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Prevalence and determinants of diagnosed and undiagnosed diabetes in Hungary based on the nationally representative cross-sectional H-UNCOVER study

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ABSTRACT

Aims: To estimate prevalence of diagnosed (dDM) and undiagnosed diabetes (uDM) in Hungary and investigate determinants of uDM.
Methods: Data was obtained from the nationally representative H-UNCOVER study. As laboratory measurements were available for 11/19 Hungarian counties, n = 5,974/17,787 people were eligible. After exclusions, 5,673 (representing 4,976,097 people) were included. dDM was defined by self-reporting, while uDM as negative self-reporting and elevated fasting glucose (≥7 mmol/l) and/or HbA1c (≥48 mmol/mol). Logistic regression for complex samples was used to calculate comparisons between dDM and uDM adjusted for age and BMI.
Results: Diabetes prevalence was 12.0 %/11.9 % (women/men, 95 %CI:10.7–13.4 %/10.7–13.2 %), while 2.2 %/2.8 % (1.7–2.8 %/2.2–3.6 %) of women/men were uDM. While the proportion of uDM vs. dDM was similar for women ≥ 40, men in their forties had the highest odds for uDM. Neither unemployment (women/men OR:0.58 [0.14–2.45]/0.50 [0.13–1.92]), nor education level (tertiary vs. primary; women/men OR: 1.16 [0.53–2.56]/0.53 [0.24–1.18]) were associated with uDM. The risk of uDM was lower in both sexes with chronic morbidities.
Conclusions: We report higher prevalence of diabetes and undiagnosed diabetes than previous Hungarian estimates. The finding that socioeconomic factors are not associated to uDM suggests that universal health care could provide equitable access to diabetes diagnosis.

1. Introduction

The increasing prevalence of diabetes mellitus is a global public health concern [1]. In 2021, approximately one in ten adults was affected by diabetes [1]. Accordingly, the prevalence of diabetes in Hungary is similar to other European estimates (9.1 % vs 9.2 %) [1], and we clearly see an upward trend [2–7] based both on surveys (self-reported diabetes – from 6.2 % to 11.7 %) and on the use of antidiabetic medications (from 5 % to 8.8 %) between the early 2000 s and 2019 [2–7].

The comparison of diabetes prevalence between countries or even within the same country over time is hindered by the fact that studies

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sample different age cohorts/ranges, however the occurrence of diabetes is age-dependent [8]. Most Hungarian studies report on diabetes prevalence among those > 18 years of age [2,4–6], except for one that investigates adults 20–69 years old [3].

Reported prevalence can also differ based on the diagnostic method used to define diabetes, for instance fasting glucose, hemoglobin A1c (HbA1c), self-reported disease status, physician claim, prescribed antidiabetics, or different combinations of these. According to a *meta*-analysis comparing different methods to the gold standard oral glucose tolerance tests, HbA1c with a cut-off value of 6.5 % (48 mmol/mol) had a sensitivity of 50 % and a specificity of 97 %, while fasting glucose with a cut-off value of 7 mmol/l had 59.4 % and 98.8 %, respectively [9]. Furthermore, the overlap between the different diagnostic methods could be as low as 17 %, and only 59 % of oral glucose tolerance test (OGTT) based diabetes cases had their diagnosis confirmed over an extended follow-up [10,11]. However, the same study also suggested that patients with unconfirmed diagnosis had similar risk of vascular complications as the background population [10]. Unfortunately, there is only one study based on a representative sample from Hungary that used a biochemical diagnosis of diabetes (based on fasting glucose) and there is no data available on the prevalence based on HbA1c [3].

Significant differences can also arise if studies define diabetes based on self-report, physician claim, or prescribed medications. For example, the sensitivity and specificity of self-reported diabetes against fasting glucose, use of antidiabetic medications, or HbA1c ranged between 59–71 % and 96–97 %, respectively in the Atherosclerosis Risk in Communities Study [12]. The suggested best use of administrative data is if physician claims were supplemented with antidiabetic medication prescription (sensitivity of 82.6 %, specificity of 99.2 %) [13]. The prevalence studies from Hungary fall into 3 categories but none follow the above-described best use scenario. There are 2 reports that used self-reported diabetes based on nationally representative surveys that show an alarming increase in the prevalence from 6.2 % to 11.7 % between 2002 and 2012 [2,4]. There is one report using fasting glucose supplemented by claims data from volunteer general practices that report an overall prevalence of 8.65 % and claims-based prevalence of 7.2 % in 2005 [3]. Furthermore, claims data are also reported by the Central Statistics Office as 7.9 %, 8.0 %, and 8.8 % for the years 2009, 2014, and 2019 [6]. While these data clearly show a continuous increase in diabetes prevalence, prescription data suggests an increase from 5 % to 8 % until 2012 but no further increase thereafter until 2016 [5].

Furthermore, there are substantial regional differences in the occurrence of undiagnosed diabetes. A *meta*-analysis encompassing over 215 countries suggests that ~ 23–45 % of patients may be unaware of their diabetes globally [14]. Approximately, 3.4 % of the total population had undiagnosed diabetes in the US [15], whereas this proportion was lower at 1.4 % in Hungary in 2005 [3]. After 2005, there were very few studies published on the prevalence of undiagnosed diabetes in Hungary that hinders outlining trends for undiagnosed diabetes.

While most risk factors of diabetes, such as unhealthy lifestyle habits, obesity, low socioeconomic status, and low level of attained education are widely known [2,16–18], less is known about factors that affect the recognition of diabetes, although unrecognized diabetes leads to a more frequent occurrence of vascular complications [19]. There is some evidence that younger age, rural residence, low socioeconomic status, certain ethnicities, and lack of health insurance may be associated with undiagnosed diabetes, while diagnosed comorbidities, such as hypertension, may in fact increase detection rates [20–22].

