 298-303.

Sagheri, D., McLoughlin, J. and Clarkson, J. J. (2007) 'A comparison of dental caries levels in two communities with different oral health prevention strategies stratified in different social classes', *J Public Health Dent*, 67(1), pp. 1-7.

Sampaio, F. C. and Levy, S. M. (2011) 'Systemic fluoride', *Fluoride and the Oral Environment*, 22, pp. 133-145.

Sanchez, G. F. L., Smith, L., Koyanagi, A., Grabovac, I., Yang, L., Veronese, N., Shin, J. I., Loosemore, M. and Jacob, L. (2020) 'Associations between self-reported physical activity and oral health: a cross-sectional analysis in 17,777 Spanish adults', *British Dental Journal*, 228(5), pp. 361-365.

Sánchez-Niubo, A., Sialm, A., Bickenbach, J. and Gonzalez, J. R. (2020) *Strategy brief on harmonization and integration methods: European Union's Horizon 2020 Research and Innovation Programme*. Available at: <https://click.endnote.com/viewer?doi=10.5281%2Fzenodo.6389806&token=WzM0MDQ4MzUsIjEwLjUyODEvemVub2RvLjYzODk4MDYiXQ.bOr2jZNeyGDdYC-UNEz1dRmJbTY> (Accessed: 14/06/2023).

Sanders, A. E., Spencer, A. J. and Slade, G. D. (2006) 'Evaluating the role of dental behaviour in oral health inequalities', *Community dentistry and oral epidemiology*, 34(1), pp. 71-79.

Sarikaya, A., Correll, M., Bartram, L., Tory, M. and Fisher, D. (2019) 'What do we talk about when we talk about dashboards?', *IEEE Transactions on Visualization and Computer Graphics*, 25(1), pp. 682-692.

- Scaglioni, S., De Cosmi, V., Ciappolino, V., Parazzini, F., Brambilla, P. and Agostoni, C. (2018) 'Factors influencing children's eating behaviours', *Nutrients*, 10(6), pp. 1-17.
- Scannapieco, F. A., Torres, G. and Levine, M. J. (1993) 'Salivary  $\alpha$ -amylase: role in dental plaque and caries formation', *Critical Reviews in Oral Biology & Medicine*, 4(3), pp. 301-307.
- Scheinin, A., Mäkinen, K. K., Tammisalo, E. and Rekola, M. (1975) 'Turku sugar studies XVIII. Incidence of dental caries in relation to 1-year consumption of xylitol chewing gum', *Acta Odontologica Scandinavica*, 33(5), pp. 269-278.
- Schüpbach, P., Neeser, J. R., Golliard, M., Rouvet, M. and Guggenheim, B. (1996) 'Incorporation of caseinoglycomacropeptide and caseinophosphopeptide into the salivary pellicle inhibits adherence of mutans streptococci', *Journal of Dental Research*, 75(10), pp. 1779-1788.
- Schwendicke, F., Dorfer, C. E., Schlattmann, P., Foster Page, L., Thomson, W. M. and Paris, S. (2015) 'Socioeconomic inequality and caries: a systematic review and meta-analysis', *Journal of Dental Research*, 94(1), pp. 10-18.
- Schwendicke, F. and Krois, J. (2022) 'Data dentistry: how data are changing clinical care and research', *Journal of Dental Research*, 101(1), pp. 21-29.
- Scientific Advisory Committee on Nutrition, S. (2015) *Carbohydrates and Health* London. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/445503/SACN\\_Carbohydrates\\_and\\_Health.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/445503/SACN_Carbohydrates_and_Health.pdf) (Accessed: 22/04/2022).
- Selwitz, R. H., Ismail, A. I. and Pitts, N. B. (2007) 'Dental caries', *The Lancet*, 369(9555), pp. 51-59.
- Seow, W. K. (2012) 'Environmental, maternal, and child factors which contribute to early childhood caries: a unifying conceptual model', *International Journal of Paediatric Dentistry*, 22(3), pp. 157-168.
- Sfeatcu, R., Balgiu, B. A., Mihai, C., Petre, A., Pantea, M. and Tribus, L. (2022) 'Gender differences in oral health: self-reported attitudes, values, behaviours and literacy among Romanian adults', *Journal of Personalized Medicine*, 12(10), pp. 1-13.
- Shastry, S. P., Kaul, R., Baroudi, K. and Umar, D. (2014) 'Hemophilia A: dental considerations and management', *Journal of International Society of Preventive & Community Dentistry*, 4(Suppl 3), pp. S147–S152.
- Shavers, V. L. (2007) 'Measurement of socioeconomic status in health disparities research', *Journal of the National Medical Association*, 99(9), pp. 1013-1023.

