Master's Thesis of Medicine

Determinants of prediabetes reversion to normoglycemia: modifiable factors and changes in obesity

당뇨병 전단계 성인의 정상 혈당 회복을 위한 요인 탐색: 교정 가능한 요인 및 비만의 변화

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Abstract

Background

Prediabetes glycemic status prevalence is increasing worldwide. This stage of hyperglycemia is crucial as it puts people at high risk of developing type 2 diabetes and other diseases, but still potentially reversible to normoglycemia. Therefore, it is necessary to know which factor can contribute to its reversion to normoglycemia and which factor can be the risk of progression to type 2 diabetes.

Methods

Study 1

This study included 10,358 participants with prediabetes glycemic status from a previous study called Health Examinees-Gem (HEXA-G) study. Modifiable factors, including body mass index, abdominal obesity, smoking status, physical activity, alcohol consumption, diet quality, hypertension, and dyslipidemia, were assessed to determine their associations with changes in glycemic status to normoglycemia or type 2 diabetes at follow-up. Additionally, modifiable factor scores were calculated, and their association with changes in glycemic status was also analyzed. The association between considered modifiable factors and modifiable factors score was evaluated by obtaining odds ratio (OR) using multinomial logistic regression with 95% confidence interval (CI).

Study 2

This study used a nested case-control design by including 31,104 frequently

matched participants from the NHIS-HEALS cohort databases who had prediabetes glycemic status based on their fasting plasma glucose level and participated in two or more repeated measurements of body mass index (BMI) and waist circumference (WC) in a span of six measurement points. We assessed the changes in obesity status, both general obesity (body mass index of ≥25 kg/m^2) and abdominal obesity (waist circumference of ≥90 cm for men and ≥85 cm for women), from baseline measurement to the measurement time before outcome and set them as the exposure. Additionally, we analyzed the trajectory of obesity status during the follow-up period using the latent class trajectory modeling. The association between changes in obesity status as well as the obesity trajectories and changes in glycemic status to normoglycemia or diabetes was examined using multinomial logistic regression to obtain OR with 95% CI.

Results

Study 1

After a median follow-up of four years (ranging from one to seven years), 31.8% of participants had reversion to normoglycemia and 8.1% had progression to diabetes. BMI ≥25 kg/m^2 (adjusted OR 0.71 [95% CI 0.63–0.79]), abdominal obesity (0.76 [0.68–0.86]), heavy drinking (0.74 [0.60–0.91]), hypertension (0.71 [0.64–0.79]), and dyslipidemia (0.78 [0.70–0.85]) were found to decrease the odds of reversion to normoglycemia. BMI ≥25 kg/m^2 (1.58 [1.29–1.94]), abdominal obesity (1.31 [1.11–1.55]), current smoking (1.43 [1.07–1.91]), and hypertension (1.26 [1.07–1.49]) were observed to increase the odds of progression to diabetes. Furthermore, having more favorable modifiable factors was also associated with reversion to normoglycemia (1.46 [1.30–1.64]) and progression to type 2 diabetes

(0.62 [0.49–0.77]).

Study 2

In the evaluation of general obesity, compared with the ‘stable obese’ group, ‘obese to non-obese’ (OR 1.22 [1.04–1.43]) and ‘stable non-obese’ (OR 1.17 [1.08–1.26]) had greater odds of normoglycemia reversion. Furthermore, ‘stable non-obese’ group (OR 0.69 [0.64–0.75]) and ‘non-obese to obese’ group (OR 0.73 [0.63–0.84]) were less likely to have diabetes progression compared with ‘stable obese’ group. In the evaluation of changes in abdominal obesity, ‘obese to non-obese’ and ‘stable non-obese’ group had higher odds of reversion to normoglycemia (OR 1.22 [1.06–1.41] and 1.71 [1.06–1.30] respectively) as well as lower odds of progression to diabetes (OR 0.82 [0.71–0.94] and 0.65 [0.59–0.71]) compared with ‘stable obese’ group. Two to four latent classes were ascertained for the trajectory of general and abdominal obesity status in each follow-up time group. In all groups, ‘stable non-obese’ trajectory was more likely to have reversion to normoglycemia reversion and less likely to have progression to diabetes compared with ‘stable obese’ trajectory.

Conclusion

Some modifiable factors were found to be associated with changes in glycemic status from prediabetes. Moreover, people who have more favorable modifiable were more likely to return to normoglycemia and less likely to progress to diabetes. Furthermore, non-obese participants who maintained their normal BMI and WC were more likely to have reversion to normoglycemia and less likely to have progression to diabetes. Additionally, changing to non-obese from obese may

prevent the development of type 2 diabetes from prediabetes. Therefore, it is recommended for individuals with prediabetes to manage their BMI, WC, blood pressure, and lipid profile, as well as pay attention to their habit of consuming alcohol and smoking.

Keywords

Prediabetes, normoglycemia, diabetes, glycemic status change, modifiable factors, general obesity, abdominal obesity.

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List of Abbreviations

ADA, American Diabetes Association

BMI, body mass index

CI, confidence interval

DQI-K, Diet Quality Index for Koreans

FPG, fasting plasma glucose

HbA1c, hemoglobin A1c

HDL-C, high density lipoprotein cholesterol

HEXA-G, Health Examinees-Gem

IFG, impaired fasting glucose

KoGES_HEXA, Health Examinees of the Korean Genome and Epidemiology

LDL-C, low density lipoprotein cholesterol

OGTT, oral glucose tolerance test

OR, odds ratio

WC, waist circumference

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1. Introduction

1.1 Study Background

1.1.1 Hyperglycemia Problem: Diabetes and Prediabetes

Referring to the definition from American Diabetes Association (ADA), glycemic level is considered in the normal range or normoglycemia if the fasting plasma glucose (FPG) is less than 100 mg/dl, or hemoglobin A1c (HbA1c) is less than 5.7%, or oral glucose tolerance test (OGTT) is less than 140 mg/dl, depending on the kind of test used (1). People with glycemic levels above any of those ranges are considered to have elevated blood glucose or hyperglycemia. FPG between 100-125 mg/dl (also called impaired fasting glucose or IFG), or HbA1c between 5.7-6.4%, or OGTT between 140-199 mg/dl (also called impaired glucose tolerance or IGT) is considered as prediabetes stage; and over any of these ranges is diabetes stage (1). Other than ADA, some other organizations also provide criteria for glycemic status, including the World Health Organization (WHO), and International Excellence Committee, National Institute for Health and Clinical Excellence.

Diabetes, particularly type 2 diabetes, is one of the well-known public health problems which now has affected more than a half million people in the world, according to recent data from the International Diabetes Federation (IDF) (2). The number is predicted to keep increasing in the future, possibly reaching 783 million people by the year 2045 (2). Not only hyperglycemia at the diabetes level, but the problem of high blood glucose at the prediabetes level has also become a concern as the prevalence keeps increasing globally, although the estimated

number is differed according to the criteria used, the type of test, and the region (3). According to the report by IDF, 10.6% and 6.2% of the worldwide population currently have IGT and IFG respectively, and these numbers are projected to increase to 11.4% and 6.9% in 2045 (2).

Other than the matter of its prevalence, the effect of putting people with this condition at higher risk of developing subsequent diseases has also accentuated the prediabetes problem. Compared to people with normoglycemia, people with prediabetes glycemic status are more likely to have type 2 diabetes and other health problems, such as cardiovascular disease, cancer, and even mortality (1, 4-8)

1.1.2 Changes in Prediabetes Glycemic Status

Glycemic status is likely to change over time. People with prediabetes were reported to have a higher risk to develop type 2 diabetes compared with those with normoglycemia (4) However, arguably, the prediabetes condition is still potentially reversible to normoglycemia (9). Depending on the glycemic status definition, the number of people with prediabetes who had a reversion to normoglycemia and progression to type 2 diabetes varies. Nevertheless, in a study by Lazo-Porras M *et al.*, according to any definition of glycemic status, the proportion of participants who had prediabetes reversion was larger compared to participants with type 2 diabetes progression (10).

Having diabetes are likely to rise other health problems, and thus remaining in prediabetes stage is probably desirable (9,11). However, compared to constantly having prediabetes, having the blood glucose returned to normoglycemia was found to be advantageous as it reduced the risk of cardiovascular and microvascular disease, as well as mortality according to the

previous reports (9,11-15). Therefore, examining the prediabetes reversion to normoglycemia may be one of the keys to preventing chronic disease occurrence. Moreover, the prognosis of individuals with prediabetes worsened over time, showing that the cumulative incidence of type 2 diabetes increased and the regression to normoglycemia decreased over time (16). Thus making the exploration of factors that affect glycemic status changes important .

1.1.3 Modifiable Factors and Changes in Prediabetes Glycemic Status

According to The Korean Clinical Practice Guidelines for Diabetes, people with prediabetes can control their body weight by adjusting their diet and physical activity. Other suggestions such as avoiding alcohol consumption as well as managing hypertension and dyslipidemia were also made with a purpose to control blood glucose levels (17). The WHO mentioned that the risk of non-communicable diseases, including diabetes, may be increased by tobacco use, inadequate physical activity, inappropriate diet, alcohol consumption, being overweight or obese, and having hyperlipidemia (18). Furthermore, according to the ADA, some lifestyle factors may also contribute to the prevention of type 2 diabetes, including nutrition intake, physical activity, and weight control (9).

To prevent prediabetes from progressing to type 2 diabetes, many previous observational studies have explored the factors that can be the risk of the progression, including lifestyle or modifiable factors. Reports from some of the studies suggested that having high body mass index (BMI), high waist circumference (WC), high triglyceride, less engagement in physical activity, and smoking were likely to increase the risk of type 2 diabetes progression from prediabetes (10,19-21). Combined healthy behaviors by scoring analyses have also

been reported, showing that higher adherence to a healthy lifestyle was associated with a lower risk of diabetes progression from prediabetes (22).

Although knowing the modifiable factors that can contribute to reversion to normoglycemia may be as equally important, the number of population-based observational studies regarding this topic is not evenly reported. Some studies were conducted and reported that having higher BMI and WC, insufficient physical activity, high blood pressure, and high triglyceride were associated with lower probability of reversion to normoglycemia from prediabetes (19-21,23-25). However, other modifiable factors have not been explored regarding their effect on prediabetes regression to normoglycemia. For example, the roles of the amount of cigarettes smoked, the amount of ethanol intake from alcoholic drinks, as well as the score of lifestyle or modifiable factors. Moreover, studies that evaluated changes in modifiable factors to see their association with changes in prediabetes glycemic status are still limited.

1.1.4 Studies of Body Mass Index and Waist Circumference Trajectory

BMI and WC fluctuate from time to time, thus making it necessary to see their trajectory or changes in between several time points instead of just two-time points. Calculating the changes in BMI and WC can be done conventionally by comparing the measurement at a certain time point and the initial measurement. But in recent years, trajectory modeling technique to obtain latent information from longitudinal data has gained a lot of interest. This method allows the classification of individuals into groups (distinct trajectories) based on their similar characteristics (26).

A lot of studies have explored trajectories of BMI and WC in certain age

periods or throughout the lifetime and health outcomes, including the risk of type 2 diabetes with a various number of trajectories found, which suggested that trajectories of BMI and WC may be the predictors of type 2 diabetes progression (27,28). Regardless of the number of studies investigating BMI and WC trajectories' roles on health outcomes, no study has been conducted to see their associations with changes in prediabetes glycemic status. Moreover, most studies evaluated the trajectory of BMI and WC in continuous variables.

1.1.5 Limitation of Previous Studies

While the evidence from population-based studies regarding the roles of modifiable risk factors in prediabetes progression to diabetes has been widely established, their impact on prediabetes reversion to normoglycemia has not been equally explored. For example, no study has observed the associations between smoking pack-year, level of alcohol intake by considering the type of alcohol and amount of ethanol, overall diet quality, and modifiable factors or lifestyle factors score with normoglycemia reversion from prediabetes. Therefore, a study that explored the associations between these factors and prediabetes reversion to normoglycemia is warranted. Moreover, most of the previous studies that observed normoglycemia reversion included relatively small sample sizes which may have reduced their statistical power.

Referring to the explanation from The Korean Clinical Practice Guidelines for Diabetes (17), WHO (18), and ADA (9) regarding the management of blood glucose to prevent the development of type 2 diabetes, we selected several relevant factors that are available in our data source for this study. It included obesity, smoking status, physical activity, alcohol consumption, diet quality,

hypertension, and dyslipidemia. We refer to these factors using the term ‘modifiable factors.’

Not only the baseline condition of obesity status, but changes in it may also affect a health condition. However, there was only a few studies that have evaluated the association of changes in obesity status with changes in prediabetes glycemic status. Particularly in the present study, we found obesity as a strong predictor of prediabetes change to normoglycemia and diabetes in the first study. Therefore, in the second study, we would like to expand the evaluation of this variable, not only an obesity status from a one-time assessment but also the change of this status. Furthermore, current evidence exploring the trajectory of BMI and WC among individuals with prediabetes and their roles in glycemic status changes is still limited. A previous study analyzed longitudinal changes in BMI and WC among people with prediabetes but did not necessarily evaluate their association with prediabetes changes (29). Given the roles of BMI and WC trajectory on explaining other health outcomes, it may be important to observe their trajectories among individuals with prediabetes and see if they are associated with the changes in glycemic status.

1.2 Purpose of Study

The general purpose of this study was to examine the factors that can contribute to the changes in prediabetes glycemic status, including reversion to normoglycemia and progression to type 2 diabetes progression. The specific purposes of this study consisted of two points and are described as follows.

1. To evaluate the associations between modifiable factors and prediabetes

reversion to normoglycemia, as well as progression to type 2 diabetes. The modifiable factors included in the present study were obesity, smoking habit, physical activity, alcohol consumption, diet quality, hypertension, and dyslipidemia.

2. To observe changes in general and abdominal obesity as well as the trajectory of general and abdominal obesity over time among individuals with prediabetes and see their associations with changes from prediabetes to normoglycemia and type 2 diabetes.

2. Methods and Results

2.1 Modifiable Factors and Changes in Prediabetes Glycemic Status

This is an accepted manuscript of an article with the title of "Associations Between Modifiable Risk Factors and Changes in Glycemic Status Among Individuals With Prediabetes" by Nabila S, Kim JE, Choi J, Park J, Shin A, Lee SA, Lee JK, Kang D, and Choi JY, published by Diabetes Care on 2023. DOI: 10.2337/dc22-1042. PMID: 36625739.

2.1.1 Methods

Source Population

The study used data from participants of a prior cohort study named Health Examinees-Gem (HEXA-G) that was derived from the Health Examinees of the Korean Genome and Epidemiology (KoGES_HEXA). Briefly, KoGES_HEXA is a population-based study among Korean population aged 40-69 years about epidemiological characteristics, genomic features, and gene-environment interactions that were assessed by interview-based survey and biological sample collection at 38 health examination centers and hospitals. There were two phases of baseline assessment: Phase I was conducted between 2004-2008 and Phase II was conducted between 2009-2013 with a total of 167,169 participants from both phases. Among them, 65,642 had been followed up between 2012-2016.

From KoGES_HEXA study, HEXA-G was derived by excluding centers for pilot study, centers with different methods of data collection, and centers that participated for less than two years. Out of all the baseline participants of KoGES_HEXA, 139,344 were included as HEXA-G participants, and among them,

64,485 were those who had participated in the follow-up survey. Further information on the studies is described in prior articles (30-32).

Study Population

This study included participants who had completed the follow-up survey. Furthermore, to maintain the consistency of the collected data, the present study only included participants who were recruited from Phase II of HEXA-G study. Thus, 26,195 people with follow-up data from Phase I were excluded. Furthermore, individuals with missing information on FPG and HbA1c at baseline (n = 6 and 10,253) and missing information on FPG and HbA1c at follow-up (n = 2 and 9) were also excluded, remaining 27,041 participants. Following the definition by ADA and according to their FPG and HbA1c levels, those participants were grouped into normoglycemia, prediabetes, and diabetes. Then, individuals with normoglycemia (n = 13,762) and diabetes (n = 2,439) were excluded. Another exclusion was made for participants who reported a history of diabetes (n = 482). Finally, 10,358 individuals with prediabetes glycemic status remained for the analysis. The flowchart of participant selection is shown in Figure 1.