Given that no recent estimate is available for Hungary on the rate of diagnosed and undiagnosed diabetes and there is equivocal evidence on the role of socioeconomic status on the risk of undiagnosed diabetes, we aimed (1) to estimate the prevalence of diagnosed and undiagnosed diabetes and (2) to test whether socioeconomic factors, such as lower education and lack of employment, hinder the recognition of diabetes using data from a nationally representative survey conducted in 2020.

2. Methods

2.1. Setting and participants

The cross-sectional H-UNCOVER study was performed between May 1 and May 16, 2020 [23]. The study aimed to examine the frequency and determinants of current and past severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infections in a representative sample of the non-institutionalized Hungarian adult (>14 years of age) population. Thus, our study is a *post hoc* analysis of data from the H-UNCOVER survey. H-UNCOVER was approved by the Committee of Science and Research Ethics of Medical Research Council (IRB IV/4060–3/2020/EKU). Written informed consent was obtained from each participant.

The source of the study population consists of all people aged 14 years or older living in non-institutionalized living conditions in Hungary in January 2020 [24]. During the two-stage stratified sampling process, settlements (settlement is defined as a place, where people establish a community and is recognized by the government, such as hamlets, villages, towns, and cities) were first selected as primary sampling units (PSU) followed by the recruitment of individuals within these PSUs in the second stage. To ensure equal precision, seven regions with equal population sizes were constructed. In the study, all larger settlements were included along with any settlements with at least five confirmed COVID-19 cases, resulting in 181 PSUs. Within each region, individual stratums were assigned to any settlement with at least 1–4 confirmed cases, while the rest of the PSUs were stratified by settlement size, average income, and proportion of population that attained a tertiary education. A total of 154 strata were selected and two PSUs were chosen with equal probability proportional to size within each stratum, resulting in the inclusion of 489 out of 3177 settlements. During the second stage, individuals were selected using systematic random sampling within each selected settlement after ordering individuals by age. A minimum of 4 individuals were selected from each selected settlement. The total size of the sample was determined by assuming 10 % sampling frame error and 70 % participation rate. Thus, a total of 17,787 individuals were selected to reach an effective sample size of 11,206. Participants were assigned weights for the number of individuals they represent in the total population [23]. Data collection period was restricted to the 16 days following May 1st, 2021.

Of the 17,787 individuals aged over 14 that were invited, approximately 59 % participated, resulting in a total survey population of 10,474 individuals [23]. As fasting glucose and HbA1c levels were only measured in 10 of the 19 counties as well as in the capital (Budapest), our study population represents the central and South-Eastern parts of the country [23]. By design, 4,500 individuals were excluded from the present analyses leaving 5,974 potentially eligible individuals. Further 301 individuals were excluded due to missing data on outcomes or covariates leading to a final analytical sample of 5,673 individuals (94.9 %) that represent 4,976,097 people (approximately 51 % of the total eligible Hungarian population) (Fig. 1).

The survey consisted of 2 parts. First, data was collected with a questionnaire that was filled in either online or in person in the presence of an interviewer. All questionnaire data is based on self-reporting. Patients also had a fasting blood draw according to standardized protocols for the determination of basic laboratory parameters including blood glucose and HbA1c. Blood glucose and HbA1c levels were determined by hexokinase and HPLC methods, respectively on automated laboratory systems at the central laboratories of Semmelweis University and University of Szeged. Both laboratories follow ISO 9001 standards for quality management.

2.2. Outcomes

Diagnosed diabetes was defined by self-report on the questionnaire. Participants without self-reported diabetes but with either elevated fasting glucose (≥7 mmol/l) and/or Hb1Ac levels (6.5 % [≥48 mmol/

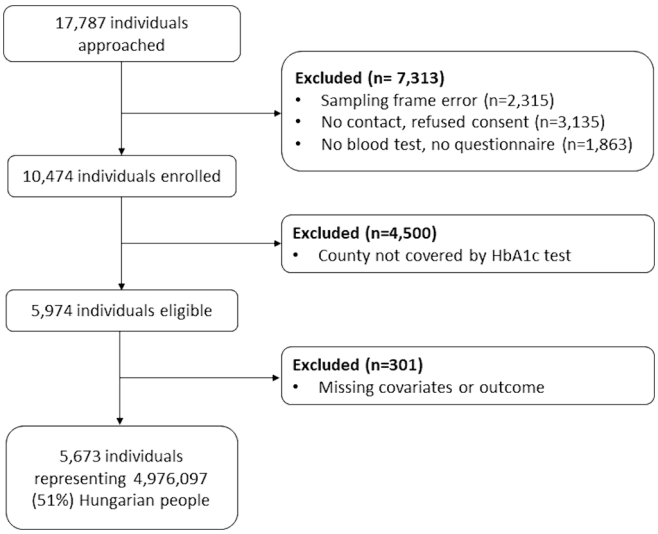

Fig. 1. Flow chart of the selection of survey participants.

mol]) were categorized as undiagnosed diabetes cases. In a sensitivity analysis, we defined undiagnosed diabetes based on a negative self-report and elevated HbA1c values only. Diabetes-free individuals were defined as participants without diagnosed or undiagnosed diabetes.

