

# BMJ Open Oral glucose tolerance testing as a complement to fasting plasma glucose in screening for type 2 diabetes: population-based cross-sectional analyses of 146 000 health examinations in Västerbotten, Sweden

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## ABSTRACT

**Objective** To assess the effect of adding an oral glucose tolerance test (OGTT) to fasting plasma glucose (FPG) in terms of detection of type 2 diabetes (T2D) and impaired glucose tolerance (IGT).

**Design** Retrospective analysis of serial cross-sectional screening study.

**Setting** Population-based health examinations within primary care in Västerbotten County, Sweden.

**Participants** Individuals aged 40–50 and 60 years with participation from 1985 to 2017. Those with previously diagnosed diabetes and FPG $\geq$ 7 mmol/L were excluded.

**Primary and secondary outcome measures** Prevalence of hyperglycaemia on the OGTT (IGT and T2D defined as 2-hour postload capillary plasma glucose of 8.9–12.1 mmol/L and  $\geq$ 12.2 mmol/L, respectively). Analyses were further stratified by age, sex and risk factor burden to identify groups at high or low risk of IGT and T2D on testing. The numbers needed to screen (NNS) to prevent one case of T2D through detection and treatment of IGT was estimated, combining prevalence numbers with average progression rates and intervention effects from previous meta-analyses.

**Results** The prevalence of IGT ranged from 0.9% (95% CI 0.7% to 1.1%) to 29.6% (95% CI 27.4% to 31.7%), and the prevalence of T2D ranged from 0.06% (95% CI 0.02% to 0.11%) to 7.0% (95% CI 5.9% to 8.3%), depending strongly on age, sex and risk factor burden.

The estimated NNS to prevent one case of T2D through detection and lifestyle treatment of IGT ranged from 1332 among 40-year-old men without risk factors, to 39 among 60-year-old women with all risk factors combined.

**Conclusions** The prevalence of hyperglycaemia on OGTT is highly dependent on age, sex and risk factor burden; OGTT should be applied selectively to high-risk groups to avoid unnecessary testing in the general population.

## INTRODUCTION

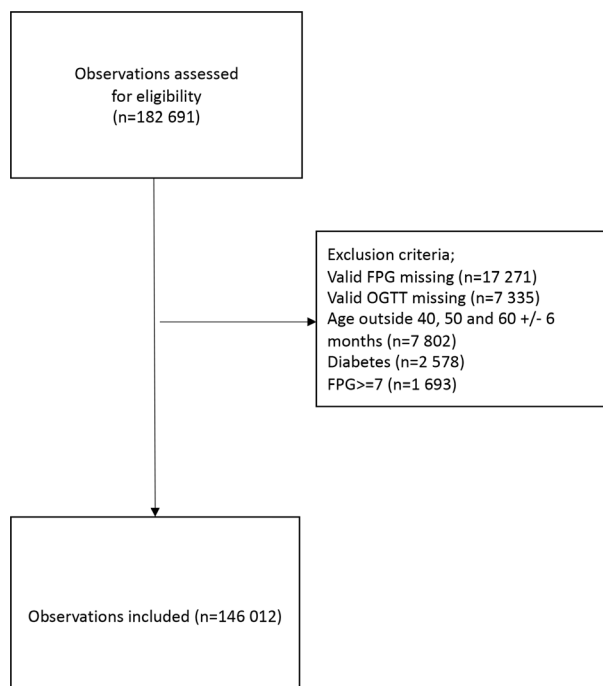
Elevated blood glucose is among the most important risk factors for premature death and disability worldwide, with an estimated global

## STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Population-based study in a primary healthcare setting, making results highly applicable to general population screening.
- ⇒ Large sample size (146 000 examinations), permitting stratified analyses with separate prevalence estimates for age, sex and risk factor subgroups.
- ⇒ Glycated haemoglobin, which is the third recommended screening method, was not routinely collected, and hence could not be included in the analysis.
- ⇒ The included population was predominantly white/Caucasian, limiting the generalisability to other ethnic groups.

