Contents available at ScienceDirect

Diabetes Research and Clinical Practice

journal homepage: www.elsevier.com/locate/diabres

International Diabetes Federation

Prevalence and correlates of diagnosed and undiagnosed type 2 diabetes mellitus and pre-diabetes in older adults: Findings from the Irish Longitudinal Study on Ageing (TILDA)

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ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form
7 October 2015
Accepted 8 October 2015
Available online 19 October 2015

Keywords:
Diabetes mellitus, Type 2
Prediabetes
Undiagnosed
HbA1c
Ageing
Prevalence

ABSTRACT

Aims: The prevalence of type 2 diabetes and pre-diabetes has increased rapidly in recent decades and this trend will continue as the global population ages. This study investigates the prevalence of, and factors associated with, diagnosed and undiagnosed type 2 diabetes mellitus and pre-diabetes in older adults in Ireland.

Methods: Cross-sectional data from 5377 men and women aged 50 and over from Wave 1 of the Irish Longitudinal Study on Ageing (TILDA) was analysed. Diagnosed diabetes was defined using self-reported doctors' diagnosis and medications data. Glycated haemoglobin (HbA_{1c}) analysis was used to identify undiagnosed and pre-diabetes. Age and sex-specific prevalence estimates were generated. Logistic regression was used to investigate the association between diabetes classification and the demographic, health and lifestyle characteristics of the population.

Results: The prevalence of diagnosed and undiagnosed type 2 diabetes was 8.6% (95% confidence interval (CI): 7.6–9.5%) and 0.9% (95% CI: 0.6–1.1%) respectively. Diabetes was more prevalent in men than women and increased with age. The prevalence of pre-diabetes was 5.5% (95% CI: 4.8–6.3%) and increased with age. Diabetes and pre-diabetes were independently associated with male sex, central obesity and a history of hypertension, while undiagnosed diabetes was associated with geographic location and medical costs cover.

Conclusion: Despite high rates of obesity and other undiagnosed health conditions, the prevalence of undiagnosed and pre-diabetes is relatively low in community-dwelling older adults in Ireland. Addressing lifestyle factors in this population may help to further reduce the prevalence of pre-diabetes and improve outcomes for those with a previous diagnosis.

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http://dx.doi.org/10.1016/j.diabres.2015.10.015
0168-8227/

1. Introduction

Diabetes is a leading cause of death and disability globally [1,2]. The disease is increasingly prevalent, affecting approximately 8.3% of adults worldwide, with this figure projected to increase by 55% over the next two decades [3]. Type 2 diabetes mellitus accounts for over 90% of cases. Major risk factors for type 2 diabetes include increasing age, obesity and physical inactivity [4]. The consequences of the disease are manifold. The development of diabetic retinopathy, nephropathy and neuropathy as well as the increased risk of macrovascular disease may result in reduced physical function, poorer quality of life, an increased number of years lived with disability and early mortality [1,2,5]. Consequently, diabetes is estimated to account for over 10% of global healthcare expenditure [6].

Type 2 diabetes can be asymptomatic and therefore remain undiagnosed for several years, with complications often manifest at the time of diagnosis [4]. Undiagnosed diabetes accounts for up to 50% of all cases [7] and has been associated with poorer cardiovascular outcomes [8]. Pre-diabetes, defined as having a blood glucose concentration higher than normal but lower than diabetes thresholds, is also becoming increasingly common. It is estimated that pre-diabetes affects 35% of all adults in the United States, rising to >50% in those aged 65 and over. Up to 70% of individuals with pre-diabetes will go on to develop diabetes at a rate of 5–10% per year [9]. Recent data from the UK indicates that the prevalence of pre-diabetes in adults more than trebled from 11.6% in 2003 to 35.3% in 2011. In those aged 40 and over, the prevalence increased from 17.9% to 48.7% in the same time period [10]. Many of the micro- and macrovascular complications of diabetes may also be present in pre-diabetes [9].

There is limited information available regarding the population prevalence of diagnosed and undiagnosed type 2 diabetes and pre-diabetes in the Republic of Ireland. A 2007 study of 1200 adults aged 45+ estimated a prevalence of diabetes of 8.9% and pre-diabetes of 19.8% [11,12]; however, these findings need to be confirmed, in a larger sample.

The aim of this study is to document the prevalence of diagnosed, undiagnosed and pre-diabetes in community dwelling adults aged 50 and over in Ireland, and to identify associated demographic, health and lifestyle characteristics.