2.3. Covariates

For our analyses, the following additional questionnaire data (self-reported) was used as covariates: sex (male/female), age (years), employment status (employed, retired, unemployed, dependent), level of education (primary or less than primary, secondary, tertiary), presence of chronic diseases (hypertension, cardiovascular disease, respiratory disease, renal disease, liver disease, immune disease, and cancer; yes/no), weight (kg), and height (m). As the dependent group (employment status) included a mixture of individuals on maternity leave and those in education and no men had undiagnosed diabetes in this group, no estimates are provided for the dependent group. For easier interpretation, age was divided into the following categories: <40, 40–49; 50–59, 60–69, 70–79, and 80+ years. Total number of chronic diseases was categorized as no chronic diseases, one chronic disease, and ≥2 chronic diseases. Body mass index (BMI) was calculated using self-reported weight and height.

2.4. Statistical analysis

All analyses were done taking into account the 2-stage sampling design of the survey using methods for complex samples in SPSS. Descriptive data are given as estimated counts and percentages (with respective 95 % confidence intervals [95 % CI]) for the source population for categorical variables and means and 95 % CIs for continuous variables. To enhance the comparability of diabetes prevalence data to other Hungarian and international results, we used direct standardization based on the global, European, and the Hungarian standard populations of the United Nations World Population Prospects from 2021 for those aged 20–79 years [25].

For the baseline tables the 3 study groups (diabetes-free/undiagnosed diabetes/diagnosed diabetes) were compared using chi-squared tests and general linear models. Furthermore, we provide 2 predetermined contrasts or all analysis. First, we compared diabetes-free participants to all (diagnosed and undiagnosed) diabetes cases. Then, we compare undiagnosed diabetes cases to diagnosed diabetes cases.

For the investigation of the association between the independent covariates (employment status, level of education, and number of chronic diseases) and the outcomes binary (diabetes-free vs. all diabetes cases) and multinomial (diabetes-free vs. undiagnosed diabetes vs. diagnosed diabetes) logistic regression models were built. For these models, results are given as odds ratios (OR) and 95 % CIs. For the multinomial models we report the pre-planned comparison between diagnosed and undiagnosed diabetes cases. We report the result of 3 sets of models. First, we investigated the association between each independent variable with the outcomes in age adjusted (linear and quadratic terms) models (*Model 1*). Then, we further adjusted these models for BMI (linear and quadratic terms; *Model 2*). Finally, we provide results for a mutually adjusted model that includes employment status, level of education, number of comorbidities in addition to age and BMI. All analyses were stratified by sex.

A sensitivity analysis was also conducted where undiagnosed diabetes was defined on elevated HbA1c and no self-reported diabetes without considering fasting glucose.

Statistical significance was set at a two-sided $p < 0.05$. IBM SPSS Statistics 28.0.1.0 was used for all statistical analyses.

3. Results

3.1. Estimated prevalence of type 2 diabetes

Sociodemographic characteristics stratified by diabetes status are presented in Table 1. The estimated prevalence of diabetes (diagnosed and undiagnosed) was 12.0 % (95 % CI: 10.7–13.4 %) for women and 11.9 % (95 % CI: 10.7–13.2 %) for men in the represented regions of Hungary among people > 14 years of age. These figures translate to an overall diabetes prevalence of 9.22 % (95 % CI: 8.43–10.00 %), 12.09 % (95 % CI: 11.11–13.07 %), and 12.21 (95 % CI: 11.23–13.19) using the global, European, and the Hungarian standard population structures, respectively (Supplementary Table 1).

We found a positive association between age and the prevalence of diabetes with prevalence peaking at ages 70–79 years at 28.7/39.0 % (women/men), followed by a slightly lower prevalence in those ≥ 80 years of age. The point estimates were lower for men below 50 but are higher above 50 years of age compared to women (Fig. 2).

The estimated prevalence of diagnosed diabetes was 9.8/9.1 % (men/women, 95 % CI: 8.6–11.1/8.0–10.3 %). These figures translate to an overall diagnosed diabetes prevalence of 7.66 % (95 % CI: 7.07–8.25 %), 10.06 % (95 % CI: 9.27–10.84 %), and 10.15 (95 % CI: 9.36–10.93) using the global, European, and Hungarian standard population structures, respectively (Supplementary Table 1).

The prevalence of diagnosed diabetes by age mostly paralleled that of all diabetes with a peak in the oldest age group in women (23.9 %) and men ages 70–79 years (30.8 %). Men above the age of 50 had a higher prevalence of diagnosed diabetes compared to women (Fig. 2).

The overall proportion of undiagnosed diabetes was 2.2/2.8 % (95 % CI: 1.7–2.8/2.2–3.6 %). These figures translate to an overall undiagnosed diabetes prevalence of 2.25 (95 % CI: 1.86–2.64 %), 3.07 (95 % CI: 2.48–3.66), and 3.12 % (2.53–3.71 %) using the global and Hungarian standard population structures, respectively (Supplementary Table 1).

While the highest prevalence of undiagnosed diabetes was found in women ages 70–79, the highest prevalence of undiagnosed diabetes was associated with the highest age-group among men. Furthermore, men had higher point estimates of undiagnosed diabetes compared to women in all age groups except for the youngest (Fig. 2).

When we compared the odds of undiagnosed diabetes to that of diagnosed diabetes, we found the lowest odds ratios in the youngest age group in both sexes (although it was non-significant in women). While the other groups in women showed largely similar odds ratios compared to women ages 40–49, men aged 40–49 had an increased odds of being undiagnosed compared to the other age groups of the same sex (Fig. 2).

Table 1
Characteristics of survey participants stratified by diabetes status.