Sheethal, K., Shiva, K. and Manju, P. (2023) 'A systematic review of the relationship between parental stress and early childhood caries', *Dent Oral Sci*, 5(2), pp. 1-15.

Sheiham, A. (1977) 'Is there a scientific basis for six-monthly dental examinations?', *The Lancet*, 310(8035), pp. 442-444.

Sheiham, A. (1983) 'Sugars and dental decay', *The Lancet*, 321(8319), pp. 282-284.

Sheiham, A. (1991) 'Why free sugars consumption should be below 15 kg per person per year in industrialised countries: the dental evidence', *British Dental Journal*, 171(2), pp. 63-65.

Sheiham, A. (2005) 'Oral health, general health and quality of life', *Bulletin of the World Health Organization*, 83(9), pp. 644.

Sheiham, A. (2006) 'Dental caries affects body weight, growth and quality of life in pre-school children', *British Dental Journal*, 201(10), pp. 625-626.

Sheiham, A. and James, W. P. (2014a) 'A new understanding of the relationship between sugars, dental caries and fluoride use: implications for limits on sugars consumption', *Public Health Nutrition* 17(10), pp. 2176-84.

Sheiham, A. and James, W. P. (2015a) 'Diet and dental caries: the pivotal role of free sugars reemphasized', *Journal of Dental Research*, 94(10), pp. 1341-7.

Sheiham, A. and James, W. P. (2015b) 'Diet and dental caries: the pivotal role of free sugars reemphasized', *Journal of Dental Research*, 94(10), pp. 1341-1347.

Sheiham, A. and James, W. P. T. (2014b) 'A reappraisal of the quantitative relationship between sugar intake and dental caries: the need for new criteria for developing goals for sugar intake', *BMC Public Health*, 14(1), pp. 1-8.

Sheiham, A. and Watt, R. G. (2000) 'The common risk factor approach: a rational basis for promoting oral health', *Community Dentistry and Oral Epidemiology*, 28(6), pp. 399-406.

Shen, A., Bernabé, E. and Sabbah, W. (2021) 'Systematic review of intervention studies aiming at reducing inequality in dental caries among children', *International Journal of Environmental Research and Public Health*, 18(3), pp. 1-11.

Shepherd, R. (1999) 'Social determinants of food choice', *Proceedings of the Nutrition Society*, 58(4), pp. 807-812.

Shim, J. S., Oh, K. and Kim, H. C. (2014) 'Dietary assessment methods in epidemiologic studies', *Epidemiol Health*, 36, pp. 1-8.

Shqair, A. Q., Pauli, L. A., Costa, V. P. P., Cenci, M. and Goettems, M. L. (2019) 'Screen time, dietary patterns and intake of potentially cariogenic food in children: a systematic review', *Journal of Dentistry*, 86, pp. 17-26.