2. Materials and methods

2.1. Sample design

Cross-sectional data from Wave 1 of the Irish Longitudinal Study on Aging (TILDA) was analysed. TILDA is a large, nationally representative prospective study on ageing comprised of community dwelling adults aged 50 and over residing in the Republic of Ireland. The study design is described in detail elsewhere [13]. Briefly, TILDA Wave 1 took place between October 2009 and February 2011. 8175 adults aged 50 and over from 6279 households completed a computer-aided personal interview (CAPI), representing a response rate of 62%. 84.6% (n = 6915) of the sample completed an additional self-completion questionnaire (SCQ) and 72.1% (n = 5895) consented to, and participated in, a health assessment. Of those attending a health assessment, 91.4% (n = 5388) provided a blood sample for long term storage. The study was approved by the Trinity College Dublin Faculty of Health Sciences Research Ethics Committee and all respondents provided written informed consent.

2.2. Diabetes classification

Table 1 describes the classification of four phenotypes investigated in this study—'No Diabetes', 'Pre-Diabetes', 'Diagnosed Diabetes' and 'Undiagnosed Diabetes'. Diagnosed diabetes was identified during the CAPI with the question 'Has a doctor ever told you that you have Diabetes or high blood sugar?' Those indicating a previous diagnosis were asked how old they were when first diagnosed. A comprehensive list of all currently prescribed medications was obtained from each respondent. Diabetes medications were identified using the Anatomic Therapeutic Classification (ATC) codes 'A10A' for insulin and 'A10B' for oral anti-glycaemic medications. Respondents who were prescribed either insulin or oral anti-glycaemic medication at the time of interview, but did not report a doctor's diagnosis of the condition, were also classified as having 'Diagnosed Diabetes'. Respondents were not explicitly asked what type of diabetes they had been diagnosed with. Therefore, eleven respondents who reported a doctors diagnosis of diabetes before the age of 40 and who were on insulin therapy at the time of interview were excluded from analysis due to the suspicion that they may have type 1 diabetes.

Pre-diabetes and undiagnosed diabetes were defined by measurement of glycated haemoglobin (HbA_{1c}) as per American Diabetes Association cut-off values [4]. HbA_{1c} reflects an individual's average glycaemic control over the previous 8–12 weeks and is an accepted method for the identification of diabetes and pre-diabetes [4,14]. The TILDA protocol for blood sample collection, processing and storage has been described previously [13]. Briefly, 10 ml of fresh whole blood was collected in EDTA coated tubes and transported to a central processing laboratory in temperature-controlled shipping boxes which maintained the samples at 2–8 °C for up to 48 h. Buffy coat samples were then isolated in 1 ml aliquots and placed in long term storage at −80 °C. Buffy coat refers to aliquots of white blood cells, taken from the plasma/red cell interface in centrifuged whole blood, which also inevitably contain some plasma and red cells [15]. Between April and December 2014, buffy coat samples were thawed for HbA_{1c}

Table 1 – Diabetes classification criteria.

Classification	Criteria
No diabetes	HbA_{1c} <5.7% (39 mmol/mol) AND no doctors diagnosis/diabetes medication
Pre-diabetes	HbA_{1c} 5.7–6.4% (39–47 mmol/mol) AND no doctors diagnosis/diabetes medication
Diagnosed diabetes	Self-reported doctors diagnosis or taking diabetes medication
Undiagnosed diabetes	HbA_{1c} > = 6.5% (48 mmol/mol) AND no doctors diagnosis/diabetes medication

analysis. HbA_{1c} concentration was analysed by reversed-phase cation exchange chromatography using an ADAMS A_{1c} HA-8180V analyser which is traceable to the internationally agreed standard developed by the International Federation of Clinical Chemistry (IFCC) [16]. The analysis of HbA_{1c} from frozen buffy coat samples is uncommon as HbA_{1c} is predominately assayed from fresh whole blood. We are aware of one previous investigation which validated the measurement of HbA_{1c} from buffy coat samples and found an excellent correlation between fresh whole blood and frozen buffy coat results in a clinical population [15]. Wary of potential differences between clinical and non-clinical populations and variability between systems used to analyse HbA_{1c}, we validated the measurement of HbA_{1c} from frozen buffy coat against fresh whole blood in a subsample of TILDA respondents. One hundred TILDA participants provided a fresh blood sample for analysis. HbA_{1c} was assayed on fresh whole blood within 48 h of obtaining the sample. A 1 ml aliquot of buffy coat was isolated from the sample and frozen at −80 °C for a two week period before being thawed for HbA_{1c} analysis. Both assays were analysed using the Adams A_{1c} HA-8180V system.