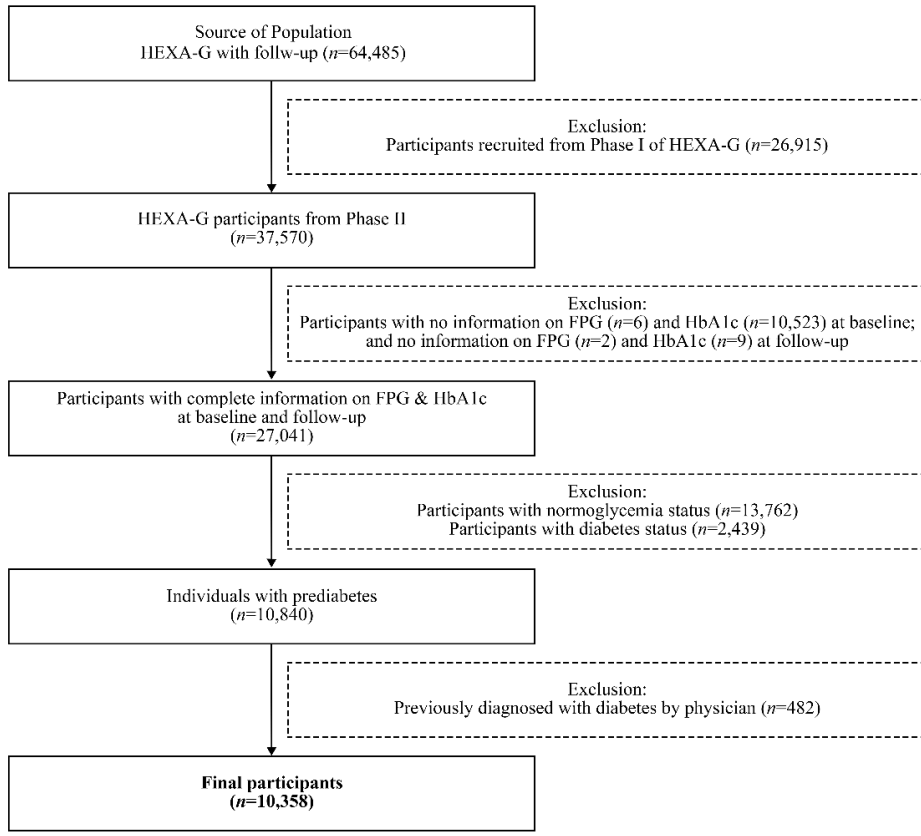


Figure 1. Flowchart of participant selection (adopted from Nabila *et al.*, Diabetes Care. 2023)

Because there was a large number of participants were excluded from the original study, we evaluated the characteristics of excluded and included participants. Based on the evaluation of the standardized differences, we did not find any substantial imbalance among the groups. The result of the evaluation is presented in Appendix 1 to Appendix 3.

This study was approved by the Institutional Review Board (IRB) of Seoul National University (IRB No. E-2111-024-1269). All the procedures were performed in accordance with the relevant guidelines and regulations. Informed consent was collected from all of the participants before they were involved in HEXA_KoGes.

Ascertainment of Prediabetes

The participants included in this study were those who had prediabetes glycemic status at baseline, defined by their FPG and HbA1c levels according to the ADA criteria (1) and based on their history of diabetes diagnosis. They were considered to have prediabetes if their FPG level was between 100-125 mg/dl, HbA1c was between 5.7-6.4%, or both (1). Furthermore, despite their FPG and HbA1c levels, participants were not included if they reported a history of diabetes at baseline.

Ascertainment of Outcomes

The outcomes of this study were reversion to normoglycemia and diabetes progression, according to their glycemic status at follow-up. Participants were considered to have reversion to normoglycemia if in the follow-up data, they had a normal range of both FPG (<100 mg/dl) and HbA1c (<5.7%). If there was a

presence of either or both IFG (FPG between 100-125 mg/dl) and elevated HbA1c (between 5.7-6.4%), participants were defined as having prediabetes persistence. Furthermore, if their FPG ≥126 mg/dl, HbA1c ≥6.5%, or both, participants were defined as progressing to diabetes. In addition, individuals who reported a history of being diagnosed with diabetes between the period of baseline and follow-up survey were considered to have diabetes progression, without considering their FPG and HbA1c values at follow-up.

Modifiable Factors and Modifiable Factors Score

The modifiable factors included in this study were BMI, abdominal obesity, smoking status, smoking pack-year, physical activity, alcohol consumption, diet quality, hypertension, and dyslipidemia at baseline. The definition of each modifiable factor is detailed in Table 1 below.

Table 1. Definition and categories of each modifiable factor (adopted from Nabila *et al.*, Diabetes Care. 2023)

Modifiable factors	Definition	Categories
BMI	Calculated by dividing the value of body weight in kg by the square of the height in meters (33).	1. <23 kg/m^2 and ≥23 kg/m^2 2. <18.5 kg/m^2, 18.5–22.9 kg/m^2, 23–24.9 kg/m^2, and ≥25 kg/m^2
Abdominal obesity	Waist circumference ≥90 cm for men and ≥85 cm for women (33).	No and yes
Smoking status	Defined by participants' answers about their current smoking habits, whether they never smoked (never smokers), used to smoke (former smokers), or currently smoking (current smokers).	Never smokers, former smokers, and current smokers
Smoking pack-year	Derived by multiplying the number of cigarette packs smoked per day by the total smoking year. The total smoking pack-years were then categorized into light smokers (0.1–20 pack-year), moderate smokers (20.1–40 pack-year), and heavy smokers (>40 pack-years) (34).	Never smokers, light smokers, moderate smokers, and heavy smokers
Physical activity	Calculated by multiplying the average exercise frequency per week by the duration (in minutes) of exercise for each session. The total minutes per week were grouped into <150 min and ≥150 min (35).	No regular exercise, <150min/week, and ≥150min/week
Alcohol consumption	Calculated by multiplying the average drinking frequency per day, drink amount per session, and ethanol composition of each type of alcohol. Then, the results of ethanol intake from all types of alcohol were summed to obtain the total alcohol intake per day. The ethanol content of each alcohol type was 19% for soju, 5% for beer, 6% for	Non-drinkers, light drinkers, moderate drinkers, and heavy drinkers

Modifiable factors	Definition	Categories
	makgeolli, 43% for strong spirits, and 13% for Cheongju (36). Based on their total daily intake, participants were identified as light drinkers (<0.1–19.9 g/day for men and 0.1–9.9 g/day for women), moderate drinkers (20–39.9 g/day for men and 10–19.9 g/day for women), or heavy drinkers (≥40 g/day for men and ≥20 g/day for women). Those not consuming alcohol were grouped into the non-drinkers category (37).	
Diet quality	Assessed using the Diet Quality Index for Koreans (DQI-K) (38). Based on the median value of the total DQI-K score, participants were grouped into a good diet quality group if they scored 0–3 and poor diet quality if they scored 4–9.	Good diet quality and poor diet quality
Hypertension	Had one or more of the following conditions: 1. Self-report of history of being diagnosed with hypertension by a physician. 2. Systolic blood pressure ≥140 mmHg (39) 3. Diastolic blood pressure ≥90 mmHg (39)	No and yes
Dyslipidemia	Had one or more of the following conditions: 1. Self-report of history of being diagnosed with hyperlipidemia by a physician. 2. Hypercholesterolemia (total cholesterol ≥240 mg/dl) (40) 3. High LDL-C (LDL-C ≥160 mg/dl) (40) 4. Hypertriglyceridemia (triglyceride ≥200 mg/dl) (40) 5. Low HDL-C (HDL-C <40 mg/dl) (40)	No and yes

A modifiable factors score was derived by summing the total score of dichotomizing several factors, including abdominal obesity, smoking status, physical activity, alcohol consumption, diet quality, hypertension, and dyslipidemia. The more favorable category was given a score of one, while the other category was given a score of 0; and with that, the total score ranged from 0 to 7.

The inclusion of abdominal obesity as one of the components to represent the presence of obesity in participants was based on the reference saying that central obesity is more associated with morbidity and metabolic syndrome than BMI (41,42). However, we made another scoring for sensitivity analysis by replacing abdominal obesity with BMI in the component as the sensitivity analysis. The detail on how the scoring was made is shown in Table 2 below.

Table 2. Components of modifiable factors score (adopted from Nabila *et al.*, Diabetes Care. 2023)

Factors	Categories	Score
Modifiable factors score		
Abdominal obesity	No	1
	Yes	0
Smoking status	Non-smoker and former smoker	1
	Current smoker	0
Physical activity	150 minutes/week or more	1
	<150 minutes/week	0
Alcohol consumption	Non-drinker to moderate drinker	1
	Heavy drinker	0
Diet quality	Good diet quality	1
	Poor diet quality	0
Hypertension	No	1
	Yes	0
Dyslipidemia	No	1
	Yes	0
		Total=7
Modifiable factors score for sensitivity analysis		
BMI	<23 kg/m^2	1
	≥23 kg/m^2	0
Smoking status	Non-smoker and former smoker	1
	Current smoker	0
Physical activity	150 minutes/week or more	1
	<150 minutes/week	0
Alcohol consumption	Non-drinker to moderate drinker	1
	Heavy drinker	0
Diet quality	Good diet quality	1
	Poor diet quality	0
Hypertension	No	1
	Yes	0
Dyslipidemia	No	1
	Yes	0
		Total=7

Based on tertiles of the total score, participants were grouped into three; unfavorable group if the score was between 0-4, intermediate group if the score was 5, and favorable group if the score was between 6-7.

Covariates

Some potential covariates were included in this study, which consisted of sociodemographic and other factors. The sociodemographic factors comprised of sex, age (40–49, 50–59, 60–69 years group), education level (middle school or below, high school, college or above), and income (<200, 200–399, ≥400 per 10.000 Korean Won). Furthermore, for the other factors, baseline FPG, HbA1c (every 0.1 increase), and family history of diabetes were included.

Statistical Analysis

Multinomial logistic regression was performed to obtain odds ratio (OR) with 95% confidence interval (CI) of reversion to normoglycemia and progression to diabetes. The prediabetes persistence group was set as the reference group in the analysis. Some adjusting variables were included, consisting of sex (binary), age (continuous), education (categorical), income (categorical), baseline FPG (continuous), baseline HbA1c (continuous), and family history of diabetes (binary). The modifiable factors score analysis was performed as several types of variables; as continuous variable, categorical variable (unfavorable, intermediate, and favorable), as well as the ordinal category of number of modifiable factors score.

Two additional analyses were performed. One was to evaluate the standardized difference between participants who were excluded from the original study and who were included in the present study where a greater P-value than 0.2

indicated an imbalance between the groups (43). The other one was an analysis stratifying by sex to see the difference in the associations between men and women. Whether there was any difference between the two sex groups was evaluated by performing heterogeneity test using Cochran's Q and Higgins' I^2 test. *P*-value <0.1 or I^2 >50% indicated a significant difference (44). Three other sensitivity analyses were performed; (1) analysis by excluding participants with follow-up period less than three years, (2) analysis by defining the glycemic status only by FPG value, (3) analysis of modifiable factors score by replacing abdominal obesity as BMI in the scoring component.

All analyses were performed using Statistical Package for Social Science (SPSS) version 26.0 (IBM Company, New York, NY, USA), SAS statistical software version 9.4 (SAS Institute, Cary, NC, USA), and R Statistical Software version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria).

2.1.2 Results

Among the 27,041 people in the original cohort study who had complete data, 10,358 of them were classified as having prediabetes and were included in our investigation based on both their FPG and HbA1c levels. If only using FPG level, 4,443 (16.4%) participants were classified as having prediabetes, and if only using HbA1c, 8,976 (33.2%) individuals with prediabetes were defined. Thus, as a result, employing both markers improved the sensitivity of prediabetes detection. Detailed information on the participants' glycemic status at baseline according to each marker and history of diabetes diagnosis is provided in Appendix 4.

After the median follow-up period of four years (ranging from one to seven years), 3,293 (31.8%) participants had their glycemic status back to normoglycemia and 843 (8.1%) had diabetes progression. The remaining 6,222 participants (60.1%) had prediabetes persistence. The complete results of the baseline characteristics are presented in Table 3.

Table 3. Baseline characteristics and odds ratios of glycemic status change (adopted from Nabila *et al.*, Diabetes Care. 2023)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
		N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Sociodemographic factors						
Sex						
Men	3545 (34.2)	2216 (35.6)	943 (28.6)	Reference	386 (45.8)	Reference
Women	6813 (65.8)	4006 (64.4)	2350 (71.4)	1.32 (1.18–1.46)	457 (54.2)	0.63 (0.53–0.74)
Age (mean ± SD)	55.4±7.4	55.7±7.2	54.6±7.7	1.00 (0.99–1.00)	55.7±7.6	0.98 (0.97–0.99)
Age						
40–49	2181 (21.1)	1184 (19.0)	810 (24.6)	Reference	187 (22.2)	Reference
50–59	4862 (46.9)	2986 (48.0)	1504 (45.7)	0.91 (0.81–1.03)	372 (44.1)	0.59 (0.48–0.74)
60–69	3315 (32.0)	2052 (33.0)	979 (29.7)	0.97 (0.84–1.11)	284 (33.7)	0.56 (0.44–0.71)
Education						
Middle school or less	3413 (33.1)	2128 (34.4)	989 (30.2)	Reference	296 (35.3)	Reference
High school	4126 (40.0)	2424 (39.2)	1374 (41.9)	1.22 (1.09–1.38)	328 (39.1)	0.84 (0.69–1.03)
College or above	2768 (26.9)	1639 (26.5)	915 (27.9)	1.22 (1.06–1.40)	214 (25.5)	0.69 (0.55–0.87)
Income (10.000 won)						
<200	3214 (31.8)	1935 (31.9)	1005 (31.1)	Reference	274 (33.3)	Reference
200–399	4554 (45.0)	2754 (45.4)	1435 (44.5)	0.90 (0.80–1.01)	365 (44.3)	0.90 (0.74–1.09)
≥400	2354 (23.3)	1382 (22.8)	788 (24.4)	0.98 (0.85–1.13)	184 (22.4)	0.95 (0.74–1.20)
Modifiable factors						
BMI						
<23 kg/m^2	3439 (33.2)	1894 (30.5)	1373 (41.7)	Reference	172 (20.5)	Reference
≥23 kg/m^2	6910 (66.8)	4323 (69.5)	1919 (58.3)	0.74 (0.67–0.81)	668 (79.5)	1.38 (1.14–1.67)
<18.5 kg/m^2	134 (1.3)	68 (1.1)	64 (1.9)	1.10 (0.75–1.61)	2 (.2)	0.45 (0.11–1.90)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence N (%)	Reversion to normoglycemia		Progression to diabetes	
			N (%)	OR 95% CI	N (%)	OR 95% CI
18.5–22.9 kg/m^2	3305 (31.9)	1826 (29.4)	1309 (39.8)	Reference	170 (20.2)	Reference
23–24.9 kg/m^2	2911 (28.1)	1801 (29.0)	907 (27.6)	0.78 (0.69–0.88)	203 (24.2)	1.04 (0.82–1.31)
≥25 kg/m^2	3999 (38.6)	2522 (40.6)	1012 (30.7)	0.71 (0.63–0.79)	465 (55.4)	1.58 (1.29–1.94)
Abdominal obesity						
No	7590 (73.3)	4438 (71.4)	2636 (80.1)	Reference	516 (61.4)	Reference
Yes	2758 (26.7)	1779 (28.6)	655 (19.9)	0.76 (0.68–0.86)	324 (38.6)	1.31 (1.11–1.55)
Smoking status						
Never smokers	7429 (71.9)	4393 (70.8)	2518 (76.6)	Reference	518 (61.7)	Reference
Former smokers	1743 (16.9)	1126 (18.1)	454 (13.8)	0.93 (0.77–1.12)	163 (19.4)	0.94 (0.71–1.26)
Current smokers	1164 (11.3)	689 (11.1)	316 (9.6)	0.97 (0.79–1.18)	159 (18.9)	1.43 (1.07–1.91)
Smoking pack-year						
Never smokers	7429 (72.1)	4393 (71.0)	2518 (76.7)	Reference	518 (61.8)	Reference
Light smokers	1578 (15.3)	982 (15.9)	442 (13.5)	0.96 (0.80–1.15)	154 (18.4)	1.05 (0.79–1.40)
Moderate smokers	1002 (9.7)	625 (10.1)	255 (7.8)	0.94 (0.76–1.17)	122 (14.6)	1.29 (0.94–1.78)
Heavy smokers	301 (2.9)	188 (3.0)	69 (2.1)	0.99 (0.71–1.38)	44 (5.3)	1.39 (0.90–2.16)
Physical activity						
No regular exercise	4575 (44.3)	2714 (43.8)	1492 (45.4)	Reference	369 (44.0)	Reference
<150min/week	1177 (11.4)	696 (11.2)	383 (11.7)	0.96 (0.83–1.13)	98 (11.7)	1.07 (0.83–1.39)
≥150min/week	4570 (44.3)	2790 (45.0)	1408 (42.9)	0.95 (0.86–1.05)	372 (44.3)	0.98 (0.83–1.16)
Alcohol consumption						
Non-drinkers	5941 (57.6)	3527 (56.9)	1980 (60.3)	Reference	434 (51.7)	Reference
Light drinkers	2844 (27.6)	1689 (27.2)	923 (28.1)	1.03 (0.92–1.15)	232 (27.6)	0.94 (0.77–1.14)
Moderate drinkers	739 (7.2)	467 (7.5)	199 (6.1)	0.83 (0.68–1.02)	73 (8.7)	1.02 (0.75–1.40)
Heavy drinkers	798 (7.7)	517 (8.3)	180 (5.5)	0.74 (0.60–0.91)	101 (12.0)	1.20 (0.90–1.61)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence N (%)	Reversion to normoglycemia		Progression to diabetes	
			N (%)	OR 95% CI	N (%)	OR 95% CI
Diet quality						
Good diet quality	5342 (51.8)	3222 (52.0)	1678 (51.2)	Reference	442 (52.7)	Reference
Poor diet quality	4971 (48.2)	2973 (48.0)	1602 (48.8)	0.93 (0.85–1.02)	396 (47.3)	1.02 (0.87–1.20)
Hypertension						
No	6880 (66.5)	3967 (63.8)	2447 (74.4)	Reference	466 (55.5)	Reference
Yes	3467 (33.5)	2249 (36.2)	844 (25.6)	0.71 (0.64–0.79)	374 (44.5)	1.26 (1.07–1.49)
Dyslipidemia						
No	5768 (55.7)	3316 (53.3)	2066 (62.7)	Reference	386 (45.8)	Reference
Yes	4590 (44.3)	2906 (46.7)	1227 (37.3)	0.78 (0.70–0.85)	457 (54.2)	1.17 (0.99–1.37)
Hypercholesterolemia						
No	8662 (83.6)	5161 (82.9)	2804 (85.2)	Reference	697 (82.7)	Reference
Yes	1696 (16.4)	1061 (17.1)	489 (14.8)	0.90 (0.79–1.02)	146 (17.3)	1.03 (0.83–1.27)
High LDL-C Level						
No	8929 (86.2)	5323 (85.6)	2877 (87.4)	Reference	729 (86.5)	Reference
Yes	1429 (13.8)	899 (14.4)	416 (12.6)	0.87 (0.76–1.00)	114 (13.5)	0.98 (0.78–1.24)
Hypertriglyceridemia						
No	8726 (84.2)	5190 (83.4)	2906 (88.2)	Reference	630 (74.7)	Reference
Yes	1632 (15.8)	1032 (16.6)	387 (11.8)	0.79 (0.69–0.91)	213 (25.3)	1.30 (1.07–1.57)
Low HDL-C Level						
No	9285 (89.6)	5554 (89.3)	3011 (91.4)	Reference	720 (85.4)	Reference
Yes	1073 (10.4)	668 (10.7)	282 (8.6)	0.86 (0.73–1.01)	123 (14.6)	1.31 (1.04–1.66)
Other factors						
Family history of diabetes						
No	8056 (77.9)	4810 (77.5)	2676 (81.4)	Reference	570 (67.9)	Reference