prevalence of 400 million in 2014.<sup>1,2</sup> Impaired fasting glucose (IFG), impaired glucose tolerance (IGT) and elevated glycated haemoglobin (HbA1c), often referred to as pre-diabetes or non-diabetic hyperglycaemia have all been associated with increased risk of developing type 2 diabetes (T2D).<sup>3,4</sup>

Screening recommendations for T2D differ between organisations. Whereas the American Diabetes Association (ADA) recommends screening in all adults aged 45 years or older,<sup>5</sup> the US Preventive Services Task Force recently published a draft recommendation suggesting screening in asymptomatic adults with overweight or obesity aged 35–70 years.<sup>6</sup> Three screening tests are recommended; fasting plasma glucose (FPG), oral glucose tolerance test (OGTT) or HbA1c; none of which is recommended over the others.<sup>5,6</sup> Of note, FPG is the starting point for an OGTT, and thus, FPG levels may guide whether to proceed with glucose loading. In addition,



**Figure 1** STROBE flow chart for selection of participants. FPG, fasting plasma glucose; OGTT, oral glucose tolerance test; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

the OGTT is more expensive, time-consuming, and demanding for both healthcare and patients compared with FPG and HbA1c.

The Västerbotten Intervention Programme (VIP) is an ongoing health programme in Västerbotten County in Sweden, aiming to invite all inhabitants for a health examination, including an FPG and an OGTT, the year they turn 40, 50 and 60 years.<sup>7</sup> The aim of this study was to assess the added value of an OGTT over FPG for diabetes screening in the general middle-aged population. We estimated the prevalence of IGT and T2D in people without previous T2D and an FPG <7.0 mmol/L, that is, those that would proceed with an OGTT in clinical practice. Furthermore, we estimated the numbers needed to screen (NNS) to prevent one case of T2D through lifestyle interventions directed towards people with IGT.

## METHODS

### Design and setting

We used data from the VIP to create a series of population-based cross-sectional studies, on an annual basis from 1985 to 2017. Full details of the VIP have been reported previously.<sup>7</sup> Briefly, the VIP is an ongoing health care intervention, aiming to invite all residents of the Västerbotten County in northern Sweden aged 40, 50 or 60 years for a health examination at their local health centre, including FPG and OGTT for all non-diabetic participants. On invitation to the health examination, participants were informed that their health data are collected in a database that may be used for research purposes. They were

given the option to be removed from the database (opt-out procedure). Participants who donated blood for future research provided written informed consent. The VIP was launched in a pilot area in 1985 and was gradually introduced in other parts of Västerbotten until the entire region was engaged by the early 1990s. The overall rate of participation has ranged from 48% to 67%, without substantial differences in socioeconomic status between participants and non-participants.<sup>8</sup>

### Participants

Individuals who participated in the VIP between 1985 and 2017 were eligible for inclusion. Participants without valid FPG and OGTT recordings, age not equal to 40, 50 or 60±1 years at the time of the health examination, previously diagnosed diabetes and FPG ≥7 mmol/L were excluded (figure 1). The exclusion of people with previous diabetes or diabetic FPG levels mimics the clinical situation of diabetes screening with OGTT, because people with previous diabetes should not be screened and further glucose loading in people with diabetic FPG levels is not advisable. Of note, some participants were included in the analysis at several time points (age 40, 50 and 60 years). However, no individual appears twice in any estimation because age categories were separated throughout the analytical process.

### Glycaemic measures

After an overnight fast, participants in the VIP underwent FPG testing. Those without previous diabetes and an FPG <7.0 mmol/L were offered an OGTT, performed according to the WHO criteria, using a 75 g oral glucose load.<sup>9</sup> Glucose concentrations were measured on capillary plasma samples using Reflotron benchtop analyzers up until 2004, after which, Hemocue benchtop analysers were introduced (Quest Diagnostics). During the study period, analysers have been regularly tested in a calibration scheme provided by the External Quality Assurance in Laboratory Medicine in Sweden.

### Other variables

Data on previous diabetes and cardiovascular diseases, medications, physical activity, smoking and educational level were collected through questionnaires. Physical activity was categorised according to the Cambridge physical activity index<sup>10</sup> and educational level was classified as primary school, secondary school or university degree. Blood pressure was measured manually until approximately 2000, after which individual health centres gradually shifted to automated digital blood pressure measurement devices. Blood lipids were analysed using Reflotron benchtop analyser (Roche Diagnostics) until 2009, after which routine methods at the clinical chemistry department of the local hospital were used; methods have been validated against each other with comparable results. Body mass index (BMI) was calculated from height without shoes, rounded to the nearest centimetre and weight in light clothing, rounded to the nearest kilogram.