2.3. Covariates

TILDA records extensive information related to the health, social and economic circumstances of participants. Demographic and social factors considered in this analysis included age, sex, educational attainment (a three level variable indicating 'primary level or no education', 'secondary level' and 'third level or higher education'), household location (classified as 'Dublin city or county', 'other urban area' or 'other rural area') and marital status. Lifestyle factors examined were smoking history ('never', 'past' or 'current'), physical activity level (classified as 'low', 'medium' or 'high' using the International Physical Activity Questionnaire (IPAQ) [17]) and overweight/obesity measured using body mass index (BMI) and waist circumference (WC). Overweight and obesity were classified as a BMI of 25–29.9 kg/m^2 and >30 kg/m^2 respectively. Elevated WC was defined as a WC of 80–88 cm in women and 94–102 cm in men, while central obesity was defined as a WC > 88 cm in women and >102 cm in men. Health status variables included self-rated health, self-reported history of cardiovascular disease (including previous heart attack, heart failure, angina, heart murmur, stroke or transient ischaemic attack) and doctor diagnosed hypertension and high cholesterol. Healthcare utilisation was assessed by self-reported number of general practitioner (GP) visits in the previous 12 months and whether the respondent had public, private or no medical costs cover.

2.4. Statistical Analysis

Analyses were carried out using STATA 12 (StataCorp, College Station, TX, USA). For the validation analysis of HbA_{1c} measurement from frozen buffy coat samples, Pearson's correlation was used to establish the strength of the relationship between the methods. Deming regression was employed to investigate the agreement between methods. This is an appropriate technique when there is error in both measurement methods as opposed to standard linear regression which assumes that the reference method is without random error [18]. The weighted Cohen's kappa statistic was used to study the agreement between methods when categorising HbA_{1c} values into 'Normal', 'Pre-Diabetes' and 'Diabetes' groups. Population weights were calculated by comparing the TILDA sample with the 2010 Irish Quarterly National Household Survey with respect to age, sex and educational attainment. The two-stage, stratified clustering sample design of TILDA was accounted for when computing confidence intervals and standard errors. Prevalence estimates and descriptive statistics were weighted for survey non-response, non-attendance at the health assessment component of the study, and whether or not respondents provided a blood sample for storage. Prevalence estimates are reported as percentages and 95% confidence interval (CI). Descriptive statistics were used to describe the characteristics of the sample by diabetes classification and are reported as mean and standard deviation for continuous variables and frequency counts and proportions for categorical values. Multinomial logistic regression was employed to investigate the factors associated with diabetes (diagnosed and undiagnosed combined) and pre-diabetes when compared to those with no diabetes. Binary logistic regression was used to investigate the factors differentiating diagnosed and undiagnosed diabetes. Regression outputs are reported as adjusted relative risk ratios (RRR) or odds ratios (OR) with 95% CI. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Validation of HbA_{1c} analysis in frozen buffy coat samples

Mean (SD) HbA_{1c} was 5.5% (2.7%) (36.2 mmol/mol (6.3 mmol/mol)) measured from fresh whole blood and 5.4% (2.8%) (35.9 mmol/mol (6.8 mmol/mol)) measured from frozen buffy coat. Fig. 1 illustrates the relationship between HbA_{1c} measured from fresh whole blood and frozen buffy coat. A correlation coefficient of $r = 0.90$ was observed between the methods. Deming regression revealed no significant difference between the two methods (slope = 0.92 (95%CI: 0.80–1.04); mean offset 3.18 mmol/mol (95%CI: −1.08 to 7.44)). When HbA_{1c} was used to classify the sample into 'Normal', 'Pre-Diabetes' and 'Diabetes' categories, a weighted kappa statistic of 0.82 (95% CI: 0.68–0.91) was observed between the two methods, indicating almost perfect agreement.

3.2. Prevalence of diagnosed, undiagnosed and pre-diabetes

The final sample size for analysis was 5,377. The weighted prevalence of diagnosed diabetes was 8.6% (95% CI: 7.6–9.5%). An additional 0.9% (95% CI: 0.6–1.1%) of the population had evidence of undiagnosed diabetes, giving a total prevalence of type 2 diabetes of 9.5% (95% CI: 8.5–10.4%). The prevalence of pre-diabetes was 5.5% (95% CI: 4.8–6.3%). Fig. 2 illustrates the trends in prevalence of total type 2 diabetes and pre-diabetes by age group and sex. Type 2 diabetes was more prevalent in

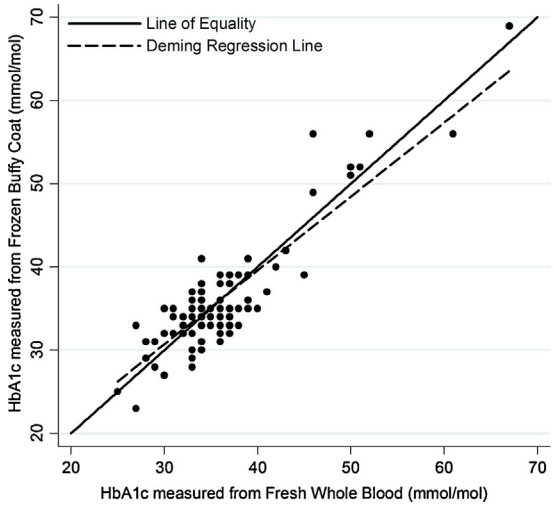

Fig. 1 – Scatterplot of the relationship between HbA1c measured from fresh whole blood and frozen buffy coat.