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
		N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Yes	2279 (22.1)	1397 (22.5)	612 (18.6)	0.82 (0.73–0.92)	270 (32.1)	1.53 (1.28–1.82)
Baseline FPG (mean ± SD)	96.0 ± 10.2	97.1 ± 9.4	91.7 ± 9.5	0.92 (0.92–0.93)	104.5 ± 10.8	1.07 (1.06–1.08)
Baseline HbA1c (mean ± SD)	5.8 ± 0.3	5.8 ± 0.3	5.7 ± 0.2	0.73 (0.71–0.75)	6.0 ± 0.3	1.37 (1.33–1.42)
DQI Components						
Daily protein intake						
<100% RNI	4958 (48.1)	2983 (48.2)	1547 (47.2)	Reference	428 (51.1)	Reference
100-150% RNI	3932 (38.1)	2369 (38.2)	1259 (38.4)	0.95 (0.86–1.05)	304 (36.3)	0.90 (0.75–1.07)
>150% RNI	1423 (13.8)	843 (13.6)	474 (14.5)	0.94 (0.82–1.09)	106 (12.6)	1.02 (0.80–1.32)
Percentage of energy from fat						
<22.5%	9651 (93.6)	5814 (93.8)	3057 (93.2)	Reference	780 (93.1)	Reference
≥22.5%	662 (6.4)	381 (6.2)	223 (6.8)	1.08 (0.89–1.30)	58 (6.9)	1.07 (0.78–1.47)
Percentage of energy from saturated fat						
<7%	10278 (99.7)	6178 (99.7)	3267 (99.6)	Reference	833 (99.4)	Reference
≥7%	35 (.3)	17 (.3)	13 (.4)	1.96 (0.84–4.57)	5 (.6)	1.66 (0.55–5.02)
Daily cholesterol intake						
<300mg	9066 (87.9)	5436 (87.7)	2895 (88.3)	Reference	735 (87.7)	Reference
≥300mg	1247 (12.1)	759 (12.3)	385 (11.7)	0.94 (0.81–1.09)	103 (12.3)	1.03 (0.81–1.31)
Daily whole-grain intake						
Non-daily	8615 (83.2)	5194 (83.5)	2728 (82.8)	Reference	693 (82.2)	Reference
Daily	1743 (16.8)	1028 (16.5)	565 (17.2)	1.03 (0.91–1.17)	150 (17.8)	1.07 (0.87–1.32)
Daily vegetable intake						
<200g	8205 (79.6)	4922 (79.5)	2612 (79.6)	Reference	671 (80.1)	Reference
≥200g	2108 (20.4)	1273 (20.5)	668 (20.4)	0.96 (0.86–1.08)	167 (19.9)	1.03 (0.84–1.25)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence N (%)	Reversion to normoglycemia		Progression to diabetes	
			N (%)	OR 95% CI	N (%)	OR 95% CI
Daily fruit intake						
<200g	6640 (64.4)	3997 (64.5)	2059 (62.8)	Reference	584 (69.7)	Reference
≥200g	3673 (35.6)	2198 (35.5)	1221 (37.2)	0.99 (0.90–1.09)	254 (30.3)	0.90 (0.75–1.07)
Daily sodium intake						
<2000mg	4263 (41.3)	2553 (41.2)	1367 (41.7)	Reference	343 (40.9)	Reference
≥2000mg	6050 (58.7)	3642 (58.8)	1913 (58.3)	0.95 (0.87–1.05)	495 (59.1)	1.02 (0.87–1.20)
Total DQI-K score (mean ± SD)	3.7 ± 1.3	3.7 ± 1.3	3.7 ± 1.2	0.98 (0.95–1.02)	3.7 ± 1.2	1.01 (0.95–1.08)

OR, adjusted odds ratio adjusted for age (continuous), education, income, baseline FPG (continuous), baseline HbA1c (continuous), and family history of diabetes. FPG, fasting plasma glucose; RNI, reference nutrient intake; DQI-K, diet quality index for Koreans. The income is in Korean 10.000 won. Abdominal obesity was defined as a waist circumference ≥ 90 cm for men and ≥ 85 cm for women. Smoking pack-year was grouped into light (0, 1–20 pack-year), moderate (20.1–40 pack-year), and heavy smokers (>40 pack-year). Alcohol consumption was categorized into light (<0.1–19.9 g/day for men and 0.1–9.9 g/day for women), moderate (20–39.9 g/day for men and 10–19.9 g/day for women), or heavy drinkers (≥40 g/day for men and ≥20 g/day for women). Diet quality was considered good if the DQI-K score was 0–3 and poor if the score was 4–9.

Reversion to normoglycemia

The results of reversion to normoglycemia analysis are presented in Table 3. Among the sociodemographic factors, we found significant difference in odds of reversion to normoglycemia between men and women (OR 1.32, 95% CI 1.18–1.46). Similarly, higher education (OR 1.22, 95% CI 1.09–1.38 for high school level and OR 1.22, 95% CI 1.06–1.40 for college or above level) was also related to reversion to normoglycemia. Of all the modifiable factors, BMI ≥25 kg/m^2 (OR 0.71, 95% CI 0.63–0.79), abdominal obesity (OR 0.76, 95%:0.68–0.85), heavy drinking (OR 0.74, 95% CI 0.60–0.91), hypertension (OR 0.71, 95% CI 0.64–0.79), and dyslipidemia (OR 0.78, 95% CI 0.70–0.85) appeared to have lower odds of reversion to normoglycemia. Similarly, a family history of diabetes (OR 0.82, 95% CI 0.73–0.92), higher baseline FPG (OR 0.92, 95% CI 0.91–0.93), and higher baseline HbA1c (0.73, 95% CI 0.71–0.71) also lowered the odds of normoglycemia reversion.

Progression to diabetes

The results regarding diabetes progression are shown in Table 3. Of all the sociodemographic factors, lower odds of diabetes progression was found in women (OR 0.63, 95% CI 0.96–0.99 compared to men) and older age groups (OR 0.56,95% CI 0.44–0.71), and education level of college or above (OR 0.69, 95% CI 0.54–0.87). In the analysis of modifiable factors, greater odds of progression to diabetes was observed in BMI ≥25 kg/m^2 (OR 1.58, 95% CI 1.29–1.94), abdominal obesity (OR 1.31, 95% CI 1.11–1.55), current smokers (OR 1.43, 95% CI 1.07–1.91), and hypertension (OR 1.26, 95% CI 1.07–1.49). Likewise, people with a family history of diabetes (OR 1.53, 95% CI 1.28–1.82) or have higher values of

baseline FPG or HbA1c (OR 1.07, 95% CI 1.06–1.08 and 1.37, 95% CI 1.33–1.42 respectively) were more likely to have diabetes progression.

Table 4. Associations between modifiable factors score and glycemic status change (adopted from Nabila *et al.*, Diabetes Care. 2023)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
		N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Modifiable factors score (continuous, mean ± SD)	4.6 ± 1.3	4.5 ± 1.3	4.9 ± 1.2	1.15 (1.10–1.19)	4.1 ± 1.3	0.88 (0.82–0.93)
Modifiable factors category						
Unfavorable group	4502 (43.8)	2850 (46.2)	1162 (35.6)	Reference	490 (58.5)	Reference
Intermediate group	3049 (29.7)	1814 (29.4)	1013 (31.1)	1.19 (1.06–1.33)	222 (26.5)	0.81 (0.67–0.98)
Favorable group	2717 (26.5)	1507 (24.4)	1085 (33.3)	1.46 (1.30–1.64)	125 (14.9)	0.62 (0.49–0.77)
Number of modifiable factors score						
0	22 (.2)	17 (.3)	3 (.1)	0.38 (0.10–1.39)	2 (.2)	0.82 (0.18–3.78)
1	110 (1.1)	71 (1.2)	13 (.4)	0.47 (0.25–0.90)	26 (3.1)	1.90 (1.10–3.30)
2	487 (4.7)	312 (5.1)	109 (3.3)	0.78 (0.61–1.01)	66 (7.9)	1.32 (0.94–1.86)
3	1322 (12.9)	859 (13.9)	312 (9.6)	0.78 (0.66–0.92)	151 (18.0)	1.20 (0.94–1.53)
4	2561 (24.9)	1591 (25.8)	725 (22.2)	0.90 (0.79–1.02)	245 (29.3)	1.20 (0.97–1.49)
5	3049 (29.7)	1814 (29.4)	1013 (31.1)	Reference	222 (26.5)	Reference
6	2147 (20.9)	1217 (19.7)	827 (25.4)	1.19 (1.05–1.35)	103 (12.3)	0.77 (0.59–1.00)
7	570 (5.6)	290 (4.7)	258 (7.9)	1.39 (1.14–1.70)	22 (2.6)	0.71 (0.43–1.18)

OR, adjusted odds ratio adjusted for age (continuous), education, income, baseline FPG (continuous), baseline HbA1c, and family history of diabetes. All modifiable factors score is the sum of abdominal obesity, smoking status, physical activity, alcohol consumption, diet quality, hypertension, and dyslipidemia scores. All factors score was divided into three groups based on tertiles scores. Scores of 0–4 were categorized as unfavorable, 5 as intermediate, and 6–7 as favorable.

Modifiable factors score

The results from the scoring analyses are presented in Table 4. It shows that along with every one-point increase in modifiable factors score, the odds of reversion to normoglycemia increased (OR 1.15, 95% CI 1.10–1.19) and progression to diabetes decreased (OR 0.88, 95% CI 0.82–0.93).

The median of the total score was 5, comprising 30.9% of the participants. Those who scored lower than the median were less likely to have reversion to normoglycemia and more likely to have progression to diabetes. Meanwhile, those who scored higher than the median score appeared to have the opposite trend. In the analysis as the categorical variable, participants who were in the favorable group were more likely to go back to normoglycemia (OR 1.46, 95% CI 1.30–1.64) and less likely to have diabetes progression (OR 0.62, 95% CI 0.49–0.77).

Figure 2 (a) presents the adjusted odds ratios of each component of the modifiable factors score for glycemic status change. It indicates that hypertension component (OR 1.42, 95% CI 1.28–1.58 for having no hypertension compared to the presence of hypertension) was observed to have the highest OR of normoglycemia reversion. Furthermore, smoking status component (OR 0.69, 95% CI 0.54–0.87 for currently not smoking compared to currently smoking) had the highest OR of diabetes progression. Although the figure shows that some components (physical activity and diet quality) tend to have similar OR of reversion to normoglycemia and diabetes progression, Figure 1.2 (b) indicates that the distribution of people with favorable modifiable scores for each component is different. The proportion of people with higher scores for each component is larger in favorable group, then in intermediate group, and lastly the smallest is in the

unfavorable group. The proportion of participants in each component of favorable, intermediate, and unfavorable group respectively was: 97.1%, 83.3%, 52.2% for no abdominal obesity; 99.0%, 44.3%, 28.2% for currently not smoking; 70.7%, 44.3%, 28.2% for 150 minutes/week of physical activity; 97.7%, 93.1%, 72.1% for non-drinker to moderate drinker of alcohol; 76.8%, 48.0%, 31.2% for good diet quality; 92.6%, 73.9%, 45.7% for no hypertension; and 87.0%, 62.9%, 31.8% for no dyslipidemia.