Data on ethnicity were not available, but the included population was predominantly white/Caucasian.

### Statistical analysis

Participants were categorised based on FPG and 2-hour postload capillary plasma glucose following OGTT according to WHO criteria; IFG was defined as FPG 6.1–6.9 mmol/L, IGT was defined as 2-hour postload capillary plasma glucose 2-hour plasma glucose following OGTT 8.9–12.1 mmol/L.<sup>11</sup> Those with 2-hour postload capillary plasma glucose  $\geq 12.2$  mmol/L were classified as having T2D based on a single measurement because signs or symptoms of diabetes or confirmatory measurements were not available in the VIP database.

To assess the added value of OGTT over FPG, we calculated the prevalence of hyperglycaemia at the OGTT (IGT and T2D) for each age and sex subgroup separately, using the Clopper-Pearson exact method to generate confidence intervals. Because it was not recommended to perform OGTT if FPG was  $\geq 7.0$  mmol/L in the VIP, and because the clinical usefulness of OGTT in this situation is questionable, participants with FPG  $\geq 7.0$  mmol/L were excluded from all analyses. Age and sex subgroups were further stratified according to the presence or absence of three main risk factors; overweight (BMI  $\geq 25$  kg/m<sup>2</sup>), systolic blood pressure  $\geq 130$  mm Hg and IFG. Apart from being associated with non-diabetic hyperglycaemia and T2D, we chose these risk factors as they can easily be assessed when a potential screenee enters the health-care facility and we wanted our results to be able to guide further testing based on an initial bedside evaluation. Cut-off values were chosen based on several factors; we wanted to include clinically established thresholds with reasonable power in all subgroups and fairly low diabetes prevalence in the no risk factor subgroups.

To calculate the NNS to prevent one case of T2D through lifestyle interventions directed towards screen-detected IGT, we used the prevalence of IGT multiplied by the estimated progression rate from IGT to T2D from a recent systematic review (45.5 per 1000 person-years),<sup>12</sup> and the average effect of lifestyle interventions (36% relative risk reduction).<sup>13</sup> NNS were calculated per 3 years as that was the median duration of the intervention studies in the referred systematic review.

All analyses were performed using R statistical software V.4.0.3 (R Core Team).

### Patient and public involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

### RESULTS

Out of 182 691 observations in the VIP dataset, 146 012 fulfilled the inclusion criteria (figure 1). A total of 75 815 (52%) of the included observations were in women; 48 828 (33%) were 40 years old, 51 292 (35%) were 50

years old and 45 892 (31%) were 60 years old. Among the included observations, 81 252 (56%) were in overweight or obese people, 58 957 (41%) had a systolic blood pressure higher than 130 mm Hg and 18 749 (13%) had IFG (table 1).

The prevalence of IGT was substantially modified by the presence of other risk factors, spanning from below 1% in 40-year-old males without risk factors to almost 30% in overweight or obese 60 years old with IFG and systolic blood pressure  $\geq 130$  mm Hg (table 2). For each age and sex category, the prevalence of IGT was about 10-fold higher among those with all three risk factors compared with those without any of the included risk factors.

For T2D, risk modification was even more pronounced, with prevalence estimates around 0.1% for 40-year-olds and 50-year-olds without risk factors, compared with estimates of 5%–7% in overweight or obese 60-year-olds with IFG and systolic blood pressure  $\geq 130$  mm Hg. For each age and sex category, the prevalence of T2D was about 20-fold to 30-fold higher in those with all three risk factors compared with those without any of the included risk factors.

In 40- and 50-year-olds with less than three risk factors (approximately 98% of 40 years and 95% of 50 years), the prevalence of T2D was lower than 1%. (table 2). In 60-year-olds, the prevalence of T2D was lower than 1% in people with less than two risk factors, placing about half of participants in the low-risk category.