men (11.8%, 95% CI: 10.3–13.3%) than women (7.3%, 95% CI: 6.0–8.5%) and increased with age from 5.0% (95% CI: 4.0–6.0%) in 50–59 year olds to 16.0% (95% CI: 10.7–21.4%) in those aged 80+. Pre-diabetes prevalence was similar among men (5.4%, 95% CI: 4.4–6.4%) and women (5.7%, 95% CI: 4.5–6.8%) and increased with age from 4.1% (95% CI: 3.1–5.1%) in those aged 50–59 to 13.4% (95% CI: 8.4–18.5%) in those aged 80+.

3.3. *Factors associated with diabetes and pre-diabetes*

Table 2 describes the characteristics of the sample by diabetes classification. Table 3 illustrates the results of the multinomial logistic regression examining factors associated with diabetes and pre-diabetes compared to those with no diabetes. Male sex, having a self-reported history of hypertension and being centrally obese were independently associated with both diabetes and pre-diabetes. Increasing age, a self-reported history of high cholesterol, having poor or fair self-rated health and reporting low levels of physical activity were further associated with having diabetes but not pre-diabetes, while lower levels of education and a history of smoking (past or current) were associated with pre-diabetes only.

3.4. *Factors associated with undiagnosed diabetes*

Household location and medical costs cover were independently associated with having undiagnosed compared to diagnosed diabetes (Table 3). Compared to those living in Dublin city or county, persons living in other urban (OR 4.32, 95% CI: 1.39–13.44) or rural (OR 3.27, 95% CI: 1.13–9.48) areas were more likely to have undiagnosed diabetes, while those with private health insurance were less likely to have undiagnosed diabetes compared to those with neither public or private medical costs cover (OR 0.22, 95% CI: 0.06–0.77).

4. Discussion

This paper outlines the prevalence and correlates of diagnosed, undiagnosed and pre-diabetes in the community-dwelling population aged 50 years and over in Ireland. The total prevalence of type 2 diabetes is 9.5%, with approximately 10% of cases undiagnosed. Diabetes is more prevalent in men than women and increases with advancing age, peaking at 25.2% in men aged 80 years and over. A further 5.5% of the population are estimated to have pre-diabetes.

Compared to other populations, the prevalence of undiagnosed and pre-diabetes in older adults resident in Ireland is relatively low. In comparable European countries, undiagnosed diabetes is estimated to account for 36.6% of all adult cases while the corresponding proportion in the United States is 39.8% [7]. However, there is significant variability in findings between countries. Specific to older adults, findings from Wave 2 (2004–2005) of the English Longitudinal Study on Ageing suggested a diabetes prevalence of 9.1% in 52–79 year olds, with undiagnosed diabetes accounting for 18.5% of cases [19]. Similarly, a 2001 study of 8654 French men and women aged 65+ found a prevalence of 9.6%, of which 14.9% were undiagnosed [20]. Previous estimates of undiagnosed diabetes prevalence in the Irish population are in conflict with our observations. Similar to the current study, the 2007 Survey of Lifestyle, Attitudes and Nutrition in Ireland (SLAN) indicated a total prevalence of diabetes of 8.9% in adults aged 45+ [11]. However, 31.2% of these cases were undiagnosed, significantly higher than the proportion observed in the current study. A seperate investigation based on an analysis of 2047 non-population representative Irish adults aged 50–69 indicated a

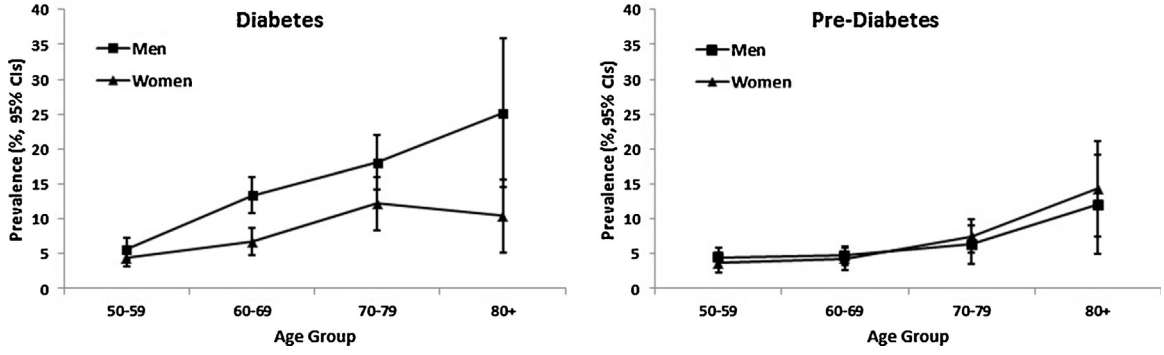

Fig. 2 – Weighted prevalence (with 95% confidence interval) of total type 2 diabetes and prediabetes by age and gender in TILDA.