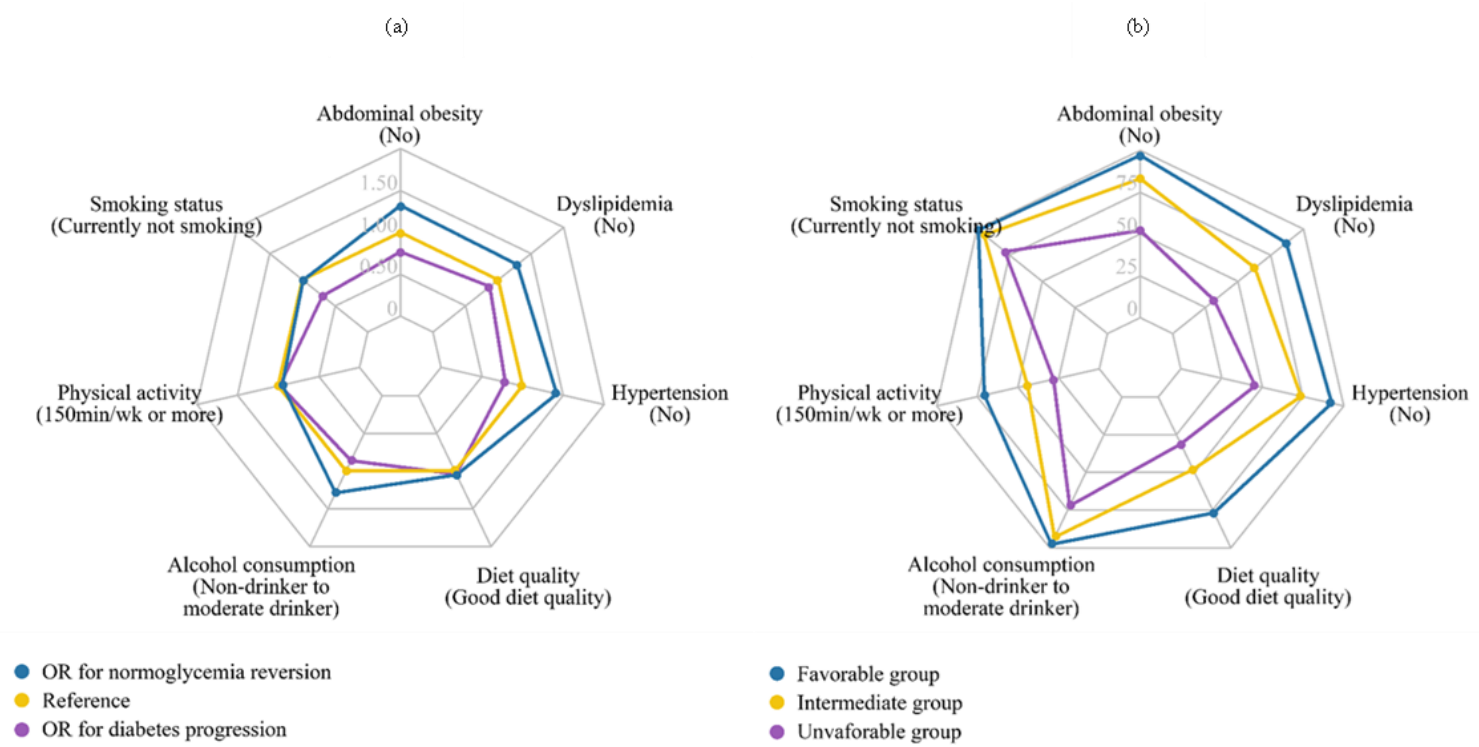


Figure 2. Odds ratios of glycemic status change of each modifiable factors score component and distribution of participants with a favorable score in each component (adopted from Nabila *et al.*, Diabetes Care. 2023)

(a): Odds ratios of glycemic status change of each modifiable factors score component adjusted for age (continuous), education, income, baseline FPG (continuous), baseline HbA1c (continuous), and family history of diabetes.
(b): Distribution of participants with a favorable score in each component (participants who were given a score of 1 in each scoring component).

Additional and sensitivity analyses

Results from stratified analysis by sex indicated that most of the odds ratios of changes in glycemic status were not different between men and women (Appendix 5 and Appendix 6). A substantially different association was observed in the educational level of college for normoglycemia reversion. The sensitivity analysis excluding participants with a follow-up time of less than 3 years showed consistent results in Appendix 7. For the sensitivity analysis by using only FPG to define the glycemic status, the results appeared to be similar to the main analysis in terms of significance, except for sex and hypertension which showed non-significant associations with diabetes progression (Appendix 8). Furthermore, the result from the scoring analysis after replacing abdominal obesity with BMI was also comparable to the main result of the modifiable factor score in Appendix 9.

2.2 Changes in General and Abdominal Obesity, and Trajectory of General and Abdominal Obesity

2.2.1 Methods

Data source

The data source for this study was the National Health Insurance Service–Health Screening (NHIS–HEALS) cohort database. The details of this study have been described somewhere else (45). Briefly, NHIS–HEALS is a cohort database constructed in 2002–2003 by Korean National Health Insurance Service (NHIS) which accounted for around 10% of Koreans who joined the health screening programs.

The present study included data of NHIS–HEALS from 2008 to 2019 because the assessment of WC was not performed before 2008. We assigned every two years as one measurement time, 2008 and 2009 as the first measurement and baseline, 2010–2011 as the second measurement, 2012–2013 as the third measurement, 2014–2015 as the fourth measurement, 2016–2017 as the fifth measurement, and 2018–2019 as the sixth. The second through sixth measurement were considered as the follow-up period. In each measurement time, we defined each participant's glycemic status, obesity status, and the other covariates. This study was approved by the Institutional Review Board of the Seoul National University Hospital, Seoul, Korea (IRB No: E–2205–112–1325) and all methods were performed in accordance with relevant guidelines and regulations.

Study design and study population

We conducted a nested case-control study including participants with prediabetes glycemic status at baseline. We performed a frequency matching

method to select participants from each glycemic status group in each measurement time according to their sex and age. The frequency number of participants were decided according to the lowest number of glycemic status group in each measurement time. The decision to conduct a nested case-control study was because of the large differences in follow-up duration of participants who experienced normoglycemia reversion, diabetes progression, and remained in prediabetes.

During the baseline period, we first selected participants from NHIS–HEALS who were eligible for this study. Among all NHIS–HEALS participants (N= 514,866), we excluded participants who were recruited before 2008, thus, 361,043 participants remained. Further, we excluded participants with missing information on any of FPG, BMI, or WC at baseline (n = 115, 120, and 640 respectively). For the remaining participants, their FPG was grouped into prediabetes, normoglycemia, and diabetes following the criteria from ADA (1). Then, participants with normoglycemia (n = 228,615) and diabetes (n =30,050) were excluded, leaving participants with prediabetes at baseline. A further exclusion was made for participants who reported a history of diabetes diagnosis (n = 12,326) and other chronic diseases, including CVD and cancer (n = 19,168 and 6,661 respectively). CVD and cancer cases were defined by the ICD-10. The CVD included stroke (I60 to I64), coronary heart disease (I20 to I25), and heart failure (I50). Because this study would like to analyze changes in obesity, those who did not participate in any measurement during follow-up were not included (n = 2,445). Finally, 70,685 eligible participants were included in this study.

Among the eligible participants, we did frequency matching by randomly

selecting participants from the control group (prediabetes persistence) and case groups (reversion to normoglycemia reversion and progression to diabetes) in each measurement time. Prediabetes persistence was defined as FPG was between 100–128 mg/dl; reversion to normoglycemia was defined as normal range of FPG (<100 mg/dl); and progression to diabetes was defined as FPG ≥126 mg/ or if they reported history of diabetes diagnosis between baseline and follow-up period. We defined the participants' glycemic status in each measurement time during the follow-up period to know whether they were in control or case groups. If they have their glycemic status change to normoglycemia or diabetes, they were considered as cases, and their data in the following measurement time was ignored. Meanwhile, for participants who did not change or still maintain their prediabetes status, they were considered to be in the control group, and their data in the following measurement time. After categorizing the control and case groups, we performed the matching with replacement method in which the same individual from the control group could be sampled repeatedly, resulting in a total of 55,634 matched participants. The methods for participant selection and the detailed number of control and cases in each measurement time can be found in Figure 3.

In this study, we would like to see the changes in obesity status before the outcome, therefore, we only included participants from the third measurement, and so on. Finally, 31,104 participants were included in the analysis. Among them, 20,507 participants were sampled once, 4,268 participants were sampled twice, 627 participants were sampled three times, and 45 participants were sampled four times. The details regarding participant selection are presented in Figure 3 and the detailed number of matched participants is presented in Appendix 11 and Appendix 12.

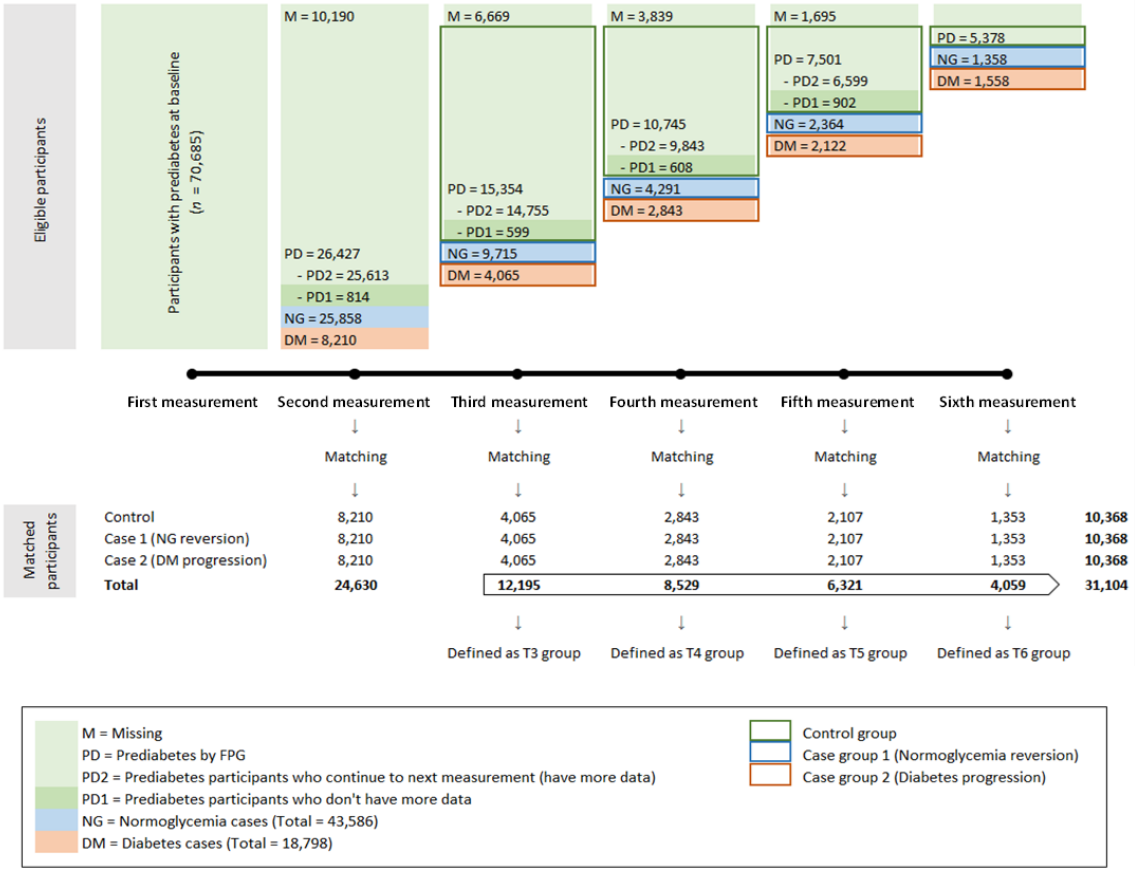


Figure 3. Scheme of participant selection for the changes in obesity status study

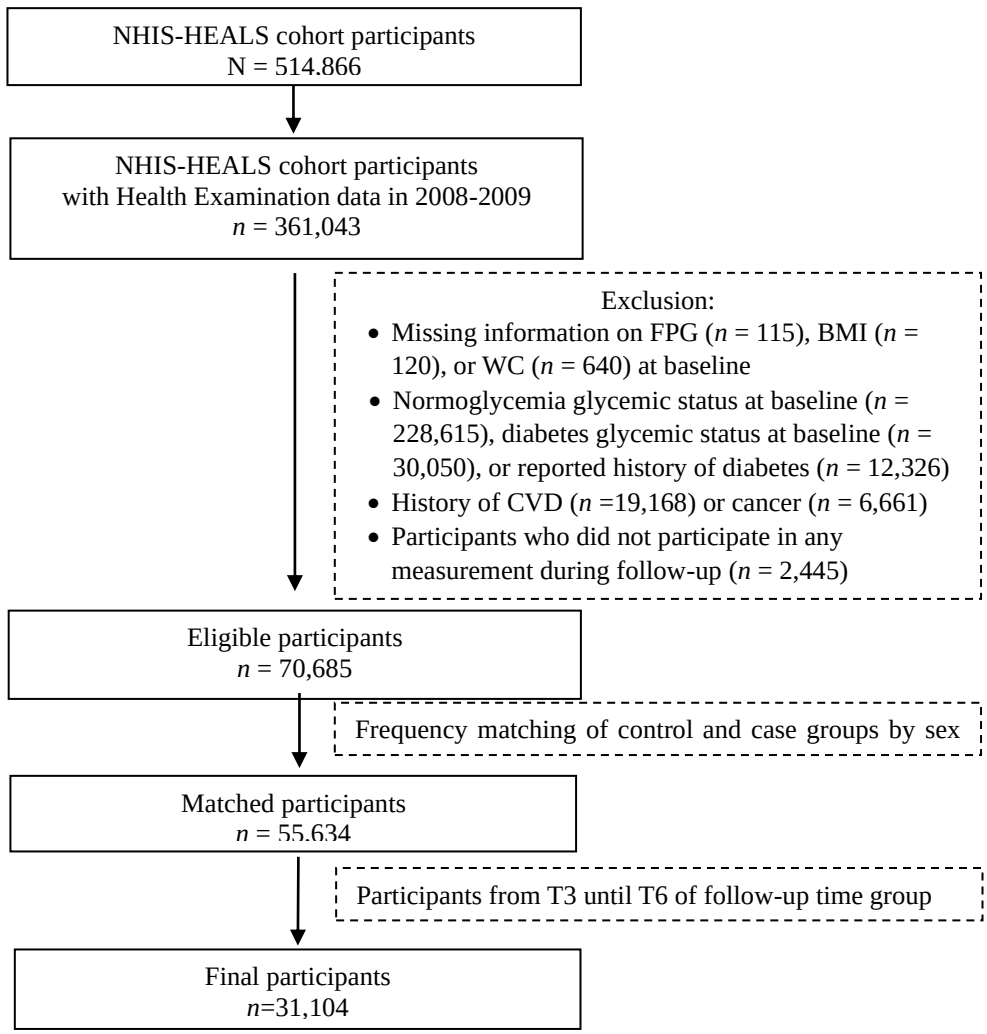


Figure 4. Flowchart of participant selection for the changes in obesity status study

Follow-up time group

In this study, we performed several subgroup analyses according to the follow-up time. Therefore, for clarity, we grouped the participants according to their last measurement time and regarded each group as follows; T2 group as a group of participants who were followed up until the second measurement (2010-2011); T3 as a group of participants who were followed up until the third measurement (2012-2013); T4 as participants who were followed up until the fourth measurement (2014-2015); T5 as a group of participants who were followed up until the fifth measurement (2016-2017); and T6 as a group of participants who were followed up until the final or sixth measurement (2018-2019).

Definition of exposures: changes and trajectory of obesity

The first exposure was changes in obesity status from baseline to the measurement time before outcome. For example, for participants in the T5 group, the exposure was changes in obesity status from baseline to the fourth measurement. We included both changes in general obesity, which was defined by BMI, and changes in abdominal obesity, which was defined by WC. Following the definition by Obesity Guidelines for the Management of Obesity in Korea, general obesity was defined as BMI $\geq$ 25 kg/m^2, and abdominal obesity was defined as WC$\geq$90 cm for men and $\geq$85 cm for women (34). Using these cut-points, participants were grouped as obese and non-obese at baseline. Then, they were categorized into 'stable obese', 'obese to non-obese', 'stable non-obese', and 'non-obese to obese', depending on how their obesity status changed.

The second exposure of this study was the trajectory of obesity throughout the follow-up period from baseline until the previous measurement time before the

outcome. For example, for participants in the T5 group, we used their obesity status data from the baseline, second, third, and fourth measurements. The trajectory of obesity was derived using the latent class trajectory modeling which allows a grouping of participants with similar patterns into several latent classes by maximizing the homogeneity within and heterogeneity across the groups (46,47). It also allows missing information on the dependent variable and assumes that the data is missing at random (46). We also performed the analysis of BMI and WC trajectory as continuous variables. In the model, the trajectory of obesity, BMI, or WC was specified as the dependent variable explained by time, separately among men and women. To obtain the best model, the analyses were performed repeatedly by changing the number of classes from two to a maximum of five, with the same starting value derived from the 1–class model. For the trajectory of obesity status, we did not assign a random effect in the model because it was a binary variable (obese or non-obese). For the trajectory of continuous variables, we tested linear parameters as well as non–linear parameters with quadratic and cubic polynomials. After performing several models, we selected the best one by examining the proportion of individuals in each trajectory, Bayesian information criterion, mean posterior probability, graphs of the trajectories, and the minimum percentage of participants in a class, which was 5% (46,47). This modeling was performed using using the 'lcmm' in R software (version 3.4.3) (46).