- Shyama, M., Al-Mutawa, S. A., Morris, R. E. and Sugathan, T. (2001) 'Dental caries experience of disabled children and young adults', *Community Dental Health*, 18(3), pp. 181-186.
- Silva, A., Mattos, I. E. and Carmo, C. (2018) 'Factors associated with self-rated oral health in adolescents in São Luís, Maranhão, Brazil, 2014', *Annals of Dentistry and Oral Health*, 2, pp. 1-8.
- Silva, A. E. R., Menezes, A. M. B., Assunção, M. C. F., Gonçalves, H., Demarco, F. F., Vargas-Ferreira, F. and Peres, M. A. (2014) 'Validation of self-reported information on dental caries in a birth cohort at 18 years of age', *PLoS ONE*, 9(9), pp. 1-8.
- Silva, P. A. (1990) 'The Dunedin multidisciplinary health and development study: a 15 year longitudinal study', *Paediatric and Perinatal Epidemiology*, 4(1), pp. 76-107.
- Simmonds, M., Llewellyn, A., Owen, C. G. and Woolacott, N. (2016) 'Predicting adult obesity from childhood obesity: a systematic review and meta-analysis', *Obesity Reviews*, 17(2), pp. 95-107.
- Singh, A., Harford, J., Schuch, H. S., Watt, R. G. and Peres, M. A. (2016) 'Theoretical basis and explanation for the relationship between area-level social inequalities and population oral health outcomes - a scoping review', *SSM Popul Health*, 2, pp. 451-462.
- Sisson, K. L. (2007) 'Theoretical explanations for social inequalities in oral health', *Community Dentistry and Oral Epidemiology*, 35(2), pp. 81-88.
- Skafida, V. and Chambers, S. (2018) 'Positive association between sugar consumption and dental decay prevalence independent of oral hygiene in pre-school children: a longitudinal prospective study', *Journal of Public Health*, 40(3), pp. e275-e283.
- Slade, G. D. (2001) 'Epidemiology of dental pain and dental caries among children and adolescents', *Community Dental Health*, 18(4), pp. 219-227.
- Smirnova, E., Ivanescu, A., Bai, J. and Crainiceanu, C. M. (2018) 'A practical guide to big data', *Statistics & Probability Letters*, 136, pp. 25-29.
- Smith, V. S. (2013) 'Data dashboard as evaluation and research communication tool', *New Directions for Evaluation*, 2013(140), pp. 21-45.
- Song, J. W. and Chung, K. C. (2010) 'Observational studies: cohort and case-control studies', *Plastic and Reconstructive Surgery*, 126(6), pp. 2234-2242.
- South Eastern Health Board (1998/'99) *Oral health of children and adolescents in the South Eastern Region, 1998/'99*, Ireland: Oral Health Services Research Center. University College Cork (Accessed: 11/11/2021).
- Southern Health Board (1995) *Oral health of children and adolescents*, Cork, Ireland: Oral Health Services Research Center. University College Cork (Accessed: 11/11/2021).

Sreebny, L. M. (1982) 'Sugar availability, sugar consumption and dental caries', *Community Dentistry and Oral Epidemiology*, 10(1), pp. 1-7.

Štefanová, E., Baška, T., Holubčíková, J., Timková, S., Tatarková, M., Sovičová, M. and Hudečková, H. (2020) 'Selected behavioural factors affecting oral health in schoolchildren: results from the health behaviour in school-aged children (HBSC) Slovak study', *International Journal of Environmental Research and Public Health*, 17(20), pp. 1-11.

Stein, C., Cunha-Cruz, J. and Hugo, F. N. (2021) 'Is dietary pattern a mediator of the relationship between socioeconomic status and dental caries?', *Clinical Oral Investigations*, 25(9), pp. 5441-5447.

Stephan, R. M. (1944) 'Intra-oral hydrogen-ion concentrations associated with dental caries activity', *Journal of Dental Research*, 23(4), pp. 257-266.

Stephens, M. B., Wiedemer, J. P. and Kushner, G. M. (2018) 'Dental problems in primary care', *American Family Physician*, 98(11), pp. 654-660.

Stok, F. M., Hoffmann, S., Volkert, D., Boeing, H., Ensenaer, R., Stelmach-Mardas, M., Kiesswetter, E., Weber, A., Rohm, H., Lien, N., Brug, J., Holdsworth, M. and Renner, B. (2017) 'The DONE framework: creation, evaluation, and updating of an interdisciplinary, dynamic framework 2.0 of determinants of nutrition and eating', *PLoS One*, 12(2), pp. 1-23.

Stormon, N., Kazantzis, N., Ford, P. J. and Lalloo, R. (2019) 'Children's oral health in Australia: the past decade's research agenda', *Community Dentistry and Oral Epidemiology*, 47(2), pp. 153-161.

Su, S., Lipsky, M. S., Licari, F. W. and Hung, M. (2022) 'Comparing oral health behaviours of men and women in the United States', *Journal of Dentistry*, 122, pp. 1-8.

Szklo, M. (1998) 'Population-based cohort studies', *Epidemiologic reviews*, 20(1), pp. 81-90.

Tada, A. and Hanada, N. (2004) 'Sexual differences in oral health behaviour and factors associated with oral health behaviour in Japanese young adults', *Public Health*, 118(2), pp. 104-9.

Tagliaferro, E. P. D. S., Pereira, A. C., Meneghim, M. D. C. and Ambrosano, G. M. B. (2006) 'Assessment of dental caries predictors in a seven-year longitudinal study', *Journal of Public Health Dentistry*, 66(3), pp. 169-173.

Takahashi, N. and Nyvad, B. (2008) 'Caries ecology revisited: microbial dynamics and the caries process', *Caries Research*, 42(6), pp. 409-418.