	Diabetes-free (n = 4,666,040) n (%) / mean (SE)	Undiagnosed DM (n = 56,221) n (%) / mean (SE)	Women Diagnosed DM (n = 253,836) n (%) / mean (SE)	Heterogeneity p-value	Diabetes-free vs. all DM OR/MD (95 % CI)	Undiagnosed vs. Diagnosed DM OR/MD (95 % CI)
Age (yrs)	47.6 (0.5)	65.8 (1.9)	64.8 (1.2)	**< 0.0001**	**−17.4 (−19.6 to −15.1)**	1.1 (−3.6 to 5.7)
BMI (kg/m^2)	25.5 (0.1)	30.3 (0.5)	29.2 (0.3)	**< 0.0001**	**−3.9 (−4.5 to −3.3)**	1.1 (−0.2 to 2.3)
Fasting glucose (mmol/l)	4.0 (0.0)	7.5 (0.3)	6.5 (0.3)	**< 0.0001**	**−2.7 (−3.1 to −2.3)**	**1.0 (0.2 to 1.8)**
HbA1c (mmol/mol)	36 (0.0)	52 (1.1)	51 (1.1)	**< 0.0001**	**−15.3 (−17.5 to 14.2)**	1.1 (−3.3 to 4.4)
HbA1c (%)	5.4 (0.0)	6.9 (0.1)	6.8 (0.1)	**< 0.0001**	**−1.4 (−1.6 to −1.3)**	0.1 (−0.3 to 0.4)
Employment status				**< 0.0001**		
Employed	1,070,642 (46.9)	11,917 (21.2)	57,524 (22.7)		1 (ref.)	1 (ref.)
Retired	578,388 (25.4)	39,355 (70.0)	173,148 (68.2)		**0.18 (0.13 to 0.25)**	1.10 (0.53 to 2.25)
Dependent	286,266 (12.5)	3314 (5.9)	7568 (3.0)		1.71 (0.85 to 3.42)	2.11 (0.46 to 9.77)
Unemployed	346,099 (15.2)	1634 (2.9)	15,578 (6.1)		1.31 (0.76 to 2.25)	0.51 (0.12 to 2.09)
Level of education				**< 0.0001**		
Less than primary/primary	768,862 (33.7)	29,161 (51.9)	137,932 (54.3)		1 (ref.)	1 (ref.)
Secondary	831,809 (36.5)	18,512 (32.9)	81,749 (32.2)		**1.80 (1.37 to 2.38)**	1.07 (0.55 to 2.10)
Tertiary	680,724 (29.8)	8549 (15.2)	34,156 (13.5)		**3.46 (2.48 to 4.84)**	1.18 (0.52 to 2.72)
Number of chronic diseases				**< 0.0001**		
None	1,491,910 (65.4)	15,033 (26.7)	32,452 (12.8)		1 (ref.)	1 (ref.)
1	541,773 (23.7)	26,095 (46.4)	123,364 (48.6)		**0.12 (0.08 to 0.16)**	**0.46 (0.22 to 0.96)**
≥2	247,713 (10.9)	15,094 (26.8)	98,021 (38.6)		**0.07 (0.05 to 0.10)**	**0.33 (0.14 to 0.78)**

Men

	Diabetes-free (n =)	Undiagnosed DM (n = 66,804)	Diagnosed DM (n = 216,973)	Heterogeneity p-value	Diabetes-free vs. all DM	Undiagnosed vs. Diagnosed DM
	n (%) / mean (SE)	n (%) / mean (SE)	n (%) / mean (SE)		OR/MD (95 % CI)	OR/MD (95 % CI)
Age (yrs)	43.5 (0.4)	64.0 (1.6)	64.8 (0.9)	**< 0.0001**	**−21.1 (–22.9 to −19.2)**	−0.8 (−4.3 to 2.8)
BMI (kg/m^2)	27.0 (0.1)	30.4 (0.6)	30.0 (0.3)	**< 0.0001**	**−3.1 (−3.7 to −2.5)**	0.4 (−0.9 to 1.8)
Fasting glucose (mmol/l)	4.1 (0.0)	7.8 (0.4)	7.2 (0.3)	**< 0.0001**	**−3.3 (−3.8 to −2.8)**	0.5 (−0.4 to 1.5)
HbA1c (mol/mol)	34 (0.0)	53 (1.1)	53 (1.1)	**< 0.0001**	**−18.6 (−19.7 to −16.4)**	0.0 (−3.3 to 3.3)
HbA1c (%)	5.3 (0.0)	7.0 (0.1)	7.0 (0.1)	**< 0.0001**	**−1.7 (−1.8 to −1.5)**	0.0 (−0.3 to 0.3)
Employment status				**< 0.0001**		
Employed	1,352,105 (64.4)	28,376 (42.5)	73,823 (34.0)		1 (ref.)	1 (ref.)
Retired	285,935 (13.6)	35,198 (52.7)	124,894 (57.6)		**0.14 (0.10 to 0.19)**	0.73 (0.41 to 1.30)
Dependent	233,213 (11.1)	0 (0.0)	2670 (1.2)		**6.60 (1.98 to 21.99)**	N/A
Unemployed	229,615 (10.9)	3230 (4.8)	15,586 (7.2)		0.92 (0.51 to 1.68)	0.54 (0.14 to 2.07)
Level of education				**0.008**		
Less than primary/primary	895,761 (42.6)	41,376 (61.9)	112,354 (51.8)		1 (ref.)	1 (ref.)
Secondary	723,170 (34.4)	17,528 (26.2)	64,993 (30.0)		**1.50 (1.12 to 2.02)**	0.73 (0.38 to 1.40)
Tertiary	481,936 (22.9)	7900 (11.8)	39,625 (18.3)		**1.74 (1.16 to 2.62)**	0.54 (0.24 to 1.22)
Number of chronic diseases				**< 0.0001**		
None	1,507,027 (71.7)	19,933 (29.8)	39,731 (18.3)		1 (ref.)	1 (ref.)
1	452,888 (21.6)	28,603 (42.8)	101,129 (46.6)		**0.14 (0.10 to 0.19)**	**0.56 (0.32 to 1.00)**
≥2	140,953 (6.7)	18,268 (27.3)	76,112 (35.1)		**0.06 (0.04 to 0.09)**	**0.48 (0.23 to 1.01)**

Abbreviations: BMI: body mass index; 95% CI: 95% confidence intervals; DM: diabetes mellitus; HbA1c: hemoglobin A1c; MD: mean difference; OR: odds ratios; ref.: reference; SE: standard error; yrs: years.
Bold values: **p < 0.05**.
Heterogeneity p calculated using crosstabs for complex samples for categorical and general linear model for complex samples for continuous variables.
Odds ratios (95% CIs) and mean differences (95% CIs) were calculated using logistic regression and general linear models for complex samples respectively.