Covariates

Several covariates were considered in this study, including sociodemographic factors, lifestyle factors, and some other factors. Sociodemographic factors comprised sex, age, and income. The income was

defined by the participant's insurance type and categorized into three groups which were low insurance type 1 to 4), middle (insurance type 5 to 8), and high (insurance type 9 to 10). The lifestyle factors included smoking status, alcohol consumption, physical activity, hypertension, and dyslipidemia. Smoking status was defined by the participants' answers to the question of whether they never smoked, used to smoke (former smoker), or currently smoke (current smoker). Based on their reports on the question of whether they engage in regular physical activity, participants were grouped into 'no regular physical activity' and 'regular physical activity'. Hypertension was defined if they had systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg, or reported history of diagnosed with hypertension (39). Dyslipidemia was defined if they had hypercholesterolemia (total cholesterol ≥240 mg/dl), high LDL–C (LDL–C ≥160 mg/dl), hypertriglyceridemia (triglyceride ≥200 mg/dl), low HDL–C (HDL–C <40 mg/dl) or reported history of dyslipidemia diagnosis (40).

Statistical analysis

We performed multinomial logistic regression to obtain OR with 95% CI to evaluate the associations between the changes in obesity status as well as obesity trajectories and prediabetes changes to normoglycemia or diabetes. It was performed by setting prediabetes persistence as the reference group. We performed the analysis among all participants, and separately among men and women to see if there is differences in the effect between both groups. Several models were performed in the analysis; model 1 included the adjustment of sex and age at baseline (continuous); model 2 included the adjustment of sex, age (continuous), smoking status, alcohol consumption, and physical activity; model 3 included

adjustment of all covariates considered in this study.

We further assessed whether there was heterogeneity between follow-up time groups by obtaining ORs from stratified analysis by the groups, then performing a meta-analysis of the ORs. Heterogeneity was evaluated by Cochran's Q and Higgins' I^2 tests; a P-value <0.1 or an I2 >50% indicates a significant difference between groups (44). We also compared the common and random effect models that were obtained from the meta-analysis with the results from pooled analysis. All analyses were performed using SAS statistical software version 9.4 (SAS Institute, Cary, NC, USA) and R Statistical Software version 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria).

2.2.2 Results

Baseline characteristics of participants

Within a median follow-up of 3 years (ranging from one to eleven years), among the 70,685 eligible participants from the cohort study, we ascertained 43,586 (61,66%) participants who had reversion to normoglycemia and 18,798 (26,59%) participants who had progression to diabetes. The rest of the participants had their glycemic status remained in prediabetes 8,301 (11,74%). Further information regarding the number of outcomes among eligible participants from the original cohort is presented in Figure 2.

Among the eligible participants, we managed to randomly match 31,104 participants in total; 12,195 participants from the third measurement, 8,529 participants from the fourth measurement, 6,321 participants from the fifth measurement, and 4,059 participants from the sixth measurement. The median follow-up of the matched participants was 7 years (ranging from one to eleven

years). The mean and median follow-up year of participants in each follow-up time group showed that generally, the participants were screened regularly in every two years. The details of the distribution of outcomes among matched participants are presented in Appendix 13.

Baseline characteristics of the included participants according to outcome are presented in Table 5. All of the included covariates were found to be different across the outcome groups, except for the family history of diabetes. The value of FPG at baseline (111.05 mg/dl), BMI at baseline 25.10 kg/m^2), and WC at baseline (85.44 cm) were observed to be higher in participants who developed diabetes compared with the other groups.

Table 5. Baseline characteristics according to outcomes among matched participants

	Total	Control (Prediabetes persistence)	Case 1 (Reversion to normoglycemia)	Case 2 (Progression to diabetes)	P-value
	31104	10368	10368	10368	
Sex					1.000
Men	20343 (65.40)	6781 (65.4)	6781 (65.4)	6781 (65.4)	
Women	10761 (34.60)	3587 (34.6)	3587 (34.6)	3587 (34.6)	
Age (years)					
(mean (SD))	56.63 (7.94)	56.61 (7.98)	56.67 (8.00)	56.59 (7.83)	0.789
≤50	8661 (27.85)	2887 (27.85)	2887 (27.85)	2887 (27.85)	1.000
51-55	7116 (22.88)	2372 (22.88)	2372 (22.88)	2372 (22.88)	
56-60	6222 (20.00)	2074 (20)	2074 (20)	2074 (20)	
>60	9105 (29.27)	3035 (29.27)	3035 (29.27)	3035 (29.27)	
Income					<0.001
Low	7593 (24.41)	2390 (23.05)	2642 (25.48)	2561 (24.7)	
Middle	11674 (37.53)	3842 (37.06)	3908 (37.69)	3924 (37.85)	
High	11837 (38.06)	4136 (39.89)	3818 (36.82)	3883 (37.45)	
Follow-up time					1.000
T3 (2012-2013)	12195 (39.21)	4065 (39.21)	4065 (39.21)	4065 (39.21)	
T4 (2014-2015)	8529 (27.42)	2843 (27.42)	2843 (27.42)	2843 (27.42)	
T5 (2016-2017)	6321 (20.32)	2107 (20.32)	2107 (20.32)	2107 (20.32)	
T6 (2018-2019)	4059 (13.05)	1353 (13.05)	1353 (13.05)	1353 (13.05)	
Smoking status					<0.001
Never	19113 (63.71)	6541 (65.33)	6454 (64.47)	6118 (61.33)	
Former	4820 (16.07)	1702 (17.00)	1580 (15.78)	1538 (15.42)	
Current	6065 (20.22)	1769 (17.67)	1977 (19.75)	2319 (23.25)	
Alcohol consumption					0.002
Non-drinker	14814 (48.20)	4865 (47.53)	5055 (49.22)	4894 (47.84)	
Drinker	15922 (51.80)	5370 (52.47)	5215 (50.78)	5337 (52.16)	
Physical activity					<0.001
No regular exercise	10879 (35.27)	3503 (34.09)	3743 (36.38)	3633 (35.35)	

	Total	Control (Prediabetes persistence)	Case 1 (Reversion to normoglycemia)	Case 2 (Progression to diabetes)	P-value
Regular exercise	19965 (64.73)	6774 (65.91)	6546 (63.62)	6645 (64.65)	
Hypertension					<0.001
No	21544 (69.26)	7135 (68.82)	7509 (72.42)	6900 (66.55)	
Yes	9560 (30.74)	3233 (31.18)	2859 (27.58)	3468 (33.45)	
Dyslipidemia					<0.001
No	23037 (74.06)	7786 (75.1)	7832 (75.54)	7419 (71.56)	
Yes	8067 (25.94)	2582 (24.9)	2536 (24.46)	2949 (28.44)	
Family history of diabetes					0.320
No	12674 (40.75)	4268 (41.17)	4241 (40.9)	4165 (40.17)	
Yes	18430 (59.25)	6100 (58.83)	6127 (59.1)	6203 (59.83)	
FPG at baseline					<0.001
(mean (SD))	108.95 (6.72)	108.53 (6.36)	107.26 (6.14)	111.05 (7.06)	
BMI (kg/m^2)					
(mean (SD))	24.60 (2.82)	24.52 (2.74)	24.17 (2.78)	25.10 (2.86)	<0.001
<18.5	313 (1.39)	96 (0.93)	144 (1.39)	73 (1.01)	<0.001
18.5-23.4	8387 (31.84)	2864 (27.62)	3301 (31.84)	2222 (26.96)	
23.4-24.9	8910 (29.31)	3012 (29.05)	3039 (29.31)	2859 (28.65)	
25.0-29.9	12368 (34.96)	4075 (39.30)	3625 (34.96)	4668 (39.76)	
≥30	1126 (2.50)	321 (3.10)	259 (2.50)	546 (3.62)	
Waist circumference					<0.001
(mean (SD))	84.11 (7.72)	83.87 (7.62)	83.03 (7.75)	85.44 (7.60)	
Abdominal obesity					<0.001
No	21802 (70.09)	7409 (71.46)	7754 (74.79)	6639 (64.03)	
Yes	9302 (29.91)	2959 (28.54)	2614 (25.21)	3729 (35.97)	

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by One-way ANOVA for continuous variables.

Table 6 shows the baseline characteristics of the participants according to the changes in general obesity status among all participants. Of all participants, a larger proportion was observed in the 'stable non-obese' group (49.85%), followed by the 'stable obese' group (36.76%), the 'non-obese to obese' (6.97%), and lastly the 'obese to non-obese' group (6.42%). In the 'obese to non-obese' group, the proportion of participants in the younger age group is slightly smaller (29.16%) and the proportion of participants in the older age group is bigger (26.36%) compared to the other exposure groups. The proportion of participants from shorter follow-up time were slightly bigger in the 'stable obese' (40.02%) and 'stable non-obese' group (39.89%), compared with the other two exposure groups. Furthermore, 'stable obese' group was observed to have a higher proportion of participants with abdominal obesity at baseline (60.24%). Meanwhile, the other groups showed the opposite.

The baseline characteristics of the men and women participants according to changes in general obesity are presented in Table 7 and Table 8. Among men participants, a higher proportion was found in the youngest age group (35.52%), while among women, a higher proportion was found in the oldest age group (31.18%). This trend was also apparent across the exposure groups. Furthermore, the lifestyle covariates, including smoking, alcohol consumption, and physical activity, were different across the exposure group among men participants. Meanwhile, in women, lifestyle factors did not show differences across the groups as the P-values from the chi-square and ANOVA test were higher than 0.05.

Table 6. Baseline characteristics of participants according to changes in general obesity

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
	22290	8194 (36.76)	1430 (6.42)	11112 (49.85)	1554 (6.97)	
Sex						0.427
Men	15107 (67.77)	5596 (68.29)	983 (68.74)	7480 (67.31)	1048 (67.44)	
Women	7183 (32.23)	2598 (31.71)	447 (31.26)	3632 (32.69)	506 (32.56)	
Age (years)						
(mean (SD))	56.63 (7.94)	55.97 (7.54)	56.07 (7.01)	56.59 (7.81)	55.58 (7.20)	<0.001
≤50	6921 (31.05)	2699 (32.94)	417 (29.16)	3307 (29.76)	498 (32.05)	<0.001
51-55	5593 (25.09)	2033 (24.81)	339 (23.71)	2836 (25.52)	385 (24.77)	
56-60	4480 (20.10)	1654 (20 19)	297 (20.77)	2206 (19.85)	323 (20.79)	
>60	5296 (23.76)	1808 (22.06)	377 (26.36)	2763 (24.87)	348 (22.39)	
Income						0.130
Low	5256 (23.58)	1875 (22.88)	338 (23.64)	2688 (24.19)	355 (22.84)	
Middle	8156 (36.59)	3049 (37.21)	531 (37.13)	3974 (35.76)	602 (38.74)	
High	8878 (39.83)	3270 (39.91)	561 (39.23)	4450 (40.05)	597 (38.42)	
Follow-up time						<0.001
T3 (2012-2013)	8751 (39.26)	3279 (40.02)	518 (36.22)	4433 (39.89)	521 (33.53)	
T4 (2014-2015)	5936 (26.63)	2163 (26.40)	406 (28.39)	2988 (26.89)	379 (24.39)	
T5 (2016-2017)	4496 (20.17)	1634 (19.94)	315 (22.03)	2189 (19.70)	358 (23.04)	
T6 (2018-2019)	3107 (13.94)	1118 (13.64)	191 (13.36)	1502 (13.52)	296 (19.05)	
Smoking status						<0.001
Never	13496 (62.86)	4958 (63.05)	866 (63.12)	6743 (62.85)	929 (61.60)	
Former	3650 (17.00)	1450 (18.44)	251 (18.29)	1711 (15.95)	238 (15.78)	
Current	4325 (20.14)	1455 (18.50)	255 (18.59)	2274 (21.20)	341 (22.61)	
Alcohol consumption						0.002
Non-drinker	10132 (46.01)	3628 (44.28)	655 (45.80)	5168 (46.51)	681 (43.82)	
Drinker	11891 (53.99)	4441 (54.20)	762 (53.29)	5831 (52.47)	857 (55.15)	
Physical activity						<0.001
No regular exercise	7619 (34.48)	2676 (32.60	482 (33.71)	3958 (35.62)	503 (32.37)	
Regular exercise	14479 (65.52)	5433 (66.3)	935 (65.38)	7074 (63.66)	1037 (66.73)	

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
Hypertension						<0.001
No	15613 (70.04)	5296 (64.63)	963 (67.34)	8224 (74.01)	1130 (72.72)	
Yes	6677 (29.96)	2898 (35.37)	467 (32.66)	2888 (25.99)	424 (27.28)	
Dyslipidemia						<0.001
No	16751 (75.15)	5895 (71.94)	1054 (73.71)	8642 (77.77)	1160 (74.65)	
Yes	5539 (24.85)	2299 (28.06)	376 (26.29)	2470 (22.23)	394 (25.35)	
Family history of diabetes						0.077
No	8514 (38.20)	3210 (39.18)	549 (38.39)	4152 (37.37)	603 (38.80)	
Yes	13776 (61.80)	4984 (60.82)	881 (61.61)	6960 (62.63)	951 (61.20)	
FPG at baseline						<0.001
(mean (SD))	108.95 (6.72)	108.93 (6.67)	109.10 (6.60)	108.70 (6.54)	108.70 (6.40)	
BMI (kg/m^2)						
(mean (SD))	24.60 (2.82)	27.26 (1.94)	25.15 (0.98)	22.65 (1.70)	24.98 (1.28)	<0.001
<18.5	199 (0.89)	0 (0)	0 (0)	198 (1.78)	1 (0.06)	<0.001
18.5-23.4	5953 (26.71)	0 (0)	0 (0)	5848 (52.63)	105 (6.76)	
23.4-24.9	6514 (29.22)	0 (0)	0 (0)	5066 (45.59)	1448 (93.18)	
25.0-29.9	8852 (39.71)	7429 (90.66)	1423 (99.51)	0 (0)	0 (0)	
≥30	772 (3.46)	765 (9.34)	7 (0.49)	0 (0)	0 (0)	
Waist circumference						
(mean (SD))	84.11 (7.72)	89.35 (6.41)	85.36 (4.93)	80.14 (6.39)	85.11 (5.58)	<0.001
Abdominal obesity						<0.001
No	15759 (70.70)	3258 (39.76)	936 (65.45)	10309 (92.77)	1256 (80.82)	
Yes	6531 (29.30)	4936 (60.24)	494 (34.55)	803 (7.23)	298 (19.18)	

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by one-way ANOVA for continuous variables.