- Takahashi, N. and Nyvad, B. (2011) 'The role of bacteria in the caries process: ecological perspectives', *Journal of Dental Research*, 90(3), pp. 294-303.
- Tanzer, J. M., Livingston, J. and Thompson, A. M. (2001) 'The microbiology of primary dental caries in humans', *Journal of Dental Education*, 65(10), pp. 1028-1037.
- Taylor, S., Baker, S. R., Broomhead, T., England, R., Mason, S., Sereny, M., Tsakos, G. and Williams, D. M. (2023) 'Standardised practice-based oral health data collection: a pilot study in different countries', *International Dental Journal*, 73(4), pp. 566-573.
- Telford, C., Coulter, I. and Murray, L. (2011) 'Exploring socioeconomic disparities in self-reported oral health among adolescents in California', *Journal of the American Dental Association*, 142(1), pp. 70-8.
- Tennant, P. W. G., Murray, E. J., Arnold, K. F., Berrie, L., Fox, M. P., Gadd, S. C., Harrison, W. J., Keeble, C., Ranker, L. R., Textor, J., Tomova, G. D., Gilthorpe, M. S. and Ellison, G. T. H. (2020) 'Use of directed acyclic graphs (DAGs) to identify confounders in applied health research: review and recommendations', *International Journal of Epidemiology*, 50(2), pp. 620-632.
- Tham, R., Bowatte, G., Dharmage, S. C., Tan, D. J., Lau, M. X., Dai, X., Allen, K. J. and Lodge, C. J. (2015) 'Breastfeeding and the risk of dental caries: a systematic review and meta-analysis', *Acta Paediatrica (Oslo, Norway: 1992)*, 104(467), pp. 62-84.
- Thomas, D. and Hunt, A. (2019) *The pragmatic programmer*. Addison-Wesley Professional.
- Thomas, W. M. (1972) *Report on a survey of the incidence of dental caries in national school children in the Tullamore urban area Co. Offaly*, Portlaoise: Midland Health Board (MHB). Available at: <http://hdl.handle.net/10147/333367> (Accessed: 12/11/2021).
- Thompson, F. E. and Byers, T. (1994) 'Dietary assessment resource manual', *The Journal of Nutrition*, 124(suppl\_11), pp. 2245s-2317s.
- Thompson, F. E. and Subar, A. F. (2017) 'Dietary assessment methodology', in Coulston, A.M., Boushey, C.J., Ferruzzi, M.G. and Delahanty, L.M. (eds.) *Nutrition in the Prevention and Treatment of Disease*. Fourth ed: Academic Press pp. 5-48.
- Thomson, W. M., Mejia, G. C., Broadbent, J. M. and Poulton, R. (2012) 'Construct validity of Locker's global oral health item', *Journal of Dental Research* 91(11), pp. 1038-42.
- Thomson, W. M., Poulton, R., Kruger, E. and Boyd, D. (2000) 'Socio-economic and behavioural risk factors for tooth loss from age 18 to 26 among participants in the Dunedin multidisciplinary health and development study', *Caries Research*, 34(5), pp. 361-366.

Thomson, W. M., Williams, S. M., Broadbent, J. M., Poulton, R. and Locker, D. (2010) 'Long-term dental visiting patterns and adult oral health', *Journal of Dental Research*, 89(3), pp. 307-311.

Thornley, S., Bach, K., Bird, A., Farrar, R., Bronte, S., Turton, B., Atatoa Carr, P., Fa'Alili-Fidow, J., Morton, S. and Grant, C. (2021) 'What factors are associated with early childhood dental caries? A longitudinal study of the Growing Up in New Zealand cohort', *International Journal of Paediatric Dentistry*, 31(3), pp. 351-360.

Thornton, M., Williams, J., McCrory, C., Murray, A. and Quail, A. (2011) *Derived variables in the 9-year cohort of Growing Up in Ireland*, Dublin: The Economic and Social Research Institute and Trinity College Dublin. Available at: [https://www.ucd.ie/issda/t4media/Derived%20variables\\_document.pdf](https://www.ucd.ie/issda/t4media/Derived%20variables_document.pdf) (Accessed: 12/12/2023).