3.2. Characteristics of people by diabetes status

We found significant heterogeneity between the 3 groups (diabetes-free/undiagnosed/diagnosed diabetes) for all investigated characteristics. However, this was mostly related to the large difference between diabetes-free people and those with diabetes. People with diabetes were 17.4/21.1 years older, had a higher BMI (by 3.9/3.1 kg/m^2) and had higher fasting glucose and HbA1c values than those without diabetes (Table 2).

Retired people were less likely to be diabetes-free compared to employed people both in men and women (OR: 0.18/0.14), however whether someone was employed or not had no association with the risk of diabetes. There was a strong graded association between higher level of education and lower risk of diabetes in both sexes (OR for tertiary education vs. up to primary: 3.46/1.74), although the association was much steeper among women. Finally, the risk of diabetes was higher among those with any chronic conditions (Table 2).

In contrast, people with diagnosed and undiagnosed diabetes had very similar characteristics except for a stepwise decreasing risk of undiagnosed diabetes among those with chronic diseases (Table 2).

Age adjustment substantially attenuated the difference in the risk of diabetes between retired and employed people, while the other differences showed similar attenuations after age and BMI adjustments. However, all differences between people with and without diabetes

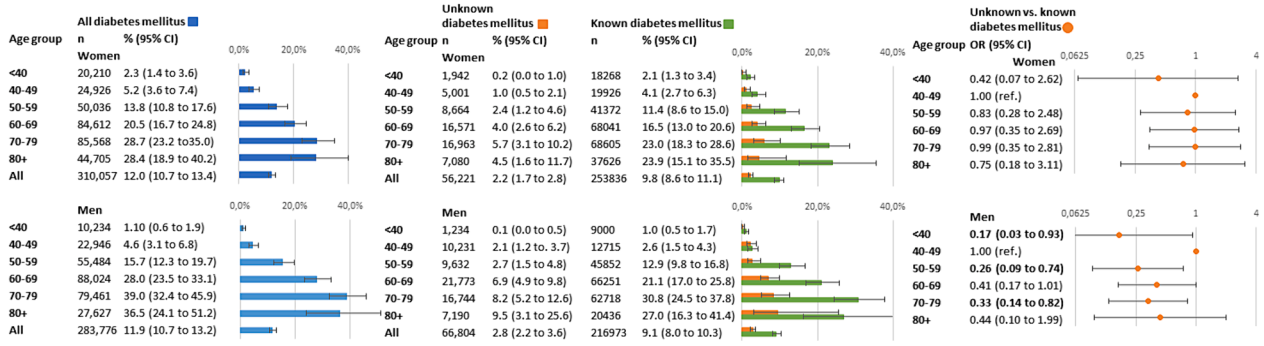

Fig. 2. Prevalence of all diabetes, diagnosed diabetes, undiagnosed diabetes and the risk for being undiagnosed (vs diagnosed) with diabetes by age groups and sex Abbreviations: 95% CI: 95% confidence interval; OR: odds ratio; ref.: reference. Prevalences were estimated using frequencies for complex samples, odds ratios were calculated with logistic regression for complex samples. Error bars show 95% confidence intervals.

remained significant except for the level of education in men (Table 2).

In age and BMI adjusted models, employment status and level of education had no significant association with the risk of diabetes being undiagnosed (vs. diagnosed). After adjustment the association between the number of chronic diseases and the risk of undiagnosed diabetes became even stronger (Table 2). The mutually adjusted models (adjusted for age, BMI, employment status, level of education, and number of comorbidities) showed very similar findings in this regard to the age and BMI adjusted models with almost identical point estimates (Fig. 3).

The mutually adjusted models (adjusted for age, BMI, employment status, level of education, and number of comorbidities) showed very similar findings for employment status as well: retired women and men had a 42 % reduced risk of being diabetes-free compared to employed people, however unemployed and employed people had similar risks for diabetes with point estimates close to unity. There was a higher risk of being diabetes-free with higher levels of education in both sexes (although it became non-significant in men). The number of known chronic diseases was associated with a lower risk of being diabetes-free with overlapping confidence intervals in men and women (Fig. 3).

Our sensitivity analysis where diabetes diagnosis was based solely on HbA1c grossly corroborates the results of the main analysis (Supplementary Tables 2–4).