Table 7. Baseline characteristics of men participants according to changes in general obesity

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
	15107	5596 (37.04)	983 (6.51)	7480 (49.51)	1048 (6.94)	
Age (years)						
(mean (SD))	55.55 (7.59)	54.06 (6.92)	55.26 (7.59)	55.58 (7.99)	54.61 (7.26)	<0.001
≤50	5366 (35.52)	2169 (38.76)	318 (32.35)	2493 (33.33)	386 (36.83)	<0.001
51-55	3977 (26.33)	1518 (27.13)	261 (26.55)	1929 (25.79)	269 (25.67)	
56-60	2708 (17.93)	1002 (17.91)	182 (18.51)	1323 (17.69)	201 (19.18)	
>60	3056 (20.23)	907 (16.21)	222 (22.58)	1735 (23.2)	192 (18.32)	
Income						0.001
Low	2958 (19.58)	1016 (18.16)	193 (19.63)	1562 (20.88)	187 (17.84)	
Middle	5390 (35.68)	2007 (35.86)	353 (35.91)	2620 (35.03)	410 (39.12)	
High	6759 (44.74)	2573 (45.98)	437 (44.46)	3298 (44.09)	451 (43.03)	
Follow-up time						<0.001
T3 (2012-2013)	5941 (39.33)	2254 (40.28)	341 (34.69)	2997 (40.07)	349 (33.30)	
T4 (2014-2015)	4017 (26.59)	1475 (26.36)	274 (27.87)	2014 (26.93)	254 (24.24)	
T5 (2016-2017)	3038 (20.11)	1099 (19.64)	232 (23.60)	1465 (19.59)	242 (23.09)	
T6 (2018-2019)	2111 (13.97)	768 (13.72)	136 (13.84)	1004 (13.42)	203 (19.37)	
Smoking status						<0.001
Never	6601 (45.77)	2456 (43.89)	434 (44.15)	3266 (43.66)	445 (42.46)	
Former	3610 (25.03)	1436 (25.66)	246 (25.03)	1690 (22.59)	238 (22.71)	
Current	4211 (29.20)	1417 (25.32)	250 (25.43)	2212 (29.57)	332 (31.68)	
Alcohol consumption						0.049
Non-drinker	4417 (29.54)	1581 (28.25)	292 (29.70)	2257 (30.17)	287 (27.39)	
Drinker	10535 (70.46)	3944 (70.48)	681 (69.28)	5157 (68.94)	753 (71.85)	
Physical activity						<0.001
No regular exercise	4647 (31.04)	1574 (28.13)	295 (30.01)	2474 (33.07)	304 (29.01)	
Regular exercise	10323 (68.96)	3960 (70.76)	679 (69.07)	4947 (66.14)	737 (70.32)	
Hypertension						<0.001
No	10650 (70.50)	3704 (66.19)	653 (66.43)	5540 (74.06)	753 (71.85)	
Yes	4457 (29.50)	1892 (33.81)	330 (33.57)	1940 (25.94)	295 (28.15)	

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
Dyslipidemia						<0.001
No	11855 (78.47)	4209 (75.21)	752 (76.50)	6090 (81.42)	804 (76.72)	
Yes	3252 (21.53)	1387 (24.79)	231 (23.50)	1390 (18.58)	244 (23.28)	
Family history of diabetes						0.230
No	5041 (33.37)	1907 (34.08)	345 (35.10)	2444 (32.67)	345 (32.92)	
Yes	10066 (66.63)	3689 (65.92)	638 (64.90)	5036 (67.33)	703 (67.08)	
FPG at baseline						0.056
(mean (SD))	109.21 (6.77)	109.19 (6.67)	109.49 (6.76)	109.11 (6.73)	108.71 (6.41)	
BMI (kg/m^2)						
(mean (SD))	24.56 (2.69)	27.18 (1.73)	25.67 (0.73)	22.57 (1.62)	24.17 (0.75)	<0.001
<18.5	137 (0.91)	0 (0)	0 (0)	136 (1.82)	1 (0.10)	<0.001
18.5-23.4	3855 (25.52)	0 (0)	0 (0)	3788 (50.64)	67 (6.39)	
23.4-24.9	4536 (30.03)	0 (0)	0 (0)	3556 (47.54)	980 (93.51)	
25.0-29.9	6156 (40.75)	5177 (92.51)	979 (99.59)	0 (0)	0 (0)	
≥30	423 (2.80)	419 (7.49)	4 (0.41)	0 (0)	0 (0)	
Waist circumference						<0.001
(mean (SD))	85.81 (7.02)	91.00 (5.65)	87.52 (4.43)	81.71 (5.52)	85.41 (4.51)	
Abdominal obesity						<0.001
No	10733 (71.05)	2250 (40.21)	653 (66.43)	6977 (93.28)	853 (81.39)	
Yes	4374 (28.95)	3346 (59.79)	330 (33.57)	503 (6.72)	195 (18.61)	

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by one-way ANOVA for continuous variables.

Table 8. Baseline characteristics of women participants according to changes in general obesity

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
	7183	2598 (36.17)	447 (6.22)	3632 (50.56)	506 (7.04)	
Age (years)						
(mean (SD))	58.65 (8.18)	58.43 (8.22)	58.59 (8.60)	5787 (8.13)	57.49 (8.08)	<0.001
≤50	1555 (21.65)	530 (20.40)	99 (22.15)	814 (22.41)	112 (22.13)	<0.001
51-55	1616 (22.50)	515 (19.82)	78 (17.45)	907 (24.97)	116 (22.92)	
56-60	1772 (24.67)	652 (25.10)	115 (25.73)	883 (24.31)	122 (24.11)	
>60	2240 (31.18)	901 (34.68)	155 (34.68)	1028 (28.30)	156 (30.83)	
Income						0.005
Low	2298 (31.99)	859 (33.06)	145 (32.44)	1126 (31.00)	168 (33.20)	
Middle	2766 (38.51)	1042 (40.11)	178 (39.82)	1354 (37.28)	192 (37.94)	
High	2119 (29.50)	697 (26.83)	124 (27.74)	1152 (31.72)	146 (28.85)	
Follow-up time						0.047
T3 (2012-2013)	2810 (39.12)	1025 (39.45)	170 (39.60)	1436 (39.54)	172 (33.99)	
T4 (2014-2015)	1919 (26.72)	688 (26.48)	132 (29.53)	974 (26.82)	125 (24.70)	
T5 (2016-2017)	1458 (20.30)	535 (20.59)	83 (18.57)	724 (19.93)	116 (22.92)	
T6 (2018-2019)	996 (13.87)	350 (13.47)	55 (12.30)	498 (13.71)	93 (18.38)	
Smoking status						0.339
Never	6895 (97.82)	2502 (96.30)	432 (96.64)	3477 (95.73)	484 (95.65)	
Former	40 (0.57)	14 (0.54)	5 (1.12)	21 (0.58)	0 (0)	
Current	114 (1.62)	38 (1.40	5 (1.12)	62 (1.71)	9 (1.78)	
Alcohol consumption						0.114
Non-drinker	5715 (80.82)	2047 (78.79)	363 (81.21)	2911 (80.15)	394 (77.87)	
Drinker	1356 (19.18)	497 (19.13)	81 (18.12)	674 (18.56)	104 (20.55)	
Physical activity						0.290
No regular exercise	2972 (41.69)	1102 (42.42)	187 (41.83)	1484 (40.86)	199 (39.33)	
Regular exercise	4156 (58.31)	1473 (56.70)	256 (57.27)	2127 (58.56)	300 (59.29)	
Hypertension						<0.001
No	4963 (69.09)	1592 (61.28)	310 (69.35)	2684 (73.90)	377 (74.51)	
Yes	2220 (30.91)	1006 (38.72)	137 (30.65)	948 (26.10)	129 (25.49)	

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
Dyslipidemia						0.005
No	4896 (68.16)	1686 (64.90)	302 (67.56)	2552 (70.26)	356 (70.36)	
Yes	2287 (31.84)	912 (35.10)	145 (32.44)	1080 (29.74)	150 (29.64)	
Family history of diabetes						0.034
No	3473 (48.35)	1303 (50.15)	204 (45.64)	1708 (47.03)	258 (50.99)	
Yes	3710 (51.65)	1295 (49.85)	243 (54.36)	1924 (52.97)	248 (49.01)	
FPG at baseline						<0.001
(mean (SD))	108.46 (6.59)	108.82 (6.67)	109.47 (6.81)	108.24 (6.46)	107.74 (5.83)	
BMI (kg/m^2)						
(mean (SD))	24.66 (3.05)	27.61 (2.10)	25.81 (0.92)	22.37 (1.61)	24.10 (0.71)	<0.001
<18.5	62 (0.86)	0 (0)	0 (0)	62 (1.71)	0 (0)	<0.001
18.5-23.4	2098 (29.21)	0 (0)	0 (0)	2060 (56.72)	38 (7.51)	
23.4-24.9	1978 (27.54)	0 (0)	0 (0)	1510 (41.57)	468 (92.49)	
25.0-29.9	2696 (37.53)	2252 (86.68)	444 (99.33)	0 (0)	0 (0)	
≥30	349 (4.86)	346 (13.32)	3 (0.67)	0 (0)	0 (0)	
Waist circumference						<0.001
(mean (SD))	80.91 (7.96)	86.59 (6.46)	82.96 (5.19)	76.21 (6.05)	8082 (5.69)	
Abdominal obesity						<0.001
No	5026 (69.97)	1008 (38.80)	283 (63.31)	3332 (91.74)	403 (79.64)	
Yes	2157 (30.03)	1590 (61.20)	164 (36.69)	300 (8.26)	103 (20.36)	

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by one-way ANOVA for continuous variables.

Table 9 presents the baseline characteristics of the participants according to the changes in abdominal obesity status among all participants. A larger proportion was observed in the ‘stable non-obese’ group (60.57%), followed by the ‘stable obese’ group (19.24%), the ‘non-obese to obese’ (10.13%), and lastly the ‘obese to non-obese’ group (10.06%). Opposite from the changes in general obesity, the distribution of alcohol consumption and physical activity were not different across the exposure groups. Furthermore, the ‘stable non-obese’ group was found to have a higher number of participants who had a BMI lower than 25 kg/m^2, unlike the other groups, in which the distribution was the opposite. This distribution was also similar in men and women (Table 10 and Table 11).

Among men participants, more people were in the ‘obese to non-obese’ group (10.04%) compared to the ‘non-obese to obese’ group (9.58%) (Table 10). Meanwhile, among women participants, the proportion of ‘obese to non-obese’ group (10.11%) was slightly smaller than the ‘non-obese to obese’ group (11.26%) (Table 11).

Table 9. Baseline characteristics of participants according to changes in abdominal obesity

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
	22290	4289 (19.24)	2242 (10.06)	13502 (60.57)	2257 (10.13)	
Sex						<0.001
Men	15107 (67.77)	2858 (66.64)	1516 (67.62)	9285 (68.77)	1448 (64.16)	
Women	7183 (32.23)	1431 (33.36)	726 (32.38)	4217 (31.23)	809 (35.84)	
Age (years)						
(mean (SD))	56.63 (7.94)	57.03 (8.35)	56.63 (8.22)	55.28 (7.63)	5686 (7.88)	0.001
≤50	6921 (31.05)	1147 (26.74)	651 (29.04)	4481 (33.19)	642 (28.44)	<0.001
51-55	5593 (25.09)	1006 (23.46)	500 (22.30)	3529 (26.14)	558 (24.72)	
56-60	4480 (20.10)	886 (20.66)	462 (20.61)	2673 (19.80)	459 (20.34)	
>60	5296 (23.76)	1250 (29.14)	629 (28.06)	2819 (20.89)	598 (26.50)	
Income						0.004
Low	5256 (23.58)	1065 (24.83)	522 (23.28)	3146 (23.30)	523 (23.17)	
Middle	8156 (36.59)	1642(38.28)	803 (35.82)	4890 (36.02)	821 (36.38)	
High	8878 (39.83)	1582 (36.89)	917 (40.90)	5466 (40.48)	913 (40.45)	
Follow-up time						<0.001
T3 (2012-2013)	8751 (39.26)	1732 (40.38)	865 (38.58)	5378 (39.83)	776 (34.38)	
T4 (2014-2015)	5936 (26.63)	1118 (26.07)	618 (27.56)	3617 (26.79)	583 (25.83)	
T5 (2016-2017)	4496 (20.17)	864 (20.14)	469 (20.92)	2661 (19.71)	502 (22.24)	
T6 (2018-2019)	3107 (13.94)	575 (13.41)	290 (12.93)	1846 (13.67)	396 (17.55)	
Smoking status						<0.001
Never	13496 (62.86)	2616 (60.99)	1361 (60.70)	8132 (60.23)	1387 (61.45)	
Former	3650 (17.00)	724 (16.88)	414 (18.47)	2164 (16.03)	348 (15.42)	
Current	4325 (20.14)	783 (18.26)	368 (16.41)	2733 (20.24)	441 (19.54)	
Alcohol consumption						0.089
Non-drinker	10132 (46.01)	1956 (45.61)	1038 (46.30)	6105 (45.22)	1033 (45.77)	
Drinker	11891 (53.99)	2268 (52.88)	1179 (52.59)	7256 (53.74)	1188 (52.64)	
Physical activity						0.142
No regular exercise	7619 (34.48)	1526 (35.58)	780 (34.79)	4545 (33.66)	768 (34.03)	
Regular exercise	14479 (65.52)	2727 (63.58)	1441 (64.27)	8849 (65.54)	1462 (64.78)	

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
Hypertension						<0.001
No	15613 (70.04)	2620 (61.09)	1472 (65.66)	10000 (74.06)	1521 (67.39)	
Yes	6677 (29.96)	1669 (38.91)	770 (34.34)	3502 (25.94)	736 (32.61)	
Dyslipidemia						<0.001
No	16751 (75.15)	3008 (70.13)	1646 (3.42)	10449 (77.39)	1648 (73.02)	
Yes	5539 (24.85)	1281 (29.87)	596 (26.58)	3053 (22.61)	609 (26.98)	
Family history of diabetes						<0.001
No	8514 (38.20)	1749 (40.78)	830 (37.02)	4976 (36.85)	959 (42.49)	
Yes	13776 (61.80)	2540 (59.22)	1412 (62.98)	8526 (63.15)	1298 (57.51)	
FPG at baseline						<0.001
(mean (SD))	108.95 (6.72)	109.16 (6.74)	109.51 (6.72)	108.78(6.62)	108.78 (6.51)	
BMI (kg/m^2)						
(mean (SD))	24.60 (2.82)	27.67 (2.36)	25.97 (1.92)	23.27 (2.12)	25.32 (1.92)	<0.001
<18.5	199 (0.89)	1 (0.02)	0 (0)	198 (1.47)	0 (0)	<0.001
18.5-23.4	5953 (26.71)	36 (0.84)	116 (5.17)	5567 (41.23)	234 (10.37)	
23.4-24.9	6514 (29.22)	399 (9.3)	549 (24.49)	4851 (35.93)	715 (31.68)	
25.0-29.9	8852 (39.71)	3177 (74.07)	1517 (67.66)	2875 (21.29)	1283 (56.85)	
≥30	772 (3.46)	676 (15.76)	60 (2.68)	11 (0.08)	25 (1.11)	
Waist circumference						<0.001
(mean (SD))	84.11 (7.72)	93.50 (4.84)	90.82 (3.25)	80.12 (5.66)	83.76 (4.14)	
Abdominal obesity						<0.001
No	15759 (70.70)	0 (0)	0 (0)	13502 (100)	2257 (100)	
Yes	6531 (29.30)	4289 (100)	2242 (100)	0 (0)	0 (0)	

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by one-way ANOVA for continuous variables.

