

PREVALENCE AND CHARACTERISTICS OF HYPOMINERALISED SECOND PRIMARY MOLARS (HSPM) IN IRISH SCHOOLCHILDREN

A thesis submitted in partial fulfilment of the requirements of the degree of
Doctorate in Dental Surgery (D.Ch.Dent) in Paediatric Dentistry

2025

Dr Hugh David McGrory

Supervisors:

Professor Anne C O'Connell

Dr Rona Leith

Division of Child and Public Dental Health

Dublin Dental University Hospital

Trinity College Dublin

The University of Dublin

Declaration

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university. It is entirely my own work, except where references indicate otherwise in the text.

I agree to deposit this thesis in the University's open access institutional repository or allow the library to do so on my behalf, subject to Irish copyright Legislation and trinity College library conditions of use and acknowledgement.

I consent to the examiner retaining a copy of the thesis beyond the examining period, should they wish (EU GDPR May 2018).



Hugh McGrory

Abstract

Background: Hypomineralised teeth have been reported in the literature for many decades using many different terminologies. Weerheijm coined the term Molar Incisor Hypomineralisation, defined as hypomineralisation of systematic origin affecting one or more first permanent molars, with or without incisor involvement (Weerheijm 2003). In 2008, Elfrink introduced the term Deciduous Molar Hypomineralisation (DMH) due to limited studies available on this presentation of the same clinical entity in primary teeth. This term was revised and changed to Hypomineralised Second Primary Molars (HSPM) which was defined as idiopathic hypomineralisation of one to four SPMs (Elfrink et al. 2008). The prevalence of HSPM is unreported in the Irish population, and this study seeks to explore HSPM prevalence with an adequately powered sample size.

Purpose: The aim of this study is to investigate the prevalence and characteristics of HSPM and to assess its association with dental caries and Molar Incisor Hypomineralisation (MIH).

Methods: Following ethical approval, a cross-sectional study was completed for children aged 4-6 years, investigating the clinical characteristics of HSPM, MIH and dental caries. Participants were examined in school settings using the MIH/HSPM and d_{v3mft} diagnostic criteria. Five examiners were trained and calibrated for each standardized index ($\kappa > 0.80$). The clinical examination was accompanied by a parental questionnaire.

Results: A total of 401 children were examined [Age-Mean (SD)= 5.4(0.68) years; Males=53%]. Eighty-four children (Males=58%) had HSPM defects resulting in a prevalence of 21%. Most participants had only one affected primary molar (51%). Demarcated opacities were the most common lesion (62%), followed by atypical caries (23%), post eruptive breakdown (6%), atypical restoration (2%). Lesion extension and severity were significantly related ($P<0.5$). Only 43.4% children had at least one erupted permanent molar, of which 51 had MIH defects, giving a prevalence of MIH as 29%. The co-occurrence of MIH and HSPM was 10%. The caries prevalence was 34% in the entire sample (mean $d_{v3}mft$ was 1.7), with 92% of teeth untreated. A significant relationship was noted between HSPM, dental caries ($P=.004$) and MIH ($P<.001$).

Conclusion: The prevalence of HSPM is 21% and is associated with MIH and caries in children aged 4-6 years. These findings highlight the need for greater clinical awareness, targeted resources, and enhanced support within paediatric and primary care dentistry, to manage the impact of this enamel defect more effectively.

Acknowledgements

Research projects like these cannot happen without a team, with enthusiasm and a wealth of experience behind them. With that in mind, I would like to express my deepest gratitude to all those who played their part. Firstly, to Dr Charlotte McCarra for a huge amount of work on this project prior to me taking over, as completion of this was impossible for her due to the Covid-19 pandemic.

To my supervisors Professor O'Connell and Dr Leith for their continued guidance throughout this project. Their insight, constructive feedback and patience was instrumental to this work. To my colleagues who helped with data collection Drs Robyn Crowley, Isabel Olegario, Kirsten Fitzgerald and the DDUH nursing staff, without your help this project would not have happened. To all the principals, members of board of management and parents for their participation in the school screenings. To Dr Honari for help with statistical analysis. I also extend my deepest gratitude to all those whose contribution, whether direct or indirect, helped produce this work. Your support has not gone unnoticed.

I am also grateful to all the staff in the Child and Public Dental Health Department of the Dublin Dental University Hospital, Trinity College Dublin for the support and resources in the completion of this thesis.

A huge thank you specifically to the academic and clinical support from; Professor Anne O'Connell our course director, Drs Rona Leith, Kirsten Fitzgerald, Aisling Cant, and Kate Kenny whose experience, insights and intellectual guidance have created a motivating and encouraging space for our specialist training in Paediatric Dentistry.

A special mention to my colleague and now dear friend Robyn Crowley, the countless discussions, shared experiences, and mutual encouragement has played a huge role in keeping me focused, inspired and sane over the past three years. Finally, I would like to express my greatest gratitude to my family, my wife Maeve, daughter Lucy, parents Breda and Hugh and parents in law, Johanna and Denis. Without all your love, support and encouragement I would not be where I am today. I am eternally grateful!

1 Table of Contents

ABSTRACT	III
ACKNOWLEDGEMENTS	V
LIST OF ABBREVIATIONS.....	IX
LIST OF TABLES	X
LIST OF FIGURES	XII
1. LITERATURE REVIEW	1
1.1 BACKGROUND AND NOMENCLATURE OF MIH AND HSPM	1
1.2 TOOTH DEVELOPMENT	2
1.3 AETIOLOGY	3
1.3.1 <i>Genetics</i>	3
1.3.2 <i>Prenatal factors</i>	5
1.3.3 <i>Perinatal factors</i>	8
1.3.4 <i>Postnatal factors</i>	10
1.4 MIH AND HSPM DIAGNOSTIC INDICES	13
1.4.1 <i>Developmental defects of enamel (DDE)</i>	13
1.4.2 <i>Modified Developmental defects of enamel (mDDE)</i>	14
1.4.3 <i>EAPD judgement criteria</i>	15
1.4.4 <i>MIH/HSPM Index</i>	18
1.5 CLINICAL PRESENTATION OF HSPM	20
1.6 PREVALENCE OF HSPM.....	54
1.7 DIFFERENTIAL DIAGNOSES.....	60
1.7.1 <i>Amelogenesis imperfecta (AI)</i>	60
1.7.2 <i>Fluorosis</i>	60
1.7.3 <i>Hypoplasia</i>	61
1.7.4 <i>Caries</i>	62
1.8 ASSOCIATION OF HSPM AND MIH	63
1.9 DENTAL CARIES.....	67
1.9.1 <i>Dental Caries Diagnostic criteria</i>	68
1.9.2 <i>Caries experience of Irish children</i>	69
1.10 ASSOCIATION OF HSPM WITH CARIES.....	72
1.11 INTRODUCTION TO RESEARCH QUESTION.....	77
1.11.1 <i>Aims</i>	77
1.11.2 <i>Objectives</i>	78
1.11.3 <i>Null Hypotheses</i>	78
2 METHODS.....	79
2.1 ETHICAL APPROVAL.....	79
2.2 STUDY DESIGN.....	79
2.3 STUDY SETTING.....	79
2.4 SAMPLE SIZE CALCULATION	81
2.5 INCLUSION AND EXCLUSION CRITERIA	81
2.6 RECRUITMENT	81
2.7 HSPM DIAGNOSTIC CRITERIA	83
2.8 CARIES DIAGNOSTIC CRITERIA.....	86
2.9 CALIBRATION.....	86
2.10 EXAMINATION	87
2.11 QUESTIONNAIRE DEVELOPMENT.....	89
2.12 DATA COLLECTION	91
2.13 CROSS INFECTION CONTROL	92
2.14 CONFIDENTIALITY	92
2.15 DATA ANALYSIS	93
3 RESULTS	94
3.1 CALIBRATION.....	94

3.2	RECRUITMENT	94
3.3	DEMOGRAPHICS.....	95
3.4	HSPM PREVALENCE	96
3.5	HSPM LESION CHARACTERISTICS	98
3.6	HSPM LESION EXTENSION	99
3.7	ASSOCIATION OF HSPM WITH MIH	100
3.8	CARIES PREVALENCE.....	101
3.9	RELATIONSHIP OF HSPM AND DENTAL CARIES.....	102
3.10	QUESTIONNAIRE	102
4	DISCUSSION.....	108
4.1	LIMITATIONS	116
5	CONCLUSION	117
6	FUTURE RESEARCH RECOMMENDATIONS	118
7	REFERENCES	119
8	APPENDICES	132
8.1	ETHICAL APPROVAL	132
8.2	LETTER OF INVITATION	133
8.3	SCHOOL CONSENT FORM	136
8.4	PARTICIPANT INFORMATION SHEET	137
8.5	PARTICIPANT QUESTIONNAIRE	144
8.6	PARTICIPANT CONSENT FORM	145
8.7	DATA COLLECTION FORM	147
8.8	PROFORMA LETTER FOR IDENTIFIED DENTAL NEEDS	148

List of Abbreviations

CWF- Community Water Fluoridation

DDE- Developmental Defects of Enamel

DMFT- Decayed Missing Filled Teeth (Permanent teeth)

dmft- Decayed Missing Filled Teeth (Primary teeth)

dv₃mft- Decayed (cavitation visual to dentine) Missing Filled Teeth (Primary teeth)

ECC- Early Childhood Caries

mDDE- modified Developmental Defects of Enamel

EAPD- European Academy of Paediatric Dentistry

FPM- First permanent molar

HSPM- Hypomineralised Second Primary Molars

IVF- In vitro fertilization

MIH- Molar Incisor Hypomineralisation

SPM- Second primary molar

WHO- World Health Organisation

List of tables

Table 1.1 Description of the mDDE Index (Clarkson and O'Mullane 1989)

Table 1.2 EAPD judgment criteria (Lygidakis et al. 2010)

Table 1.3 Additions to EAPD diagnostic criteria (Lygidakis 2010)

Table 1.4 MIH/HSPM Diagnostic Criteria (Ghanim et al 2015)

Table 1.5 Study Characteristics and findings of those investigating HSPM prevalence

Table 1.6 Diagnostic criteria used in HSPM prevalence studies

Table 1.7 Studies investigation the relationship between HSPM and MIH

Table 1.8 Description of dmft/DMFT index

Table 1.9 Results of Irish National Surveys on dental caries experience of 5-year-old children

Table 1.10 Results of Eastern Health Board regional surveys on dental caries experience of 5-year-old children

Table 1.11 Results of County Dublin surveys on dental caries experience of 5-year-old children

Table 1.12 Studies investigating the relationship between caries and HSPM

Table 2.1 Inclusion and exclusion criteria

Table 2.2 Diagnostic Criteria Ghanim et al 2015

Table 2.3 dmft diagnostic criteria (WHO 2019)

Table 2.4 Data collection timeline

Table 3.1 Relationship of HPSM and Sex

Table 3.2 Number of teeth affected by HSPM and severity.

Table 3.3 Association of HSPM lesion severity and lesion extension.

Table 3.4. Association of HSPM and MIH.

Table 3.5 Association of HSPM and Dental Caries

Table 3.6 Questions 1-2: Pre-natal risk factors for HSPM with counts and valid percentages, including crosstabs for HSPM

Table 3.7 Questions 3-6: Peri-natal risk factors associated with HSPM with counts and valid percentages including crosstabs for HSPM

Table No. 3.8 Questions 7-8: Feeding methods of participants with counts and valid percentages and crosstabs for HSPM

Table No. 3.9 Questions 9-10: Post-natal risk factors for HSPM with counts and valid percentages with crosstabs for HSPM

List of figures

Figure 2.1- School setting and examination zones set up with dentist and dental nurse, at one of the primary schools attended in County Dublin.

Figure 2.2- Diagnostic criteria Ghanim et al 2015- images per diagnostic code

Figure 2.3 Examination armamentarium for school screenings

Figure 2.4 Example of screening zone set up in one school visited in County Dublin during data collection.

Figure 3.1 Recruitment flow chart with participant numbers.

Figure 3.2 Geographic distribution of schools screening in County Dublin

Figure 3.3- Age distribution of participants

Figure 3.4 Number of affected teeth per participant

Figure 3.5 Distribution of affected teeth

Figure 3.6 HSPM defect characteristics

1. Literature review

1.1 Background and nomenclature of MIH and HSPM

Developmental defects of enamel (DDE) are relatively common conditions reported worldwide. The Developmental Defects of Enamel index, which was modified in 1989 is the most widely used index for classification of DDE. They are broadly categorised into diffuse defects, demarcated opacities and hypoplastic defects (Clarkson and O'Mullane 1989). Hypoplastic defects are quantitative and refer to the lack of enamel structure whereas hypomineralised defects are qualitative defects due to decreased mineral content of affected tooth structure. Hypomineralised teeth have been documented in the literature for several decades, though they garnered increased attention in the early 2000s. Both hypoplasia and hypomineralisation can affect primary and permanent teeth. In the permanent dentition, hypomineralised first permanent molars (FPMs) are frequently seen alongside affected incisors—a condition known as Molar Incisor Hypomineralisation (MIH), which has been reported in the literature since the 1980s. Historically MIH has been described as cheese molars or idiopathic enamel hypomineralisation. In 2001, Weerheijm lead an expert study group at the European Academy of Paediatric Dentistry (EAPD) interim seminar in Athens, Greece to define MIH and introduced the definition of MIH to include hypomineralisation of systematic origin of one or more first permanent molars with or without incisor involvement (Weerheijm 2003). The EAPD continues to endorse this definition in the most current guidance on MIH due to global acceptance and applicability to most scenarios (Lygidakis et al. 2022). The EAPD

does however acknowledge the potential risks associated with this definition including under-diagnosis (Lygidakis et al. 2022). Demarcated opacities have been reported on teeth not included in this definition such as cusp tips of canines and second permanent molars. As such, future efforts should be made to devise a new fully inclusive definition.

While many studies focused on the FPM in the early 2000s, clinicians frequently noted similar defects in the second primary molars (SPM). In 2008, Elfrink introduced the term Deciduous Molar Hypomineralisation (DMH) due to limited studies available on this presentation in primary teeth. This term was revised and changed to Hypomineralised Second Primary Molars (HSPM) which was defined as idiopathic hypomineralisation of one to four SPMs, (Elfrink et al. 2008) which is now globally accepted and endorsed by the EAPD (Lygidakis et al. 2022).

1.2 Tooth development

Tooth development is a genetically controlled process which is extremely sensitive to environmental circumstances. The second primary molars development commences from 18th gestational week until complete crown formation within the first year (Avery D.R. 2022). The formation of the SPM overlaps that of the first permanent molar and permanent incisors with their calcification beginning around the 3rd gestational trimester and birth to one year respectively. Given this overlap it is hypothesised that the aetiology of both HSPM and MIH is the same, with variations in the time of insult to the developing ameloblasts (Lima, Ramos-Jorge, and Soares 2021). The importance of timing of tooth development and

presence of aetiological factors of HSPM is well established. The second primary molars continue to mature until approximately one year of age. Disturbances in amelogenesis during this period are hypothesised to be the reason for such clinical presentations (Lopes-Fatturi et al. 2019). Other studies which aimed to investigate single aetiological factors, such as specific events/illnesses like infections, asthma, otitis media, for HSPM failed to do so and found general themes among studies, all of which relate to timing of many factors, as such providing further support for the critical time of exposure and resultant clinical presentation. Elfrink et al., 2014 reported 'general perinatal morbidity', Ghanim et al., 2012 found that 'any perinatal events' were the most significant factors and Silva et al., 2019 reported the shared environmental factors as 'instrumental' for HSPM development. Insults affecting the ameloblasts during this phase may result in a permanent defect on the tooth surface.

1.3 Aetiology

The aetiology of HSPM is considered multifactorial, as current research including a systematic review and meta-analysis have failed to identify any one aetiological factor, (Lima, Ramos-Jorge, and Soares 2021). Research thus far has explored causes in the pre-, peri, and post-natal periods as well as socio-economic influences. The rationale for research at these time points is due to the chronology of tooth development.

1.3.1 Genetics

The knowledge of the genetic determinants of dental defects has been improving in recent years with the identification of many genes associated with amelogenesis

imperfecta (AI) and dentinogenesis imperfecta (DI). However, with regard to HSPM and MIH the genetic determinants are inconclusive. It would be assumed given the similar clinical presentation that MIH and HSPM may share some genetic aetiological factors of that of AI, however this is not explored. The strongest evidence that supports the genetic association of HSPM and MIH are studies investigating the prevalence and characteristics of these conditions in twins. Silva et al., 2019 investigated these differences in groups of monozygotic and dizygotic twins. Monozygotic twins share one hundred percent genetic information, whereas dizygotic only share half of their genetic make-up. Using this model, the research team could determine the shared, non-shared and genetic aetiological factors of HSPM. In this study of 172 pairs of twins, 19.8% of children had HSPM defects, with an overall concordance of 0.47. This study failed to show a significant difference between monozygotic and dizygotic twins, showing little evidence for the genetic relationship to the development of HSPM. Besides genetics, the study identified shared factors that twins experience, which contribute to HSPM, including maternal health, infections during pregnancy, such as birth complications, and early childhood infections common to both twins. This supports the epigenetic theory and importance of environmental factors in disease development. This is further supported by the policy document on MIH developed by the EAPD, in reviewing the literature available they conclude the aetiology is multifactorial and likely has both genetic and epigenetic components (Lygidakis et al. 2022). Interestingly, Texiera et al 2018 found that monozygotic twins are twice as likely to develop MIH (Teixeira et al. 2018). However, this study only investigated MIH and cannot extrapolate the possible genetic link between HSPM and MIH. The fewer number of monozygotic twins in the former study may

account for different significances and as such further exploration of this topic is warranted in future research.

1.3.2 Prenatal factors

Given the timing of the second primary molar development, most of the research has been aimed at investigating prenatal conditions such as maternal illness and medication use, smoking and alcohol use and methods of conception, that could form associations with the development of HSPM.

There is conflicting evidence for the association between In vitro fertilization (IVF) and HSPM. The twin study by (Silva et al. 2019) highlighted among many other factors that IVF had a positive association with HSPM development (OR 2.97 (1.36 to 5.71)). Contrastingly, Kar et al 2014 conducted a cross-sectional study on 153 IVF children compared with spontaneously conceived children and found no association between IVF and any developmental defects of enamel. Although in this study, opacities, such as those seen in HSPM and MIH were the most common, approximately 2% prevalence of opacities was reported in each group. However, this study used the modified Developmental Defects of enamel index, for the entire dentition, not specifically assessing HSPM or MIH, which does provide direct comparison to that of the Silva 2019 study when investigating HSPM defects. Interestingly, in the cross-sectional study by Kar et al 2014, no child conceived through IVF had demarcated opacities on their second primary molars, only primary incisors, whereas in the study by Silva et al 2019 IVF was a positively associated risk factor. Due to these methodological differences, these studies were not included in the meta-analysis investigating HSPM risk factors by (Lima, Ramos-Jorge, and Soares 2021).

Maternal illness during pregnancy is a significant risk factor for HSPM. Ghanim et al 2012 conducted a validated questionnaire to investigate risk factors for HSPM development and found that maternal illness, and specifically the timing of any illnesses to be significantly associated with HSPM development (Ghanim et al. 2012). Significantly more children were affected if the illness occurred during the second or third gestational trimester. A systematic review reported the presence of arterial hypertension as a significant risk factor for HSPM but did not find any significant association for other illnesses such as infection or Diabetes Mellitus (Lima, Ramos-Jorge, and Soares 2021). It is postulated however, that the maternal gestational illness is related to enamel defects as these conditions are linked to premature births and lower birth weight.

Smoking during pregnancy is another prenatal factor that is associated with HSPM development. A meta-analysis was conducted on two studies by (Lira A de LS de 2021) and (Lopes-Fatturi et al. 2019) and resulted in the OR 2.88 (0.80 to 2.20) for maternal smoking as a risk factor for HSPM (Lima, Ramos-Jorge, and Soares 2021). This supports animal research in which rats were exposed to smoke during gestational period and offspring had resultant enamel mineralisation defects (Dong et al. 2011).

The use of alcohol during pregnancy is another factor that is thought to be linked to enamel defect formation however there is little evidence for this association. Elfrink et al. (2014) reported a positive association between alcohol consumption and the development of HSPM; however, the study has limitations related to alcohol dosage, timing of exposure, and lacks causal clarity due to the absence of associations with other expected etiological factors in the statistical analysis.

Animal models have noted mineralisation issues due to changes in cell differentiation. However systematic reviews investigating the aetiology of both HSPM and MIH have failed to show an association with alcohol consumption and the development of both conditions (Lima, Ramos-Jorge, and Soares 2021; Garot et al. 2022). Further research on this single risk factor is necessary due to the lack of investigation on the amount and dose of alcohol consumption as well as dose required to cause damage to the ameloblasts.

Medication use during pregnancy has also been investigated and no associations have been found. Elfrink et al 2014, using a parental questionnaire found no association between antimicrobials and other medications used for allergies and respiratory conditions such as asthma. These studies lacked information regarding dose, mode of intake and duration of use of such medications as well as recall bias with regard accuracy of information reported. Therefore, further investigations are required to make definitive conclusions. More recently a systematic review also failed to find any evidence for maternal use of medicines during pregnancy and development of HSPM (Serna Muñoz et al. 2020). In fact, supplementation of vitamin D during pregnancy was found to be a protective factor for HSPM development in a double blind clinical trial (Nørrisgaard et al. 2019). A high dose Vitamin D supplementation was resulted in a 50% reduced risk of enamel defects, including demarcated opacities, enamel breakdown and atypical restoration. In contrast with this study, a longitudinal study by Borsting et al 2022 investigated the dentitions of 7-year-old children of mothers who were enrolled in the Training in Pregnancy Study (TRIP), Norway. This study failed to show any significance between maternal vitamin D levels, recorded during gestation period as

insufficient or sufficient, with the development of either HSPM or MIH. This study concluded that vitamin D is neither a protective nor risk factor (Børsting et al. 2022). Of note, vitamin D levels were not the primary aim in this project, only supplemental data that was recorded and analysed. In the former study, Nørrisgaard et al. 2019 implemented a high-dose supplementation protocol, which may have led to a level not detectable in the general population cohort of Børsting et al., 2022 where vitamin D levels were measured but not experimentally altered. Given these contradictory findings, further research is required to assess variations in vitamin D levels, either natural or with supplementation and the incidence of HSPM.

1.3.3 Perinatal factors

Several perinatal factors have been investigated for their relationship in HSPM and MIH development including low birth weight, prematurity, and delivery complications.