4. Discussion

4.1. Short summary

According to our population-based survey, the overall prevalence of diabetes was approximately 12.0 % (95 % CI: 10.7–13.4 %) in women and 11.9 % (95 % CI: 10.7–13.2 %) in men in people > 14 years of age in Hungary in 2020. Of the whole population 2.2 % (95 % CI: 1.7–2.8 %) of women and 2.8 (95 % CI: 2.2–3.6 %) of men were unaware of their diabetes status meaning that 18.3 % of women and 23.5 % of men with diabetes were undiagnosed. The prevalences of all diabetes, diagnosed and undiagnosed diabetes was higher among men compared to women in all age groups > 50 years. In general, the prevalence of undiagnosed diabetes was lowest in the youngest age group probably reflecting the highest relative proportion of type 1 diabetes in these people. While the proportion of undiagnosed diabetes were similar in all age groups > 40 in women, we found that men in their forties had the highest odds for undiagnosed diabetes. Our study confirmed already reported associations between older age, higher BMI, lower level of education and higher number of comorbidities and the risk of diabetes. According to our multiple adjusted models, neither unemployment (OR: 0.58, 95 % CI: 0.14–2.45 in women, OR: 0.50, 95 % CI: 0.13–1.92 in men), nor level of education (tertiary vs. primary OR: 1.16, 95 % CI: 0.53–2.56 in women, OR: 0.53, 95 % CI: 0.24–1.18 in men) were associated with the risk of being undiagnosed with diabetes. In contrast, the risk of being undiagnosed was substantially lower in both men and women with other chronic diseases.

4.2. Results in context of the literature

4.2.1. Diabetes prevalence

Our prevalence of approximately 12 % for diabetes overall is substantially higher than the 8.1 % from the Central Statistics Office in Hungary for 2019 [6] or the 7 % (95 % CI: 5.3–8.8 %) from the IDF Atlas for Hungary in Hungary in 2021 [26]. Even if we only consider diagnosed diabetes, our results (9.1 % in women, 9.8 % in men) are somewhat higher than the prevalence according to the Central Statistics Office (8.1 %) that represents all doctor diagnosed diabetes cases but well corresponds to the global IDF estimate for adults 20–79 of 9.1 % (95 % CI: 7.2–11.8 %) [6,26]. As for undiagnosed diabetes, our estimates of 18.3/23.5 % (women/men) are substantially higher than the 16.7 % reported for Hungary in the IDF Atlas, although it is lower than the estimated 35 % for the whole of Europe [26].

The interpretation of the different estimates is complicated by the differences in diagnostic and sampling methods. Regarding diagnostics, it should be noted that our study utilized both fasting glucose and HbA1c for the diagnosis of diabetes that well corresponds to clinical practice and novel guidelines [27]. HbA1c levels in general are much less influenced by recent events and are more reliable than OGTT [28]. Our sampling frame included people 14–20 years of age as well as people older than 80 that could limit the external validity of our findings, but still gives an estimate for the whole population. Due to technical issues, our sample was only representative of half of Hungary that may have biased our estimates for the whole country.

4.2.2. Determinants of overall diabetes prevalence

Our study confirms some of the classical risk factors of diabetes, such as advanced age (including retirement), higher BMI, lower socioeconomic status (including education), and higher number of chronic diseases [29,30].

We found that the association between being retired and the risk of diabetes was not completely explained by the age and BMI difference between retired and employed participants. Furthermore, the association remained significant even after adjustment for chronic diseases probably partly related to the crudeness of our measure of chronic diseases. According to a systematic review, most studies found no association between retirement and the risk of diabetes probably related to the fact that retirement had distinct effects on adiposity and physical activity by the type of work individuals previously had [31].

Lower socioeconomic status (usually defined by education, occupation, and income) is a well-accepted risk factor for the development of diabetes [29] and also prediabetes [32]. We found that lower attained education was a risk factor for diabetes overall and for diagnosed diabetes even after adjusting for age (both sexes) and BMI (women).

Table 2
Association between employment status, level of education, and the number of chronic diseases with the risk of diabetes and being undiagnosed (vs. diagnosed) with diabetes in models stratified by sex and adjusted for age and BMI.

	Model 1 (adjusted for age)		Model 2 (adjusted for age and BMI)	
	Diabetes-free vs. all DM OR (95 % CI)	Undiagnosed vs Diagnosed DM OR (95 % CI)	Diabetes-free vs. all DM OR (95 % CI)	Undiagnosed vs Diagnosed DM OR (95 % CI)
	Women			
Employment status				
Employed	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
Retired	**0.43 (0.29 to 0.64)**	0.83 (0.31 to 2.21)	**0.51 (0.35 to 0.74)**	0.75 (0.28 to 2.02)
Dependent	0.51 (0.21 to 1.22)	3.54 (0.65 zo 19.21)	0.58 (0.23 to 1.43)	3.42 (0.58 to 20.20)
Unemployed	1.01 (0.57 to 1.79)	0.57 (0.14 to 2.32)	1.04 (0.57 to 1.89)	0.55 (0.13 to 2.31)
Level of education				
Less than primary/ primary	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
Secondary	**1.49 (1.12 to 2.00)**	1.05 (0.54 to 2.07)	**1.37 (1.02 to 1.83)**	1.11 (0.56 to 2.21)
Tertiary	**2.55 (1.78 to 3.66)**	1.19 (0.53 to 2.67)	**2.12 (1.42 to 3.18)**	1.29 (0.58 to 2.88)
Number of chronic diseases				
None	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
1	**0.21 (0.15 to 0.30)**	**0.32 (0.16 to 0.63)**	**0.26 (0.18 to 0.37)**	**0.27 (0.13 to 0.55)**
≥2	**0.15 (0.11 to 0.22)**	**0.21 (0.09 to 0.49)**	**0.21 (0.14 to 0.30)**	**0.17 (0.07 to 0.38)**
	Men			
Employment status				
Employed	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
Retired	**0.53 (0.32 to 0.87)**	0.71 (0.30 to 1.67)	**0.50 (0.31 to 0.82)**	0.70 (0.31 to 1.61)
Dependent	0.48 (0.11 to 2.08)	0.00 (0.00 to 0.00)	0.34 (0.07 to 1.59)	N/A
Unemployed	0.83 (0.44 to 1.58)	0.54 (0.14 to 2.07)	0.84 (0.44 to 1.60)	0.53 (0.14 to 2.04)
Level of education				
Less than primary/ primary	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
Secondary	1.17 (0.85 to 1.61)	0.72 (0.38 to 1.36)	1.17 (0.82 to 1.66)	0.73 (0.38 to 1.37)
Tertiary	**1.57 (1.05 to 2.36)**	0.54 (0.24 to 1.20)	1.41 (0.93 to 2.14)	0.55 (0.24 to 1.25)
Number of chronic diseases				
None	1 (ref.)	1 (ref.)	1 (ref.)	1 (ref.)
1	**0.39 (0.28 to 0.54)**	**0.55 (0.30 to 1.00)**	**0.46 (0.33 to 0.65)**	**0.53 (0.29 to 0.96)**
≥2	**0.22 (0.14 to 0.35)**	**0.44 (0.21 to 0.92)**	**0.29 (0.18 to 0.46)**	**0.40 (0.19 to 0.85)**