### NNS to prevent T2D

The NNS to prevent one case of diabetes through detection and lifestyle interventions directed towards IGT are presented in table 3. Among 40-year-old males with normal FPG, BMI and blood pressure, more than 1000 individuals would need to be screened with OGTT to prevent one case of T2D during 3 years of follow-up, whereas in overweight or obese 60-year-old women with IFG and systolic blood pressure  $\geq 130$  mm Hg, the NNS was 39.

Among 40 and 50 years, the NNS were higher than 100 unless all three risk factors were present. In 60 years, the NNS were higher than 100, except for men with all three risk factors and women with at least two risk factors. In total, 128 707 out of 144 760 individuals (89%) appeared in a group where the NNS to prevent T2D through screening and lifestyle intervention was higher than 100.

### DISCUSSION

In this population-based cross-sectional study, including 146 000 health examinations of non-diabetic individuals, we found that the added value of OGTT over FPG for diabetes screening is highly dependent on age, sex, FPG, systolic blood pressure and BMI. Among 40-year-olds with normal FPG, systolic blood pressure  $< 130$  mm Hg, and a BMI  $< 25$ , the prevalence of IGT was about 1% and the prevalence of T2D was less than 0.1%. The corresponding numbers in 60-year-olds with all three risk factors were

**Table 1** Characteristics of the study population

	40 years	50 years	60 years
Participants, No	48 828	51 292	45 892
Female, No (%)	25 115 (51)	26 621 (52)	24 079 (52)
Height, mean (SD), cm	173 (9.5)	172 (9.3)	170 (9.1)
Weight, mean (SD), kg	77 (16)	78 (15)	77 (9.3)
BMI, mean (SD)	25.7 (4.4)	26.2 (4.2)	26.5 (4.1)
BMI>25, No (%)	24 168 (43)	28 980 (57)	28 104 (61)
Impaired fasting glucose *, No (%)	4 143 (8.5)	6 608 (13)	7 998 (17)
Blood pressure, mean (SD), mm Hg			
Systolic	120 (13.7)	126 (16.3)	134 (18.1)
Diastolic	76 (10.1)	80 (10.7)	82 (10.2)
Systolic blood pressure >130mm Hg, No (%)	11 221 (23)	20 537 (40.2)	27 199 (60)
Hypertension diagnosis, No (%)	6 784 (14)	12 138 (24)	16 585 (36)
Treatment for hypertension, No (%)	1 508 (3.1)	5 948 (12)	11 839 (26)
Total cholesterol, mean (SD), mmol/L	5.2 (1.0)	5.6 (1.1)	5.9 (1.2)
HDL-C, mean (SD), mmol/L	1.4 (0.7)	1.4 (0.8)	1.5 (0.8)
LDL-C, mean (SD), mmol/L	3.2 (1.0)	3.6 (1.0)	3.8 (1.0)
Triglycerides, mean (SD), mmol/L	1.3 (0.8)	1.4 (0.9)	1.4 (0.8)
Treatment for hyperlipidemia, No (%)	198 (0.4)	1 209 (2.4)	3 815 (8.3)
Previous myocardial infarction, No (%)	59 (0.1)	299 (0.6)	1 220 (2.7)
Physical activity (Cambridge-index), No (%)			
Inactive	6 985 (14)	7 264 (14)	6 537 (14)
Moderately inactive	12 384 (25)	14 476 (28)	14 511 (30)
Moderately active	13 681 (28)	13 947 (27)	12 581 (26)
Active	13 668 (28)	12 610 (25)	9 611 (20)
Data on physical activity missing	2 130 (4.3)	2 995 (5.8)	4 980 (11)
Smoking, No (%)			
Smoker	7 890 (16)	9 819 (19)	7 596 (17)
Ex-smoker	12 032 (25)	16 052 (31)	17 194 (38)
Non-smoker	28 381 (58)	24 802 (48)	20 372 (44)
Data on smoking missing	525 (1.1)	619 (1.2)	730 (1.6)
Education, No (%)			
Primary school or less	7 760 (16)	17 696 (35)	25 769 (56)
Secondary school	23 074 (47)	17 366 (34)	8 627 (19)
University degree	17 746 (36)	15 907 (31)	11 167 (24)
Data on education missing	248 (0.5)	323 (0.6)	329 (0.7)