Thornton, M., Williams, J., McCrory, C., Murray, A. and Quail, A. (2013) *Growing Up in Ireland national longitudinal study of children: design, instrumentation and procedures for the infant cohort at wave one (9 months)*, Dublin: ESRI/TCD/DCYA (Infant Cohort Technical Report No. 2. Available at: <https://www.esri.ie/system/files/media/file-uploads/2015-07/BKMNEXT252.pdf> (Accessed: 17/06/2021).

Tickle, M., Blinkhorn, A. S. and Milsom, K. M. (2008) 'The occurrence of dental pain and extractions over a 3-Year period in a cohort of children aged 3-6 Years', *Journal of Public Health Dentistry*, 68(2), pp. 63-69.

Touger-Decker, R. and Van Loveren, C. (2003) 'Sugars and dental caries', *The American Journal of Clinical Nutrition*, 78(4), pp. 881S-892S.

Townsend, P., Whitehead, M. and Davidson, N. (1992) *Inequalities in Health: The Black Report & the Health Divide (new third edition)*. Penguin Books Ltd.

Tsakos, G., Watt, R. G. and Guarnizo-Herreño, C. C. (2023) 'Reflections on oral health inequalities: theories, pathways and next steps for research priorities', *Community Dentistry and Oral Epidemiology*, 51(1), pp. 17-27.

Twohig, P. A., Rivington, J. R., Gunzler, D., Daprano, J. and Margolius, D. (2019) 'Clinician dashboard views and improvement in preventative health outcome measures: a retrospective analysis', *BMC Health Services Research*, 19(1), pp. 1-3.

Usha, C. and Sathyanarayanan, R. (2009) 'Dental caries - A complete changeover (Part I)', *Journal of Conservative Dentistry* 12(2), pp. 46-54.

Valenzuela, M. J., Waterhouse, B., Aggarwal, V. R., Bloor, K. and Doran, T. (2021) 'Effect of sugar-sweetened beverages on oral health: a systematic review and meta-analysis', *European Journal of Public Health*, 31(1), pp. 122-129.

van der Tas, J. T., Kragt, L., Veerkamp, J. J. S., Jaddoe, V. W. V., Moll, H. A., Ongkosuwito, E. M., Elfrink, M. E. C. and Wolvius, E. B. (2016) 'Ethnic disparities in



dental caries among six-year-old children in the Netherlands', *Caries Research*, 50(5), pp. 489-497.

van Loveren, C. (2019) 'Sugar restriction for caries prevention: amount and frequency. Which Is more Important?', *Caries Research*, 53(2), pp. 168-175.

van Meijeren-van Lunteren, A. W., Voortman, T., Elfrink, M. E. C., Wolvius, E. B. and Kragt, L. (2021) 'Breastfeeding and childhood dental caries: results from a socially diverse birth cohort study', *Caries Research*, 55(2), pp. 153-161.

Victora, C. G., Bahl, R., Barros, A. J. D., França, G. V. A., Horton, S., Krasevec, J., Murch, S., Sankar, M. J., Walker, N. and Rollins, N. C. (2016) 'Breastfeeding in the 21st century: epidemiology, mechanisms, and lifelong effect', *The Lancet*, 387(10017), pp. 475-490.

Victora, C. G. and Barros, F. C. (2006) 'Cohort Profile: The 1982 Pelotas (Brazil) Birth Cohort Study', *International Journal of Epidemiology*, 35(2), pp. 237-242.

Vos, M. B., Kaar, J. L., Welsh, J. A., Van Horn, L. V., Feig, D. I., Anderson, C. A. M., Patel, M. J., Munos, J. C., Krebs, N. F., Xanthakos, S. A. and Johnson, R. K. (2017) 'Added sugars and cardiovascular disease risk in children: a scientific statement from the American Heart Association', *Circulation*, 135(19), pp. e1017-e1034.

Vrijheid, M., Casas, M., Bergström, A., Carmichael, A., Cordier, S., Eggesbø, M., Eller, E., Fantini, M. P., Fernández, M. F., Fernández-Somoano, A., Gehring, U., Grazuleviciene, R., Hohmann, C., Karvonen, A. M., Keil, T., Kogevinas, M., Koppen, G., Krämer, U., Kuehni, C. E., Magnus, P., Majewska, R., Andersen, A.-M. N., Patelarou, E., Petersen, M. S., Pierik, F. H., Polanska, K., Porta, D., Richiardi, L., Santos, A. C., Slama, R., Sram, R. J., Thijs, C., Tischer, C., Toft, G., Trnovec, T., Vandentorren, S., Vrijkotte, T. G. M., Wilhelm, M., Wright, J. and Nieuwenhuijsen, M. (2012) 'European birth cohorts for environmental health research', *Environmental Health Perspectives*, 120(1), pp. 29-37.