Abbreviations: BMI: body mass index; 95% CI: 95% confidence interval; DM: diabetes mellitus; OR: odds ratio; ref.: reference.
Bold values: **p < 0.05**.
Model 1 adjusted for age. Model 2 further adjusted for BMI.
Odds ratios and 95% CIs were calculated using logistic regression for complex samples.

Education may exert its effect on health through several pathways including a more health-conscious lifestyle (BMI, physical activity, and nutrition), improved social support, and better access to health care [33].

The association between the number of chronic diseases and the risk of diabetes is partly mediated through the associations between age, BMI, and both diabetes and chronic diseases. This fact is reflected by the substantial attenuation of the strength of the association in models adjusted for age and BMI. However, there remained a clinically significant association in line with the concept of the metabolic syndrome [34].

4.2.3. Determinants of being undiagnosed with diabetes

In contrast to our hypothesis, we found no association between the risk of being undiagnosed with diabetes and employment status. We think that the fact that Hungary has a universal healthcare coverage and healthcare is provided to all citizens for free (if truly unemployed) or for a nominal fee (if self-employed) means that unemployed people can retain the health insurance and receive the necessary preventive services. In contrast, in countries where unemployment leads to a loss of health insurance (i.e., the US and Mexico), having health insurance is associated with increased attendance to diabetes screening and consequential diagnosis of diabetes [35–37].

We found that the level of education was not related to being undiagnosed (vs. diagnosed) with diabetes although higher level of education seemed to be associated with a decreased risk of being undiagnosed among men. These findings highlight that there may be an interaction between sex and education on the risk of being undiagnosed with diabetes and may partly explain the equivocal observations in the literature. Some studies found that lower level of education is associated with undiagnosed diabetes [21,38], while other studies reported null findings [39,40].

According to our data, the presence of comorbidities is an important determinant of being diagnosed with diabetes with a steeper association in women compared to men. This is in line with the general observation that non-infectious diseases (and diabetes) are recognized more often in the presence of other comorbidities [30]. This observation is most likely related to referral bias, the increased number of healthcare visits and laboratory determinations in patients with known chronic conditions compared to seemingly healthy individuals leading to higher detection rates of diabetes.

4.3. Strengths and weaknesses

A major strength of our study is that it is representative for a well-described region of the whole country. Furthermore, the relatively large sample size and low rates of missing data allowed to estimate the prevalence and predictors of even undiagnosed diabetes, a relatively less well understood portion of the diabetes population.

All laboratory determinations were performed in 2 central laboratories of medical universities that assures the precision and reliability of these measurements. Moreover, our laboratory diagnosis of diabetes included HbA1c, which has a low test–retest variability and is recommended by current guidelines [27,41].

We also have to acknowledge certain limitations. First, our study was a *post hoc* analysis of a survey that aimed to investigate the effect of the SARS-CoV-2 pandemic on Hungary. While oversampling of settlements with COVID-19 cases could have potentially biased our analysis, we think that this issue has only a minimal effect. First, all large settlements (n = 170) were selected as PSUs, thus COVID-19 cases could have no effect on estimates for large settlements. Among the 3017 small settlements, only 11 were selected based on known COVID-19 cases, while 308 (96.6 %) were randomly selected. Even if the 11 small settlements with COVID-19 cases would have different diabetes prevalence rates and socioeconomic structure compared to the rest of settlements, based on the above numbers this might only minimally bias our estimates.