The association of low birth weight and the incidence of all developmental defects of enamel is long established (Nelson et al. 2013; Masumo, Bårdsen, and Astrøm 2013; Nelson et al. 2010; Seow et al. 1984; Jacobsen et al. 2014). Low birth weight is described as infant born weighing 2500 grams or less, whereas very low birth weight describes babies born less than 1500 grams (WHO 2025). Several studies have found associations with HSPM and low birth weight (Ghanim et al. 2012; Elfrink et al. 2014). The systematic review by (Lima, Ramos-Jorge, and Soares 2021) is also in agreement with these findings, reporting the OR 1.50 (1.15-1.96) for low

birth weight and HSPM. Further corroborating these findings is that a systematic review investigating the aetiology of MIH found low birth weight to be a risk factor (Wu et al. 2020). Wu et al 2020 reported that low birth weight results in three times increased risk of MIH development.

A preterm infant refers to any infant born before 37 weeks' gestation (WHO 2023). Both HSPM and MIH are positively associated with prematurity (Lima et al. 2020; Wu et al. 2020). The meta-analysis by Wu et al 2020 reported the OR 1.57 of MIH development with prematurity. Further analysis of these studies highlights that low birth weight is often associated with other perinatal complications such as preterm labour and prematurity and immediate postnatal complications such as need for incubator and other medical interventions. Given these compounding factors it is difficult to say conclusively if any of these factors alone is the aetiological factor involved in HSPM development.

Delivery complications are another perinatal complication group which has been associated with HSPM and MIH development. Three studies were included in a meta-analysis, however only one reported on the exact nature of the delivery complication (prolonged labour) (Lopes-Fatturi et al. 2019; Ghanim et al. 2012; Lira A de LS de 2021). Ghanim et al 2012 reported positive associations of HPSM with prolonged labour, retained placenta and maternal hypoxia. Interestingly, the cross-sectional study by Lopes-Fatturi et al 2019 found initial association with delivery complications however, following adjustment for prenatal factors there was no such association. It is postulated that the prolonged labour is related to possible hypoxia which can affect ameloblast function altering the mineralisation

process. It is also hypothesised that caesarean section delivery is associated with hypoxia however the type of delivery (natural versus caesarean section) was not associated with HSPM (Lima et al. 2020; Lira A de LS de 2021).

The systematic review and meta-analysis by Lima et al 2021 reported that the risk of HSPM is increased in infants with the following combined: born prematurely, with low birth weight and in need of incubator to aid growth and development immediately following birth. However, among all the studies included, conclusions are difficult to make due to inherent heterogeneity among study design, lack of definition of 'delivery complications' for comparison and low sample sizes investigated.

1.3.4 Postnatal factors

Neonatal complications such as jaundice, hypoxia, incubation, and respiratory distress have conflicting evidence for their association with HSPM and MIH development. Ghanim et al 2012 reported these issues as potential risk factors however studies by Elfrink et al 2014, who investigated these complications through assessment of APGAR scores showed no significance. Apgar scores are given to infants immediately upon birth based on physical health and its use is endorsed by the American Academy of Obstetricians. Similarly, with MIH there are no significant associations with the above-mentioned complications (Wu et al. 2020).

Based on data from the systematic review and meta-analysis by (Lima, Ramos-Jorge, and Soares 2021), breastfeeding is reported as a protective factor against

HSPM. Two studies were included in this analysis (Elfrink et al. 2014; Lopes-Fatturi et al. 2019), with odds ratios of HSPM development of 1.26 and 1.33 respectively. It is postulated that not breastfeeding may be associated with malnutrition which in turn can be associated with developmental defects of enamel. With regard HSPM and MIH, this must be interpreted with caution given the confounding factors, including health and socio-economic factors related to not breastfeeding.

The role of antibiotics during infancy remains unclear despite significant enamel defects noted in the animal model and contradictory evidence in human studies. Interestingly, Elfrink et al 2014 found that antibiotic use in the first year of life had no association with HSPM (Elfrink et al. 2014). This lack of association was supported by a systematic review by Serna-Munoz et al 2020, where no evidence was found for any medications during the first year of life being associated with HSPM (Serna Muñoz et al. 2020). The results from this review should be cautiously interpreted as out of the seven studies included for analysis only one had used a diagnostic criterion sufficient for HSPM diagnosis. Others used modified Developmental Defects of Enamel, the modified Tooth Surface level of Fluorosis and others had no description of diagnostic criteria used. Conflicting evidence was reported in the systematic review by Lima et al 2020. A significant association was found between antibiotic use and HSPM based on three studies in their meta-analysis, (Elfrink et al. 2014; Lopes-Fatturi et al. 2019; Lima et al. 2020; Lima, Ramos-Jorge, and Soares 2021). These results should be interpreted with caution, as two studies which found no association with HSPM and antibiotic use, were excluded from this meta-analysis due to heterogeneity in study design to enable comparison. Furthermore, very few studies include sufficient descriptive data on

antibiotic class, dose, duration, and route of administration. Another issue with research on medication use and associations with either HSPM or MIH that warrants adjustment for statistical analysis is the reason for prescription of such medication. Given the inherent difficulties in study design, confounding factors cannot be excluded, as a result it is difficult to conclude if the antibiotics or the illness requiring antibiotics is the associated factor (Elfrink, Moll, et al. 2013).

There is no evidence for the association of chronic childhood illnesses and HSPM (Ghanim et al. 2012). Certain acute childhood illnesses are more likely to be associated with HSPM or MIH development, which is also supported by the timing factors in the development of these conditions. Illnesses, or chronic conditions with acute presentations have been investigated such as asthma, pneumonia, atopic dermatitis (Eczema) and otitis. The meta-analysis by Lima et al 2021 included two primary studies (Lima et al. 2020; Lopes-Fatturi et al. 2019) for the association of HSPM and asthma and found a significant association, although two other studies which were not included did not find such association (Silva et al. 2019; Mialhe 2014). The later studies investigated aetiological agents as secondary aims only and had small sample sizes in their investigation, therefore interpretation of these results is not without caution. In the systematic review and meta-analysis by Lima et al., 2021, pneumonia and otitis were not associated with HSPM (Lima, Ramos-Jorge, and Soares 2021). Interestingly, pneumonia and otitis are conditions which are often associated with antibiotic use and fever, which the same review found to be significant factors in HSPM development (Lima, Ramos-Jorge, and Soares 2021).

Despite the abundance of evidence available investigating aetiological factors in HSPM and MIH development, some limitations must be considered. There is a predominance of cross-sectional study design with relatively small sample sizes compared with that advised by (Elfrink et al. 2015) for aetiologic studies ($n > 1000$). This type of study design has inherent recall and memory bias which is a major limitation. Very few studies collected data prospectively, (Elfrink, Moll, et al. 2013; Elfrink et al. 2014; Silva et al. 2019). The aetiology of HSPM and MIH is multifactorial in nature, which was highlighted in the study by Ghanim et al 2012 where no one factor investigated was associated with HSPM, rather than combinations of risk factors (Ghanim et al. 2012). This may cause great difficulty with regard data analysis for many researchers as consideration of confounding factors must be included in the statistical analysis. Many studies do highlight their adjustments (Ghanim et al. 2012; Elfrink, Moll, et al. 2013; Elfrink et al. 2014; Lopes-Fatturi et al. 2019; Silva et al. 2019). The presence of confounding factors, cross-sectional design and lack of randomisation together may conclude the real relationship between aetiological agents and HSPM may be masked, exaggerated, or weakened.

1.4 MIH and HSPM diagnostic indices

1.4.1 Developmental defects of enamel (DDE)

The Developmental Defects of Enamel index was the first of its kind to aid recording developmental anomalies of enamel. It is exhaustive with respect to the data parameters collected. It records defect type, number, and location on each tooth as well as aetiology for the defect. Despite this index being novel when

produced which aimed to help standardise studies, there are many drawbacks with its use. It is particularly tedious for the practitioner to use with multiple codes and is time consuming and complicated to analyse (Clarkson and O'Mullane 1989). The major differentiating factor within this index relates to the difference in diffuse and demarcated opacities without regard for colour, which at the time of development may have been more important. However, studies in the past 20 years have highlighted the need for differentiation in colour due to the difference in severity of the condition. This index also cannot differentiate between mild or severe lesions (Clarkson and O'Mullane 1989).

1.4.2 Modified Developmental defects of enamel (mDDE)

Due to the drawbacks of the DDE index, Clarkson and O'Mullane in 1989 developed the modified Developmental Defects of Enamel (mDDE) index (Clarkson and O'Mullane 1989). The main changes in the modified version were to the defect coding and relative weight of factors associated. Three coding systems were introduced for simplification; demarcated opacities, diffuse opacities, and hypoplasia. With regard to the diagnosis of HSPM and MIH using these criteria, there are many disadvantages; post-eruptive breakdown (PEB) cannot be scored and could be misdiagnosed as hypoplasia, there are also no diagnostic codes for atypical caries, restorations, or extractions. The use of this index for studies on these conditions could result in under diagnosis and representation of both HSPM and MIH (Elfrink et al. 2015; Ghanim et al. 2017).

Although many studies have used the mDDE criteria for their studies on HSPM and MIH prevalence's there are major drawbacks associated with its use. (Elfrink et al 2015)

- (1) mDDE is more time consuming to use and record
- (2) Scoring PEB is not possible with these criteria or else it may be scored incorrectly as enamel hypoplasia
- (3) Atypical caries and restorations as well as extractions due to HSPM are not considered in the diagnosis using mDDE index. (Elfrink et al. 2015)

Table 1.1 Modified Developmental Defects of Enamel Index

Diagnostic Criteria	Description
mDDE	Normal
	Demarcated opacity <i>White/cream</i> <i>Yellow/Brown</i>
	Diffuse opacity <i>Lines</i> <i>Patchy</i> <i>Confluent</i> <i>Confluent/patchy + staining + loss of enamel</i>
	Hypoplasia <i>Pits</i> <i>Missing enamel</i> <i>Any other defect</i>
	Extent of defect <i>Normal</i> <i><1/3</i> <i>At least 1/3 <2/3</i> <i>At least 2/3</i>

1.4.3 EAPD judgement criteria

The EAPD judgment criteria was developed following the EAPD consensus meeting on MIH diagnostics in Athens 2003, (Weerheijm 2003). These criteria set out

several definitions for MIH presentations (See table 1.2. below). Given the commonality in HSPM and MIH presentations, these diagnostic criteria are also widely used for HSPM diagnosis. The major advantage of these criteria is the ease of use due to simple diagnostic descriptions for clinical practice. However, its use in research is limited, as there are no clear codes or standardised recording protocol, limiting the comparability between individual studies. There is also no option for the clinician or researcher to comment or record the extent of lesions on a tooth level.

Continued use of these diagnostic criteria is encouraged and endorsed by the EAPD Best clinical practice guidance on MIH (Lygidakis 2010, 2021), with specific mention for its use in HSPM as well as MIH. In 2010, several additional parameters were added to report on MIH severity (see table 1.3 below).

Table 1.2 EAPD judgment criteria

EAPD Criteria	Description
Clinical	
Characteristic	
Demarcated opacity	‘A demarcated defect involving an alteration in the translucency of the enamel which is variable in degree. The enamel affected has a smooth surface and is of normal thickness with a well-defined boundary. These opacities can be white, yellow, or brown in colour.’
Post-eruptive breakdown	‘A defect that indicates the loss of initially formed surface enamel after tooth eruption. Enamel loss is often associated with a pre-existing enamel opacity.’
Atypical restoration	‘Restorations that vary in terms of their size and shape that do not conform to typical caries picture. Restorations can extend to the buccal or palatal smooth surfaces with demarcated opacities often present at the restoration

	border. In incisors a buccal restoration can be present that is not trauma related.'
Extracted due to MIH	'Absence of a first permanent molar should be viewed in the context of the whole dentition. A MIH diagnosis should be suspected where a FPM is missing in conjunction with visible opacities/atypical restorations in the remaining FPMs. In addition, absence of FPMS in an intact dentition in combination with demarcated opacities on incisors is suspicious for MIH diagnosis. '
Atypical caries	Reference is also made to FPMS affected by large carious lesions associated with demarcated opacities and how this occurrence should be described as MIH.

Table 1.3 Additions to EAPD diagnostic criteria (Lygidakis 2010)

EAPD criteria	Description
Enamel disintegration	'The level of porosity varies in affected areas. Severely hypomineralised enamel, which is subjected to occlusal loading soon breaks down, exposing dentine and causes rapid caries development.'
Tooth sensitivity	'Sensitivity of affected teeth may be reported. Variation in severity ranges from mild response to external stimuli to spontaneous hypersensitivity. Affected teeth may be challenging to anaesthetise.'
Recording of defect severity	• 'Mild defects involve demarcated opacities only without breakdown of enamel, occasional sensitivity to external stimuli e.g. air/water but not brushing. • 'Severe defects refer to teeth affected by demarcated opacities with enamel breakdown, caries ongoing/spontaneous hypersensitivity affecting function,'

The EAPD judgement criteria is adequately diagnostic for HSPM/MIH defects in a clinical setting. This index gives appropriate description of clinical presentations of these defects to aid in diagnosis but there are no associated coding parameters for use in research to allow truly comparable data. This index can distinguish mild and severe HSPM/MIH based on presence of post-eruptive breakdown however extent of the specific defect is not recorded.

1.4.4 MIH/HSPM Index

The MIH/HSPM index was developed by Ghanim et al 2015 due to lack of standardised studies and indices for MIH and HSPM diagnosis. This index incorporates elements of the EAPD judgment criteria and the mDDE. This index aims to be superior for MIH and HSPM diagnosis as it fully incorporates all possible clinical presentations of these conditions unlikely previously developed indices. This index classifies teeth based on their eruption status and clinical presentation with consideration for the extent of the HSPM/MIH defect. Within this index, there are two options for data collection: the short form for index teeth only and long form for all teeth. The long form includes data parameters for eruption status and tooth surfaces affected, which the short form does not. This index has been validated and is reproducible, with high level of agreement for face, construct, and content validity (Ghanim, Marino, and Manton 2019). This index aims to overcome the disadvantages of previous indices for community research with the publication of a practice guide for its use as well as specific charting forms and appropriate coding for each defect presentation. The use of this index is now

considered gold standard in epidemiological research for HSPM and MIH for data synthesis and analysis (Table 1.6).

Table 1.4 MIH/HSPM Diagnostic Criteria (Ghanim et al. 2015)

<u>Code</u>	<u>Description</u>	
0	No visible enamel defect	Tooth is free of <u>All</u> enamel defects
1	Enamel defect, Not HSPM/MIH	These defects include diffuse opacities, hypoplasia, AI and hypomineralised defects (non-MIH/HSMP)
2a Demarcated opacities- white/creamy		Alteration in the translucency of the enamel with a clear distinct border with adjacent enamel. Opacities are variable in degree and can be white, yellow, or brown in colour
2b Demarcated opacities- yellow or brown		The defective enamel is of a normal thickness with a smooth surface
3	Post eruptive breakdown (PEB)	Loss of initially formed surface enamel after eruption. Commonly associated with a pre-existing demarcated opacity and found on surfaces that are traditionally low caries risk such as cuspal ridges/smooth surfaces. Usually, rough edges and uneven margins
4	Atypical restoration	Do not confirm to traditional picture of caries in terms of size and shape and commonly involve buccal and palatal/lingual surfaces. Pre-existing demarcated opacities may be present at the restoration margin.
5	Atypical Caries	Caries onset can be atypical involving surfaces that are not usually prone such as the buccal and palatal/lingual surfaces. Pre-existing demarcated opacities may be present. These lesions are typically seen in an otherwise caries-free mouth
6	Missing due to MIH/HSPM	Absence of a SPM in otherwise healthy dentition and associated with opacities, PEB, atypical caries/restoration in <u>at least one SPM</u> .

7a	Cannot be scored	A tooth with extensive coronal breakdown where potential cause is impossible to determine
7b	Stainless steel crown (due to HSPM)	A SPM with a stainless-steel crown in an otherwise caries free dentition with clinical signs of HSPM affecting one or more remaining SPMs
X	Unerupted/partially erupted	Partially erupted refers to a tooth that is not visible or less than 1/3 of the occlusal table is visible
Lesion extension	I – up to 1/3 of the tooth affected II- at least 1/3 but less than 2/3 tooth affected III – More than 2/3 tooth affected	Defects greater than 1mm in diameter are recorded. Lesion extension is based on a visual of the total sum of affected 'defects' relative to the whole tooth.

1.5 Clinical presentation of HSPM

Teeth affected by HSPM and MIH are characterised by reduced mineralisation (Wright, Carrion, and Morris 2015). The EAPD describes specific diagnostic criteria for HSPM and MIH including affected teeth (at least one SPM, at least one FPM and permanent incisors), demarcated opacities, and post-eruptive breakdown (Lygidakis et al. 2022). Demarcated opacities are the most common clinical presentation of HSPM affected teeth, reported by all studies investigating this (see table for studies investigating clinical characteristics). Creamy white opacities appeared to be reported more commonly than yellow brown opacities (Ghanim et al. 2013; Mittal and Sharma 2015; Owen et al. 2018; Goyal et al. 2019; Lima, Ramos-Jorge, and Soares 2021).

Post-eruptive breakdown (PEB) is commonly reported as the second most common clinical characteristic of HSPM (Børsting et al. 2022; Ghanim et al. 2013; Goyal et al. 2019; Halal and Raslan 2020; Kühnisch et al. 2014; Lima, Ramos-Jorge, and Soares 2021; Sidhu et al. 2020). Interestingly, both studies by Ghanim et al., 2015 and Owen et al., 2018 found PEB to be most associated with yellow-brown opacities. This may indicate that these coloured opacities are more severe than the creamy-white opacities. The study by Farah et al 2010, employed laser fluorescence to assess mineral density in hypomineralised teeth. This provides evidence that with colour change from creamy-white to yellow-brown reported higher Diagnodent scores, which is reflective of lower mineral density, and as such the severity of HSPM or MIH (Farah et al. 2010).

In all the studies that have reported on clinical characteristics of HSPM, atypical caries, restoration and extractions account for the lowest prevalence. This may be partially related to the use of several indices which do not include these HSPM/MIH specific presentations such as modified Developmental Defects of Enamel index (mDDE) and EAPD judgement criteria. It is difficult to conclude on their relative frequency of presentation given the possible misdiagnosis and underestimation in the literature. These specific presentations are included in the newest index developed by Ghanim et al., 2015. Interestingly, following publication of this index, several studies have reported atypical caries and restorations respectively as the second most common, following opacities (Amend et al. 2021; Gambetta-Tessini et al. 2018; Al-Huzaimi and Ibrahim 2025). It is generally accepted that atypical restorations and extractions account for the least

presentations due to difficulties with access to care and co-operative challenges in the age groups studied.

Several studies reported that the occlusal and buccal surfaces of the second primary molar are the most affected surfaces (Ghanim et al. 2013; Goyal et al. 2019; Halal and Raslan 2020; Mittal and Sharma 2015). Without looking specifically at the surface affected Sidhu et al., 2019 reported that single surface lesions are more commonly diagnosed, highlighting the likelihood that many teeth affected are mild lesions with respect to surface area of the tooth affected (Sidhu et al. 2020).

Many studies have failed to find any difference in presentation with regard to gender (Oyedele, Folayan, and Oziegbe 2016; Negre-Barber et al. 2016; Halal and Raslan 2020; Quintero et al. 2022; Rodríguez-Rodríguez et al. 2021; Elfrink, Moll, et al. 2013; da Silva Figueiredo Sé et al. 2017).

There is conflicting evidence in the literature as to the location of affected SPM in either maxillary or mandibular arches. Nevertheless, the majority found no difference in location (Elfrink et al. 2008; Lima et al. 2020; Owen et al. 2018; Borrego-Martí et al. 2021; Estivals et al. 2023; Costa Silva et al. 2013; Negre-Barber et al. 2016; Oyedele, Folayan, and Oziegbe 2016). Mittal et al. 2015 and Halal and Raslan 2020 reported that maxillary molars were more commonly affected, whereas Ghanim et al 2013 and Goyal et al 2019 reported mandibular molars were more commonly affected. However, all these studies failed to show any statistically significant difference in location of the affected SPM (Ghanim et al.

2013; Goyal et al. 2019; Halal and Raslan 2020; Mittal and Sharma 2015). Similarly, no differences were found among this group of studies for preference of left or right-side SPMs.

There are notable differences in how severity is classified among the differing indices available for HSPM diagnosis. Some indices such as EAPD judgement criteria (Lygidakis et al. 2022), assess severity based on clinical presentation, such as PEB and atypical caries or restorations. Contrastingly, the MIH/HSPM index proposed by Ghanim et al 2017, evaluate severity based on lesion extension relative to total tooth surface.

Owen et al., 2018 reported a positive association with the clinical severity and lesions extension. With regard clinical severity, Elfrink et al., 2012 reported most children were diagnosed with severe HSPM whereas Mittal et al., reported that most lesions are mild to moderate with regard lesion extension.

Elfrink et al., 2008, described HSPM as affecting one to four second primary molars. Most studies have reported 1-2 teeth on average affected (da Silva Figueiredo Sé et al. 2017; Elfrink et al. 2008; Estivals et al. 2023; Ghanim et al. 2013; Goyal et al. 2019; Lima, Ramos-Jorge, and Soares 2021; Mittal and Sharma 2015; Negre-Barber et al. 2016; Sidhu et al. 2020; Silva et al. 2019; Owen et al. 2018) . Interestingly, Halal and Raslan 2020 reported that all four SPMs being affected in the majority (>50%) of their sample. The authors of this study have attributed their increased prevalence and numbers of teeth affected to the conditions of war, malnutrition, and social deprivation due to the nature of social

circumstances in Syria at the time of investigation. Borrego-Marti et al., 2021 reported 62% of affected participants had 3 or more affected SPMs, similar results to that of (Halal and Raslan 2020).

There is conflicting evidence on the association of number of teeth affected and severity of the lesions. Owen et al., 2018 reported increased severity with increasing number of teeth affected. This study noted that participants with 2 or less affected SPMs were more likely to have opacities without PEB versus three or more affected teeth having opacities with PEB. Contrastingly, Estavlis et al., 2023 and da Silva Figueiredo Se et al., 2017 reported no significant relationship between number of affected teeth and severity (da Silva Figueiredo Sé et al. 2017; Estivals et al. 2023; Owen et al. 2018).