Table 2 – Descriptive statistics of the TILDA sample by diabetes classification.

	No diabetes (*n* = 4685)	Pre-diabetes (*n* = 258)	Diagnosed (*n* = 389)	Undiagnosed (*n* = 45)
Age (y, mean (SD))	62.4 (9.0)	66.2 (10.5)	67.1 (9.4)	65.4 (9.1)
Sex (Male, *n* (%))	2110 (45.0)	132 (51.2)	239 (61.4)	23 (51.1)
Education (*n* (%))				
Primary/none	1112 (23.7)	103 (39.9)	139 (35.7)	15 (33.3)
Secondary	1946 (41.6)	101 (39.2)	152 (39.1)	19 (42.2)
Third/Higher	1626 (34.7)	54 (20.9)	98 (25.2)	11 (24.4)
Marital status (*n* (%))				
Married	3453 (73.7)	183 (70.9)	266 (68.4)	28 (62.2)
Single	363 (7.8)	15 (5.8)	40 (10.3)	5 (11.1)
Widowed	553 (11.8)	49 (19.0)	64 (16.4)	9 (20.0)
Sep/divorced	316 (6.7)	11 (4.3)	19 (4.9)	3 (6.7)
Locality (*n* (%))				
Dublin city/county	1229 (26.3)	65 (25.2)	113 (29.1)	5 (11.1)
Other urban	1296 (27.7)	64 (24.8)	105 (27.1)	15 (33.3)
Rural	2156 (46.1)	129 (50.0)	170 (43.8)	25 (55.6)
Previous CVD (*n* (%))	615 (13.1)	48 (18.6)	99 (25.5)	14 (31.1)
Hypertension (*n* (%))	1518 (32.4)	139 (53.9)	241 (62.0)	24 (53.3)
High cholesterol (*n* (%))	1860 (39.7)	108 (41.9)	218 (56.0)	19 (42.2)
Self-rated health (Poor/fair, *n* (%))	536 (11.5)	45 (17.5)	113 (29.3)	11 (24.4)
Body mass index (kg/m^2, mean (SD))	28.2 (4.6)	31.1 (5.6)	31.8 (6.1)	34.8 (8.1)
Normal (*n* (%))	1128 (24.3)	30 (11.7)	33 (8.5)	2 (4.7)
Overweight (*n* (%))	2094 (45.1)	88 (34.2)	135 (34.7)	11 (25.6)
Obese (*n* (%))	1425 (30.7)	139 (54.1)	221 (56.8)	30 (69.8)
Waist Circumference (cm, mean (SD))	93.9 (13.1)	101.9 (13.6)	105.9 (14.7)	108.1 (14.0)
Normal WC (*n* (%))	1212 (26.0)	29 (11.4)	31 (8.0)	1 (2.3)
Elevated WC (*n* (%))	1267 (27.1)	45 (17.7)	73 (18.9)	5 (11.6)
Centrally obese (*n* (%))	2192 (46.9)	181 (71.0)	283 (73.1)	37 (86.1)
Smoking (*n* (%))				
Never	2178 (46.5)	89 (34.5)	147 (37.8)	18 (40.0)
Past	1783 (38.1)	122 (47.3)	178 (45.8)	21 (46.7)
Current	724 (15.5)	47 (18.2)	64 (16.5)	6 (13.3)
IPAQ physical activity (*n* (%))				
High	1302 (28.0)	89 (34.9)	164 (42.6)	14 (31.1)
Medium	1652 (35.5)	86 (68.6)	131 (34.0)	17 (37.8)
Low	1695 (36.5)	80 (31.4)	90 (23.4)	14 (31.1)
GP visits (*n*, mean (SD))	3.6 (5.0)	4.2 (4.3)	5.8 (6.0)	5.1 (5.9)
Healthcare entitlement (*n* (%))				
No cover	502 (10.7)	25 (9.7)	23 (5.9)	6 (13.3)
Medical card	1910 (40.8)	158 (61.2)	240 (61.7)	30 (66.7)
Private insurance	2270 (48.5)	75 (29.1)	126 (32.4)	9 (20.0)

total diabetes prevalence of 8.5%, of which 41.4% was undiagnosed [21]. Both of these studies used HbA_{1c} to estimate undiagnosed diabetes prevalence.