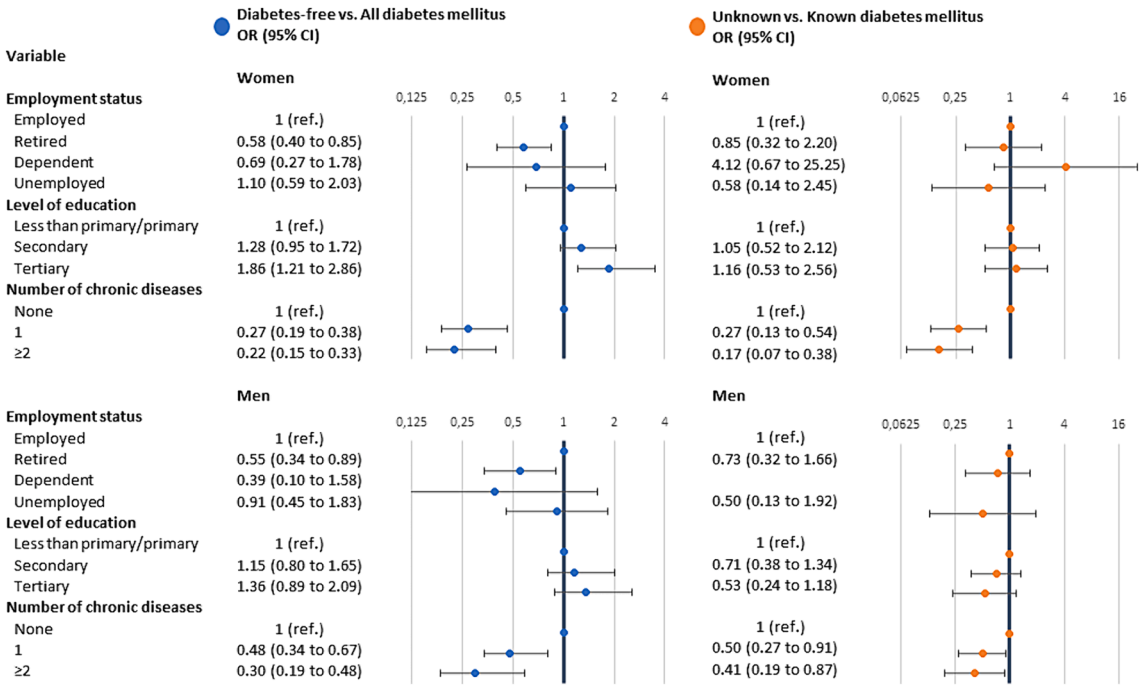

Fig. 3. Association between employment status, level of education, and the number of chronic diseases with the risk of diabetes and being undiagnosed (vs diagnosed) with diabetes in mutually adjusted (adjusted for age, body mass index, employment status, level of education, and number of comorbidities) models stratified by sex Abbreviations: 95% CI: 95% confidence interval; OR: odds ratio; ref.: reference. Odds ratios and 95% CIs were calculated using logistic regression for complex samples. Prevalence and determinants of diagnosed and undiagnosed diabetes in Hungary based on the nationally representative cross-sectional H-UNCOVER study.

Moreover, because the main goal of the study was to examine the effect of the COVID-19 pandemic, some potentially relevant information for diabetes was also missing from our database (such as ethnicity, different lifestyle factors, blood pressure, income). It is also important to note that our results probably underestimate the true prevalence of diabetes, as the blood collection protocol did not require the use of glycolysis inhibitor and thus blood sugar may have fallen before determination especially for samples that were drawn farther away from study laboratories. While this may have affected our overall prevalence estimates, its effect is most likely minimal, as samples were centrifuged within an hour after blood draw. Moreover, preanalytical error is unlikely to bias the association between social factors and diagnosis. This is further corroborated by the fact that our sensitivity analysis (using only HbA1c for the diagnosis of diabetes) mainly confirms our main analysis. Notably, the underreporting is also counterbalanced by the use of a combination of HbA1c and fasting glucose in our case definition. Another potential limitation is that diagnosed diabetes was defined by self-report only without confirmation by medication use or administrative data leading to the potential for recall bias. Social desirability bias could have affected our BMI estimates that were calculated from self-reported weight and height. Although it is well-known that participants usually overreport height and underreport weight, the BMI calculated using self-reported information is an acceptable measure that can rank individuals across different sociodemographic groups [42]. We had no information on the type of diabetes, and therefore our results are not directly translatable to type 2 diabetes, although over 90 % of adult diabetes cases are type 2. Moreover, the lack of fasting glucose and HbA1c measurements for certain regions of Hungary limited the external validity of our findings for the whole country. Similarly, people without a valid address (like homeless people) were excluded from the sampling by design although they may have an increased rate of undiagnosed diabetes. Last, the cross-sectional nature of our study precludes the investigation of direction of causality in the observed associations.

In conclusion, our study is the first Hungarian population-based study that uses HbA1c and fasting glucose (reflecting current clinical practice and guideline recommendations) for the diagnosis of diabetes in Hungary. Overall, we report somewhat higher diabetes prevalence (12 %) and proportion of diagnosed diabetes (18–24 %) compared to previous estimates. In addition to age and BMI, the risk of diabetes showed a strong social gradient that should be considered in screening and prevention. We identified a subgroup (men in their forties) with an increased risk of being undiagnosed with diabetes. Screening programs should take efforts to improve the recruitment of these people. The finding that no association between being undiagnosed and employment status as well as level of education could be confirmed suggests that universal health care could provide equitable access to screening and diagnosis of diabetes.

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Author Contributions

Study design and conception: VFP, BAD, and AGT. Analysis and interpretation: all authors. Drafting of the article: VFP, BAD, and AGT. Critical revision for intellectual content: all authors. AGT had full access to all the data used in these analyses and takes full responsibility for the integrity of the data and the accuracy of the data analysis. The first version of the manuscript was drafted by VFP and BAD. All authors reviewed and accepted the submitted version of this manuscript.

Ethics approval

This is a post hoc analysis of data from the H-UNCOVER survey. H-UNCOVER was approved by the Committee of Science and Research Ethics of Medical Research Council (IRB IV/4060-3/2020/EKU).

Consent to participate

Written informed consent was obtained from each participant.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Vince Fazekas-Pongor: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Beatrix A. Domján:** Writing – original draft, Formal analysis, Conceptualization. **Dávid Major:** Writing – review & editing, Visualization, Formal analysis. **Anna Péterfi:** Writing – review & editing, Methodology, Formal analysis. **Viktor J. Horváth:** Writing – review & editing, Methodology, Formal analysis. **Szilvia Mészáros:** Writing – review & editing, Methodology, Formal analysis. **Zoltán Vokó:** Writing – review & editing, Resources, Methodology, Formal analysis. **Barna Vásárhelyi:** Writing – review & editing, Validation, Resources, Formal analysis. **Attila J Szabó:** Writing – review & editing, Methodology, Formal analysis. **Katalin Burián:** Writing – review & editing, Validation, Formal analysis. **Béla Merkely:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Adam G. Tabák:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.diabres.2024.111834.

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