Table 1.5 Study Characteristics and findings of publications investigating HSPM prevalence

Author and study design	Location	Age range	Diagnostic Criteria	Examination conditions	Prevalence child (No. HSPM/Sample size) (%)	Prevalence tooth	Clinical presentation	Number affected SPM	Associated clinical and severity	Max or mand	Left or right
(Mittal and Sharma 2015) Cross Sectional	India	3 to 5	EAPD, ICDAS	School	10/223 (4.4%)	NR	Opacities n=8, PEB n=2		NR	NR	NR
(Borrego-Martí et al. 2021) Cross sectional	Spain	3 to 5	EAPD	Dental clinic	29/153 (18.95%)	NR	Opacities n=62, PEB n=15, Atypical restoration n=4	1n=6, 2n=5, 3n=7, 4n=11	Significantly more mild, significantly more severe on lower and mild on upper	No difference	No difference
(Estivals et al. 2023) Cross sectional	France	7 to 9	MIH/HSPM Ghanim	School	81/856 (9.4%)		Opacities most common	59%, 2.4 average per child	No of affected teeth did not increase with severity	No difference	NR
(da Silva Figueiredo Sé et al. 2017) Cross sectional	Brazil	6 to 11	EAPD	School	103/1592 (6.4%)	2.19%	Opacities most common followed by PEB	1n=78, 2n=16, 3n=5, 4n=4	Most were mild n=80, No association with number and severity	NR	NR

(Elfrink, Moll, et al. 2013) Cross sectional	Netherlands	5 to 6	EAPD	Medical centre	499/5561 (8.9%)	955/23722	Opacities (76%), PEB (31%), Atypical restorations (19%), Atypical caries (14%), Atypical extractions (11%)	Mostly only one tooth affected, mean no. teeth affected 1.9	Most had severe HSPM (302 out of 499)	NR	NR
(Reyes et al. 2019) Cross sectional	Brazil	8	mDDE	School	13.70%	NR	Opacities most common.	NR	NR	NR	NR
(Silva et al. 2019) Cross sectional	Australia	6	MIH/HSPM Ghanim	Research facility	68/344 (19.76%)	141/1382	Opacities most common (52.9%)	One tooth affected most commonly (45%), 20% had 2, 14% had 3, 19% had 4 affected SPMS.	NR	NR	NR
(Temilola and Folayan 2015)	Nigeria	1 to 19	EAPD	House	15/1169 (1.2%)	NR	NR	NR	NR	NR	NR

(Mittal and Sharma 2015) Cross sectional	India	6 to 8	EAPD	School	55/976 (5.63%)	136/3912	Record by surface, opacities most common defect noted 69% affected surfaces. 30% affected surfaces had PEB. No atypical restorations or extractions recorded. Mostly buccal and occlusal surfaces. Very few extended to lingual surfaces, for both MIH and HSPM.	Most had 2 teeth affected, mean no affected 2.47 +/- 1.07	NR	NR	NR
(Oyedele, Folayan, and Oziegbe 2016) Cross sectional	Nigeria	6 to 8	EAPD, dmft	School	27/496 (5.44%)	73/1876	Opacities most common, 48.14%.	NR	NR	No difference	No difference

(Negre-Barber et al. 2016)	Spain	8 to 9	MIH/HSPM Ghanim	School	60/414 (14.4%)	NR	Majority were mild defects (91%) - can infer this is opacities.	Mean no. of affected teeth 1.96.	NR	No difference	No difference
(Elfrink et al. 2008) Cross sectional	Netherlands	5	EAPD	Clinic	19/386 (4.9%)	55/1517	By tooth: Opacities most common 87%, PEB 40%, Atypical restorations 15%.	NR	NR	NR	NR
(Costa Silva et al. 2013) Cross sectional	Brazil	4 to 6	EAPD	School	27/134 (20.14%)	64/864	Only demarcated opacities noted.	NR	NR	NR	NR
(Fernandes, Forte, and Sampaio 2021)	Brazil	6 to 12	EAPD	School	7/610 (1.14%)	10/1804	Opacities 90%.	NR	NR	No difference	No difference
(Lima et al. 2020) Cross sectional	Brazil	5	EAPD	School	121/811 (14.91%)	238/2344	By tooth: White cream opacities (71%, yellow brown 28%, PEB 11%, atypical restorations 1.7, atypical caries 11%).	Mean no. affected SPMs 1.97. 61% presented with 2 or more affected SPMs.	Majority were mild with less 1/3 extensions (79%).	No difference	No differences

(Sidhu et al. 2020) Cross sectional	Canada		MIH/HSPM Ghanim	Hospital	19/365 (5.2%)		Opacities most common, 60% of defects in SPMs. PEB 24%, atypical restorations and caries not identified in SPMs. Most lesions affected buccal surfaces.	Most likely to have two teeth affected.	Lesion extensions mostly less than 1/3 surfaces. Teeth with only one surface affected was more common than 2 or more surfaces.	NR	NR
(Halal and Raslan 2020) Cross sectional	Syria	4 to 5	MIH/HSPM Ghanim	School	246/600 (41%)	715/2400	Opacities most common followed by PEB.	n=1 (36), n=2(63), n=3(32), n=4(115)	NR	NR	NR
Zakirulla	Saudi Arabia	7 to 10	EAPD	Dental clinic	32/596 (5.3%)	110/2292	Opacities most common 76%, followed by PEB 52% of affected teeth.	n=1(9), n=2(11), n=3(7), n=4 (5)	NR	No difference	No difference
(Ng et al. 2015) Cross sectional	Singapore	7	EAPD	Dental clinic	31/1083 (2.8%)	52/4277	Opacities most common followed by PEB.	NR	NR	NR	NR

(Goyal et al. 2019) Cross sectional	India	3 to 6	EAPD	School	237/3013 (7.8%)		By tooth 3-6 Cream demarcated opacities n=176 (36.7%) Yellow demarcated opacities n =138 (28.8%) Brown demarcated opacities n=165 (34.4%) PEB n=101 (21.1%) Atypical restoration n=20 (4.1%) Atypical extraction n=33 (6.9%)	Mean no. affected 1.9. 50% had 1, 26% had 2, 16% had 3 and 6.8% had 4 SPM affected.	NR	No difference	No difference
(Kühnisch et al. 2014) Cohort	Germany	10	EAPD	Hospital	28/693 (4.04%)		Opacities most common reported defect, 89% of defects recorded followed by PEB (2.7%). Mostly affecting buccal and occlusal surfaces.	NR	NR	NR	NR
(Elger et al. 2020) Cohort	Germany	1 to 6	EAPD	Research facility	38/958(3.96%)		NR	NR	NR	NR	NR

(Gambetta-Tessini et al. 2019) Cross sectional	Chile		MIH/HSPM Ghanim ICDAS II	School	29/577 (5.02%)		NR	NR	NR	NR	NR
(Owen et al. 2018) Cross sectional	Australia	3 to 5	EAPD, mDDE	School	88/623 (14.12%)		Demarcated creamy-white opacity in 42.4% (<i>N</i> = 61), demarcated yellow-brown opacity in 26.4% (<i>N</i> = 38), demarcated yellow-brown opacity with PEB in 16.7% (<i>N</i> = 24), demarcated creamy-white opacity with PEB in 11.8% (<i>N</i> = 17) and AR in 2.8% (<i>N</i> = 4)	<i>N</i> =1(52), <i>N</i> =2(21), <i>n</i> =3(10), <i>n</i> =4(5)	Increase in HSPM lesion extent and increasing number of HSPM per child was statistically significant	No difference	No difference

(Ghanim et al. 2013) Cross sectional	Iraq	7 to 9	EAPD	School	53/809 (6.5%)		Opacities most common (70%), followed by PEB, 21%). Buccal surfaces mostly affected by opacities and PEB affected occlusal surfaces.	The majority of the subjects had one tooth affected (58.5%), 30.2% had two teeth affected, whereas 7.5% and 3.8% of them had three or four affected teeth, respectively.	NR	No difference	No difference
(Amend et al. 2021) Cross sectional	Germany	6 to 12	EAPD	School	3.20%		Opacities most common followed by atypical restorations.	NR	NR	NR	NR
(Rodríguez-Rodríguez et al. 2021) Cross sectional	Venezuela	6 to 12	EAPD	Healthcare centre	29/145 (20%)		NR	NR	NR	NR	NR

(Tessari et al. 2024) Cross sectional	Brazil	4 to 6	MIH/HSPM Ghanim	School	159/653 (24.5%)	NR	NR	NR	NR	NR	NR
(van der Knaap-Kind et al. 2025) Cross sectional	Netherlands	4	MIH/HSPM Ghanim	Photographic review	79/535 (14.76%)	NR	NR	NR	NR	NR	NR
(Quintero et al. 2022) Cross sectional	Colombia	6 to 7	MIH/HSPM Ghanim	School	106/450 (23.78%)	NR	NR	NR	NR	NR	NR
(Bani-Hani, Taha, and Al-Batayneh 2025) Cross sectional	Jordan	6 to 8	MIH/HSPM Ghanim	School	344/783 (44%)	19.80%	Opacities were most common.	Majority of participants had only one molar affected.	NR	NR	NR

(Marcianes et al. 2023) Cross sectional	Spain	7 to 10	EAPD	Clinical records	103/426 (24.17%)	NR	NR	NR	NR	NR	NR
(Børsting et al. 2022) Longitudinal	Norway	7 to 9	EAPD	Clinic	38/176 (22%)	NR	Opacities most common, followed by PEB, atypical caries and restoration.	Majority of participants had only one molar affected.	NR	NR	NR
(Al-Huzaimi and Ibrahim 2025) Cross sectional	Saudi Arabia	8-10	EAPD	School	37/325 (11.4%)	NR	Atypical caries most common (42.4%)	NR	Majority of affected SPM were extension III	NR	NR

NR= not recorded, EAPD= European Academy of Paediatric Dentistry judgement criteria, ICDAS= International Caries detection and assessment system, dmft-= decayed missing and filled primary teeth index, MIH/HSPM Ghanim index

1.6 Prevalence of HSPM

In Ireland, there are currently no well-powered and representative prevalence reports of HSPM. Globally, there is huge variation in the literature, with reported prevalences ranging from 0-44%. Table 1.5 summarises the prevalence data available for HSPM. As with any study design, there are limitations, and the results should be interpreted with caution. HSPM prevalence was reported at 0% by Kar et al., 2014 in a sample of 305 Indian 3–5-year-old children using the mDDE index and only natural light conditions. This study failed to report on specific diagnostic criteria training and calibration of examiners. The lack of ideal conditions in this study, may indeed account for no HSPM diagnoses. However, natural variation will occur.

It was postulated that variations in the literature were related to the differing indices available for use in epidemiological studies. Despite differences in the mean HSPM prevalence using the EAPD or MIH/HSPM index (7.54%) versus mDDE or self-devised indices (3.65%), a meta-analysis by McCarra et al., 2021 failed to show any significant difference. Demarcated opacities are included in all existing indices and represent the most frequent clinical manifestation of HSPM. This likely explains why there are no significant differences in reported HSPM prevalence across these indices. It is agreed and widely accepted that training and calibration of any index used for epidemiological studies is required. Several published studies on HSPM prevalence have failed to report on any method or training and calibration, weakening their strength and introducing a possible bias to their results. Table 1.6 highlights the index used for diagnosis and identifies those

studies with no trained and calibrated examiners reported (Costa Silva et al. 2013; Elfrink, Moll, et al. 2013; Oyedele, Folayan, and Oziegbe 2016; Silva et al. 2019; Temilola and Folayan 2015).

Table 1.6 Diagnostic criteria used in HSPM prevalence studies

Author and study design	Location	mDDE, Self devised criteria	EAPD Judgement criteria	MIH/HSPM Ghanim 2017	Training and calibration
(Mittal and Sharma 2015) Cross Sectional	India		*		Yes
(Borrego-Martí et al. 2021) Cross sectional	Spain		*		Yes
(Estivals et al. 2023) Cross sectional	France			*	Yes
(da Silva Figueiredo Sé et al. 2017) Cross sectional	Brazil		*		Yes
(Elfrink, Moll, et al. 2013) Cross sectional	Netherlands		*		NR
(Reyes et al. 2019) Cross sectional	Brazil	*			Yes
(Silva et al. 2019) Cross sectional	Australia			*	NR
(Temilola and Folayan 2015)	Nigeria		*		NR
(Mittal and Sharma 2015) Cross sectional	India		*		Yes
(Oyedele, Folayan, and Oziegbe 2016) Cross sectional	Nigeria		*		NR
(Negre-Barber et al. 2016)	Spain			*	Yes
(Elfrink et al. 2008) Cross sectional	Netherlands		*		Yes
(Costa Silva et al. 2013) Cross sectional	Brazil		*		NR
(Fernandes, Forte, and Sampaio 2021) Cross Sectional	Brazil		*		Yes
(Lima et al. 2020) Cross sectional	Brazil		*		Yes
(Sidhu et al. 2020) Cross sectional	Canada			*	Yes
(Halal and Raslan 2020) Cross sectional	Syria			*	NR
Zakirulla	Saudi Arabia		*		NR
(Ng et al. 2015) Cross sectional	Singapore		*		NR

(Goyal et al. 2019) Cross sectional	India		*		Yes
(Kühnisch et al. 2014) Cohort	Germany		*		Yes
(Elger et al. 2020) Cohort	Germany		*		Yes
(Gambetta-Tessini et al. 2019) Cross sectional	Chile			*	Yes
(Owen et al. 2018) Cross sectional	Australia	*	*		Yes
(Ghanim et al. 2013) Cross sectional	Iraq		*		Yes
(Amend et al. 2021) Cross sectional	Germany		*		Yes
(Rodríguez-Rodríguez et al. 2021) Cross sectional	Venezuela		*		Yes
(Tessari et al. 2024) Cross sectional	Brazil			*	Yes
(van der Knaap-Kind et al. 2025) Cross sectional	Netherlands			*	Yes
(Quintero et al. 2022) Cross sectional	Colombia			*	Yes
(Bani-Hani, Taha, and Al-Batayneh 2025) Cross sectional	Jordan			*	Yes
(Marcianes et al. 2023) Cross sectional	Spain		*		Yes
(Børsting et al. 2022) Longitudinal	Norway		*		Yes

Regional variation is another possible factor that may influence prevalence results. There is a broad global representation of HSPM prevalence investigations, although the majority have been conducted in Europe or South America, see tables 1.5 and 1.6. Some authors have reported this as a potential factor in their results, Halal and Raslan 2020 hypothesised that the high HSPM prevalence is due to conditions of war, pollution, poverty and malnutrition in this country (Halal and Raslan 2020). Similar results were reported from a study conducted in Jordan, with HSPM prevalence reported as 44%. Despite differing social and environmental circumstances, these countries are neighbouring and inevitably will have some commonality, which may account for their similar, yet high prevalence of HSPM. As for other global areas investigated, there appears to be more variation in reported prevalence despite country proximity across the continents (see table 1.5).

The quality of the study design is undoubtedly a huge factor in validity of reported results. Many of the studies completed were carried out in school settings and some without artificial light for illumination (Kar et al., 2014, (Temilola and Folayan 2015; Costa Silva et al. 2013; Fernandes, Forte, and Sampaio 2021; Oyedele, Folayan, and Oziegbe 2016). Some studies failed to report on examination conditions entirely (Ng et al. 2015). Despite dental clinics having the ideal conditions for examination, they introduce bias in study design for prevalence studies as their sample is not representative of the general population. These participants are often referred or are attending a dental clinic for specific dental needs. Many studies have been completed in such facilities (Elfrink, Moll, et al. 2013; Negre-Barber et al. 2016; Ng et al. 2015; Nørrisgaard et al. 2019; Sidhu et al.

2020; Silva et al. 2019). This heterogeneity in study design, irrespective of diagnostic criteria, will alter prevalence results and readers should interpret with caution especially, when comparison of literature is being considered.

Another methodology factor that may introduce a bias into prevalence reported is the population studied. Two studies have reported HPSM prevalence in specific populations; twins (Silva et al. 2019) and orofacial cleft patients (Tessari et al. 2024). Both these studies cite prevalence rates at 19.76% and 24.5% respectively, much higher than the global estimation as previously discussed, exact aetiological factors are unknown, but it is hypothesised that these clinical situations may be associated with common risk factors, such as preterm birth or birthing difficulties with twins and genetic factors relating in orofacial development, which may also have an impact on amelogenesis.

The highest level of evidence available, is the systematic review and meta-analyses by McCarra et al 2022, reporting a prevalence of 6.8%. This comprehensive review highlights the relatively common occurrence of this condition across many populations and geographic areas. The systematic review and meta-analysis also reported the tooth level prevalence is lower than the child level. This is to be expected as we are aware from the definition that HSPM and MIH can affect one to four SPM. This trend is also commonly reported in various studies available in the literature, see table 1.1 for HSPM prevalence study characteristics and findings.

1.7 Differential diagnoses

Hypomineralised Second Primary Molars and Molar Incisor Hypomineralisation may be misdiagnosed due to the variation in their clinical presentation. HPSM and MIH must be differentiated from other possible developmental defects of enamel including those from genetically caused structural defects (e.g. Amelogenesis imperfecta, hypoplasia), exogenous causes (e.g. dental caries, trauma) and endogenously caused defects (e.g. fluorosis). A combination of the clinical presentation and medical history for each individual should allow such differentiation to be made.

1.7.1 Amelogenesis imperfecta (AI)

AI is an inherited defect in enamel formation due to genetic alterations in genes encoding for ameloblast function. These genetic alterations result in enamel presentations that may be broadly categorised as hypoplastic, hypocalcified or hypomature. AI has various reported prevalence rates in the literature from 1 in 400 to 1 in 7000 and is less common than both HSPM and MIH (Crawford, Aldred, and Bloch-Zupan 2007). Clinically, AI is diverse in its presentation, however, tends to affect the whole dentition including primary and permanent teeth. Despite similarities in individual tooth presentation to that of HSPM and MIH, the generalised pattern of effect is the distinguishing factor between these conditions.

1.7.2 Fluorosis

Fluorosis refers to the diffuse hypomineralisation of enamel due to the ingestion of excessive fluoride during the period of tooth formation, originally noted by

Dean and co-workers during investigations into the fluoride levels of drinking water and prevalence of dental caries and mottled teeth (Dean 1942). Affected enamel has diffuse, linear or patchy areas of hypomineralisation that have no well-defined boundary. More severe lesions may have areas of pitting or with complete loss of enamel surface (Ghanim et al. 2017). HSPM with demarcated opacities, with well-defined margins are distinctly different from those diffuse opacities present in fluorosis. In addition to the difference in clinical presentation, the teeth affected by HSPM and MIH are specific as per their respective definitions (Ghanim et al. 2017). Teeth affected by fluorosis often affect the whole dentition in a bilateral chronological, symmetrical way. In contrast with HSPM and MIH, teeth affected by fluorosis tend to be caries resistant (Weerheijm 2004). Analysis of historical fluoride ingestion may be important to differentiate between the later conditions and mild fluorotic lesions.

1.7.3 Hypoplasia

The Federation Dentaire International (FDI 1992) describe the presentation of hypoplasia as occurring in either; pits (tiny areas of enamel loss), grooves/lines or partial or complete absence of enamel over a considerable area of the tooth. Clinically, hypoplasia tends to display variations in teeth affected; numbers of teeth affected, symmetry of such and the extent of the hypoplastic lesions (Elcock et al. 2006). Hypoplastic lesions can be easily confused by clinicians with HSPM/MIH related enamel loss (post eruptive breakdown (PEB)). As previously discussed PEB presents with irregular sharp, well-defined borders whereas the borders of hypoplastic lesions tend to be smooth and rounded.

1.7.4 Caries

The initial carious lesion, white spot lesion, can be confused with some HSPM/MIH related demarcated. Initial caries is marked by a white, chalky, and opaque discolouration with an irregular surface. The main distinction between these two defects is in the definition, dental caries is a biofilm mediated demineralisation of hard dental structures. This implies it will occur where the biofilm is accumulated close to contact areas and on smooth surfaces such as at the gingival margin, areas where hypomineralisation tends not to present (Ghanim et al. 2017; Seow 2018). Demarcated opacities due to HSPM may also present as yellow- brown lesions, which carious enamel lesions do not. These demarcated opacities are most commonly irregular circular/ovoid in shape whereas dental caries tends to be linear in the areas of plaque accumulation. Difficulties may arise in areas of post eruptive breakdown and cavitated carious lesions, given the similar colour of such lesions. However, there are stark differences in their location as in general caries traditionally occurs in pits and fissures and interproximal areas whereas HSPM and MIH tend to occur on buccal surfaces, cusp tips and in the coronal one third of molars.

1.8 Association of HSPM and MIH

Molar Incisor Hypomineralisation has a reported prevalence of 11% in an Irish population (Dublin n=86/786), (Nic Ghearrailt et al. 2025). However, there is currently no available data examining the association of MIH and HSPM in the Irish cohort. Studies conducted elsewhere have investigated this relationship, which provided useful comparisons and highlighting the need for similar data sets from an Irish population.

Many studies have shown HSPM to be a significant risk factor and predictor for MIH with odds ratios ranging from 3.7 to 18.2 (Gambetta-Tessini et al. 2019; Negre-Barber et al. 2016) and co-occurrence rates ranging from 1.9% to 22.7%, see table 1.7. Other studies have reported that while these conditions may occur in the same participant, they are not predictive of MIH (Costa Silva et al. 2013; Ghanim et al. 2013; Sidhu et al. 2020; Bani-Hani, Taha, and Al-Batayneh 2025). A systematic review completed in 2018 included five studies to assess the predictive nature of HSPM for MIH. This review concluded that the risk of MIH following HSPM is 4.66, approximately five times increased risk compared with normal controls (Garot et al. 2018). Within the five studies included in this review one had a very small sample size and was the only study that did not show that HSPM to be predictive (Costa Silva et al. 2013). As highlighted by Elfrink et al., 2015, a minimum of 300 participants should be required for prevalence studies. If such were considered as an inclusion criterion for this review the study by Costa-Silva would not be included, which would further strengthen the predictive results of HSPM for MIH. Since the publication of the systematic review in 2018, several well-designed and adequately powered studies have been completed and are now

available for comparison. An updated meta-analysis would likely reveal a significantly greater predictive value of HSPM for MIH given the results of new studies outlined in table 1.7 below.

Several studies have investigated different clinical presentations that may affect the predictive nature, such as number of teeth affected, extent of lesions and severity of HSPM lesions. Several studies have shown that the number of SPM affected by HSPM is predictive of MIH, specifically, if more than one SPM are hypomineralised (Elfrink, Moll, et al. 2013; Ghanim et al. 2013; Mittal and Sharma 2015; Reyes et al. 2019). However, the studies by (Elfrink, ten Cate, et al. 2013; Ghanim et al. 2012; Mittal and Sharma 2015) were cross-sectional and therefore limited in establishing causality. Mittal and Sharma (2015) supported this link in an Indian population, although methodological weaknesses and diagnostic inconsistencies reduce the reliability of their findings. The most robust evidence comes from Reyes et al. (2019), who conducted a longitudinal study and confirmed that children with multiple HSPMs were more likely to develop MIH over time, supporting a potentially causal relationship. Collectively, these studies suggest that multiple HSPMs reflect a greater systemic disturbance, thereby increasing the risk of MIH, however further longitudinal research with diverse populations and improved control of confounding factors is needed to strengthen this predictive model.

Elfrink et al., 2012 and Mittal et al., 2015 both reported that milder HSPM lesions were more commonly associated with MIH. The former author reported an odds ratio of 5.0 for mild HPMS and odds ratio of 4.0 for severe HSPM. This was further

endorsed by the systematic review by Garot et al 2018. It has been hypothesised by Mittal and Sharma 2015 that aetiological factors and insults to the developing SPM likely occur later in mild cases and such also affect the developing FPM (Mittal and Sharma 2015).