\*Defined as fasting plasma glucose 6.1–6.9 mmol/L.  
 BMI, body mass index; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.; .

almost 30% for IGT and 5% to 7% for T2D. The massive difference between groups highlights the need to consider age, sex and risk factors when deciding whom to screen for diabetes using the OGTT. Importantly, when age, sex and other risk factors were used to stratify participants, 9 out of 10 people appeared in groups with less than 1% risk of screening-detected T2D, and an estimated NNS to prevent one case of T2D through screening and lifestyle interventions higher than 100, making further testing with OGTT highly questionable.

### Comparison with previous studies

The prevalence of screening-detected IGT and T2D varied considerably across subgroups in our study, but was generally lower compared with prevalence estimates from previous population-based studies.<sup>14 15</sup> This is not surprising as we excluded participants who had known diabetes, as well as those with a FPG level of 7.0 mmol/L or higher. Hence, the prevalence estimates in our study reflects the prevalence of previously undiagnosed T2D



**Table 2** Prevalence of IGT and T2D in people without previous diagnosis of diabetes and an FPG <7.0 mmol/L, stratified by age, sex and number of risk factors

		Women			Men		
			IGT	T2D*		IGT	T2D*
Age	No. risk factors†	n (%)	Prevalence, % (95% CI‡)	Prevalence, % (95% CI‡)	n (%)	Prevalence, % (95% CI‡)	Prevalence, % (95% CI‡)
40 years	0	12 547 (50.4)	1.80 (1.58 to 2.05)	0.06 (0.02 to 0.11)	6745 (28.6)	0.86 (0.65 to 1.11)	0.09 (0.03 to 0.19)
	1	9029 (36.3)	3.51 (3.14 to 3.91)	0.27 (0.17 to 0.40)	10 427 (44.3)	1.93 (1.67 to 2.21)	0.08 (0.03 to 0.15)
	2	2952 (11.9)	9.35 (8.23 to 10.4)	0.47 (0.26 to 0.79)	5735 (24.3)	3.63 (3.16 to 4.14)	0.35 (0.21 to 0.54)
	3	346 (1.39)	19.9 (15.9 to 24.6)	2.60 (1.20 to 4.88)	648 (2.75)	11.9 (9.49 to 14.6)	1.70 (0.85 to 3.02)
50 years	0	9082 (34.5)	2.69 (2.36 to 3.04)	0.11 (0.05 to 0.20)	4991 (20.4)	1.52 (1.20 to 1.90)	0.14 (0.06 to 0.29)
	1	10 216 (38.8)	4.86 (4.45 to 5.29)	0.27 (0.18 to 0.40)	9567 (39.0)	3.19 (2.85 to 3.96)	0.33 (0.23 to 0.47)
	2	5987 (22.7)	10.1 (9.39 to 10.9)	0.68 (0.49 to 0.93)	8373 (34.2)	6.25 (5.74 to 6.79)	0.74 (0.57 to 0.96)
	3	1054 (4.00)	24.1 (21.5 to 26.8)	3.80 (2.72 to 5.13)	1559 (6.37)	18.5 (16.6 to 20.6)	4.04 (3.12 to 5.14)
60 years	0	4834 (20.3)	5.25 (4.64 to 5.92)	0.37 (0.22 to 0.59)	2980 (13.8)	3.76 (3.10 to 4.50)	0.30 (0.14 to 0.57)
	1	8943 (37.5)	8.59 (8.01 to 9.19)	0.73 (0.56 to 0.93)	7169 (33.1)	6.29 (5.74 to 6.88)	0.78 (0.59 to 1.01)
	2	8312 (34.8)	14.6 (13.9 to 15.4)	1.80 (1.53 to 2.11)	9130 (42.2)	11.1 (10.4 to 11.7)	1.24 (1.02 to 1.49)
	3	1770 (7.42)	29.6 (27.4 to 31.7)	7.01 (5.86 to 8.30)	2364 (10.9)	24.6 (22.9 to 26.4)	5.20 (4.34 to 6.18)

\*Defined as 2-hour plasma glucose >12.1 mmol/L.