Regarding pre-diabetes, in the 2010 US National Health and Nutrition Examination Survey 19.3% of adults aged 18+ were estimated to have HbA_{1c} in the pre-diabetic range. A further 16.9% of the population had pre-diabetes when defined using fasting plasma glucose (FPG) [22]. Specific to older adults, analyses from the 2011 Health Survey of England indicate a prevalence of HbA_{1c}-measured pre-diabetes of 48.7% in adults aged 40+, which has risen from 17.9% in 2003 [10]. There have been two studies on pre-diabetes prevalence in adults aged 45 years and over in Ireland. The prevalence of pre-diabetes in the 2007 SLAN sample was estimated at 19.8% [12]. In a recent study, a non-population representative sample of over 29500 Irish adults aged 45–75 years without a previous diagnosis of diabetes were screened between 2009 and 2012 using FPG. 2.2% of the sample was found to have undiagnosed diabetes and a further 7.0% had pre-diabetes as defined by FPG of 5.6-6.9 mmol/L, similar to the prevalence observed in the present study [23].

The low prevalence of undiagnosed and pre-diabetes observed in this analysis is surprising for a number of reasons. Firstly, previous reports from TILDA indicate high levels of undiagnosed health conditions, specifically hypertension [24], atrial fibrillation [25] and osteoporosis [26] in the older population in Ireland. It is therefore unexpected that diabetes does not follow this pattern. Secondly, there is no formal screening program for cardiovascular disease risk factors in Ireland. Diabetes care is largely unstructured and there is no

Table 3 – Logistic regression analysis of factors associated with diabetes classification in the TILDA sample.

	Factors associated with diabetes (n = 434) and pre-diabetes (n = 258) compared to no diabetes (n = 4685)		Factors associated with undiagnosed (n = 45) compared to diagnosed diabetes (n = 389)
	Diabetes RRR (95% CI)	Pre-diabetes RRR (95% CI)	Undiagnosed diabetes OR (95% CI)
Age (per year)	1.04 (1.03–1.06)***	1.01 (0.99–1.04)	0.98 (0.93–1.04)
Age^2 (per year^2)	1.00 (0.99–1.00)	1.00 (1.00–1.00)	1.00 (0.99–1.00)
Sex ('Male' = Ref)	0.47 (0.37–0.59)***	0.74 (0.56–0.98)*	1.46 (0.69–3.06)
Education ('Third/higher' = Ref)			
Primary	1.12 (0.84–1.51)	1.62 (1.11–2.36)*	0.92 (0.33–2.50)
Secondary	1.25 (0.95–1.63)	1.38 (0.97–1.97)	1.06 (0.43–2.61)
Marital status ('Married' = Ref)			
Single	1.24 (0.86–1.51)	0.72 (0.41–1.24)	1.55 (0.51–4.72)
Widowed	0.95 (0.69–1.32)	0.96 (0.65–1.43)	1.64 (0.62–4.37)
Separated/Divorced	0.92 (0.57–1.49)	0.72 (0.38–1.37)	2.21 (0.55–8.99)
Locality ('Dublin city/county' = ref)			
Other urban	0.89 (0.67–1.18)	0.86 (0.59–1.25)	4.32 (1.39–13.44)*
Rural	0.87 (0.67–1.13)	1.05 (0.76–1.45)	3.27 (1.13–9.48)*
Previous CVD	1.08 (0.83–1.41)	0.88 (0.61–1.26)	2.11 (0.96–4.65)
Diagnosed hypertension	1.94 (1.55–2.42)***	1.84 (1.39–2.43)***	0.71 (0.34–1.49)
Diagnosed high cholesterol	1.43 (1.15–1.79)**	0.95 (0.72–1.25)	0.52 (0.25–1.09)
Poor/fair self rated health	2.01 (1.53–2.63)***	1.27 (0.87–1.86)	0.73 (0.32–1.70)
Waist circumference ('Normal' = ref)			
Elevated WC	2.20 (1.43–3.38)***	1.50 (0.92–2.46)	3.01 (0.32–28.71)
Central obesity	4.31 (2.94–6.31)***	3.05 (2.00–4.65)***	7.51 (0.91–62.2)
Smoking ('Never' = ref)			
Past	1.06 (0.84–1.35)	1.46 (1.09–1.97)*	1.20 (0.56–2.62)
Current	1.29 (0.93–1.77)	1.68 (1.14–2.48)**	0.82 (0.28–2.42)
IPAQ Physical Activity ('High' = Ref)			
Low	1.48 (1.12–1.96)**	1.01 (0.72–1.42)	0.48 (0.19–1.18)
Medium	1.29 (0.93–1.77)	0.97 (0.70–1.34)	0.78 (0.34–1.80)
Healthcare entitlement ('No cover' = Ref)			
Medical card	1.16 (0.75–1.81)	1.29 (0.78–2.12)	0.49 (0.15–1.63)
Private insurance	0.95 (0.62–1.47)	0.80 (0.49–1.32)	0.22 (0.06–0.77)*
GP visits (per visit)	1.01 (0.99–1.03)	0.98 (0.95–1.01)	0.96 (0.89–1.04)