Based on the literature, HSPM is predictive of MIH and should be used as a diagnostic tool and risk assessment for patients under six years of age, or prior to FPM eruption. Early identification of patients with HSPM will allow for anticipation of risk of tooth destruction, post-eruptive breakdown and sensitivity development in MIH affected teeth. It will allow for implementation of high-risk preventative protocols and as such minimise the issues caused by this condition.

Table 1.7 Studies investigation the relationship between HSPM and MIH

Author and study design	Country	Diagnostic Criteria	Findings
(Mittal and Sharma 2015) *	India	EAPD	Children with HSPM were 7.8 times more likely to develop MIH compared to those unaffected (OR). Slightly higher OR for mild HSPM defects (8.9) compared to severe. Subjects with ≥ 2 HSPM had significantly higher OR for MIH
(Estivals et al. 2023)	France	MIH/HSPM Ghanim	160/856 MIH, 52% risk of MIH if HSPM present
(da Silva Figueiredo Sé et al. 2017)	Brazil	EAPD	Significant relationship between HSPM and MIH, OR 6.31
(Elfrink, Moll, et al. 2013) *	Netherlands	EAPD	With more than one SPM affected higher odds of developing MIH compared with only one SPM affected. Caution due to small no of more than one tooth affected. 26% co-occurrence rate. OR for MIH 4.4
(Ghanim et al. 2013) *	Iraq	EAPD	No significant association found.
(Temilola and Folayan 2015)	Nigeria	EAPD	34.% rate of co-occurrence.
(Reyes et al. 2019)	Brazil	mDDE	HSPM significantly related to MIH prevalence. The higher the number of teeth affected by HSPM the higher the MIH prevalence.
(Negre-Barber et al. 2016) *	Spain	MIH/HSPM Ghanim	Co-occurrence of 11.1%. OR 18.2 (9.39-35.48). Concluded HSPM can be predictor for MIH but absence does not rule out appearance of MIH.
(Costa Silva et al. 2013)	Brazil	EAPD	Co-occurrence rate of 5.22%. No significant relationship with or without HSPM and MIH development.
(Sidhu et al. 2020)	Canada	MIH/HSPM Ghanim	HSPM was not predictive of MIH. Rate of co-occurrence was 1.9%.
(Gambetta-Tessini et al. 2019)	Chile	MIH/HSPM Ghanim	Three times increased risk of MIH if HSPM present. OR 3.7 CI 1.65-8.15

(Amend et al. 2021)	Germany	EAPD	22.3% co-occurrence. OR 11.32 (CI: 6.73-19.03)
(Quintero et al. 2022)	Colombia	MIH/HSPM Ghanim	22.7% co-occurrence rate of HSPM and MIH
(Bani-Hani, Taha, and Al-Batayneh 2025)	Jordan	MIH/HSPM Ghanim	HSPM and MIH were significantly related, but HPSM was not predictive of MIH with regard odds ratio. OR 1.17 CI 0.95-1.44
(Marcianes et al. 2023)	Spain	EAPD	The odds ratio was 4.64 (95% CI = 2.79–7.71)

OR= odds ratio, *=studies included in systematic review by Garot et al., 2018

1.9 Dental Caries

Dental caries is a biofilm-mediated, diet modulated, multifactorial, non-communicable, dynamic disease, resulting in net mineral loss of dental hard tissues (Fejerskov 1997). It affects individuals of all genders, ages, and socio-economic backgrounds. Dental caries is one of the most prevalent childhood diseases worldwide. A recent systematic review investigating the global burden of various diseases worldwide noted a prevalence of dental caries in the primary dentition and permanent dentition as 531 million and 2.3 billion respectively. (James 2018). Early Childhood Caries (ECC) is defined as “the presence of one or more decayed (non-cavitated or cavitated lesions), missing (due to caries), or filled tooth surfaces in any primary tooth” in a child under the age of six (Drury et al. 1999). Regardless of many preventative strategies outlined globally, ECC continues to be a hugely prevalent childhood disease affecting 12% - 48% of 2-6-year-old children globally (Seow 2018; Zhou et al. 2011; Dye et al. 2015; Plonka et al. 2012; Do and Spencer 2011; Whelton et al. 2004). ECC generally follows a sequential pattern, affecting primary teeth based on their eruption timing. Maxillary incisors are usually the first teeth affected, followed by first molars,

canines and second molars (O'Sullivan and Tinanoff 1996). Contrastingly, as previously discussed, the atypical caries presentation of those affected by HSPM does not follow this pattern (Elfrink et al. 2008).

Pain, sepsis, reduced quality of life, lost school time and diminished performances in school, sports and extra-curriculars are all possible consequences of untreated dental caries (Listl et al. 2015). In addition to the personal consequences, dental caries poses a significant cost, not only to families but also to society and is a substantial public health burden. It is imperative that regular public health reviews for caries experience are conducted to adequately inform the policy development on the success and benefits of preventative strategies employed on local, regional, and national levels.

1.9.1 Dental Caries Diagnostic criteria

Caries lesion detection is the identification of the consequence of the carious process, which can be diagnosed at various thresholds and stages of the disease. (Machiulskiene et al. 2020) For epidemiological purposes a reliable, reproducible, and realistic detection method is essential. Various dental caries indices are reported in the literature with the WHO Dental Caries Index, or the International Caries Detection and Assessment System (ICDAS) being the most frequently used indices.

The WHO Dental Caries Index records the absence or presence carious lesions as either a function of decayed, missing and filled teeth (DMFT) or surfaces (DMFS)

(WHO 2013). The capital letter notation used refers to the permanent dentition whereas lowercase notation refers to primary dentition (see Table No. 1.8)

Table 1.8 Description of dmft/DMFT index

Code	Description
Decayed (d/D)	Any tooth whose crown has an unmistakable cavitation on the pits and fissures or on a tooth surface or a filled crown, when it has one or more restorations with decay
Filled (f/F)	Filled crown with no decay, when it has one or more restoration and there is no caries anywhere on the crown
Missing(m/M)	Missing tooth due to caries, where the tooth has been extracted due to caries

This index calculates the caries experience of an individual however does not discriminate between current and previous experience. Other issues identified with this index include the inability to determine treatment need and the lack of reporting on initial carious lesions as the decayed function applies to cavitated lesions only. The DMFT/dmft index was introduced to overcome the issues with reproducibility with community examinations for epidemiological studies. Despite some of the challenges with this index it is still routinely used for caries research due to its ease of use in community setting, reliability, and reproducibility among investigating clinicians.

1.9.2 Caries experience of Irish children

Fortunately, over the past few decades, Ireland has seen a dramatic reduction in the caries experience of Irish children. This is largely attributed to the

implementation of fluoride to the mains water supply in the 1960s and the availability of fluoride containing toothpastes commercially since the 1970s (Sharma et al. 2024; O'Mullan et al. 1986).

Periodic oral health surveys have been conducted at both regional and national levels in the Republic of Ireland (RoI) with the primary aim of establishing the prevalence and severity of dental caries experience among Irish children and adolescents following the introduction of community water fluoridation (CWF) (O'Mullan et al. 1986). Three national studies were completed in 1953, 1984 and 2002, see table 1.9. Each of these surveys recorded dental caries using the dmft/DMFT index. However, in the 2002 North South survey, the caries threshold differed, the addition of the WHO visual dentinal caries ($d_{3vc}mf$) was added to the diagnostic criteria for examination.

Table 1.9 Results of Irish National Surveys on dental caries experience of 5-year-old children

Age group	1952	1960s	1985		2002	
5 years	Survey ('Report on the dental caries survey. Dental caries in Ireland' 1953)	Survey (Health 1962)	Survey (O'Mullan et al. 1986)		Survey (Whelton et al. 2004)	
	Pre CWF	Pre CWF	CWF	No CWF	CWF	No CWF
No. of participants	n=704	n=9823	n=869	n=836	n=3614	n=2159
Mean d _{3vc} mf scores (SD)	5.9	5.66(5.59)	1.8 (2.8)	2.0 (3.7)	1.0	1.7
Percentage Caries-free	0.4	19.98	52.1	38.5	63.1	45.5

CWF- community water fluoridation

In the 2001-2002 All Ireland National Oral Health Survey, Irish 5-year-olds exhibited a mean dmft of 1.0 and 1.7 in fluoridated and non-fluoridated areas respectively, with a reported caries prevalence of 31.5% of those residing in fluoridated areas. Interestingly, for 5-year-old children in the Dublin area, the results from the Fluoride and Caring for Children's Teeth (FACCT) study reported

a caries prevalence of 55% (mean dmft 0.7), with similar reports (56%) for the Cork/Kerry areas, all of which have community water fluoridation (James et al. 2018; Nic Ghearrailt et al. 2025).

1.10 Association of HSPM with caries

It is theorised that due to the 20-30% reduction of mineral content in those teeth with yellow-brown opacities (Elfrink, ten Cate, et al. 2013), and disorganised enamel structure bacterial and acid penetration, resulting in caries development is less of a challenge compared with sound enamel. This in theory can account for the increased risk of carious lesion development with hypomineralised teeth. Macroscopically these teeth tend to have areas of post-eruptive breakdown and may be sensitive. As reported by Lygidakis et al 2010 PEB can occur soon after eruption of these teeth or later, which could be related to occlusal loading during mastication (Lygidakis et al. 2010). Both these situations may result in altered, or limited oral hygiene practices by affected individuals, further potentiating the carious lesion progression.

The typical pattern of early childhood caries is that it follows the primary tooth eruption sequence (Veerkamp and Weerheijm 1995). The first primary molar erupts approximately 10 months prior to the second primary molar, and it is assumed that the first primary molar would have more severe caries experience compared with the SPM. However, clinical examination often reveals otherwise. This is considered atypical caries in terms of pattern, and it is hypothesised that developmental defects, such as HSPM, account for the difference in caries

prevalence affecting primary molars. This is evident in the study by Halal and Raslan 2020, the authors noted in their analysis per quadrant, that the SPM was more severely affected by dental caries compared with other teeth in the same quadrant. This was also significant compared with non HSPM patients in a reported high caries risk population (Halal and Raslan 2020).

Elfrink et al 2010 concluded in their study investigating caries risk factors in five-year-old Dutch children that HSPM and mothers birth country were significant risk factors, one of the first studies to identify HSPM as a risk factor for caries.

According to the literature available, there is a consensus that HSPM and dental caries are closely related. Table 1.12 summarises the studies investigating their relationship. A combination of dmft and ICDAS indices have been explored and to date, no differences are observed with regard to the association of HSPM and dental caries. All studies using the dmft index have shown that participants with HSPM have a higher dmft compared with normal controls (Amend et al. 2021; Halal and Raslan 2020; Oyedele, Folayan, and Oziegbe 2016; Rodríguez-Rodríguez et al. 2021). Studies that used the ICDAS index for caries assessment also reported increased caries prevalence in most cases, likely due to the increased sensitivity of this index and the ability to diagnose early carious lesions (Gambetta-Tessini et al. 2018, 2019; Ghanim et al. 2013; Mittal and Sharma 2015). Ghanim et al., 2013 reported that ICDAS scores 4-6 were three times more likely in HSPM participants compared with non-affected SPM. The same study concluded that caries risk (ICDAS 4-6) was twelve times more likely in participants with PEB compared with demarcated opacities. A cross sectional study conducted by Gambetta-Tessini et

al., 2018 in Chile supported these findings. This study utilised both ICDAS and PUFA (pulp, ulceration, fistula, and abscess) indices. They reported a significant relationship between caries and HSPM and specifically increased pulpal involvement in HSPM-affected molars.

It appears from the literature that the likelihood of caries development in HSPM affected teeth is related to the population caries risk. As a limitation of the studies investigating this relationship, very few reported on the overall population caries risk (Gambetta-Tessini et al. 2018; Ghanim et al. 2013; Halal and Raslan 2020; Owen et al. 2018). Those with high caries risk populations had significantly stronger associations (Ghanim et al. 2013; Halal and Raslan 2020). The cross-sectional study completed in Melbourne with a reported low caries risk was the only to find no association with HSPM and dental caries (Owen et al. 2018). Interestingly, participants with HSPM had marginally lower caries prevalence than those without (36.4% versus 37.4% respectively). Far from disproving a link between HSPM and caries, it suggests that in settings with strong preventive care, structural tooth defects may not always translate into clinical disease, but the evidence is not robust enough to generalise. These authors concluded that in a low caries risk population, demarcated opacities are less of a caries risk factor.

Table 1.12 Studies investigating the relationship between caries and HSPM

Author and study design	Country	Caries risk reported	Diagnostic Criteria	Findings
(Halal and Raslan 2020) Cross sectional	Syria	High	dmft	Children with HSPM had a higher prevalence of caries (OR 6.69) when compared with children without HSPM. In each quadrant, SPM significantly more affected by caries when compared to first primary molars
(Mittal and Sharma 2015) Cross sectional	India	NR	ICDAS	Increased likelihood caries and positive relationship between increased caries and defect severity in hypomineralised molars
(Oyedele, Folayan, and Oziegbe 2016) Cross sectional	Nigeria	NR	dmft	More children with HSPM had Caries ($P<0.001$)
(Gambetta-Tessini et al. 2019) Cross sectional *	Chile	NR	ICDAS II	Participants with MIH or HSPM had higher dmft than those without, OR 3.7.
(Owen et al. 2018) Cross sectional	Australia	Low	ICDAS II	The children affected by enamel hypomineralisation had a lower prevalence of dental carious lesions (36.4%), compared with unaffected individuals (37.4%)
(Gambetta-Tessini et al. 2018) Cross sectional *	Australia	Low	ICDAS II PUFA	Children with either HSPM or MIH had increased prevalence and more severe dental carious lesions and pulpal involvement.
(Ghanim et al. 2013)	Iraq	High	ICDAS II	Positive association with dental caries (ICDAS

Cross sectional				codes 4-6) and HSPM. OR 12.18, CI 3.82-38.76
(Amend et al. 2021)	Germany	NR	dmft	Mean dmft without hypomineralisation was much lower than those with HSPM.
Cross sectional				
(Rodríguez-Rodríguez et al. 2021)	Venezuela	NR	dmft	Caries was significantly associated with HSPM
Cross sectional				

OR- odds ratio; NR- not reported; dmft-decayed, missing filled teeth; ICDAS- International Caries Detection and assessment system, PUFA- pain, ulceration, fistula, abscess, *= studies included in systematic review

1.11 Introduction to research question

The pilot for the current study, conducted by McCarra et al. 2021, reported a prevalence of HSPM as 38.74% (n=31) in a sample of eighty-one boys in County Dublin, which is significantly higher than the expected prevalence based on global data available and identified the need for data specific to Irish children. Despite having a low sample size, this pilot study identified trends consistent with previously published results, further supporting the fact that affected individuals most commonly have one molar affected (n=28, 35.48%) and demarcated opacities (n=25, 80.64%) are the most common clinical presentation of HSPM.

To date there is no well powered data of HSPM prevalence for an Irish population.

The overall aim of this thesis is to answer the following:

- What is the prevalence of HSPM in a sample of the Irish population?
- What are the clinical characteristics of HSPM?
- Is HSPM associated with MIH and dental caries?
- What is the background medical history of the participants diagnosed with HSPM?

1.11.1 Aims

Primary Aim

- To determine the prevalence and characteristics of HSPM in 4–6-year-old children attending primary schools in County Dublin

Secondary Aims

- To record the medical background of the pre-, peri- and post-natal period of 4-6-year-old children
- To establish the dental caries experience (dmft) of in 4-6-year-old children attending primary schools in County Dublin
- To determine the association between HSPM and MIH
- To determine the association of HPSM and dental caries experience

1.11.2 Objectives

- To examine the dentitions of a sample of 4–6-year-old children attending primary schools in County Dublin
- To obtain the pregnancy history and medical history (from 0-3 years) of this sample of children from their parents

1.11.3 Null Hypotheses

1. There is no association between HSPM and gender
2. There is no association between HSPM and dental caries
3. There is no association between HSPM lesion severity and lesion extension size.
4. There is no association between HSPM and MIH

2 Methods

2.1 Ethical approval

The approval for this research was sought as an extension of an existing project (Reference No.190403) that could not be completed due to the Covid-19 pandemic. Due to the time gap between original application and this application for an extension several changes were made, involving a change of research personnel and updated data protection precautions. A data protection impact assessment (DPIA) was submitted and approved by local Data protection officer (DPO) in the Dublin Dental University Hospital (DDUH). Ethical approval was granted from the Faculty of Health Sciences, Trinity College Dublin Ethics Committee (Appendix 1) on 31/01/2023.

2.2 Study Design

This was a cross sectional study of a sample of 4-6-year-old children in County Dublin, Ireland. There were 2 components for data collection for all participants:

1. A dental examination of the child
2. Parental questionnaire relating to maternal pregnancy history and participants past medical history

2.3 Study Setting

This study was conducted within primary schools in County Dublin. Dental screenings took place in the participating primary schools with the aim increased

participation in the study as well as reducing the potential time away from school for each participant. County Dublin was selected for convenience of the research team to travel to such schools from the Dublin Dental University Hospital in Trinity College Dublin.



Figure 2.1- School setting and examination zones set up with dentist and dental nurse, at one of the primary schools attended in County Dublin.

2.4 Sample size calculation

The sample size was based on the established EAPD endorsed protocol for prevalence of HSPM/MIH studies which stated a minimum of three hundred participants, based on an expected prevalence of 5%. This protocol follows the validated formula where “ $N = [Z^2 \times P(1-P)/d^2]$ ” where N is the sample size, Z is the confidence interval (0.95), P is expected prevalence and d is the precision (0.05). Using an estimation of prevalence from a recent systematic review, this formula adjusted from expected prevalence of 5% to 6.8% which resulted in a sample size to 336 participants required.

2.5 Inclusion and exclusion criteria

Inclusion and exclusion criteria are discussed in table 2.1 below.

Table 2.1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Age 4-6 years old	Outside included age range
Parental consent for participation	No signed consent form
Present of day of examination	Absent from school on day of examination
Co-operative for dental examination	Lack of co-operation for dental examination

2.6 Recruitment

From April 2023 until April 2024 several primary schools in the Dublin area were invited to participate in this study. Contact details for each primary school was

sought through the Department of Education website where a full list of all primary schools is accessible to the public. Schools were selected through randomisation of this list in Excel and ten schools were selected, using random number generator at each email invitation timepoint. Randomised groups of ten schools were sent invitation emails until a satisfactory sample size was generated throughout this allocated recruitment time period.

A proforma email and letter of invitation (Appendix 2) was addressed to the principal and board of management, asking them to contact the Research Team if they wished to take part. One week following the email of invitation a phone call to the secretary or principal was made confirm each school's participation or refusal of such. Once the principal and board of management granted consent, a signed consent form was returned to the lead investigator (Appendix 2).

Following each school's consent to participate, each child in junior and senior infant class groups were invited to take part in the study. A participant package including a participant information letter, consent form and questionnaire (Appendices 4,5,6) was compiled by the research team and given to each class group. The teachers distributed these forms to each student. Parents of all invited children were given two weeks to read and sign consent forms or contact the research team if they had any queries. They were instructed to return these forms to the school on or before the planned date of examination. On the day of examination in school, the forms were brought by the child directly to the research team at the time of their dental screening examination.

2.7 HSPM diagnostic criteria

The criteria used for HSPM diagnosis and recording was the MIH/HSPM index developed by Ghanim et al 2015 (see table 2.2 below). For the purposes of this study one modification was made to include the code (7b) which was a primary molar restored with a stainless-steel crown (SSC) where there are signs of HSPM affecting other primary molars. First permanent molars and second primary molars were screened for the presence of MIH or HSPM, and their clinical status and extent of lesion was recording based on the diagnostic criteria. With regard to the first permanent molars, they were only recorded if more than one third of the tooth is erupted. If there was uncertainty regarding the score, the least severe score was given. Where there were two criteria evident on the one tooth the most severe code was assigned for that tooth.

Table 2.2 Diagnostic Criteria Ghanim et al 2015

<u>Code</u>	<u>Description</u>	
0	No visible enamel defect	Tooth is free of <u>All</u> enamel defects
1	Enamel defect, Not HSPM/MIH	These defects include diffuse opacities, hypoplasia, AI and hypomineralised defects (non-MIH/HSMP)
2a Demarcated opacities- white/creamy		Alteration in the translucency of the enamel with a clear distinct border with adjacent enamel. Opacities are variable in degree and can be white, yellow, or brown in colour
2b Demarcated opacities- yellow or brown		The defective enamel is of a normal thickness with a smooth surface
3	Post eruptive breakdown (PEB)	Loss of initially formed surface enamel after eruption. Commonly associated with a pre-existing demarcated opacity and found on surfaces that are traditionally low caries risk such as cuspal ridges/smooth surfaces. Usually, rough edges and uneven margins
4	Atypical restoration	Do not confirm to traditional picture of caries in terms of size and shape and commonly involve buccal and palatal/lingual surfaces. Pre-existing demarcated opacities may be present at the restoration margin.
5	Atypical Caries	Caries onset can be atypical involving surfaces that are not usually prone such as the buccal and palatal/lingual surfaces. Pre-existing demarcated opacities may be present. These lesions are typically seen in an otherwise caries-free mouth
6	Missing due to MIH/HSPM	Absence of a SPM in otherwise healthy dentition and associated with opacities, PEB, atypical caries/restoration in <u>at least one spm.</u>
7a	Cannot be scored	A tooth with extensive coronal breakdown where potential cause is impossible to determine
7b	Stainless steel crown (due to HSPM)	A SPM with a stainless-steel crown in an otherwise caries free dentition with clinical signs of HSPM affecting one or more remaining SPMs
X	Unerrupted/partially erupted	Partially erupted refers to a tooth that is not visible or less than 1/3 of the occlusal table is visible
Lesion extension	I – up to 1/3 of the tooth affected II- at least 1/3 but less than 2/3 tooth affected III – More than 2/3 tooth affected	Defects greater than 1mm in diameter are recorded. Lesion extension is based on a visual of the total sum of affected ‘defects’ relative to the whole tooth.