Wagner, Y. and Heinrich-Weltzien, R. (2017) 'Risk factors for dental problems: recommendations for oral health in infancy', *Early Human Development*, 114, pp. 16-21.

Walsh, T., Worthington, H. V., Glenny, A. M., Marinho, V. C. and Jeroncic, A. (2019) 'Fluoride toothpastes of different concentrations for preventing dental caries', *Cochrane Database Systematic Review*, 3, pp. 1-245.

Wamala, S., Merlo, J. and Boström, G. (2006) 'Inequity in access to dental care services explains current socioeconomic disparities in oral health: the Swedish National Surveys of Public Health 2004–2005', *Journal of Epidemiology & Community Health*, 60(12), pp. 1027-1033.

Wang, X., Bernabe, E., Pitts, N., Zheng, S. and Gallagher, J. E. (2021) 'Dental caries thresholds among adolescents in England, Wales, and Northern Ireland, 2013 at 12,

and 15 years: implications for epidemiology and clinical care', *BMC Oral Health*, 21(1), pp. 1-14.

Wark, P. A., Hardie, L. J., Frost, G. S., Alwan, N. A., Carter, M., Elliott, P., Ford, H. E., Hancock, N., Morris, M. A., Mulla, U. Z., Noorwali, E. A., Petropoulou, K., Murphy, D., Potter, G. D. M., Riboli, E., Greenwood, D. C. and Cade, J. E. (2018) 'Validity of an online 24-h recall tool (myfood24) for dietary assessment in population studies: comparison with biomarkers and standard interviews', *BMC Medicine*, 16(1), pp. 1-14.

Watson, D., Maître, B., Whelan, C. T. and James, W. (2014) *Growing up in Ireland national longitudinal study of children: dynamics of child economics vulnerability and socio-emotional development : an analysis of the first two waves of the Growing Up in Ireland study*, Dublin: ESRI, Trinity College Dublin, Department of Child and Youth Affairs Report No. 1). Available at: <https://www.esri.ie/publications/growing-up-in-ireland-dynamics-of-child-economic-vulnerability-and-socio-emotional-development-an-analysis-of-the-first-two-waves-of-the-growing-up-in-ireland-study/> <https://www.growingup.ie/pubs/BKMNEXT284.pdf> (Accessed: 22/06/2021).

Watt, R. G. and Sheiham, A. (2012) 'Integrating the common risk factor approach into a social determinants framework', *Community Dentistry and Oral Epidemiology*, 40(4), pp. 289-96.

Welsh, J. A., Sharma, A. J., Grellinger, L. and Vos, M. B. (2011) 'Consumption of added sugars is decreasing in the United States', *The American Journal of Clinical Nutrition*, 94(3), pp. 726-734.

Western Health Board (1994) *Children's dental health in the Western Health Board region*, Ireland: Oral Health Services Research Center. University College Cork. Available at: <http://hdl.handle.net/10147/237112> (Accessed: 12/11/2021).

Weston, S. J., Ritchie, S. J., Rohrer, J. M. and Przybylski, A. K. (2019) 'Recommendations for increasing the transparency of analysis of preexisting data sets', *Advances in Methods and Practices in Psychological Science*, 2(3), pp. 214-227.

Whelton, H., Crowley, E., Harding, M., Guiney, H., Cronin, M., Flannery, E. and Kelleher, V. (2006) *North South Survey of Children's Oral Health in Ireland 2002*, Ireland: The Department of Health and Children Health Services Executive, Ireland; The Department of Health Social Services and Public Safety, Northern Ireland; WHO Collaborating Centre for Oral Health Services Research University College Cork. Available at: <https://www.lenus.ie/bitstream/handle/10147/119028/OralHealthReport.pdf?sequence=1> (Accessed: 09/11/2021).

Whelton, H., O'Keefe, J. and O'Mullane, D. M. (1991) *Children's dental health in County Clare, 1991*, Cork: Mid-Western Health Board. Available at: <http://hdl.handle.net/10147/336751> (Accessed: 12/11/2021).

Whitaker, R. C., Wright, J. A., Pepe, M. S., Seidel, K. D. and Dietz, W. H. (1997) 'Predicting obesity in young adulthood from childhood and parental obesity', *New England Journal of Medicine*, 337(13), pp. 869-873.