†Presence or absence of systolic blood pressure >130 mm Hg, BMI >25 kg/m<sup>2</sup> and/or fasting plasma glucose 6.1–6.9 mmol/L.

‡Clopper-Pearson CI.

.FPG, fasting plasma glucose; IGT, Impaired glucose tolerance; T2D, type 2 diabetes.

detected through OGTT, rather than the prevalence of T2D in the general population.

The effects of population-based screening for T2D have been tested in the cluster-randomised screening and intervention study ADDITION-Cambridge.<sup>16–18</sup> Participating centres were randomised to screening or no screening, after which screening centres were further assigned to standard or intensive management. During 10 years of follow-up, there was no significant difference in cardiovascular events or death between groups.<sup>16 18</sup> In the UK Prospective Diabetes Study, intensive therapy in newly diagnosed patients with T2D reduced the risk of total mortality, indicating that early detection and treatment may be beneficial.<sup>19</sup> Of note, only 3% of screened individuals had T2D in the ADDITION-Cambridge trial, likely diluting the potential benefit among patients with newly detected T2D on a population level.<sup>16</sup> Our findings show that more than 90% of middle-aged individuals are at low risk of OGTT-detected T2D, suggesting that age, sex, systolic blood pressure, and BMI may be useful to select screenees more efficiently.

The selection of risk factors used to stratify participants in this study was based on both predictive performance and clinical feasibility. Indisputably, several additional risk factors for non-diabetic hyperglycaemia and T2D have been identified and numerous risk prediction models exist.<sup>20</sup> The uptake of such models in clinical practice is poor, however, partly due to difficulties with implementation.<sup>21</sup> We chose to stratify our analyses based on three well-known and easily assessed risk factors to maximise the clinical applicability of our findings. For example, using waist circumference to identify participants with abdominal obesity could have increased the predictive ability further compared with BMI, but may be harder to measure in a standardised fashion.<sup>22</sup> Furthermore, patients are more likely to know their height and weight than their waist circumference, making BMI more feasible than waist circumference in a clinical setting. The use of FPG for selection whom to assess with OGTT may seem impractical since it includes blood sampling. Indeed, several risk scores for diabetes offers completely non-invasive alternatives.<sup>23 24</sup> However, we wanted to



**Table 3** Numbers needed to screen (NNS) to prevent one case of T2D through detection and lifestyle intervention against IGT

	No of risk factors*	NNS† Women	NNS† Men
40 years	0	636	1332
	1	326	593
	2	123	341
	3	58	97
50 years	0	426	753
	1	236	359
	2	113	184
	3	48	62
60 years	0	219	304
	1	133	182
	2	79	104
	3	39	47

\*Presence or absence of systolic blood pressure >130 mm Hg, BMI >25 kg/m<sup>2</sup> and fasting plasma glucose 6.1–6.9 mmol/L.

†Calculated from the prevalence of IGT and its confidence intervals, multiplied by the average progression rate from IGT to diabetes (45.5/1000 person-years), the average relative risk for diabetes with lifestyle interventions in IGT (RR=0.64), for 3 years follow-up.

BMI, body mass index; IGT, impaired glucose tolerance; RR, Relative Risk; T2D, type 2 diabetes.

assess the added value of proceeding with glucose loading when FPG results are available, as FPG has a central role in diabetes screening and the overlap between IFG and IGT is limited.<sup>13 25</sup> Additionally, subsequent OGTT is a common consequence of IFG in clinical practice, as well as in previous studies,<sup>18</sup> even if HbA1c analysis is increasingly used in T2D diagnostics.

### Clinical implications

Our findings suggest that the OGTT may not be appropriate for diabetes screening in the middle-aged general population, as currently recommended by the ADA.<sup>5</sup> Although the overlap between FPG-detected and OGTT-detected diabetes is not complete, the OGTT is more resource-demanding and offers little added value in terms of diabetes detection, according to our results.