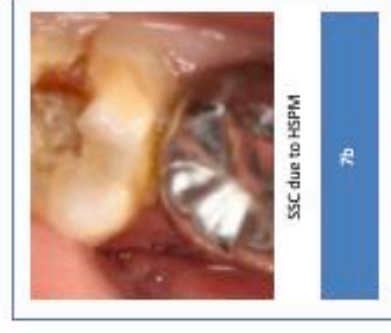
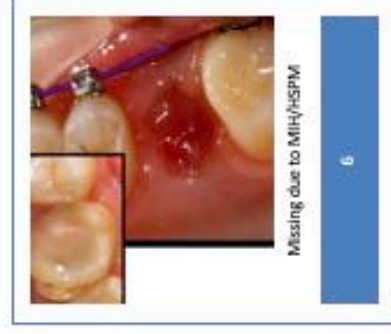
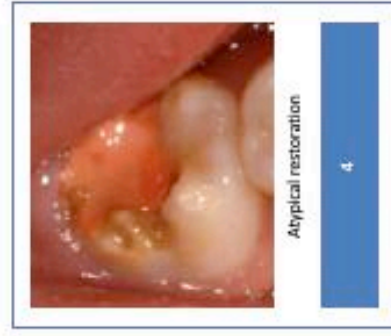
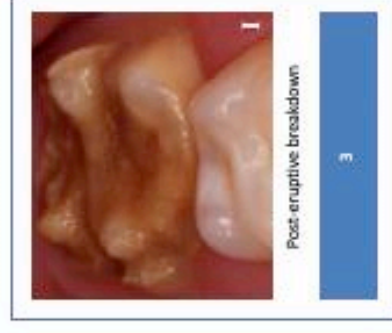


Chart 3.1 Diagnostic criteria images of MIH/HSPM Ghanim et al 2015

2.8 Caries diagnostic criteria

The caries experience of this sample of 4-6-year-old children was assessed and recorded using the modified WHO decayed missed filled index to the level of caries visible to dentine $d_{v3}mft$ (WHO, 1997). All primary teeth were included in the caries assessment and the numbers of each decayed (visible to dentine), missing (m) and filled f) teeth were recorded as well as total number of primary teeth remaining to calculate the dmft ratio per participant. Teeth were not recorded individually regarding caries presence or absence but rather total numbers of each aspect of the index as mentioned above.

Code	Description
Decayed (d)	Any tooth whose crown has an unmistakable cavitation on the pits and fissures or on a tooth surface or a filled crown, when it has one or more restorations with decay
Filled (f)	Filled crown with no decay, when it has one or more restoration and there is no caries anywhere on the crown
Missing(m)	Missing tooth due to caries, where the tooth has been extracted due to caries

Table 2.3 dmft diagnostic criteria (WHO 2019)

2.9 Calibration

All examiners (DMG, RC, IO, RL, and AOC) were trained and calibrated on both the MIH/HSPM and the $d_{v3}mft$ indices. All examiners attended two one-hour lectures on both indices including the differential diagnoses of MIH/HSPM and dental caries. Following the lecture presentations, a mock calibration and interactive discussion was completed where all examiners were able to openly discuss the

diagnostic rationale and compare with the gold standard set out by (Ghanim et al. 2017). Two calibration exercises were completed one week apart. A series of 60 photos for the MIH/HSPM criteria and 40 photos for the caries criteria were previously assessed and assigned their diagnostic criteria code. Intra-examiner and inter-examiner kappa co-efficient were calculated to assess examiner agreement.

2.10 Examination

The examination of participants included a dental screening completed in their primary school. The dental screening was approximately two minutes in duration. The dental screenings took place in an available classroom designated by the school principal, in the presence of their school-teacher. Five teams of examiners (trained and calibrated paediatric dentists) and trained dental nurses were present for each school visit. The dentist conducted the dental examination and dental nurse recorded examination findings on data collection form (see appendix 7) and assisted with infection control protocol. Teams were designated colour coded zones to assist in participant allocation by research team co-ordinator. Prior to allocation to an examining team, the team co-ordinator confirmed consent status of each participant and ensured appropriate research documents were completed.

The dental exam was completed with the participant standing upright using an illuminated dental mirror (Lumadex Denlite™). The dentition was examined wet, with gauze available to dry teeth or remove debris should that be required. All

primary teeth present were examined for the presence of any decayed, missing due to caries or treated due to caries teeth and total numbers of each record to calculate dmft. Only the HSPM and MIH index teeth (SPMs and FPMs) were examined for the presence and extent of defects Appendix No. 7-Data Collection Form). If any dental disease or other urgent treatment needs were identified on examination, a proforma letter indicating the observed dental treatment need was sent to the guardians of identified participants (see appendix no. 8).



Figure 2.3 Examination armamentarium for school screenings including: Clinical waste disposal bag, surface disinfectant wipes, zoned area, personal protective equipment, dentlite illuminated mirror, alcohol hand gel, data collection forms and appropriate stationary.



Figure 2.4 Example of screening zone set up in one school visited in County Dublin during data collection.

2.11 Questionnaire development

The questionnaire developed for this study was based on that of Ghanim et al., 2012. In that study a questionnaire of 63 items of hypothesised risk factors of HSPM was used, which was based on a similar study design by Whatling and Fearne 2008 investigating MIH risk factors. Both questionnaires were validated prior to use. In the Ghanim et al., study the questionnaire was split into health

history in the pre-natal, peri-natal, and post-natal stages along with feeding habits. These topics all had multiple sub sections on maternal illness, medication use, medical interventions, normal delivery, caesarean section delivery, use of incubator, infant illness, breastfeeding and duration, fever and infant medication use during first year of life, among other demographic parameters. In this study, the primary aim is not to investigate the risk factors of HSPM. The aim of questionnaire is to gain an understanding on the medical background and the known associated risk factors in those participants diagnosed with HSPM. Therefore, the questionnaire was simplified considerably to allow for yes/no answers of complications during each of those three stages, rather than specifics and answers on duration of feeding style, medication use and incidence of fever or infection during first year of life (see appendix 8.5 for Full questionnaire).

2.12 Data collection

Table 2.4 Data collection timeline

Prior to dental screening	
Patient information leaflet, consent form and questionnaire given to schools Forms distributed by schools two weeks prior to screening Forms collected by schools for the day of examination	
Day of data collection	
Preparation	Four examining zones/Four teams (colour coded- red, green, yellow, blue) set up in designated room in the school. See photo on zone set up (Figure 2.3 & 2.4). Teams consist of one examiner who will cross check participant information and consent, complete dental screening examination & carry out cross infection control and one assistant who will record screening data & cross infection control
Arrival of participants	Participants arrived with their teacher as a class group. Welcomed by Team coordinator On each participants turn they will be directed to one of five colour coded zones by screening coordinator Children ordered in line with their consent forms in hand as they approached the examination station.
Screening	Consent and name verified prior to examination Examination sequence: Child examined in school chair sitting upright. All teeth examined for dmft Index teeth examined and results recorded by assistant on data sheet <u>Data sheet, consent form and questionnaire all stapled together prior to placement in envelope</u> Notification of any dental disease via a proforma letter given to the child for the attention of their caregiver
After screening	Cross infection control verified Equipment collection cross checked and packed Data collection forms all stored securely and returned to lead researcher for storage
After data collection	
Data coding	Coding applied to all data (consent from alphabetical code, data sheet numerical code) by lead researcher
Data input	Data from examination sheets entered excel spreadsheet manually and cross checked for errors
Statistical analysis	Discussed with statistician

2.13 Cross infection control

A cross infection control process was developed in conjunction with a DDUH clinical nurse manager and senior registered dental nurse. Universal precautions were employed ensuring all examiners and assistants were utilising appropriate personal protective equipment and maintaining gold standard hand hygiene.

2.14 Confidentiality

Prior to conducting school screening examinations, all examiners completed appropriate training in General Data Protection Regulation (GDPR) compliance and child safeguarding protocols, including *Children First* (HSE 2024) training. Additionally, all members of the research examining team had obtained prior Garda Vetting approval, ensuring adherence to national child protection and ethical standards.

Data was collected on paper and transferred to the Dublin Dental University Hospital (DDUH) and organised in a swipe accessed room. Transfer of data was by the lead investigator and research team travelling together from the primary schools to the DDUH with data collected in locked briefcase. It was immediately placed into locked cabinet until processed.

The consent forms were stored securely in locked briefcase in a locked cabinet within a swipe accessed room in the Department of Public and Child dental health in DDUH, and will be stored for the required duration of seven years.

All paper datasets (consent forms, clinical exam document and questionnaires) were assimilated for each participant and coded electronically for pseudonymisation. The master code is held by the Department of Public and Child dental health secretary in a password protected computer in Dublin Dental University Hospital.

Data obtained during the clinical examination and questionnaire of each participant was imported into a password protected excel document on desktop computer mentioned above, with access limited to the lead investigator. Data input was verified and crosschecked by a second investigator. Once data was imported these documents were shredded.

2.15 Data Analysis

All calibration and clinical screening data was tabulated in a Microsoft® Excel® (Microsoft Inc, WA, USA) spreadsheet. Data was analysed to provide percentages of HSPM affected children (child level prevalence) and teeth (tooth level prevalence). All other clinical characteristics of HSPM affected teeth were also analysed for trends. dmft was calculated for each participant and averaged for statistical comparison. Data was input into SPSS® version 21 (IMB Inc., NY, USA) for statistical analysis. Chi-squared tests were used to analyse for any relationship between HSPM and gender, dental caries, and MIH. The level of significance was set at $p < 0.05$. The data from the questionnaire was analysed using to assess any comparison between maternal history and participant medical history and the presence of HSPM.

3 Results

3.1 Calibration

Inter and intra examiner reliability achieved Kappa scores of >0.8 for all five examiners using the MIH/HSPM diagnostic criteria. Using the d_{v3mft} index for caries diagnosis inter examiner reliability was >0.7 and intra examiner reliability was >0.8 .

3.2 Recruitment

Seven schools expressed interest in taking part in this research project. These schools had a broad geographic distribution in County Dublin including Inner City Dublin, North County Dublin, Dublin South, and West County Dublin. Among these schools 656 children were eligible for inclusion in this study. Two hundred and fifty eligible participants were absent on the day of screening or did not have parental consent. Five children were excluded due to behavioural complications. A total of 401 children were examined.

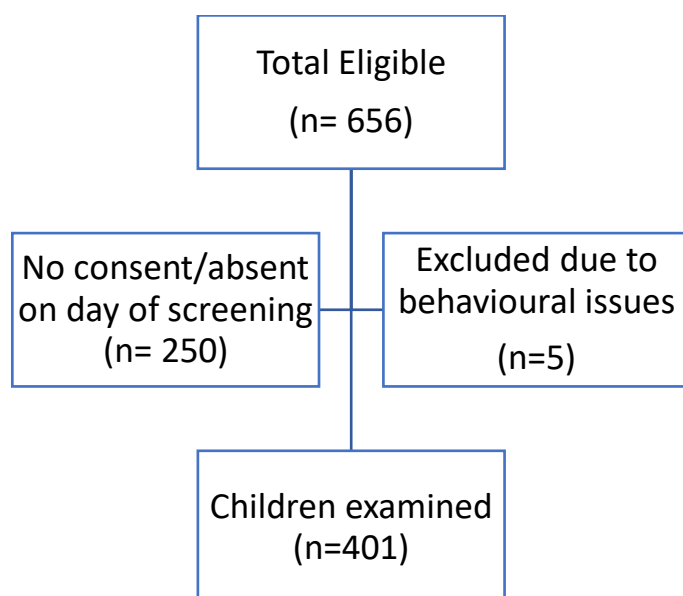


Figure 3.1 Recruitment flow chart with participant numbers.

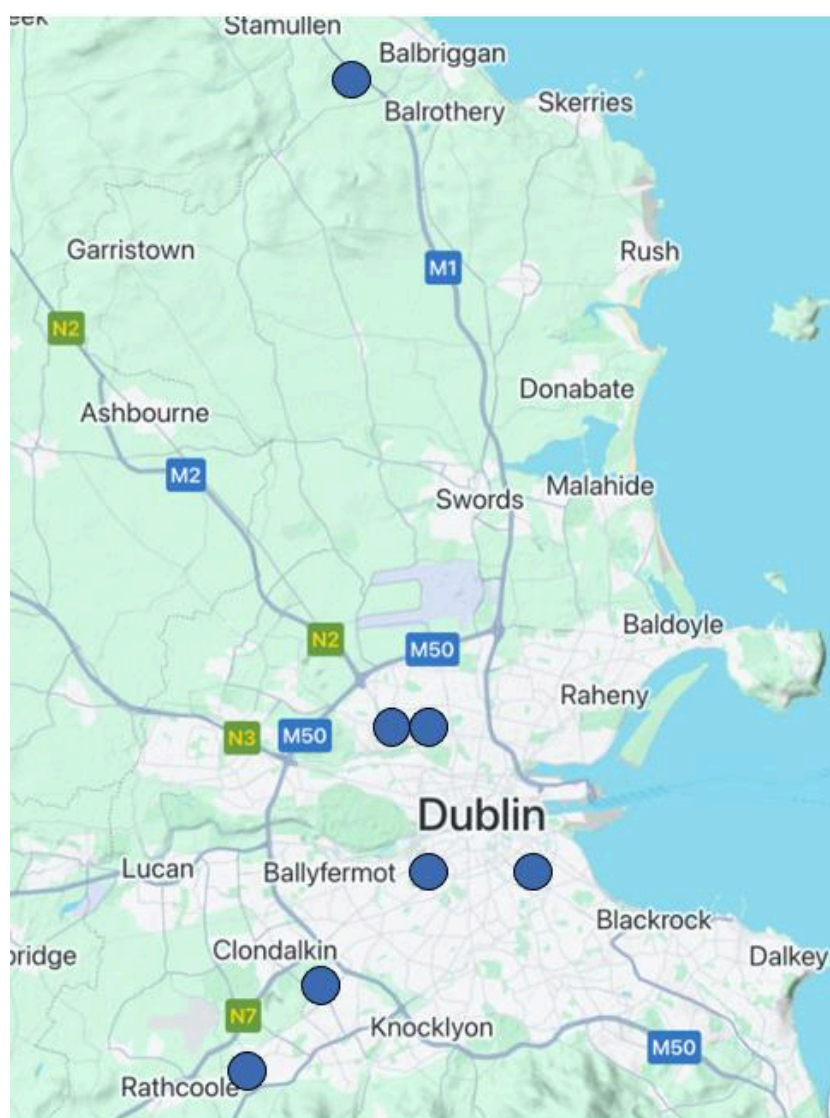


Figure 3.2 Geographic distribution of schools screening in County Dublin

3.3 Demographics

Two hundred and fourteen (53%) males and one hundred and eighty-seven females (47%) were screened (Table 3.1). The age range of included participants is four to six years old [Age-Mean (SD)= 5.4(0.68) years]. The average number of primary teeth per participant was 18.2 +/- 2.4.

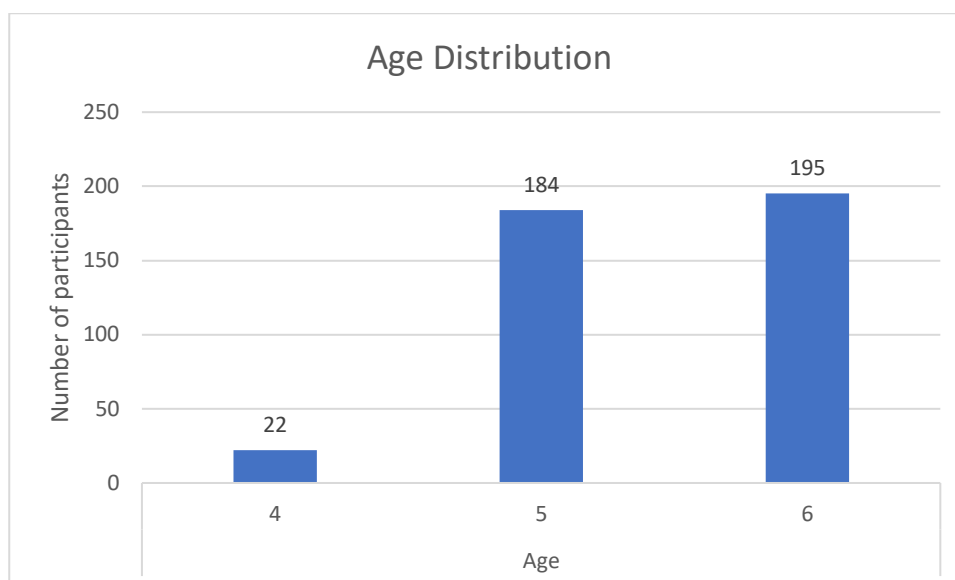


Figure 3.3- Age distribution of participants

Table 3.1 Relationship of HSPM and gender

	HSPM		
	Yes (n)	No (n)	
Male	49(12.2%)	165(41.1%)	214(53.4%)
Female	35(8.7%)	152(37.9%)	187(46.6%)
Total	84(20.9%)	317(79.1%)	401(100%)

Forty-nine (12.2%) males and 35 (8.7%) females had HSPM defects on examination (Table 3.1). Statistical analysis showed no significant association with sex and presence of HSPM (Table 3.1). Chi-squared test statistic 0.675, P-value is 0.411.

3.4 HSPM prevalence

A total number of 401 children were examined and 84 were identified as having HSPM defects resulting in a child prevalence of 20.9%. 1603 SPMs were examined

and 154 had HSPM defects resulting in a tooth level prevalence of 9.6%. Amongst the HSPM affected children (n=84) 43 (51.2%) had only one affected SPM where 19 (22.6%) had two, 15 (17.8%) had three and 7 (8.3%) had four affected SPMs, see chart 3.4.

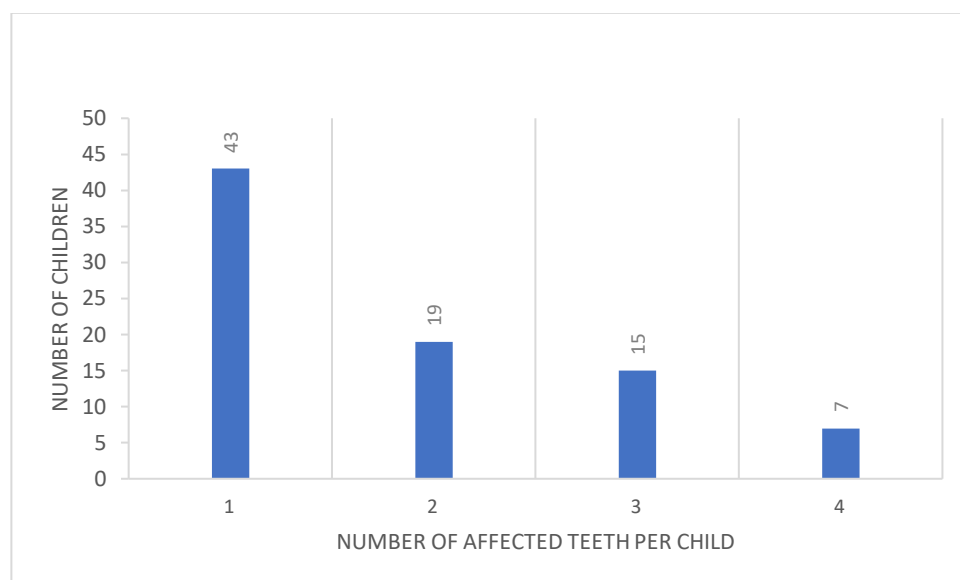


Figure 3.4 Number of affected teeth per participant

Table 3.2 Number of teeth affected by HSPM and severity.

Number of teeth affected				
	1	2	3	4
Severe HSPM				
Yes	11	4	11	5
No	32	15	4	1

Chi-squared test statistic 18.42, p-value <.001.

Of those participants with severe HSPM (PEB, atypical caries or restoration, extracted due to HSPM), 11 had one tooth affected versus 5 participants having all four SPMs affected. Whereas with mild HSPM, presenting as demarcated opacities, 32 and 1 participants had one and all four SPMs affected respectively. There is a statistically significant association between number of teeth affected by HSPM and the severity of the HSPM presentation per participant.

3.5 HSPM lesion characteristics

The distribution of the HSPM affected teeth was equal for both mandibular (n=77) and maxillary (n=77) SPMs. Slightly more right-side SPMs had HSPM defects (n=79) compared with left-side (n=75).

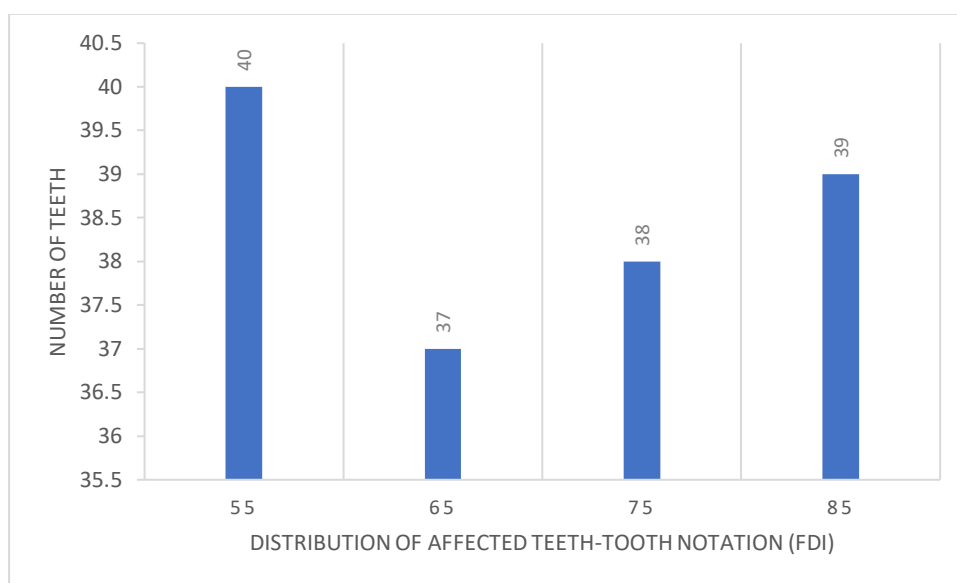


Figure 3.5 Distribution of affected teeth

Demarcated opacities were the most common defect recorded. The colour distribution of the opacities was n=81 (52.6%) white/cream opacities and n=15 (9.74%) yellow/brown opacities. Other defects recorded in order of frequency include atypical caries, post-eruptive breakdown, atypical restoration. One tooth was missing due to HSPM and seven teeth had stainless steel crowns due to HSPM. Only 7.8% (n= 6) of the 84 children with HSPM defects had received any dental intervention (restoration or extraction). Two participants previously had their SPM extracted. 154 (38.4%) participants had at least one of their FPMs sufficiently erupted for examination. Of these 154 participants, 148 participants had at least two FPMs, 125 had at least three and 121 had all four FPMs erupted.