RRR: relative risk ratio; OR: odds ratio.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

national diabetes register [27]. Finally, rates of overweight, obesity and central obesity are very high in the TILDA sample. 38% of men and 33% of women are obese according to their body mass index (BMI), while 48% of men and 56% of women are centrally obese according to their waist circumference measures [28]. This is similar to obesity prevalence estimates in older adults in both England and the United States; we would therefore expect similar rates of pre-diabetes in the Irish population given the strong association between obesity, particularly central obesity, and insulin resistance [29].

Comparisons between the studies discussed above must be interpreted with caution due to methodological differences. Investigations based on FPG or where HbA_{1c} was measured on different systems, particularly prior to 2010 IFCC standardisation, are not directly comparable and this may account for some of the variations in diabetes and pre-diabetes prevalence estimates across populations. It is possible that the prevalence of undiagnosed and pre-diabetes in older Irish adults may have been higher if assessed by FPG rather than HbA_{1c}. A number of studies have shown discordance between these diabetes classification methods and suggest that each method might identify different risk populations [30]. Factors affecting HbA_{1c} concentration and its relationship with blood glucose levels include age, ethnicity, genetics, BMI and haemoglobinopathies [30–32].

Genetic factors may be particularly relevant in explaining the difference in pre-diabetes prevalence in Ireland compared to other countries. Relative to other European countries, Ireland has an undiluted gene pool due to its isolated geography [33]. Consequently, many heritable health conditions such as haemochromatosis and cystic fibrosis are much more common than observed elsewhere. The 'thrifty genotype' hypothesis has been suggested to explain the large increases in obesity and diabetes in the developed world in

recent years. This hypothesis suggests that in times of plenty, humans are conditioned to overconsume food, accumulating energy stores for times of famine [34]. In modern society there is an overabundance of food without periods of famine and this has been suggested to explain the large increase in obesity and diabetes prevalence in recent decades. There is a suggestion that this 'thrifty gene' may have been selected out of European populations due to mortality and mass emigration. In the case of the Great Irish Famine (1845–1849), the wealthier individuals who had experienced centuries of food abundance prior to the famine and had potentially selected out the thrifty genotype were less likely to be affected by food shortages or forced to emigrate. Therefore those who remained and survived were the healthier and more robust population than the starvation-prone poor who had emigrated or died, taking the thrifty gene with them [35]. If the genetic make-up of the Irish population impacts HbA_{1c} concentration, it may be that FPG is a more accurate measure of hyperglycaemia in this population. While such genetic factors may explain differences in pre-diabetes prevalence estimates between Ireland and other countries, this does not explain the difference between our findings and those of the SLAN study which was based on a similar (albeit smaller) sample of older Irish adults.

We found diabetes and pre-diabetes to be associated with a number of demographic, health and lifestyle indicators. Common to both conditions was the association with male sex, obesity and diagnosed hypertension. High cholesterol and low physical activity were also more common in those with diabetes, while pre-diabetes was associated with lower education and being a past or current smoker. These risk factors are well established in the literature. Central obesity was the characteristic most strongly independently associated with both conditions. After adjustment for all significant covariates, older adults who were centrally obese were 4.3 more likely to have diabetes and 3.1 times more likely to have pre-diabetes compared to those with a normal waist circumference. Hypertension commonly co-exists with diabetes as part of the metabolic syndrome and can substantially increase the risk of vascular complications [36]. Optimal blood pressure control is therefore an essential component of diabetes treatment. The association between diabetes and high cholesterol is more contentious. While increased cholesterol is also a common feature of the metabolic syndrome, there is a growing body of evidence suggesting that statin use, the first line treatment for hypercholesteremia, may be an independent risk factor for diabetes development [37]. However, it is not possible to explore this relationship in cross-sectional analyses. A history of smoking was associated with pre-diabetes but not diabetes in older Irish adults. Previous research has indicated that smoking is a risk factor for both pre-diabetes and diabetes, and is associated with an increased risk of complications in those with diagnosed diabetes [38]. Obesity, hypertension, hypercholesteremia, physical inactivity and smoking are all modifiable through lifestyle change. Lifestyle interventions, particularly focusing on diet and physical activity, have been proven to delay the onset of diabetes by several years and improve glycaemic control in those with a previous diagnosis [39,40]. A substantial proportion of the TILDA population reports low levels of physical activity and this proportion increases with age [26]. Interventions which include physical activity and weight reduction components may further reduce the prevalence of pre-diabetes in this population and decrease the risk of vascular complications in those with an established diabetes diagnosis.