Table 10. Baseline characteristics of men participants according to changes in abdominal obesity

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
	15107	2858 (18.92)	1516 (10.04)	9285 (61.46)	1448 (9.58)	
Age (years)						
(mean (SD))	55.55 (7.59)	55.36 (7.75)	55.27 (7.70)	54.73 (7.50)	54.99 (7.41)	<0.001
≤50	5366 (35.52)	947 (33.14)	526 (34.70)	3395 (36.56)	498 (34.39)	<0.001
51-55	3977 (26.33)	751 (26.28)	359 (23.68)	2473 (26.63)	394 (27.21)	
56-60	2708 (17.93)	542 (18.96)	287 (18.93)	1627 (17.52)	252 (17.40)	
>60	3056 (20.23)	618 (21.62)	344 (22.69)	1790 (19.28)	304 (20.99)	
Income						0.047
Low	2958 (19.58)	587 (20.54)	306 (20.18)	1798 (19.36)	267 (18.44)	
Middle	5390 (35.68)	1067 (37.33)	509 (33.58)	3293 (35.47)	521 (35.98)	
High	6759 (44.74)	1204 (42.13)	701 (46.24)	4194 (45.17)	660 (45.58)	
Follow-up time						<0.001
T3 (2012-2013)	5941 (39.33)	1159 (40.55)	577 (38.06)	3699 (39.84)	506 (34.94)	
T4 (2014-2015)	4017 (26.59)	775 (27.12)	407 (26.85)	2470 (26.60)	365 (25.21)	
T5 (2016-2017)	3038 (20.11)	554 (19.38)	327 (21.57)	1843 (19.85)	314 (21.69)	
T6 (2018-2019)	2111 (13.97)	370 (12.95)	205 (13.52)	1273 (13.71)	263 (18.16)	
Smoking status						<0.001
Never	6601 (45.77)	1230 (43.04)	667 (44.00)	4095 (44.10)	609 (42.06)	
Former	3610 (25.03)	718 (25.12)	407 (26.85)	2141 (23.06)	344 (23.76)	
Current	4211 (29.20)	767 (26.84)	356 (23.48)	2661 (28.66)	427 (29.49)	
Alcohol consumption						0.089
Non-drinker	4417 (29.54)	806 (28.20)	445 (29.35)	2766 (29.79)	400 (27.62)	
Drinker	10535 (70.46)	2011 (70.36)	1056 (69.66)	6437 (69.33)	1031 (71.20)	
Physical activity						0.583
No regular exercise	4647 (31.04)	865 (30.27)	466 (30.74)	2868 (30.89)	448 (30.94)	
Regular exercise	10323 (68.96)	1967 (68.82)	1036 (68.34)	6340 (68.28)	980 (67.68)	
Hypertension						
No	10650 (70.50)	1787 (62.53)	1015 (66.95)	6857 (73.85)	991 (68.44)	
Yes	4457 (29.50)	1071 (37.47)	501 (33.05)	2428 (26.15)	457 (31.56)	

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
Dyslipidemia						<0.001
No	11855 (78.47)	2083 (70.88)	1160 (76.52)	7514 (80.93)	1098 (75.83)	
Yes	3252 (21.53)	775 (27.12)	356 (23.48)	1771 (19.07)	350 (24.17)	
Family history of diabetes						<0.001
No	5041 (33.37)	1041 (36.42)	488 (32.19)	2989 (32.19)	523 (36.12)	
Yes	10066 (66.63)	1817 (63.58)	1028 (67.81)	6296 (67.81)	925 (63.88)	
FPG at baseline						0.001
(mean (SD))	109.21 (6.77)	109.32 (6.76)	109.68(6.71)	109.00 (6.67)	109.09 (6.60)	
BMI (kg/m^2)						
(mean (SD))	24.56 (2.69)	27.53 (2.19)	25.98 (1.78)	23.34 (2.09)	25.35 (1.84)	<0.001
<18.5	137 (0.91)	1 (0.03)	0 (0)	136 (1.46)	0 (0)	<0.001
18.5-23.4	3855 (25.52)	19 (0.66)	62 (4.09)	3639 (39.19)	135 (9.32)	
23.4-24.9	4536 (30.03)	251 (8.78)	365 (24.08)	3463 (37.30)	457 (31.56)	
25.0-29.9	6156 (40.75)	2212 (77.40)	1059 (69.85)	2043 (22.00)	842 (58.15)	
≥30	423 (2.80)	375 (13.12)	30 (1.98)	4 (0.04)	14 (0.97)	
Waist circumference						<0.001
(mean (SD))	85.81 (7.02)	94.89 (4.23)	92.13 (2.41)	81.96 (4.84)	85.73 (3.20)	
Abdominal obesity						<0.001
No	10733 (71.05)	0 (0)	0 (0)	9285 (100)	1448 (100)	
Yes	4374 (28.95)	2858 (100)	1516 (100)	0 (0)	0 (0)	

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by one-way ANOVA for continuous variables.

Table 11. Baseline characteristics of women participants according to changes in abdominal obesity

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
	7183	1431 (19.92)	72.6 (10.11)	4217 (58.71)	809 (11.26)	
Age (years)						
(mean (SD))	58.65 (8.18)	60.39 (8.50)	59.45 (8.57)	56.51 (7.77)	58.82 (8.10)	<0.001
≤50	1555 (21.65)	200 (13.98)	125 (17.82)	1086 (25.75)	144 (17.80)	<0.001
51-55	1616 (22.50)	255 (17.82)	141 (19.42)	1056 (25.04)	164 (20.27)	
56-60	1772 (24.67)	344 (24.04)	175 (24.10)	1046 (24.80)	207 (25.59)	
>60	2240 (31.18)	632 (44.16)	285 (39.26)	1029 (24.40)	294 (36.34)	
Income						0.093
Low	2298 (31.99)	478 (33.40)	216 (29.75)	1348 (31.97)	256(31.64)	
Middle	2766 (38.51)	575 (40.18)	294 (40.50)	1597 (37.87)	300 (37.08)	
High	2119 (29.50)	378 (26.42)	216 (29.75)	1272 (30.16)	253 (31.27)	
Follow-up time						0.001
T3 (2012-2013)	2810 (39.12)	573 (40.04)	288 (39.67)	1679 (39.82)	270 (33.37)	
T4 (2014-2015)	1919 (26.72)	343 (23.97)	211 (29.06)	1147 (27.20)	218 (26.95)	
T5 (2016-2017)	1458 (20.30)	310 (21.66)	142 (19.56)	818 (19.40)	188 (23.84)	
T6 (2018-2019)	996 (13.87)	205 (14.33)	85 (11.71)	573 (13.59)	133 (16.44)	
Smoking status						0.669
Never	6895 (97.82)	1386 (96.86)	694 (95.59)	4037 (95.73)	778 (96.17)	
Former	40 (0.57)	6 (0.42)	7 (0.96)	23 (0.55)	4 (0.49)	
Current	114 (1.62)	16 (1.12)	12 (1.65)	72 (1.71)	14 (1.73)	
Alcohol consumption						0.250
Non-drinker	5715 (80.82)	1150 (80.36)	593 (81.68)	3339 (79.18)	633 (78.24)	
Drinker	1356 (19.18)	257 (17.96)	123 (16.94)	819 (19.42)	157 (19.41)	
Physical activity						0.002
No regular exercise	2972 (41.69)	661 (46.19)	314 (43.25)	1677 (39.77)	320 (39.56)	
Regular exercise	4156 (58.31)	760 (53.11)	405 (55.79)	2509 (59.50)	482 (59.58)	
Hypertension						<0.001
No	4963 (69.09)	833 (58.21)	457 (62.95)	3143 (74.53)	530 (65.51)	
Yes	2220 (30.91)	598 (41.79)	269 (37.05)	1074 (25.47)	279 (34.49)	

	Total	Stable obese	Obese to non-obese	Stable non-obese	Non-obese to obese	P-value
Dyslipidemia						0.005
No	4896 (68.16)	925 (64.64)	486 (66.94)	2935 (69.60)	550 (67.99)	
Yes	2287 (31.84)	506 (35.36)	240 (33.06)	1282 (30.40)	259 (32.01)	
Family history of diabetes						0.003
No	3473 (48.35)	708 (49.48)	342 (47.11)	1987 (47.12)	436 (53.89)	
Yes	3710 (51.65)	723 (50.52)	384 (52.89)	2230 (52.88)	373 (46.11)	
FPG at baseline						0.001
(mean (SD))	108.46 (6.59)	108.86 (6.68)	109.16 (6.73)	108.30 (6.47)	108.23 (6.32)	
BMI (kg/m^2)						
(mean (SD))	24.66 (3.05)	27.95 (2.64)	25.95 (2.19)	23.11 (2.17)	25.26 (2.05)	<0.001
<18.5	62 (0.86)	0 (0)	0 (0)	62 (1.47)	0 (0)	<0.001
18.5-23.4	2098 (29.21)	17 (1.19)	54 (7.44)	1928 (45.72)	99 (12.24)	
23.4-24.9	1978 (27.54)	148 (10.34)	184 (25.34)	1388 (32.91)	258 (31.89)	
25.0-29.9	2696 (37.53)	965 (67.44)	458 (63.09)	832 (19.73)	441 (54.51)	
≥30	349 (4.86)	301 (21.03)	30 (4.13)	7 (0.17)	11 (1.36)	
Waist circumference						<0.001
(mean (SD))	80.91 (7.96)	90.72 (4.78)	88.09 (3.08)	76.07 (5.20)	80.23 (3.18)	
Abdominal obesity						<0.001
No	5026 (69.97)	0 (0)	0 (0)	4217 (100)	809 (100)	
Yes	2157 (30.03)	1431 (100)	726 (100)	0 (0)	0 (0)	

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by one-way ANOVA for continuous variables.

Associations between changes in general obesity and changes in glycemic status

Distribution of outcomes according to changes in general obesity is presented in Table 12. A larger number of participants who had prediabetes persistence and reversion to normoglycemia came from the ‘stable non-obese’ group (50.97% and 54.94% respectively). This distribution is consistent in men and women participants. For diabetes progression in men, higher proportion was observed in the ‘stable non-obese’ group (43.74%), while in women, higher proportion was observed in the ‘stable obese’ group (43.52).

The association between changes in general obesity and changes in prediabetes glycemic status is shown in Table 13. Compared with the ‘stable obese’ group, greater odds of reversion to normoglycemia was observed in the ‘obese to non-obese’ (OR 1.22, 95% CI 1.04–1.43) and ‘stable non-obese’ (OR 1.17, 95% CI 1.08–1.26). This result is consistent across all models. Furthermore, the ‘stable non-obese’ group (OR 0.69, 95% CI 0.64–0.75) and ‘non-obese to obese’ group (OR 0.73, 95% CI 0.63–0.84) showed lower odds of diabetes progression compared with ‘stable obese’ group. The results among men participants were consistent with the results among all participants. Meanwhile, in women, a significant result for reversion to normoglycemia was only found in the ‘stable non-obese’ group (OR 1.20, 95% CI 1.04–1.38). Nevertheless, the effect sizes appeared to be similar among men and women.

Table 12. Distribution of outcome according to changes in general obesity

Changes in general obesity	Total N (%)	Control (Prediabetes persistence) N (%)	Case 1 (Reversion to normoglycemia) N (%)	Case 2 (Progression to diabetes) N (%)
	22290	8159 (36.60)	7062 (31.68)	7069 (31.71)
All				
Stable obese	8194 (36.76)	2924 (35.84)	2228 (31.55)	3042 (43.03)
Obese to non-obese	1430 (6.42)	504 (6.18)	465 (6.58)	461 (6.52)
Stable non-obese	11112 (49.85)	4159 (50.97)	3880 (54.94)	3073 (43.47)
Non-obese to obese	1554 (6.97)	572 (7.01)	489 (6.92)	493 (6.97)
Missing	8814	2209	3306	3299
Men				
Stable obese	5596 (37.04)	1986 (36.08)	1565 (32.44)	2045 (42.80)
Obese to non-obese	983 (6.51)	347 (6.30)	325 (6.74)	311 (6.51)
Stable non-obese	7480 (49.51)	2795 (50.77)	2595 (53.79)	2090 (43.74)
Non-obese to obese	1048 (6.94)	377 (6.85)	339 (7.03)	332 (6.95)
Missing	5236	1276	1957	2003
Women				
Stable obese	2598 (36.17)	938 (35.34)	663 (29.62)	997 (43.52)
Obese to non-obese	447 (6.22)	157 (5.92)	140 (6.26)	150 (6.55)
Stable non-obese	3632 (50.56)	1364 (51.39)	1285 (57.42)	983 (42.91)
Non-obese to obese	506 (7.04)	195 (7.35)	150 (6.70)	161 (7.03)
Missing	3578	933	1349	1296

Table 13. Odds ratios of reversion to normoglycemia and progression to diabetes by changes in general obesity

	Reversion to normoglycemia OR (95% CI)			Progression to diabetes OR (95% CI)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
All						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.21 (1.04-1.42)	1.21 (1.04-1.42)	1.22 (1.04-1.43)	0.90 (0.77-1.05)	0.90 (0.77-1.05)	0.87 (0.75-1.02)
Stable non-obese	1.18 (1.09-1.28)	1.17 (1.09-1.27)	1.17 (1.08-1.26)	0.69 (0.64-0.75)	0.68 (0.63-0.74)	0.69 (0.64-0.75)
Non-obese to obese	0.96 (0.83-1.11)	0.96 (0.83-1.11)	0.94 (0.81-1.08)	0.71 (0.62-0.82)	0.70 (0.61-0.81)	0.73 (0.63-0.84)
Men						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.23 (1.02-1.49)	1.22 (1.01-1.48)	1.24 (1.02-1.49)	0.92 (0.76-1.11)	0.91 (0.75-1.10)	0.89 (0.74-1.08)
Stable non-obese	1.17 (1.06-1.29)	1.16 (1.05-1.27)	1.15 (1.05-1.27)	0.73 (0.66-0.80)	0.71 (0.65-0.78)	0 .71 (0.65-0.79)
Non-obese to obese	0.92 (0.77-1.10)	0.91 (0.77-1.09)	0.90 (0.75-1.07)	0.70 (0.58-0.83)	0.68 (0.57-0.81)	0.69 (0.58-0.82)
Women						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.18 (0.89-1.56)	1.18 (0.89-1.56)	1.19 (0.89-1.57)	0.86 (0.65-1.14)	0.86 (0.65-1.14)	0.82 (0.62-1.09)
Stable non-obese	1.20 (1.05-1.38)	1.21 (1.05-1.39)	1.20 (1.04-1.38)	0.62 (0.54-0.71)	0.62 (0.54-0.72)	0.63 (0.55-0.73)
Non-obese to obese	1.05 (0.81-1.36)	1.05 (0.81-1.37)	1.03 (0.79-1.34)	0.75 (0.58-0.97)	0.75 (0.58-0.97)	0.80 (0.61-1.03)

Model 1: adjusted for sex and age at baseline.

Model 2: adjusted for sex, age, smoking status, alcohol consumption, and physical activity.

Model 3: adjusted for sex, age, income, lifestyle factors, hypertension, dyslipidemia, family history of diabetes, and fasting plasma glucose at baseline.

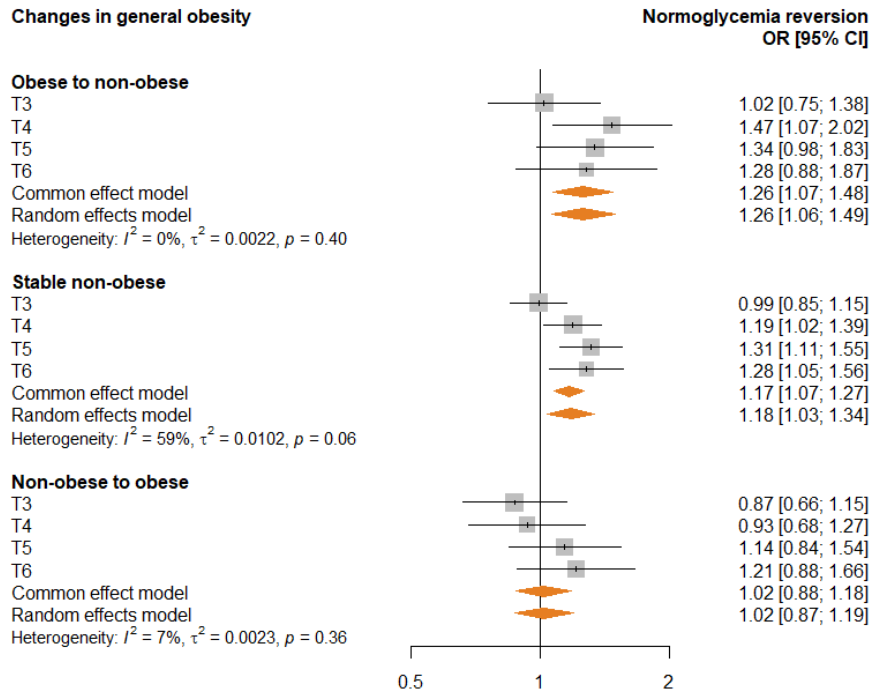
The ORs of the shift in prediabetes by changes in general obesity in each follow-up time group are presented in Table 14. The results indicated that the effect sizes were different across the groups, and the significant ORs of reversion to normoglycemia were only apparent in the longer follow-up time groups, T4 until T6 groups. Furthermore, the heterogeneity test results also indicated that there was a substantial difference across follow-up time group in the association of 'stable non-obese' with reversion to normoglycemia (I^2 = 59% and P-value of Q test = 0.06) and progression to diabetes (I^2 = 52%). Although the results appeared to be different across the follow-up time groups, the random effect model from the meta-analysis showed that there was significant associations between 'obese to non-obese' group (OR 1.26, 95% CI 1.06–1.49), as well as 'stable non-obese' group (OR 1.18, 95% CI 103–1.34) and reversion to normoglycemia; also between 'stable non-obese' (OR 0.69, 95% CI 0.61–0.78), as well as 'non-obese to obese' (OR 0.80, 95% CI 0.65–0.98) and progression to diabetes (Figure 5). Likewise, the results from common effect models also showed that 'obese to non-obese' and 'stable non-obese' were associated with reversion to normoglycemia (OR 1.29, 95% CI 1.07–1.48 and 1.17, 95% CI 1.07–1.27 respectively); and 'stable non-obese' as well as 'non-obese to obese' were associated with progression to diabetes (OR 0.68, 95% CI 0.61–0.78 and 0.79, 95% CI 0.69–0.92 respectively). These results are similar to that of the findings from the pooled analysis. Detailed information on the distribution of outcomes according to changes in general obesity in each follow-up time group can be found in Appendix 14.