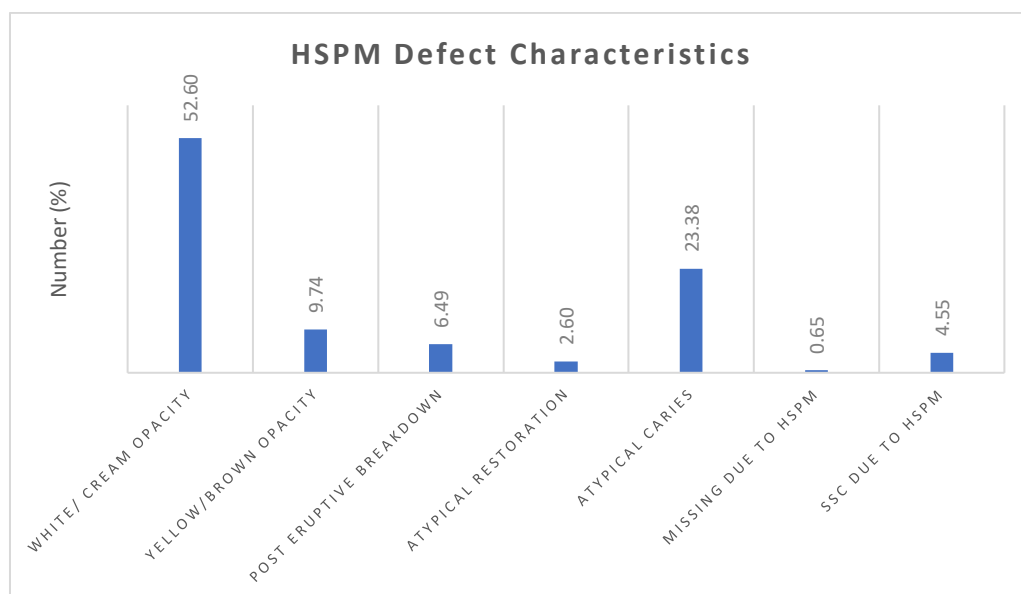


Figure 3.6 HSPM defect characteristics

3.6 HSPM lesion extension

Lesion extension codes were recorded for opacities, PEB, atypical caries and restorations. Teeth that were extracted or had stainless steel crowns could not be scored for lesion extension and were omitted from this calculation or assumed to be III. A lesion extension of code I (1/3 or less of the tooth) was the most common with for all clinical presentations of HSPM, followed by code II (1/3-2/3 tooth structure) and code III (>2/3 tooth structure), as demonstrated in table no. 3.2 below.

Table 3.3 Association of HSPM lesion severity and lesion extension.

		Extension			
		(n)			
HSPM lesion criteria		I	II	III	Totals
Mild HSPM	2a	73 (48.6%)	12(8%)	1(0.6%)	86(57.3%)
	2b	7(4.6%)	5(3.3%)	2(1.3%)	14(9.3%)
Severe HSPM	3	5(3.3%)	4(2.5%)	1(0.6%)	10(6.7%)
	4	0(0%)	3(2%)	1(0.6%)	4(2.5%)
	5	4(2.5%)	14(9.3%)	18(12%)	36(24%)
Totals		89(59.3%)	38(25.3%)	23(15.3%)	150(100%)

Gamma test statistic= 0.833, $P < .001$. There is a significant association with increasing severity of the clinical presentation (HSPM defects with PEB, atypical restoration or caries) with the extension of the HSPM.

3.7 Association of HSPM with MIH

One hundred and seventy-four participants had at least one FPM sufficiently erupted for examination [Age-Mean(SD)= 5.8(0.61) years]. Fifty-one out of the 174 participants with first permanent molars erupted had MIH resulting in a prevalence of 29.31%. Five-hundred and forty-eight first permanent molars were examined of which 96 had MIH defects identified, resulting in a tooth level prevalence of 17.51%.

Fifteen participants had both HSPM and MIH affected teeth on examination. The rate of co-occurrence of both developmental defects was 9.74%. Table 3.3 below shows population data for HSPM as a predictor for MIH.

Table 3.4. Association of HSPM and MIH.

HSPM			
MIH	Yes (n)	No (n)	Total
Yes (n)	15(9.7%)	36(23.3%)	51(33.1%)
No (n)	69(44.1%)	34(22.1%)	103(66.8%)
Total	84(54.5%)	70(45.5%)	154 (100%)

Chi-squared test statistic value is 19.43, P-value is <.001

There is a significant association between HSPM and MIH

3.8 Caries prevalence

The average dmft score among the children examined was 1.7, Median 3 (IQR 5-2). Of the 401 children assessed, 137 (34.1%) had a dmft greater than or equal to 1, indicating the prevalence of dental caries at the child level. Among those affected, 14 children had missing teeth and 19 had restored teeth due to caries. Despite this, only 8% of the children with dental caries had received any form of dental intervention. The average dmft for those participants with a dmft of 1 or more was 3.97. At the tooth level, a total of 7,323 primary teeth were examined visually, and 542 teeth (6.5%) were found to be affected by dental caries, representing the tooth-level prevalence.

3.9 Relationship of HSPM and dental caries

In this sample, 40 (9.9%) participants had both HSPM and dental caries on examination, compared with 219 (54.6%) without. Table 3.4 below shows population data for the association between HSPM and dental caries. Chi squared analysis found significant relationship was reported between HSPM and dental caries (P-value .004).

Table 3.5 Association of HSPM and Dental Caries

HSPM			
Caries	No n (%)	Yes n (%)	Total (%)
No	219(54.6%)	44(10.9%)	263 (65.5%)
Yes	98(24.4%)	40(9.9%)	138 (34.5%)
Total (%)	317 (79%)	84 (21%)	401

Chi-squared test statistic 8.21, P-value .004.

3.10 Questionnaire

The total number of respondents was 393. The response rate was 96.8%. In all 10 questions there was at least one missing answer. These submissions were included, and missing values accounted for through valid percentages (see tables 3.5, 3.6, 3.7, 3.8 below). The results for each question are reported according to pre-natal (table 3.6), peri-natal (table 3.7), feeding methods (table 3.8) and post-natal (table 3.9) risk factors associated with HSPM.

Table 3.6 highlights that 22.8% and 23.8% of the participants who had a diagnosis of HSPM were associated with maternal complications or prescribed medications during their pregnancy respectively. Statistical analysis found no significant association between maternal health and medication use during pregnancy.

Table 3.6 Questions 1-2: Pre-natal risk factors for HSPM with counts and valid percentages, including crosstabs for HSPM

Variable	Count	Valid (%)	percentage	HSPM (%)	Chi- squared test statistic (P value)	
				Yes	No	
Question 1. Did you have any significant problems/complications during pregnancy?						
Yes	94	24.4	18 (22.8)	76 (24.5)	2.411	
No	295	75.8	61 (77.2)	234 (75.5)	(P=.120)	
Totals	389	100	79	310		
Question 2. Did you take any prescribed medications during pregnancy?						
Yes	95	24.4	19 (23.8)	76 (24.6)	2.658	
No	294	75.6	61 (76.2)	233 (75.4)	(P=.103)	
Totals	389	100	80	309		

Babies born prematurely (before 38 weeks' gestation n = 68), out of those 13 had HSPM defects on examination, compared with 55 participants without HSPM, also born prematurely. 8.8% of participants weighed less than 2.5kg at birth, of which 6.3% had HSPM defects. Sixty participants had significant immediate post-natal complications which required extended hospital stay, incubator use or neo-natal intensive care stays. Of these 60 participants 14 (17.5%) had HSPM defects on examination. Statistical analysis found no significant relationship between gestation term and peri-natal complications.

Table 3.7 Questions 3-6: Peri-natal risk factors associated with HSPM with counts and valid percentages including crosstabs for HSPM

Variable	Count	Valid percentage (%)	HSPM (%)		Chi-squared test statistic (P-value)
			Yes	No	
Question 3. Was your child born to full term?					
Yes	323	83	70 (87.5)	253 (81.9)	.007 (P= .935)
No	66	17	10 (12.5)	56 (18.1)	
Totals	389	100	80	309	
Question 4. Was your child born before 38 weeks?					
Yes	68	17.4	13 (16.3)	55 (17.7)	.166 (P= .684)
No	323	82.6	67 (83.3)	256 (82.3)	
Totals	391	100	80	311	

Question 5. What birth weight was your child, please circle appropriate option. Less than 2.5kg (low) Greater or equal to 2.5kg (normal)					
Normal	354	91.2	75 (93.7)	279 (90.6)	.216 (P= .642)
Low	34	8.8	5 (6.3)	29 (9.4)	
Totals	388	100	80	308	
Question 6. Were there any problems immediately after birth necessitating your child remain in hospital?					
Yes	60	15.3	14 (17.5)	46 (14.8)	.129 (P= 0.719)
No	331	84.7	66 (82.5)	256 (85.2)	
Totals	391	100	80	311	

When questioned about feeding methods (table 3.8 below), bottle feeding was more common (78.2%) compared to breastfeeding (71.1%). Only 85 participants were not bottle feed. Breastfeeding for more than one year was the most common duration (40%), similarly with bottle feeding (77.2%). Out of the 80 participants who had HSPM diagnosed, 72.5% were breastfed whereas 80% were combinations of both. Statistical analysis found no significant relationship between any feeding methods investigated and the presence of HSPM.

Table No. 3.8 Questions 7-8: Feeding methods of participants with counts and valid percentages and crosstabs for HSPM

Variable	Count	Valid percentage (%)	HSPM (%)		Chi-Squared test statistic (P-value)
			Yes	No	
Question 7. Did you breast-feed your child?					
Yes	278	71.1	58 (72.5)	220 (70.7)	2.934 (P= .402)
No	113	28.9	22 (27.5)	91 (29.3)	
Totals	391	100	80	311	
If yes for how long? (n=/278)					
Less than 3 months	58	21.1	15	43	
3-6 months	65	23.6	14	51	
1 Year	42	15.3	11	31	
More than 1 year	110	40	18	92	
Totals	278	100	58	217	
Question 8. Did you bottle feed your child?					
Yes	305	78.2	64 (80)	241 (77.7)	0.207 (P= .649)
No	85	21.8	16 (20)	69 (22.3)	
Totals	390	100	80	310	
If yes for how long? (n=/305)					
Less than 1 year	69	22.8	13	56	
More than 1 year	234	77.2	50	184	
Totals	303	100	63	240	

Of those participants with HSPM, approximately half (51.3%) reported having infection fever in the first year or life, and 33.8% of those were prescribed antibiotics (see table 3.9 below). Similar results were found for those participants with HSPM who were not reported to have suffered from infections or fevers (48.8%) or who had taken antibiotics(66.3%) in the first three years of life. Statistical analysis found no association with HSPM and antibiotic use or illness during the first year of life.

Table No. 3.9 Questions 9-10: Post-natal risk factors for HSPM with counts and valid percentages with crosstabs for HSPM

Variable	Count	Valid percentage (%)	HSPM (%)		Chi-Squared test statistic (P-value)
			Yes	No	
Question 9. Did your child suffer from any infections or high fevers in first three years of life?					
Yes	167	42.7	41 (51.3)	126 (40.5)	4.233 (P=.120)
No	223	57	39 (48.8)	184 (59.2)	
	391	100	80	311	
Question 10. Was your child prescribed antibiotics in the first year of life?					
Yes	124	31.7	27 (33.8)	97 (31.2)	0.193 (P=.661)
No	267	68.3	53 (66.3)	214 (68.8)	
Totals	391	100	80	311	

4 Discussion

Global data on HSPM prevalence has been somewhat limited and potentially inaccurate due to the differing diagnostic indices used and lack of standardisation among study design. A need to investigate the population level prevalence in Ireland was recognised in 2019, but data collection was terminated due to the Covid epidemic (McCarra et al Unpublished results). This pilot study on HSPM reported a prevalence of HSPM in 90 children (at 38% child/20.4% tooth with 2.16 ± 1.13 teeth affected per child), similar to that reported in Syria and Jordan (Bani-Hani, Taha, and Al-Batayneh 2025; Halal and Raslan 2020). A recent meta-analysis suggested the global prevalence of HSPM to be 6.8 % (McCarra et al. 2021). The current study aimed to continue the investigation of HSPM prevalence in Ireland using the same design and criteria to achieve a representative and adequately powered sample. Even after introduction of the EAPD diagnostic criteria, and its modification (Weerheijm 2003; Lygidakis et al. 2010), some researchers continued to use the mDDE index for MIH and HSPM investigations (Owen et al. 2018; Reyes et al. 2019). This limits a valid comparison between the available studies. Elfrink et al., 2015 reported there is natural variation in the worldwide prevalence of developmental defects of enamel which can also vary depending on region and research protocol used.

In this study, a standardised methodology outlined by Ghanim et al., 2017 for HSPM and MIH prevalence studies was followed to enable comparison with studies using the same validated criteria. Adoption of the MIH/HSPM calibration

training by Ghanim et al., 2017 is recommended to minimise intra- and inter-examiner variations as well as to achieve standardisation and high reproducibility of results. This calibration method was followed in our study including training and calibration on enamel defects which are not MIH or HSPM to reduce any risk of overestimation of HSPM prevalence, and excellent intra- and inter-examiner reliability was achieved (0.84).

Examination occurred within the school setting, and the examination conditions were standardised, in line with protocols set out for epidemiological studies (Ghanim et al. 2017). According to the training manual for conducting HSPM prevalence studies, a sample size of 300 was required (Ghanim et al. 2017) Based on the systematic review (McCarra et al. 2022) which reported prevalence of 6.8%, our study adjusted this number of participants required to 336. A strength of this study is the sample achieved surpassed the required amount with 406 participants unlike some other published studies (Mittal and Sharma 2015; Børsting et al. 2022; Borrego-Martí et al. 2021).

Elfrink et al 2015 has outlined that the ideal age of examination of children for HSPM is five years old and 8 years old for MIH, which is also supported by the EAPD (Elfrink et al. 2015; Ghanim et al. 2017; Lygidakis et al. 2022; Lygidakis et al. 2010) This is due to the fact that at this age, most SPM will be erupted, children will likely be co-operative and the majority of SPM with HSPM will still be recognisable but gross destruction may still occur by this age. The age range included in our study was 4-6 years old with an average age of 5.4 years. Many studies have investigated for both HSPM and MIH prevalence at one timepoint, with age ranges from 6-12

years old. See table 1.1 for study characteristics of HSPM prevalence studies. This may complicate comparison between studies as SPMs may be unable to be fully assessed due to destruction, restoration, or extraction. A limitation of some studies in older age groups is that SPMs may have exfoliated naturally (Negre-Barber et al. 2016; Oyedele, Folayan, and Oziegbe 2016; Amend et al. 2021).

A gender balance was achieved in this study with only marginally more males (53%) than females (47%). Like many other studies, our study found no significant association with gender and HSPM diagnosis (Oyedele, Folayan, and Oziegbe 2016; Negre-Barber et al. 2016; Halal and Raslan 2020; Quintero et al. 2022; Rodríguez-Rodríguez et al. 2021; Elfrink, Moll, et al. 2013; da Silva Figueiredo Sé et al. 2017).

A large variation in HSPM prevalence is reported in the literature (0-44%). We report a prevalence of 20.95 % (n=84/401) in our cohort. When comparing this study to those which have used the same standardised methodology and diagnostic criterion, the prevalence reported for this population, would appear to be similar to that reported from Norway (22% (Børsting et al. 2022) and Spain (14-4%- 24% (Marcianes et al. 2023; Negre-Barber et al. 2016), whereas the findings from our study are higher than the Netherlands (5%- 14.76%, (Elfrink et al. 2008; van der Knaap-Kind et al. 2025), South-West France (9.4% (Estivals et al. 2023) and Germany (3.9% (Elger et al. 2020). Interestingly, the regional variation in Asia is the most obvious, with the lowest prevalence reported in India (0%- 9%) (Goyal et al. 2019; Kar, Sarkar, and Mukherjee 2014) and the highest globally, in the Middle east (41-44%) (Bani-Hani, Taha, and Al-Batayneh 2025; Halal and Raslan 2020). The reported prevalence in South-America (5-14.9%) and Australia (8-14%) are very

similar to those calculated in Europe (Gambetta-Tessini et al. 2018, 2019; Lima et al. 2020; Owen et al. 2018). Given the significant global variation in data and the lack of consensus on the exact aetiology of HSPM, it is reasonable to expect regional and population variations. Nevertheless, given the sample size in this study, the calculated prevalence of 20.95% is considered representative of the region studied. Prevalence studies are essential in paediatric dentistry as they provide critical insights into the burden and distribution of oral health conditions. These studies identify at-risk populations, guide resource allocation, and inform preventive and treatment strategies at population level.

In line with findings from previous studies (Goyal et al., 2019; Mittal & Sharma, 2015), this study reported a tooth-level prevalence of HSPM at 9.6% (see Table 1.1), with the average number of affected teeth per child ranging from 1.9 to 2.47. Notably, 51% of participants had only one second primary molar affected—a finding consistent with several other studies (Bani-Hani, Taha, and Al-Batayneh 2025; Børsting et al. 2022; da Silva Figueiredo Sé et al. 2017; Elfrink et al. 2008; Ghanim et al. 2013; Goyal et al. 2019; Owen et al. 2018; Silva et al. 2019). Furthermore, this study found no statistically significant differences in prevalence based on tooth location (left vs. right, maxillary vs. mandibular), a result that mirrors those reported in other studies examining tooth distribution patterns (see Table 1.1).

Demarcated opacities were the most common clinical feature of HSPM identified in this population with 52.6% of affected teeth having creamy-white opacities and only 9.74% of these teeth were yellow-brown opacities. All studies which have

reported on lesion characteristics have noted opacities, and specifically creamy-white opacities to be the most common (Amend et al. 2021; Bani-Hani, Taha, and Al-Batayneh 2025; Børsting et al. 2022; Costa Silva et al. 2013; da Silva Figueiredo Sé et al. 2017; Elfrink et al. 2008; Estivals et al. 2023; Gambetta-Tessini et al. 2018, 2019; Ghanim et al. 2013; Goyal et al. 2019; Halal and Raslan 2020; Lima et al. 2020; Marcianes et al. 2023; Ng et al. 2015; Owen et al. 2018; Oyedele, Folayan, and Oziegbe 2016; Quintero et al. 2022; Sidhu et al. 2020; Silva et al. 2019; Temilola and Folayan 2015). From the above studies, lesions characteristics in order of frequency are creamy-white opacities, yellow-brown opacities followed by post eruptive breakdown, with very few studies reporting on atypical caries, restorations, or extractions. Interestingly, in this study atypical caries was the second most common lesion characteristic in 23.28% of affected teeth. A cross-sectional study from Germany was the only other study where atypical restorations were the second most common lesions following opacities (Amend et al. 2021). This was explained as being reflective of the access to care this population and the severity of HSPM prevalence in this population. In the Irish cohort, this may reflect the overall caries experience with a high caries prevalence (34%) in this sample. In this study, very few children with caries had atypical restorations, extractions, or stainless-steel crowns, reflecting the lack of access to care for this age group and possibly the lack of awareness of dental issues among guardians and dentists alike. This study did not include an assessment of participants prior dental attendance or history of dental visits.

The majority of HSPM lesions were mild, less than one third of the visible surface area of the tooth, supporting other literature (da Silva Figueiredo Sé et al. 2017;

Lima et al. 2020; Sidhu et al. 2020; Silva et al. 2019). Lesion extent and severity are often analysed together, with conflicting results. In this study, a statistically significant relationship with lesion extent and severity was found ($p < .001$), indicating that as lesion severity increased so too did the extension score, supporting evidence from (Owen et al. 2018).

At the time of examination during the dental screenings, 174 participants had their first permanent molars sufficiently erupted for examination. Fifty-one of these had MIH resulting in a prevalence of 29.31%, much higher than that reported (13.5%) in the most recent systematic review on global prevalence (Lopes et al. 2021). This number and age of children is below that recommended for MIH prevalence study (a minimum of 300 participants should be screened at 6-8 years old (Ghanim et al. 2017)). While the prevalence of MIH was not the primary aim in this project, this data serves as preliminary data for the secondary aim to examine the association between HSPM and MIH. The co-occurrence rate of HSPM and MIH in this sample was 9.74% with a significant association between both conditions. This finding is most similar to the cross-sectional study from Spain reporting a co-occurrence rate of 11.1% (Negre-Barber et al. 2016). Both these findings are of the lower range compared to many co-occurrence rates in the literature, ranging from 22%- 34% (Quintero et al. 2022; Temilola and Folayan 2015). The results of this study support the association between HSPM for MIH ($p < .001$), similar to previous reports (Amend et al. 2021; da Silva Figueiredo Sé et al. 2017; Elfrink, ten Cate, et al. 2013; Estivals et al. 2023; Marcianes et al. 2023; Mittal and Sharma 2015; Negre-Barber et al. 2016; Quintero et al. 2022; Reyes et al. 2019).

The prevalence of dental caries in this population was high, with 137 out of the 401 children examined presenting with at least one carious lesion (mean dmft = 1.7). This approach was chosen to allow meaningful comparisons to reported Irish data on caries in this age group. The findings from the present study align closely with national caries levels reported in the 1985 and 2002 surveys for the same age group, which showed average dmft scores of 1.8 and 1.0, respectively (O'Mullane et al., 1986; Whelton et al., 2004). The average dmft score in the current study (1.7) represents an increase when compared to previous data from the same region, dmft 0.7 in 1993, dmft 1.5 in 1998, and dmft 0.7 in 2014, (Board 1997; James et al. 2018). This apparent rise in caries experience may reflect various contributing factors, including demographic shifts and cultural changes associated with increased immigration and SES status, all of which should be explored in an Irish population.

A significant relationship with dental caries and HSPM was found in this sample. This finding further supports previous literature on the strong association between the two conditions (Amend et al. 2021; Gambetta-Tessini et al. 2018, 2019; Ghanim et al. 2013; Halal and Raslan 2020; Mittal and Sharma 2015; Oyedele, Folayan, and Oziegbe 2016; Rodríguez-Rodríguez et al. 2021). Analysis of the literature indicates that the association of HSPM and dental caries may strongly be influenced by the overall caries risk of the population, and as such there appears to be an association with those participants who have HSPM and dental caries, rather than the individual teeth. Several studies available for comparison also investigated the effects of severity of both HSPM and dental caries lesions on

the relationship, however dmft was used in this study to assess the presence or absence of caries only and as such those comparison cannot be made.

A parental questionnaire was utilized in this study to gather supplementary information on potential aetiological factors associated with HSPM. The primary aim of the questionnaire was to provide contextual background on the population group studies and to explore possible trends or associations with known risk factors- such as systemic illnesses, nutritional status, birth history and maternal health. Identifying such trends may offer insights that could inform the design and focus of future epidemiological and aetiological investigations. SES is often a factor associated with many health conditions. As other studies failed to show an association (Elfrink et al. 2008; Ghanim et al. 2013; Goyal et al. 2019). SES data was not collected in this study.

With regard to the questionnaire, no single factor was identified as a statistically significant risk factor for HSPM in this group. In the literature, peri-natal health events were the most associated risk factor followed by maternal illness during pregnancy (Ghanim et al. 2012). In this study, participants diagnosed with HSPM were associated with maternal complications (22.8 %) or medication use (23.8%) during pregnancy, while only 17.5% had neonatal illnesses. Other questionnaire responses showed minimal differences between the HSPM and non-HSPM groups, with no statistically significant associations, likely due to the small sample size well below the minimum number recommended (1000 participants) for aetiological studies by Elfrink et al., 2015. Additionally, recall bias is a key limitation.

4.1 Limitations

This study is a cross sectional design using a convenience sample which could be a limitation of the study. This study took place in one location only (Dublin, Ireland), but a broader sample from a wide geographical area would be required to establish population prevalence of both conditions. Longitudinal, cohort studies would be preferable for identification of participants with both HSPM and MIH at the appropriate time point based on the dental development stage.