Household location and lack of private health insurance both were associated with having undiagnosed diabetes. Due to the small number of undiagnosed cases, the confidence intervals for these associations were large, and results must therefore be interpreted with caution. Nonetheless, these findings may reflect poorer access to health services for those in lower socioeconomic groups and those who reside in areas outside of Ireland's major city and warrant further investigation. Previous studies have indicated that undiagnosed diabetes may be more common in men, those with a history of hypertension [41] and obese individuals [42], which was not evident in this study. Due to the small number of cases of undiagnosed diabetes, the analysis may have been underpowered to detect significant differences for these and other factors.

There are a number of limitations to this study. The TILDA Wave 1 sample included only community dwelling older adults without a diagnosis of dementia or severe cognitive impairment. The findings presented here are not therefore applicable to older adults in institutional care or those living with dementia or severe cognitive impairment. Diagnosed diabetes was based on respondent's recall and not health records, which may lead to some underreporting. The additional use of medications data to identify cases of diabetes in the absence of a reported diagnosis minimises the number of unidentified cases. However, a subgroup of respondents ($n = 108$) reporting a doctors diagnosis of diabetes were not taking anti-glycaemic medications. This may be due to a number of factors such as a reporting error by the respondent, a previous mis-diagnosis of diabetes or evidence that diabetes is being controlled through lifestyle modification. Respondents were not asked to specify whether they had type 1, type 2 or gestational diabetes. While we attempted to account for possible type 1 cases using medications data and age at diagnosis, there may be some residual misclassification. It is possible that some respondents reporting doctor diagnosed diabetes had gestational diabetes rather than type 2 diabetes. However, further analysis of the data indicates that just 10 women reporting a doctors diagnosis of diabetes and not currently on anti-diabetic medication were diagnosed before the age of 50, indicating a possibility of gestational diabetes. Common to most epidemiological studies, undiagnosed and pre-diabetes were assessed using a single HbA_{1c} test. The use of HbA_{1c} to diagnose diabetes has grown in popularity, as elevated levels are strongly associated with microvascular and macrovascular disease and increased mortality [43]. Compared to the use of FPG, a number of factors make the HbA_{1c} assay ideal for use in large scale epidemiological studies. HbA_{1c} has greater pre-analytic stability, does not require subjects to be fasting, and is less susceptible to day-to-day perturbations due, for example, to stress or illness. However, it is recommended clinically to confirm positive tests with an immediate re-test using a new blood sample [4]. Furthermore, a number of studies have recommended the simultaneous use of HbA_{1c} and FPG to predict the risk of developing diabetes and to avoid diabetes misclassification [44,45]. As stated in the methods section,

HbA_{1c} is predominately measured from fresh whole blood rather than frozen buffy coat samples. However, based on our own validation analysis and those published previously, we are satisfied that the use of buffy coat samples is an acceptable method of HbA_{1c} measurement in this population.

This is the first study to estimate the prevalence and correlates of diagnosed and undiagnosed type 2 diabetes and pre-diabetes in the older Irish population. We have found low rates of undiagnosed and pre-diabetes in community dwelling older adults, despite high rates of obesity and previous evidence of prevalent undiagnosed disease in this population. Our findings confirm previously identified associations between diabetes and pre-diabetes and several demographic, health and lifestyle indices. Longitudinal follow up of this cohort will help to establish factors that are most pertinent in predicting the transition from no diabetes or pre-diabetes to a clinical diagnosis, and help to identify novel and modifiable risk factors for diabetes and its associated complications.

Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

SL contributed to the conception and design of the study, data analysis and interpretation and drafted the manuscript. AMOH contributed to the conception and design of the study and data aquisition, analysis and interpretation. NOL contributed to data analysis and interpretation. MH and MMcC contributed to data acquisition and analysis. JOC and RAK contributed to the conception and design of the study and data analysis and interpretation. All authors critically revised the manuscript and approved the final version for publication.

Acknowledgements

The Irish Longitudinal Study on Ageing is funded by the Irish Government, the Atlantic Philanthropies and Irish Life PLC. This research was additionally supported by the Health Research Board of Ireland (Grant reference: HRA_PHS/2012/30). The sponsors played no role in study design, methods, subject recruitment, data collection, analysis or preparation of paper. We are grateful to all of the TILDA respondents for participating in the study. Researchers interested in using TILDA data may access the data for free from the following sites: Irish Social Science Data Archive (ISSDA) at University College Dublin ⟨http://www.ucd.ie/issda/data/tilda/⟩; Inter-university Consortium for Political and Social Research (ICPSR) at the University of Michigan ⟨http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/34315⟩.

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