Whittle, J. G. and Downer, M. C. (1979) 'Dental health and treatment needs of Birmingham and Salford school children. A comparison in a fluoridated and a non-fluoridated area', *British Dental Journal*, 147(3), pp. 67-71.

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., Da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R., Gonzalez-Beltran, A., Gray, A. J. G., Groth, P., Goble, C., Grethe, J. S., Heringa, J., 'T Hoen, P. A. C., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S. J., Martone, M. E., Mons, A., Packer, A. L., Persson, B., Rocca-Serra, P., Roos, M., Van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M. A., Thompson, M., Van Der Lei, J., Van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J. and Mons, B. (2016) 'The FAIR Guiding Principles for scientific data management and stewardship', *Scientific Data*, 3(1), pp. 1-9.

Winters, K. and Netscher, S. (2016) 'Proposed standards for variable harmonization documentation and referencing: a case study using QuickCharmStats 1.1', *PLoS One*, 11(2), pp. 1-15.

Woodward, M. and Walker, A. R. P. (1994) 'Sugar consumption and dental-caries - evidence from 90 countries', *British Dental Journal*, 176, pp. 297-302.

World Health Organisation (2003) *Diet, nutrition, and the prevention of chronic diseases: report of a Joint WHO/FAO Expert Consultation*, Geneva, Switzerland: World Health Organization. Available at: [http://apps.who.int/iris/bitstream/handle/10665/42665/WHO\\_TRS\\_916.pdf;jsessionid=736ED979E32A001434475B71631EA64D?sequence=1](http://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdf;jsessionid=736ED979E32A001434475B71631EA64D?sequence=1) (Accessed: 22/05/2023).

World Health Organisation (2023) *Oral health*. Available at: <https://www.who.int/news-room/fact-sheets/detail/oral-health> (Accessed: 03/03/2024).

World Health Organisation (2024a) *Breastfeeding*. Available at: <https://www.who.int/westernpacific/health-topics/breastfeeding> [https://www.who.int/health-topics/breastfeeding#tab=tab\\_2](https://www.who.int/health-topics/breastfeeding#tab=tab_2) (Accessed: 22/03/2024).

World Health Organisation (2024b) *Obesity and overweight*. Available at: <https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight> (Accessed: 24/03/2024).

World Health Organisation, W. (2015) *Guideline: sugars intake for adults and children*, Geneva, Switzerland: World Health Organisation. Available at: [www.who.int](http://www.who.int) (Accessed: 11/07/2021).

Worthington, H. V., Macdonald, L., Poklepovic Pericic, T., Sambunjak, D., Johnson, T. M., Imai, P. and Clarkson, J. E. (2019) 'Home use of interdental cleaning devices, in addition to toothbrushing, for preventing and controlling periodontal diseases and dental caries', *Cochrane Database of Systematic Reviews*, 4(4), pp. 1-162.

Xie, Y., Allaire, J. J. and Grolemond, G. (2018) *R Markdown*. 1st edn.: Chapman and Hall/CRC.

Yaman Dosdogru, E., Gorken, F. N., Erdem, A. P., Oztas, E., Marsan, G., Sepet, E. and Aytepe, Z. (2017) 'Maxillary incisor trauma in patients with class II division 1 dental malocclusion: associated factors', *Journal of Istanbul University Faculty of Dentistry*, 51(1), pp. 34-41.

Yeomans, M. R., Blundell, J. E. and Leshem, M. (2004) 'Palatability: response to nutritional need or need-free stimulation of appetite?', *British Journal of Nutrition*, 92(S1), pp. S3-S14.

Zellner, D. A., Loaiza, S., Gonzalez, Z., Pita, J., Morales, J., Pecora, D. and Wolf, A. (2006) 'Food selection changes under stress', *Physiology & behavior*, 87(4), pp. 789-793.

Zero, D. T. (2004) 'Sugars – the arch criminal?', *Caries Research*, 38(3), pp. 277-285.

Zohoori, F. V. (2020) 'Nutrition and diet', in Zohoori, F.V. and Duckworth, R.M. (eds.) *The Impact of Nutrition and Diet on Oral Health Monographs in Oral Science*. New York: Karger Medical and Scientific Publishers, pp. 1-13.

Zolkifli, N. N., Ngah, A. and Deraman, A. (2018) 'Version Control System: a review', *Procedia Computer Science*, 135, pp. 408-415.