In this study, race or ethnicity was not recorded, which may influence the prevalence of both HSPM and dental caries due to genetic and cultural differences, as highlighted in the globally variation in data from previous literature.

While the use of the dmft index for caries diagnosis is beneficial for this study to compare to previous Irish literature, there are limitations in that it is impossible to assess the association of HSPM and caries on a tooth level, only participant level. Despite having an adequately powered sample size for prevalence studies on HSPM the sample of participants with co-occurrence of MIH and HSPM was quite low, due to age and eruption status of the FPM at the time of examination, which may impact on reported association of HSPM as an indicator for MIH.

5 Conclusion

The prevalence of HSPM in 4–6-year-old children in Dublin is 21%. The prevalence of HSPM in this sample of Irish population is higher than the reported global prevalence of 6.8%. Additional investigation of HSPM on a broader sample is required to determine the true HSPM prevalence of the population. Significant associations are evident with HSPM and both MIH and dental caries in this population. Creamy-white opacities are the most common clinical presentation of HSPM. This study confirms a high prevalence of HSPM, emphasising the importance of early detection to reduce caries risk and anticipate potential development of MIH. Identification of at-risk children is imperative, allowing for early preventive care and intervention. Screenings should be completed earlier than current practice in Ireland (6-years-old) to identify risk, as this study found a significant number of participants with FPM erupted prior to the age of six. These findings highlight the need for greater clinical awareness, targeted resources, and enhanced support within paediatric dentistry to manage the impact of this enamel defect more effectively.

This study is the first to investigate prevalence of HSPM in Irish children and provides reference data for future studies on MIH and HSPM and education should be provided to all Irish practitioners to encourage early recognition of children with HSPM. The predictive association of HSPM and MIH indicates that high risk prevention strategies should be implemented until the permanent molars erupt, to ensure maintenance of optimum oral health.

6 Future research recommendations

Further investigation of HSPM and MIH prevalence in Ireland are warranted to achieve a more representative sample for the general population. These studies should build on a similar methodology to that of this study with regard training, calibration, and use of the validated, all-encompassing diagnostic criteria.

Studies should continue to investigate the relationship of HSPM with both dental caries and MIH due to the conflicting data available for comparison. A consensus on the diagnostic criteria used for these comparisons would be ideal to allow for global data synthesis and meta-analysis to be completed.

Future studies should ideally be prospective, cohort studies investigating risk factors and prevalences at appropriate time points for sufficient examination, particularly in relation to the assessment of MIH development in those patients identified with HSPM. Cohort studies will also allow for defect progression over time, something not investigated in the literature to date for primary molars.

Investigation of the aetiology of HSPM development and exploration of the specific factor(s) by conducting high quality, prospective research with an adequate sample size are important goals with regard education and prevention of complications associated with this condition.

7 References

- Al-Huzaimi, H. A., and R. M. F. Ibrahim. 2025. 'Prevalence, clinical presentation and risk factors of molar incisor hypomineralisation and hypomineralised second primary molars among children in Buraydah, Saudi Arabia: A cross-sectional study', *J Public Health Res*, 14: 22799036251341529.
- Amend, S., C. Nossol, S. Bausback-Schomakers, C. Wleklinski, C. Scheibelhut, J. Pons-Kühnemann, R. Frankenberger, and N. Krämer. 2021. 'Prevalence of molar-incisor-hypomineralisation (MIH) among 6-12-year-old children in Central Hesse (Germany)', *Clin Oral Investig*, 25: 2093-100.
- Avery D.R., Macdonald E.M. 2022. *Pediatric Dentistry for the Child and Adolescent* (Mosby Year Book: St Louis).
- Bani-Hani, T., H. Taha, and O. B. Al-Batayneh. 2025. 'Hypomineralised Second Primary Molars (HSPM): Prevalence, Clinical Characteristics and Association with Molar Incisor Hypomineralisation (MIH) in Children in Jordan', *Eur J Paediatr Dent*: 1.
- Board, Eastern Health. 1997. "Oral health of children / Eastern Health Board." In.
- Borrego-Martí, N., R. Peris-Corominas, I. Maura-Solivellas, E. Ferrés-Padró, and E. Ferrés-Amat. 2021. 'Hypomineralisation of second primary molars and primary canines: Prevalence and description of lesions in a population of 153 patients visited at a hospital paediatric dentistry service', *Eur J Paediatr Dent*, 22: 237-42.
- Børsting, T., A. Schuller, P. van Dommelen, S. N. Stafne, M. S. Skeie, A. B. Skaare, S. Mørkved, KÅ Salvesen, A. K. Stunes, M. P. Mosti, M. K. Gustafsson, U. Syversen, and T. N. Fagerhaug. 2022. 'Maternal vitamin D status in pregnancy and molar incisor hypomineralisation and hypomineralised second primary molars in the offspring at 7-9 years of age: a longitudinal study', *Eur Arch Paediatr Dent*, 23: 557-66.

- Clarkson, J., and D. O'Mullane. 1989. 'A modified DDE Index for use in epidemiological studies of enamel defects', *J Dent Res*, 68: 445-50.
- Costa Silva, Cristiane, Janice Paula, Gláucia Ambrosano, and Fábio Mialhe. 2013. 'Influence of deciduous molar hypomineralization on the development of molar-incisor hypomineralization', *Brazilian Journal of Oral Sciences*, 12: 335-38.
- Crawford, P. J., M. Aldred, and A. Bloch-Zupan. 2007. 'Amelogenesis imperfecta', *Orphanet J Rare Dis*, 2: 17.
- da Silva Figueiredo Sé, M. J., A. P. D. Ribeiro, L. A. M. Dos Santos-Pinto, R. de Cassia Loiola Cordeiro, R. N. Cabral, and S. C. Leal. 2017. 'Are Hypomineralized Primary Molars and Canines Associated with Molar-Incisor Hypomineralization?', *Pediatr Dent*, 39: 445-49.
- Dean. 1942. 'Health Effects of Ingested Fluoride', *National Academy of Sciences*: 169.
- Do, L, and A Spencer. 2011. 'Oral health of Australian children: The National Child Oral Health Study 2012–14. 2016', URL: <https://www.adelaide.edu.au/press/titles/ncohs> [accessed 2023-09-12].
- Dong, Q., H. Wu, G. Dong, B. Lou, L. Yang, and L. Zhang. 2011. 'The morphology and mineralization of dental hard tissue in the offspring of passive smoking rats', *Arch Oral Biol*, 56: 1005-13.
- Drury, T. F., A. M. Horowitz, A. I. Ismail, M. P. Maertens, R. G. Rozier, and R. H. Selwitz. 1999. 'Diagnosing and reporting early childhood caries for research purposes. A report of a workshop sponsored by the National Institute of Dental and Craniofacial Research, the Health Resources and Services Administration, and the Health Care Financing Administration', *J Public Health Dent*, 59: 192-7.

- Dye, B. A., G. Thornton-Evans, X. Li, and T. J. Iafolla. 2015. 'Dental caries and sealant prevalence in children and adolescents in the United States, 2011-2012', *NCHS data brief*: 1-8.
- Elcock, Claire, Richard N. Smith, Joanne Simpson, Abeer Abdellatif, Birgitta Bäckman, and Alan H. Brook. 2006. 'Comparison of methods for measurement of hypoplastic lesions', *European Journal of Oral Sciences*, 114: 365-69.
- Elfrink, M. E., A. Ghanim, D. J. Manton, and K. L. Weerheijm. 2015. 'Standardised studies on Molar Incisor Hypomineralisation (MIH) and Hypomineralised Second Primary Molars (HSPM): a need', *Eur Arch Paediatr Dent*, 16: 247-55.
- Elfrink, M. E., A. A. Schuller, K. L. Weerheijm, and J. S. Veerkamp. 2008. 'Hypomineralized second primary molars: prevalence data in Dutch 5-year-olds', *Caries Res*, 42: 282-5.
- Elfrink, M. E., J. M. ten Cate, L. J. van Ruijven, and J. S. Veerkamp. 2013. 'Mineral content in teeth with deciduous molar hypomineralisation (DMH)', *J Dent*, 41: 974-8.
- Elfrink, Marlies E. C., Henriette A. Moll, Jessica C. Kiefte-de Jong, Hanan El Marroun, Vincent W. V. Jaddoe, Albert Hofman, Bruno H. Stricker, Jacob M. ten Cate, and Jaap S. J. Veerkamp. 2013. 'Is Maternal Use of Medicines during Pregnancy Associated with Deciduous Molar Hypomineralisation in the Offspring? A Prospective, Population-Based Study', *Drug Safety*, 36: 627-33.
- Elfrink, Marlies E. C., Henriette A. Moll, Jessica C. Kiefte-de Jong, Vincent W. V. Jaddoe, Albert Hofman, Jacob M. ten Cate, and Jaap S. J. Veerkamp. 2014. 'Pre- and Postnatal Determinants of Deciduous Molar Hypomineralisation in 6-Year-Old Children. The Generation R Study', *PLOS ONE*, 9: e91057.

- Elger, W., C. Ilge, W. Kiess, A. Körner, J. Kratzsch, A. Schrock, and C. Hirsch. 2020. 'Relationship between deciduous molar hypomineralisation and parameters of bone metabolism in preschool children', *Int Dent J*, 70: 303-07.
- Estivals, J., C. Fahd, J. Baillet, P. Rouas, D. J. Manton, and E. Garot. 2023. 'The prevalence and characteristics of and the association between MIH and HSPM in South-Western France', *Int J Paediatr Dent*, 33: 298-304.
- Farah, R., B. Drummond, M. Swain, and S. Williams. 2010. 'Linking the clinical presentation of molar-incisor hypomineralisation to its mineral density', *Int J Paediatr Dent*, 20: 353-60.
- Fejerskov, O. 1997. 'Concepts of dental caries and their consequences for understanding the disease', *Community Dent Oral Epidemiol*, 25: 5-12.
- Fernandes, I. C., F. D. S. Forte, and F. C. Sampaio. 2021. 'Molar-incisor hypomineralization (MIH), dental fluorosis, and caries in rural areas with different fluoride levels in the drinking water', *Int J Paediatr Dent*, 31: 475-82.
- Gambetta-Tessini, K., R. Mariño, A. Ghanim, H. Calache, and D. J. Manton. 2018. 'Carious lesion severity and demarcated hypomineralized lesions of tooth enamel in schoolchildren from Melbourne, Australia', *Aust Dent J*.
- . 2019. 'The impact of MIH/HSPM on the carious lesion severity of schoolchildren from Talca, Chile', *Eur Arch Paediatr Dent*, 20: 417-23.
- Garot, E., A. Denis, Y. Delbos, D. Manton, M. Silva, and P. Rouas. 2018. 'Are hypomineralised lesions on second primary molars (HSPM) a predictive sign of molar incisor hypomineralisation (MIH)? A systematic review and a meta-analysis', *J Dent*, 72: 8-13.

- Garot, E., P. Rouas, C. Somani, G. D. Taylor, F. Wong, and N. A. Lygidakis. 2022. 'An update of the aetiological factors involved in molar incisor hypomineralisation (MIH): a systematic review and meta-analysis', *Eur Arch Paediatr Dent*, 23: 23-38.
- Ghanim, A. M., M. V. Morgan, R. J. Mariño, D. L. Bailey, and D. J. Manton. 2012. 'Risk factors of hypomineralised second primary molars in a group of Iraqi schoolchildren', *Eur Arch Paediatr Dent*, 13: 111-8.
- Ghanim, A., D. Manton, R. Mariño, M. Morgan, and D. Bailey. 2013. 'Prevalence of demarcated hypomineralisation defects in second primary molars in Iraqi children', *Int J Paediatr Dent*, 23: 48-55.
- Ghanim, A., R. Marino, and D. J. Manton. 2019. 'Validity and reproducibility testing of the Molar Incisor Hypomineralisation (MIH) Index', *Int J Paediatr Dent*, 29: 6-13.
- Ghanim, A., M. J. Silva, M. E. C. Elfrink, N. A. Lygidakis, R. J. Mariño, K. L. Weerheijm, and D. J. Manton. 2017. 'Molar incisor hypomineralisation (MIH) training manual for clinical field surveys and practice', *Eur Arch Paediatr Dent*, 18: 225-42.
- Goyal, A., A. Dhareula, K. Gauba, and S. K. Bhatia. 2019. 'Prevalence, defect characteristics and distribution of other phenotypes in 3- to 6-year-old children affected with Hypomineralised Second Primary Molars', *Eur Arch Paediatr Dent*, 20: 585-93.
- Halal, F., and N. Raslan. 2020. 'Prevalence of hypomineralised second primary molars (HSPM) in Syrian preschool children', *Eur Arch Paediatr Dent*, 21: 711-17.
- Health, Department of. 1962. "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." In.: Stationery Office.

HSE, Health Service Executive. 2024. 'Children First ', Health Service Executive, Accessed June.

<https://www.hse.ie/eng/services/list/2/primarycare/childrenfirst/>.

Jacobsen, Pernille E., Dorte Haubek, Tine B. Henriksen, John R. Østergaard, and Sven Poulsen. 2014. 'Developmental enamel defects in children born preterm: a systematic review', *European Journal of Oral Sciences*, 122: 7-14.

James. 2018. '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', *Lancet*, 392: 1789-858.

James, P, M Harding, T Beecher, C Parnell, D Browne, M Tuohy, D Kavanagh, D O'Mullane, H Guiney, M Cronin, and H Whelton. 2018. 'Fluoride And Caring for Children's Teeth (FACCT): Clinical Fieldwork Protocol [version 1; peer review: 2 approved]', *HRB Open Research*, 1.

Kar, S., S. Sarkar, and A. Mukherjee. 2014. 'Prevalence and Distribution of Developmental Defects of Enamel in the Primary Dentition of IVF Children of West Bengal', *J Clin Diagn Res*, 8: Zc73-6.

Kühnisch, J., D. Heitmüller, E. Thiering, I. Brockow, U. Hoffmann, C. Neumann, R. Heinrich-Weltzien, C. P. Bauer, A. von Berg, S. Koletzko, F. Garcia-Godoy, R. Hickel, and J. Heinrich. 2014. 'Proportion and extent of manifestation of molar-incisor-hypomineralizations according to different phenotypes', *J Public Health Dent*, 74: 42-9.

Lima, L. J. S., M. L. Ramos-Jorge, and M. E. C. Soares. 2021. 'Prenatal, perinatal and postnatal events associated with hypomineralized second primary

molar: a systematic review with meta-analysis', *Clin Oral Investig*, 25: 6501-16.

Lima, L. R. S., A. S. Pereira, M. S. de Moura, C. C. B. Lima, S. M. Paiva, Lfad Moura, and M. de Deus Moura de Lima. 2020. 'Pre-term birth and asthma is associated with hypomineralized second primary molars in pre-schoolers: A population-based study', *Int J Paediatr Dent*, 30: 193-201.

Lira A de LS de, Sousa FJ de, Sousa FDC de, Fontenele MKV, Ribeiro CKC, Ferreira LEG 2021. 'Prevalence and predisponent factors of molar-incisor hypomineralization in primary dentition', *Braz J Oral Sci.* , 20: 1–12.

Listl, S., J. Galloway, P. A. Mossey, and W. Marcenes. 2015. 'Global Economic Impact of Dental Diseases', *J Dent Res*, 94: 1355-61.

Lopes, L. B., V. Machado, P. Mascarenhas, J. J. Mendes, and J. Botelho. 2021. 'The prevalence of molar-incisor hypomineralization: a systematic review and meta-analysis', *Sci Rep*, 11: 22405.

Lopes-Fatturi, A., Jvnb Menezes, F. C. Fraiz, Lrds Assunção, and J. F. de Souza. 2019. 'Systemic Exposures Associated with Hypomineralized Primary Second Molars', *Pediatr Dent*, 41: 364-70.

Lygidakis, N. A., E. Garot, C. Somani, G. D. Taylor, P. Rouas, and F. S. L. Wong. 2022. 'Best clinical practice guidance for clinicians dealing with children presenting with molar-incisor-hypomineralisation (MIH): an updated European Academy of Paediatric Dentistry policy document', *Eur Arch Paediatr Dent*, 23: 3-21.

Lygidakis, N. A., F. Wong, B. Jälevik, A. M. Vierrou, S. Alaluusua, and I. Espelid. 2010. 'Best Clinical Practice Guidance for clinicians dealing with children presenting with Molar-Incisor-Hypomineralisation (MIH): An EAPD Policy Document', *Eur Arch Paediatr Dent*, 11: 75-81.

Machiulskiene, V., G. Campus, J. C. Carvalho, I. Dige, K. R. Ekstrand, A. Jablonski-Momeni, M. Maltz, D. J. Manton, S. Martignon, E. A. Martinez-Mier, N. B. Pitts, A. G. Schulte, C. H. Splieth, L. M. A. Tenuta, A. Ferreira Zandona, and B. Nyvad. 2020. 'Terminology of Dental Caries and Dental Caries Management: Consensus Report of a Workshop Organized by ORCA and Cariology Research Group of IADR', *Caries Res*, 54: 7-14.

Marcianes, M., P. García-Camba, A. Albaladejo, and M. Varela Morales. 2023. 'Predictive Value of Hypomineralization of Second Primary Molars for Molar Incisor Hypomineralization and Other Relationships between Both Developmental Defects of Dental Enamel', *J Clin Med*, 12.

Masumo, R., A. Bårdsen, and A. N. Astrøm. 2013. 'Developmental defects of enamel in primary teeth and association with early life course events: a study of 6-36 month old children in Manyara, Tanzania', *BMC Oral Health*, 13: 21.

McCarra, C., I. C. Olegário, A. C. O'Connell, and R. Leith. 2022. 'Prevalence of hypomineralised second primary molars (HSPM): A systematic review and meta-analysis', *Int J Paediatr Dent*, 32: 367-82.

Mialhe, Fábio. 2014. 'Influence of deciduous molar hypomineralization on the development of molar-incisor hypomineralization', *Brazilian Journal of Oral Sciences*, 12: 335-38.

Mittal, N., and B. B. Sharma. 2015. 'Hypomineralised second primary molars: prevalence, defect characteristics and possible association with Molar Incisor Hypomineralisation in Indian children', *Eur Arch Paediatr Dent*, 16: 441-7.

Negre-Barber, A., J. M. Montiel-Company, M. Boronat-Catalá, M. Catalá-Pizarro, and J. M. Almerich-Silla. 2016. 'Hypomineralized Second Primary Molars as Predictor of Molar Incisor Hypomineralization', *Sci Rep*, 6: 31929.

- Nelson, S., J. M. Albert, C. Geng, S. Curtan, K. Lang, S. Miadich, M. Heima, A. Malik, G. Ferretti, H. Eggertsson, R. L. Slayton, and P. Milgrom. 2013. 'Increased enamel hypoplasia and very low birthweight infants', *J Dent Res*, 92: 788-94.
- Nelson, S., J. M. Albert, G. Lombardi, S. Wishnek, G. Asaad, H. L. Kirchner, and L. T. Singer. 2010. 'Dental caries and enamel defects in very low birth weight adolescents', *Caries Res*, 44: 509-18.
- Ng, J. J., O. C. Eu, R. Nair, and C. H. Hong. 2015. 'Prevalence of molar incisor hypomineralization (MIH) in Singaporean children', *Int J Paediatr Dent*, 25: 73-8.
- Nic Ghearrailt, S., N. Coffey, M. Harding, H. Whelton, M. Cronin, and P. James. 2025. 'Prevalence of molar incisor hypomineralisation and associated factors amongst 8-year-olds in Ireland', *Eur Arch Paediatr Dent*.
- Nørrisgaard, P. E., D. Haubek, J. Kühnisch, B. L. Chawes, J. Stokholm, K. Bønnelykke, and H. Bisgaard. 2019. 'Association of High-Dose Vitamin D Supplementation During Pregnancy With the Risk of Enamel Defects in Offspring: A 6-Year Follow-up of a Randomized Clinical Trial', *JAMA Pediatr*, 173: 924-30.
- O'Mullan, D, J. Clarkson, T. Holland, S. O'Hickey, H. Whelton, Minister for Health, and University College Cork. 1986. "Children's dental health in Ireland, 1984: a survey conducted on behalf of the Minister for Health by University College Cork." In.: Stationery Office.
- O'Sullivan, D. M., and N. Tinanoff. 1996. 'The association of early dental caries patterns with caries incidence in preschool children', *J Public Health Dent*, 56: 81-3.
- Owen, M. L., A. Ghanim, D. Elsbey, and D. J. Manton. 2018. 'Hypomineralized second primary molars: prevalence, defect characteristics and

relationship with dental caries in Melbourne preschool children', *Aust Dent J*, 63: 72-80.

Oyedele, T. A., M. O. Folayan, and E. O. Oziegbe. 2016. 'Hypomineralised second primary molars: prevalence, pattern and associated co morbidities in 8- to 10-year-old children in Ile-Ife, Nigeria', *BMC Oral Health*, 16: 65.

Plonka, K.A., M.L. Pukallus, A.G. Barnett, T.F. Holcombe, L.J. Walsh, and W.K. Seow. 2012. 'A Longitudinal Case-Control Study of Caries Development from Birth to 36 Months', *Caries Research*, 47: 117-27.

Quintero, Y., M. Restrepo, D. F. Rojas-Gualdrón, A. L. Farias, and L. Santos-Pinto. 2022. 'Association between hypomineralization of deciduous and molar incisor hypomineralization and dental caries', *Braz Dent J*, 33: 113-19.

'Report on the dental caries survey. Dental caries in Ireland'. 1953.

Reyes, M. R. T., A. L. Fatturi, Jvnb Menezes, F. C. Fraiz, Lrds Assunção, and J. F. Souza. 2019. 'Demarcated opacity in primary teeth increases the prevalence of molar incisor hypomineralization', *Braz Oral Res*, 33: e048.

Rodríguez-Rodríguez, M., W. Carrasco-Colmenares, A. Ghanim, A. Natera, and M. G. Acosta-Camargo. 2021. 'Prevalence and Distribution of Molar Incisor Hypomineralization in children receiving dental care in Caracas Metropolitan Area, Venezuela', *Acta Odontol Latinoam*, 34: 104-1112.

Seow, W. K. 2018. 'Early Childhood Caries', *Pediatr Clin North Am*, 65: 941-54.

Seow, Wan Kim, J. P. Brown, Di Tudehope, and Michael J. O'callaghan. 1984. 'Dental defects in the deciduous dentition of premature infants with low birth weight and neonatal rickets', *Pediatric dentistry*, 6 2: 88-92.

Serna Muñoz, C., A. J. Ortiz Ruiz, A. Pérez Silva, L. A. Bravo-González, and A. Vicente. 2020. 'Second primary molar hypomineralisation and drugs used

during pregnancy and infancy. A systematic review', *Clin Oral Investig*, 24: 1287-97.

Sharma, V., M. Crowe, O. Cassetti, L. Winning, A. O'Sullivan, and M. O'Sullivan. 2024. 'Dental caries in children in Ireland: A systematic review', *Community Dent Oral Epidemiol*, 52: 24-38.