One common argument for using OGTT is that lifestyle interventions can prevent the development of T2D in individuals with IGT.<sup>26–31</sup> However, the effects of screening for, and intervening against, IGT have been questioned.<sup>13</sup> Randomised controlled trials of lifestyle interventions in IGT have only included about one-third of individuals with IGT in the population,<sup>13</sup> and the long-term adherence to lifestyle changes is poor.<sup>32</sup> Our results suggest that the NNS to prevent one case of T2D through lifestyle interventions directed towards screening-detected IGT is several hundred for the vast majority of 40- and 50-year-olds. Importantly, the NNS may be even higher in a real-world setting since the

intervention effect is likely to be lower in clinical practice compared with clinical trials.<sup>13</sup>

Individuals with T2D have an increased risk of cardiovascular disease compared with non-diabetic individuals.<sup>33</sup> Recent data suggest that patients with screening-detected T2D have substantially lower risk for cardiovascular events compared with patients diagnosed with T2D through symptomatic testing.<sup>34</sup> Thus, since screening detects low-risk individuals, the potential benefit in terms of preventing cardiovascular disease is diluted in this specific group of patients compared with estimates derived from patients with clinically detected T2D.

### Limitations

This study is a retrospective assessment of the results from FPG and OGTT screening as part of a larger health intervention. Although the prevalence of IGT and T2D differed substantially between subgroups, suggesting that risk factor-guided screening may be more efficient compared with general screening, different strategies should ideally be compared prospectively. Screening as part of a comprehensive health assessment may also affect participation rates. In the VIP, around 60% of the target population participated during the study period, as compared with almost 80% in a population-based screening programme for abdominal aortic aneurysms.<sup>35</sup> Whether non-attendees differ compared with those attending the VIP with respect to metabolic risk factors is unknown, although previous analyses suggest socio-economic factors are fairly similar between groups.<sup>8</sup> The OGTT in our study was offered to all non-diabetic participants with an FPG level <7.0 mmol/L, without any lower limit. Excluding participants with very low FPG values may have improved the value of the OGTT slightly. In the broader perspective of diabetes screening, our study is limited by the lack of HbA1c, the third pillar in diabetes screening recommended by the ADA.<sup>5</sup> However, this does not influence the relationship between FPG screening and OGTT screening. HbA1c is an alternative screening tool and further evaluation of its diagnostic performance in relation to FPG and OGTT is warranted. Additionally, the VIP database does not include confirmatory tests for those with elevated blood glucose levels. Thus, this study may overestimate the prevalence of T2D detected through the OGTT. Also, most individuals of our study were Caucasian and therefore the generalizability of our results to other ethnic groups may be limited. In a recent screening study in Pakistan, the prevalence on pre-diabetes and T2D (based in HbA1c) was 11% and 17% respectively.<sup>36</sup> Thus, the prevalence of hyperglycaemia was much higher than in our Caucasian population, and contrary to our data, there was a higher proportion of T2D than non-diabetic hyperglycaemia. Lastly, our population-based data includes few cases with cardiovascular disease and, therefore, our findings should not be generalised to this disease group. Previous studies have shown that in patients with coronary heart disease, an OGTT will diagnose more individuals with non-diabetic hyperglycaemia and diabetes compared with FPG or HbA1c.<sup>37 38</sup>

## CONCLUSIONS

In the middle-aged general population, the likelihood to detect IGT or T2D through an OGTT is highly dependent on age, sex, FPG, BMI and systolic blood pressure. Using these variables for risk stratification, 9 out of 10 individuals appeared in groups at low risk of T2D, and with high NNS to prevent T2D though detection and intervention directed towards IGT. Our findings warrant reconsideration of current guidelines for diabetes screening to avoid time consuming and costly testing in low-risk individuals.

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**Contributors** AR and MB conceived the idea, designed the study, acquired the data and drafted the article. AR and SV performed the statistical analyses. AR, JO, AS, SV, PW and MB participated in the planning and interpretation of data, revised the manuscript for important intellectual content and approved of the final version. MB is the guarantor.

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**Competing interests** None declared.

**Patient and public involvement** Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

**Patient consent for publication** Not applicable.

**Ethics approval** This study was approved by the Swedish Ethical Review Authority in October 2020, ID number 2020-04149. Participants gave informed consent to participate in the study before taking part.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data may be obtained from a third party and are not publicly available. The datasets analysed during the current study are not publicly available due to Swedish law. For questions regarding data sharing, contact the corresponding author.

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