Sidhu, N., Y. Wang, E. Barrett, and M. Casas. 2020. 'Prevalence and presentation patterns of enamel hypomineralisation (MIH and HSPM) among paediatric hospital dental patients in Toronto, Canada: a cross-sectional study', *Eur Arch Paediatr Dent*, 21: 263-70.

Silva, M. J., N. M. Kilpatrick, J. M. Craig, D. J. Manton, P. Leong, D. Burgner, and K. J. Scurrah. 2019. 'Etiology of Hypomineralized Second Primary Molars: A Prospective Twin Study', *J Dent Res*, 98: 77-83.

Teixeira, Rjpb, N. S. Andrade, L. C. C. Queiroz, F. M. Mendes, M. S. Moura, Lfad Moura, and M. D. M. Lima. 2018. 'Exploring the association between genetic and environmental factors and molar incisor hypomineralization: evidence from a twin study', *Int J Paediatr Dent*, 28: 198-206.

Temilola, Oluwaseyi, and Morenike Folayan. 2015. 'Distinguishing predisposing factors for enamel hypoplasia and molar-incisor hypomineralization in children in Ile-Ife, Nigeria', *Brazilian Journal of Oral Sciences*, 14: 318-22.

Tessari, V. S., B. L. M. Ramos, G. Fonseca-Souza, Jvnb de Menezes, M. A. B. Paschoal, J. Serra-Negra, and J. Feltrin-Souza. 2024. 'Prevalence of hypomineralized second primary molars and association with socioeconomic characteristics and dental caries in a Brazilian population of preschoolers: a cross-sectional study', *Eur Arch Paediatr Dent*, 25: 767-72.

van der Knaap-Kind, L. S., N. van der Kaaij, S. Nijst, E. Verhulst, M. Koudstaal, E. Wolvius, and L. Kragt. 2025. 'Prevalence of hypomineralised second

primary molars and molar incisor hypomineralisation in patients with cleft lip and/or palate', *Eur Arch Paediatr Dent*, 26: 131-37.

Veerkamp, J. S., and K. L. Weerheijm. 1995. 'Nursing-bottle caries: the importance of a development perspective', *ASDC J Dent Child*, 62: 381-6.

Weerheijm, K. L. 2003. 'Molar incisor hypomineralisation (MIH)', *Eur J Paediatr Dent*, 4: 114-20.

———. 2004. 'Molar incisor hypomineralization (MIH): clinical presentation, aetiology and management', *Dent Update*, 31: 9-12.

Whelton, H., E. Crowley, D. O'Mullane, M. Donaldson, V. Kelleher, and M. Cronin. 2004. 'Dental caries and enamel fluorosis among the fluoridated and non-fluoridated populations in the Republic of Ireland in 2002', *Community Dent Health*, 21: 37-44.

WHO, World Health Organisation. 2023. 'Preterm birth', Accessed June 2025.
<https://www.who.int/news-room/fact-sheets/detail/preterm-birth>.

WHO, World Health Organization. 2013. *Oral health surveys: basic methods* (World Health Organization).

———. 2025. 'Low Birth Weight ', Accessed June 2025.
<https://www.who.int/data/nutrition/nlis/info/low-birth-weight>.

Wright, J. T., I. A. Carrion, and C. Morris. 2015. 'The molecular basis of hereditary enamel defects in humans', *J Dent Res*, 94: 52-61.

Wu, X., J. Wang, Y. H. Li, Z. Y. Yang, and Z. Zhou. 2020. 'Association of molar incisor hypomineralization with premature birth or low birth weight: systematic review and meta-analysis', *J Matern Fetal Neonatal Med*, 33: 1700-08.

Zhou, Y, HC Lin, ECM Lo, and MCM Wong. 2011. 'Risk indicators for early childhood caries in 2-year-old children in southern China', *Australian Dental Journal*, 56: 33-39.

8 Appendices

8.1 Ethical Approval



Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin

Ollscoil Átha Cliath | The University of Dublin

Dr Hugh McGrory,
C/O Division of Public & Child Dental Health,
Dublin Dental University Hospital,
Lincoln Place, Dublin 2,
D02 F859

31st January 2023

Ref: 190403

Title of Study: Prevalence, Characteristics and treatment strategies for Hypomineralised second primary molars (HSPM) in Irish school children

Dear Hugh

Further to a meeting of the Faculty of Health Sciences Ethics Committee held in January 2023, we are pleased to inform you that the above project (as amended with the following changes) has ethical approval to proceed.

Please give specific details of the requested amendment(s):

- Lead investigator name change from Charlotte McCarra to Hugh McGrory
- No change in supervisor
- Change in research team personnel- Remove Elaine Shore and Emily Crossan and add Robyn Crowley and Isabel Olegario
- No change in research protocol
- Change in date of project (extension of approval until 2025) as 2025 is my final year of the postgraduate programme

As a researcher you must ensure that you comply with other relevant regulations, including DATA PROTECTION and HEALTH AND SAFETY.

Yours sincerely,

Prof. Jacintha O'Sullivan
Chairperson Faculty Research Ethics Committee

8.2 Letter of invitation



Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin
Ollscoil Átha Cliath | The University of Dublin



Division of Public and Child Dental Health
Dublin Dental University Hospital
Lincoln Place
Dublin 2

FAO: Principal

Permission to conduct research in school involving Junior and Senior Infants Classes

Dear Principal,

My name is Dr Hugh McGrory, and I am a clinical doctorate student in Paediatric Dentistry at the School of Dental Science, Trinity College Dublin. I am writing to extend an invitation for your class to take part in a research study.

Study title: Prevalence, characteristics, and treatment strategies for Hypomineralised Second Primary molars (HSPM) in Irish school children

This research study relates to a tooth defect, called 'hypomineralisation' or weak enamel. This condition results in the formation of softer enamel which can lead to discoloration, break-down and an increased risk of dental decay. This softness is thought to be caused by a disturbance at the time these teeth are forming however the exact cause remains unclear. This condition is common in the first permanent molar which erupts into the mouth at around the age of six to seven years. The second baby molar which comes into the mouth from age two to three years can also be affected.

This study aims to investigate how prevalent this condition is in 4-to-6-year-old Irish school children and how this condition appears in the mouth. We will also investigate if a link exists between this condition and certain factors such as risk of decay. The questionnaire for parents investigates the role of early childhood factors in the development of this condition, and we want a quick look at the child's mouth to determine if they have the condition. Data collected as part of this study will be used as a baseline for a future dental examination at age 7-to-8 years and may show a relationship between this condition in the second baby molar and the first permanent molar.

Ethical approval for this study has been obtained from the Faculty of Health Sciences Research Ethics Committee at Trinity College Dublin.

We would like to ask your permission for your class to participate in this study.

We will seek individual written parent/guardian consent for each child to participate in the study. The study will involve our dental team attending your school at a suitable time to examine the teeth of children aged 4-to -6 years old in Junior and Senior Infants Classes. The exam will take approximately 2 minutes per child, with a small mirror while sitting in a regular chair. Should a child have any dental decay or other treatment needs an information letter will be provided for the child's parent/guardian. Consenting parents/guardians will also need to fill out a questionnaire regarding pregnancy and early childhood health. With due consideration to child protection, we would only conduct these examinations in an open area within the school premises under your supervision or other school staff.

Should you agree, we will need your assistance in:

- **Distributing information packs to parents/guardians about the study one week prior to dental examination.**
- **Collection of signed consent forms and questionnaires from parents/guardians.**
- **If suitable, using your classroom to conduct our dental examination. If not suitable, provision of alternative safe, open space in school.**
- **Supervision of pupils during dental examination if available. Alternatively, other school staff can supervise.**

Any data provided by parent/guardian and data collected from dental examination will remain confidential. Data collected will be coded. This means that a random number will be assigned to all questionnaires and data recording sheets. This number will be used to identify and analyse data collected during the study. Consent forms will be the only documentation retained that holds personal data relating to children and their parents. These will have an alphabetical code and will be needed for verification at the time of assessment to ensure that appropriate consent has been obtained. A master key (code breaker) will be held only by the research team linking coded data to the participant identity. Linking of numerically coded data to the consent form is necessary for our related future research study. Consent forms will be stored separately to numerically coded data. Records will be securely and safely stored in a restricted-access area of the Dublin Dental Hospital for the duration of the study. It is anticipated that re-examination of the same children will occur in 2nd or 3rd class when the permanent teeth can be examined. (Due to the time lapse a separate consent form will be provided at that time).

There is no specific benefit to the child participant, but it is hoped the findings from this study will help children in the future through improved awareness and diagnosis of this condition. If dental needs are identified, parents/guardians will be informed via a proforma letter advising on the need to attend with their own dentist. This research is independent of and has no affiliation to the Health Service Executive (HSE) school dental service.

All examiners are qualified dentists from the Dublin Dental University Hospital (DDUH), and we have all completed Children's First child protection training in March 2018. We have all obtained Garda clearance in order to work at the DDUH; we are also covered under that Hospital's Clinical Indemnity Scheme.

I am hopeful that you will be happy to accept our invitation to participate in this study. It is hoped by carrying out this research, awareness of this condition will be increased in Ireland. Early diagnosis will allow preventive care to be provided which may reduce tooth breakdown and provide protection for these teeth.

Thank you for taking the time to consider this proposal. If you have any queries in relation to any aspect of this research, please do not hesitate to contact me at: hugh.mcgrory@dental.tcd.ie or by phone at 01-6127303.

8.3 School consent form

Division of Public and Child Dental Health
Dublin Dental University Hospital
Lincoln Place
Dublin 2

School Name and Address:

Confirmation of school participation in research study

**Permission to conduct research in school involving Junior and Senior Infants
Classes**

**Research Project: Prevalence and Characteristics of Hypomineralised Second
Primary Molars in Irish School Children**

Dear Dr McGrory,

We wish to confirm our school's participation in the above research study.

Name in capitals: _____
Principal

Signature: _____
Principal

Date: _____

Participant Information Leaflet

Study Title	Prevalence, characteristics, and treatment strategies for Hypomineralised Second Primary Molars (HSPM) in Irish school children.
Research Site(s)	Primary schools in County Dublin
Principal Investigator(s) and Co-Investigator(s) (Study Team) (Insert names, titles and contact details including Trinity School/Department/Unit)	Hugh McGrory Anne O’Connell Rona Leith Isabel Olegario Robyn Crowley <i>Contact details:</i> <i>Dept. of paediatric Dentistry</i> <i>Dublin Dental University Hospital</i> <i>School of Dental Science</i> <i>Trinity College Dublin</i> <i>01-6127303</i>
Data Controller(s)	Trinity College Dublin (research data)
Data Protection Officer (Research Data)	Data Protection Officer Secretary’s Office Trinity College Dublin Dublin 2

Invitation Paragraph

We would like to invite you to take part in a research study that is being carried out by the Department of Paediatric Dentistry, Dublin Dental University Hospital in Trinity College Dublin. Before you decide whether or not you wish to take part, please take time to read this information leaflet carefully and discuss it with your family, friends, or GP if you wish. If there is anything which is not clear, or if you would like more information, please ask the researchers. Don’t feel rushed or under pressure to participate or to make a quick decision. You should understand

the risks and benefits of taking part in this study so that you can make a decision that is right for you.

This leaflet has six parts:

Part 1 - The Study

Part 2 - Data Protection

Part 3 - Approval, Organising and Funding

Part 4 - Future Research (if personal data will be used in future research)

Part 5 - Further Information

Part 6 - Next Steps

Part 1 - The Study

Why is this study being done?

Some baby teeth can be softer than expected because of the way they were formed. These teeth can also be more prone to dental decay. We want to see if your child's teeth have any sign of this condition (called hypomineralisation).

Why have I been invited to take part in this study?

We are interested in knowing just how common weak enamel is in 4-to-6-year-olds and how it looks in the mouth. We want to know whether there might be a link between weak enamel and issues like getting decay. The role of pregnancy, birth and early childhood health will be looked at too.

Do I have to take part?

No, you don't have to take part in this study. It is entirely voluntary and up to you. If you decide not to take part, it won't affect your current or future dental care. You can change your mind and opt out at any time even if the study has started.

What does taking part in the study involve?

My team and I will attend your child's school on <designated date & time>. We will have a quick look at your child's teeth with a mirror while they are sitting in their chair (see picture below). The exam will be in the presence of their class teacher or other school staff and will take about 2 minutes. Each child will get their own mirror and all mirrors are single use. If your child has any dental issues, we will give you a letter explaining this and what to do. All members of our team are qualified dentists who are vetted and indemnified. We will also give out a questionnaire related to pregnancy and your child's health early in life and we will ask you to fill this out at home. If you prefer, you can contact us by phone to answer the questions.

What are the possible benefits of taking part?

There will be no specific benefit to your child, but it is hoped the findings from this study may help future children in Ireland through improved awareness and diagnosis of this condition.

What happens if I change my mind and wish to withdraw from the study?

Taking part is entirely voluntary and you and your child are under no obligations to take part.

If you decide to take part in this study, you have the right to withdraw you & your child's participation at any time. You will not be penalised in any way, and you and your child will not lose any benefits you had prior to the study.

Are there any possible disadvantages or risks from taking part?

There are no known risks involved in this study. It involves examination of teeth, no treatment to any tooth. At all times, the well-being of participants takes priority over research activities.

Health Information (Data): There is a risk that a connection to your identity could be made. Great care will be taken to ensure the confidentiality of all data and the risk to participants of a breach of confidentiality is considered very low.

What will happen to the results of the study?

The results from this study (PART 1) will be written up in a doctoral thesis which will be submitted to Trinity College Dublin. The results will also be published in articles in dental journals and will be presented at international dental conferences. These results will be used for educational and teaching purposes. The results from PART 1 will be used in the second part of the study (PART 2) to see if a link exists between soft enamel in the baby molar and adult permanent molar.

Part 2 - Data Protection

What information about me (personal data) will be used for this study? Will my medical records be accessed?

Data Collected
Contact details (Name, primary school name)
Age
Gender
Dental examination including presence or absence of teeth and their condition regarding HSPM

Questionnaires responses

Who will access my personal data?

Only the principal researcher will access your personal data / medical records. They will extract the information listed above. They will replace your name with a code before uploading to a separate secure research database, so that it will not be possible to link back this information to you directly. The research team will access the coded information only.

The study supervisor(s) may require access to coded data to ensure academic rigour.

Your personal data will not leave Ireland or the EU.

How is the information kept confidential and secure?

All personal data and data from your child's check-up will be stored safely and securely in the Dublin Dental University Hospital, with access available to the research team (lead investigator and research supervisor).

How long will my personal information used for this study be retained for?

Data will be kept for 7 years from date of collection as per GDPR guidelines and University standard procedures.

What is the lawful (legal) basis to use my personal data?

We will only use your personal information for this research project, which we hope will improve knowledge on this condition (Hypomineralised second primary molars (HSMP)). We will also ask for your consent as a requirement of the Irish Health Research Regulations.

What are my rights under Data Protection law?

You are entitled to:

- object to our use of your personal data or any further use.
- request access to your personal data and to receive a copy of it; (up to the point of anonymization)
- request inaccurate personal data be corrected or deleted.
- request restriction of our use of your personal data (if it is inaccurate).

- request deletion of your data.

By law you can exercise the above rights in relation to your personal data, unless the request would make it impossible or very difficult to conduct the research. For example, if the study results / information is to be published then we may not be able to delete it. You can exercise these rights by contacting your study researcher Dr Hugh McGrory at hugh.mcgrory@dental.tcd.ie or the Trinity College Data Protection Officer, Secretary's Office, Trinity College Dublin, Dublin 2, Ireland. Email: dataprotection@tcd.ie. Website: www.dataprotection.ie

Part 3 - Approval, Organising and Funding

Has this study been approved by a research ethics committee?

Yes, this study has been approved Faculty of Health Sciences, Trinity College Dublin ethics committee. An annual report will be provided to the REC and on completion of the study.

Who is organising and funding this study?

This study is being undertaken by Dr Hugh McGrory as part of their Postgraduate Clinical Doctorate in Paediatric Dentistry. It is self-funded.

Is there any payment for taking part?

No, we are not paying participants to take part in the study.

Part 4 - Future Research

Will my personal data be used in future studies?

The participants from this study will be re-assessed in two years to assess their first permanent molars to determine if there is a relationship between HSPM and MIH. At which time a new consent form with a participant information sheet will be distributed. Therefore, participant details will be required to recruit the same cohort of patients for part two of this investigation.

Part 5 - Further Information

Who should I contact for information or concerns?

If you have any concerns or questions, you can contact:

Principal Investigator: Dr Hugh McGrory, hugh.mcgrory@dental.tcd.ie

Data Protection Officer, Trinity College Dublin: Data Protection Officer, Secretary's Office, Trinity College Dublin, Dublin 2, Ireland. Email: dataprotection@tcd.ie. Website: www.dataprotection.ie

Under GDPR, if you are not satisfied with how your data is being processed, you have the right to raise a concern with the Office of the Data Protection

Commission, 21 Fitzwilliam Square South, Dublin 2, Ireland. Website:
www.dataprotection.ie

Part 6 - Next Steps

Next steps

If you would like to take part in this study, please sign the consent form enclosed with this information document and complete the health questionnaire and return it with you child to their primary school on the date of proposed examination (1 week from receiving this document).

Will I be contacted again?

No, we will not make any direct contact with you. We have given a time of seven (7) days for you to think about this information and decide if you would like your child to take part in this study or not.

Thank you for taking the time to read this Participant Information Leaflet.

You will be given a copy of this Leaflet and the signed Consent Form to keep. Please retain these in case they are needed for future reference.

Glossary

Anonymized Data	https://www.tcd.ie/dataprotection/assets/pdf/2.11.2.12.pdf
Coded data	https://www.tcd.ie/dataprotection/assets/pdf/2.11.4.12.pdf
Data Controller	https://www.tcd.ie/dataprotection/assets/pdf/2.11.2.1.pdf
Data Subject	https://gdpr-info.eu/art-4-gdpr/
Masked data	https://www.tcd.ie/dataprotection/assets/pdf/2.11.4.12.pdf
Personal data	https://www.tcd.ie/dataprotection/assets/pdf/2.11.2.2.pdf https://www.tcd.ie/dataprotection/assets/pdf/2.11.2.3.pdf
Pseudonymised data	https://www.tcd.ie/dataprotection/assets/pdf/2.11.4.12.pdf
Special Categories of Personal Data	https://www.tcd.ie/dataprotection/assets/pdf/2.11.2.4.pdf



8.5 Participant questionnaire

Parental/Guardian Questionnaire

NUMERICAL CODE:

Please complete the following questions by circling the most appropriate option.

If you would prefer, we can contact you by phone to answer these questions

1. Did you have any significant problems/complications during pregnancy e.g., gestational diabetes, rhesus disease, pre-/eclampsia, urinary tract infections?
Yes No
2. Did you take any prescribed medications during pregnancy?
Yes No
3. Was your child born to full term?
Yes No
4. Was your child born before 38 weeks?
Yes No
5. What birth weight was your child, please circle appropriate option.
Less than 2.5kg (low) Greater or equal to 2.5kg (normal)
6. Were there any problems immediately after birth necessitating your child remain in hospital (e.g., Jaundice, breathing issues, incubator required)
Yes No
7. Did you breast-feed your child?
Yes No
If yes, for how long?
Less than 3 months 3-6 months 1 year more than 1 year
8. Did you bottle feed your child?
Yes No
If yes, for how long?
Less than 1 year More than 1 year
9. Did your child suffer from any infections or high fevers in first three years of life?
Yes No
10. Was your child prescribed antibiotics in the first year of life?
Yes No

INFORMED CONSENT FORM

STUDY: Prevalence, Characteristics, and treatment strategies for Hypomineralised Second Primary Molars (HSPM) in Irish school children Recruitment Site: Primary schools County Dublin	
There are two sections in this form. Section 1 contains statements of understanding and asks you to tick each if you understand. Please ask any questions you may have when reading each of the statements. Section 2 asks for your informed consent. Please select either 'yes' or 'no' to indicate your choice. Thank you for participating. The end of this form is for the researchers to complete.	
1. General Understanding	Tick
I confirm that I have read and understood the Information Leaflet for the above study. The information has been fully explained to me and I have been able to ask questions, all of which have been answered to my satisfaction.	
I understand that taking part in this study is entirely voluntary. I understand that not taking part will have no negative impact on me.	
I understand that I can leave this study at any time without giving a reason. I understand that leaving this study will not affect my dental care, now or in the future.	
I understand that I will not be paid for taking part in this study or receive any benefits from any products developed as a result of this research study.	
I know how to contact the research team if I need to.	
By ticking each box above and choosing my options below <u>and</u> signing this document I agree to participate in 'X' study as described in the Participant Information Leaflet.	
2. Consent	

I agree to take part in this research study, having been fully informed of the risks and benefits in the participant information leaflet provided to me.	Yes No <table border="1"> <tr> <td></td> <td></td> </tr> </table>		
I agree to the use of information about me (personal data) including (<i>information obtained from the dental screening examination assessing the condition of the second primary molar and the first permanent molar teeth</i>) being used by the research team for this research study as described in the participant information leaflet.	Yes No <table border="1"> <tr> <td></td> <td></td> </tr> </table>		
I agree to be contacted through the school to participate in part two of this study for a second dental screening examination.	Yes No <table border="1"> <tr> <td></td> <td></td> </tr> </table>		

Participant Name (Block Capitals)

Date of Birth

Date

Witness Name/Parent

Witness Signature

Date

To be completed by the Principal Investigator or nominee.

I, the undersigned, have taken the time to fully explain to the above participant the nature and purpose of this study in a way that they could understand.

I have explained the risks and possible benefits involved. I have invited them to ask questions on any aspect of the study that concerned them.

I have given a copy of the participant information leaflet and consent form to the participant with contact details of the study team.

Researcher name: Dr Hugh McGrory

Title and qualifications

Dentist, B.A. B.Dent.Sc, Dip PCD RCSI, MFDS RCSI

Signature

Date

8.7 Data collection form

Numerical Code: _____

Dental Examination Sheet

Age: Gender: M F Class: Junior: Senior:
Please circle *Please circle*

HSPM/MIH scoring

TOOTH		16	55	65	26
MIH/HSPM	NUMERICAL SCORE				
	EXTENT SCORE				
TOOTH		46	85	75	36
MIH/HSPM	NUMERICAL SCORE				
	EXTENT SCORE				

Dv₃mft scoring (total number d,m,f)

d m f

Total number of primary teeth

8.8 Proforma letter for identified dental needs

PROFORMA LETTER IF CHILD HAS DENTAL TREATMENT NEEDS

Date:

Dear Parent/Guardian,

Thank you so much for letting us check your child's teeth, we really appreciate it!

Finding	Present
Dental infection	
Dental decay/cavities	
Tooth eruption disturbance	
Other	

When we looked at their teeth we saw:

Your child should attend with your family dentist for treatment of the above.

Kind regards,

Research team