Table 14. Odds ratios of changes in glycemic status by changes in general obesity in each follow-up time group

	Reversion to normoglycemia OR (95% CI)			Progression to diabetes OR (95% CI)		
	Model 1	Model 2	Model 3	Model 2	Model 2	Model 3
T3						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.03 (0.76-1.38)	1.02 (0.76-1.38)	1.02 (0.76-1.38)	0.81 (0.60-1.08)	0.80 (0.60-1.08)	0.79 (0.59-1.07)
Stable non-obese	1.01 (0.88-1.17)	1.00 (0.87-1.16)	0.99 (0.85-1.15)	0.61 (0.53-0.70)	0.60 (0.52-0.69)	0.61 (0.52-0.70)
Non-obese to obese	0.90 (0.68-1.19)	0.89 (0.67-1.18)	0.87 (0.66-1.15)	0.62 (0.47-0.82)	0.61 (0.46-0.80)	0.62 (0.46-0.82)
T4						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.47 (1.07-2.02)	1.46 (1.06-2.00)	1.47 (1.07-2.02)	1.05 (0.77-1.44)	1.04 (0.75-1.42)	1.02 (0.74-1.40)
Stable non-obese	1.19 (1.02-1.40)	1.19 (1.02-1.39)	1.19 (1.01-1.39)	0.69 (0.59-0.80)	0.68 (0.58-0.79)	0.69 (0.59-0.81)
Non-obese to obese	0.96 (0.71-1.29)	0.96 (0.71-1.31)	0.93 (0.69-1.27)	0.77 (0.57-1.04)	0.77 (0.57-1.04)	0.82 (0.61-1.11)
T5						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.31 (0.96-1.78)	1.31 (0.96-1.79)	1.34 (0.98-1.83)	0.82 (0.60-1.12)	0.82 (0.60-1.12)	0.79 (0.58-1.08)
Stable non-obese	1.29 (1.09-1.52)	1.29 (1.09-1.53)	1.31 (1.11-1.55)	0.71 (0.60-0.83)	0.71 (0.60-0.83)	0.69 (0.59-0.82)
Non-obese to obese	1.15 (0.85-1.54)	1.15 (0.85-1.54)	1.14 (0.85-1.54)	0.80 (0.60-1.07)	0.79 (0.59-1.06)	0.81 (0.60-1.08)
T6						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.25 (0.86-1.83)	1.26 (0.86-1.84)	1.28 (0.87-1.87)	1.07 (0.74-1.55)	1.09 (0.75-1.58)	1.03 (0.71-1.51)
Stable non-obese	1.29 (1.07-1.56)	1.29 (1.06-1.56)	1.28 (1.06-1.56)	0.81 (0.67-0.97)	0.80 (0.66-0.96)	0.82 (0.68-0.99)
Non-obese to obese	1.20 (0.88-1.65)	1.22 (0.89-1.67)	1.21 (0.88-1.66)	1.01 (0.74-1.38)	1.00 (0.73-1.36)	1.02 (0.74-1.39)

Model 1: adjusted for sex and age at baseline.
Model 2: adjusted for sex, age, smoking status, alcohol consumption, and physical activity.
Model 3: adjusted for sex, age, income, lifestyle factors, hypertension, dyslipidemia, family history of diabetes, and fasting plasma glucose at baseline.

(a)



(b)

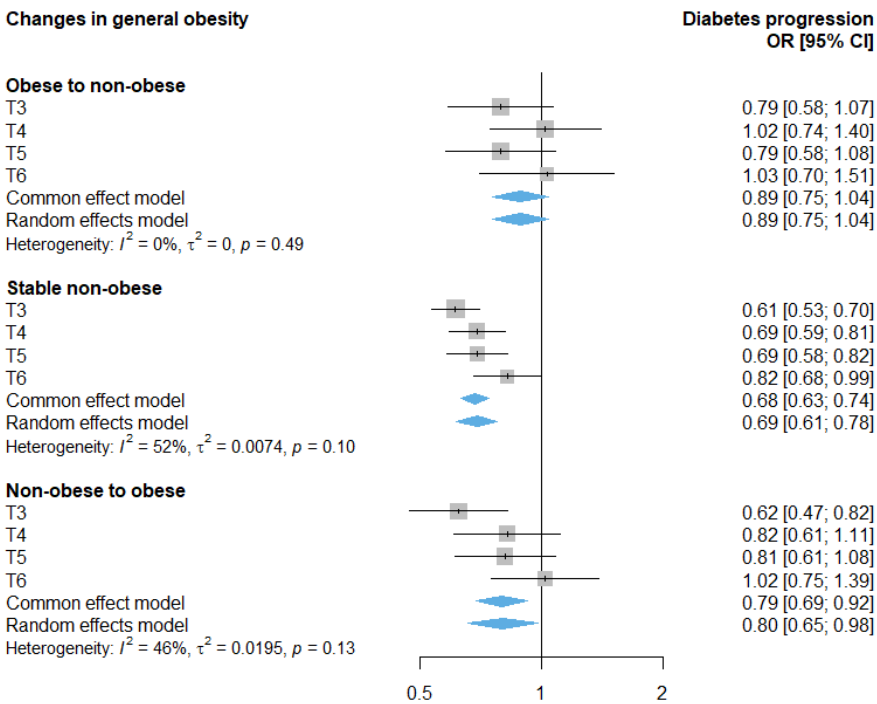


Figure 5. Forest plot of meta-analysis of changes in glycemic status by changes in general obesity. (a) Reversion to normoglycemia; (b) Progression to diabetes.

Associations between changes in abdominal obesity and changes in glycemic status

Distribution of outcomes according to changes in abdominal obesity is presented in Table 15. A higher proportion of participants was found in the 'non-obese' group (62.29% for prediabetes persistence, 64.90% for reversion to normoglycemia, and 54.28% for progression to diabetes). This distribution is consistent in men and women participants.

The association between changes in abdominal obesity and changes in prediabetes glycemic status is shown in Table 16. Compared with the 'stable obese' group, the 'obese to non-obese' and 'stable non-obese' group showed greater odds of reversion to normoglycemia (OR 1.22, 95% CI 1.06–1.41 and OR 1.71, 95% CI 1.06–1.30 respectively) as well as lower odds of progression to diabetes (OR 0.82, 95% CI 0.71–0.94 and OR 0.65, 95% CI 0.59–0.71). Furthermore, a change from non-obese to obese also showed lower odds of diabetes progression (OR 0.80, 95% CI 0.70–0.92). These results are consistent with the analysis among men participants. In women, a significant result was only observed in the association between 'stable non-obese' and diabetes progression (OR 0.62, 95% CI 0.53–0.74). Although the other groups did not show significant results with either reversion to normoglycemia reversion or progression to diabetes, the effect sizes and directions were similar to the findings from the analysis of all participants.

Table 15. Distribution of outcome according to changes in abdominal obesity

Changes in general obesity	Total N (%)	Control (Prediabetes persistence) N (%)	Case 1 (Reversion to normoglycemia) N (%)	Case 2 (Progression to diabetes) N (%)
All				
Stable obese	4289 (19.24)	1476 (18.09)	1104 (15.63)	1709 (24.18)
Obese to non-obese	2242 (10.06)	806 (9.88)	699 (9.90)	737 (10.43)
Stable non-obese	13502 (60.57)	5082 (62.29)	4583 (64.90)	3837 (54.28)
Non-obese to obese	2257 (10.13)	795 (9.74)	676 (9.57)	786 (11.12)
Missing	8814	2209	3306	3299
Men				
Stable obese	2858 (18.92)	985 (17.89)	733 (15.19)	1140 (23.86)
Obese to non-obese	1516 (10.04)	549 (9.97)	482 (9.99)	485 (10.15)
Stable non-obese	9285 (61.46)	3472 (63.07)	3169 (65.69)	2644 (55.34)
Non-obese to obese	1448 (9.58)	499 (9.06)	440 (9.12)	509 (10.65)
Missing	5236	1276	1957	2003
Women				
Stable obese	1431 (19.92)	491 (18.50)	371 (16.58)	569 (24.84)
Obese to non-obese	726 (10.11)	257 (9.68)	217 (9.70)	252 (11.00)
Stable non-obese	4217 (58.71)	1610 (60.66)	1414 (63.18)	1193 (52.07)
Non-obese to obese	809 (11.26)	296 (11.15)	236 (10.55)	277 (12.09)
Missing	3578	933	1349	1296

Table 16. Odds ratios of reversion to normoglycemia and progression to diabetes by changes in abdominal obesity

	Reversion to normoglycemia OR (95% CI)			Progression to diabetes OR (95% CI)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
All						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.20 (1.04-1.39)	1.20 (1.04-1.39)	1.22 (1.06-1.41)	0.83 (0.72-0.96)	0.84 (0.73-0.96)	0.82 (0.71-0.94)
Stable non-obese	1.18 (1.07-1.31)	1.18 (1.07-1.30)	1.17 (1.06-1.30)	0.64 (0.58-0.70)	0.64 (0.58-0.70)	0.65 (0.59-0.71)
Non-obese to obese	1.06 (0.92-1.22)	1.06 (0.92-1.22)	1.06 (0.92-1.22)	0.79 (0.69-0.90)	0.78 (0.68-0.90)	0.80 (0.70-0.92)
Men						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.19 (1.00-1.42)	1.19 (1.00-1.42)	1.22 (1.02-1.45)	0.78 (0.66-0.92)	0.78 (0.66-0.91)	0.77 (0.65-0.91)
Stable non-obese	1.19 (1.06-1.34)	1.19 (1.06-1.34)	1.18 (1.05-1.34)	0.64 (0.57-0.72)	0.64 (0.57-0.72)	0.65 (0.58-0.73)
Non-obese to obese	1.03 (0.86-1.23)	1.03 (0.86-1.23)	1.03 (0.86-1.23)	0.77 (0.65-0.91)	0.77 (0.65-0.90)	0.77 (0.65-0.92)
Women						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.22 (0.95-1.58)	1.22 (0.95-1.58)	1.24 (0.96-1.60)	0.96 (0.75-1.22)	0.95 (0.74-1.22)	0.92 (0.72-1.19)
Stable non-obese	1.16 (0.97-1.38)	1.16 (0.97-1.38)	1.15 (0.97-1.37)	0.62 (0.53-0.73)	0.62 (0.53-0.73)	0.62 (0.53-0.74)
Non-obese to obese	1.12 (0.88-1.42)	1.12 (0.87-1.42)	1.11 (0.87-1.42)	0.82 (0.65-1.04)	0.82 (0.65-1.04)	0.84 (0.66-1.07)

Model 1: adjusted for sex and age at baseline.
Model 2: adjusted for sex, age, smoking status, alcohol consumption, and physical activity.
Model 3: adjusted for sex, age, income, lifestyle factors, hypertension, dyslipidemia, family history of diabetes, and fasting plasma glucose at baseline.

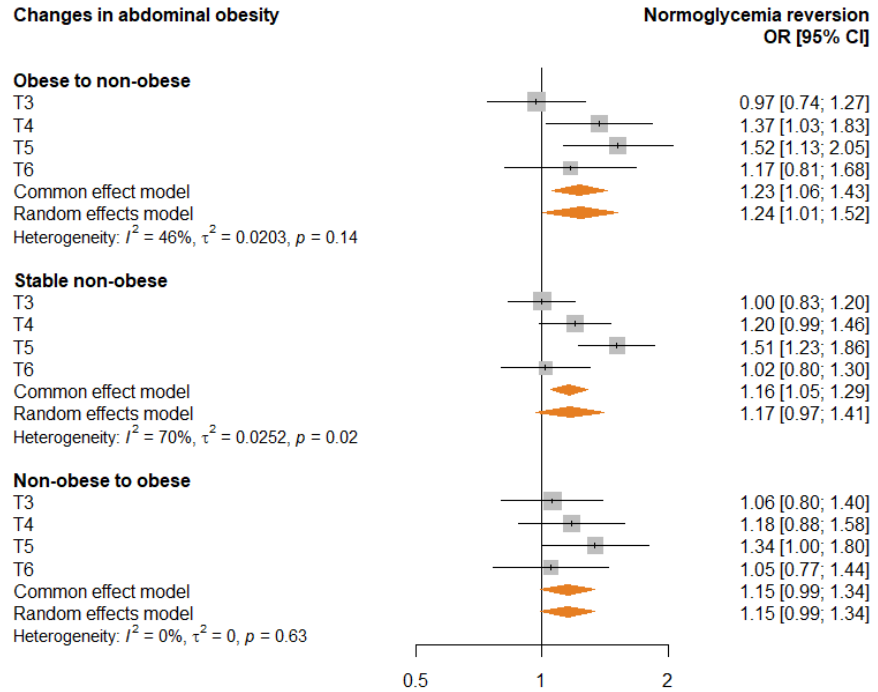
The associations between changes in abdominal obesity and prediabetes change in each follow-up time group are shown in Table 17. The results indicated that the effect sizes and significance were different across the groups. Furthermore, the heterogeneity test results showed that there was a substantial difference in the association between 'stable non-obese' and reversion to normoglycemia (I^2 = 70% and P-value of Q test = 0.02). Nevertheless, the findings from the meta-analysis also appeared to be similar to the findings from pooled analysis in terms of effect sizes and direction. It showed that 'obese to non-obese' group were more likely to go back to normoglycemia (OR from the common effect model was 1.23, 95% CI 1.06–1.46 and from the random effect model was 1.24, 95% CI 1.01–1.52). Furthermore, 'obese to non-obese' and 'stable non-obese' were less likely to have progression to diabetes (ORs from the common effect model were 0.82, 95% CI 0.71–0.95 and 0.64, 95% CI 0.58–0.71 respectively; ORs from the random effect model were 0.81, 95% CI 0.71–0.95 and 0.64, 95% CI 0.58–0.71 respectively) (Figure 6). Detailed information on the distribution of outcomes according to changes in abdominal obesity in each follow-up time group can be found in Appendix 15.

Table 17. Odds ratios for changes in glycemic status by changes in abdominal obesity in each follow-up time group

	Reversion to normoglycemia OR (95% CI)			Progression to diabetes OR (95% CI)		
	Model 1	Model 2	Model 1	Model 2	Model 2	Model 3
T3						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.20 (1.04-1.39)	0.95 (0.73-1.24)	0.97 (0.75-1.27)	0.83 (0.72-0.96)	0.72 (0.56-0.94)	0.72 (0.55-0.94)
Stable non-obese	1.18 (1.07-1.31)	1.02 (0.85-1.22)	1.00 (0.84-1.20)	0.64 (0.58-0.70)	0.55 (0.46-0.65)	0.56 (0.47-0.67)
Non-obese to obese	1.06 (0.92-1.22)	1.05 (0.79-1.39)	1.06 (0.80-1.40)	0.79 (0.69-0.90)	0.79 (0.60-1.05)	0.79 (0.60-1.05)
T4						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.34 (1.01-1.78)	1.35 (1.01-1.80)	1.37 (1.03-1.83)	0.84 (0.63-1.11)	0.84 (0.64-1.12)	0.82 (0.62-1.08)
Stable non-obese	1.21 (0.99-1.47)	1.21 (0.99-1.47)	1.20 (0.98-1.46)	0.66 (0.55-0.79)	0.65 (0.54-0.79)	0.66 (0.55-0.80)
Non-obese to obese	1.15 (0.86-1.54)	1.17 (0.88-1.57)	1.18 (0.88-1.58)	0.77 (0.59-1.02)	0.78 (0.59-1.04)	0.81 (0.61-1.07)
T5						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.49 (1.11-2.00)	1.49 (1.11-2.01)	1.52 (1.13-2.05)	0.92 (0.69-1.22)	0.93 (0.70-1.23)	0.91 (0.68-1.21)
Stable non-obese	1.50 (1.22-1.84)	1.50 (1.22-1.84)	1.51 (1.23-1.86)	0.74 (0.61-0.89)	0.74 (0.61-0.89)	0.73 (0.60-0.89)
Non-obese to obese	1.34 (1.00-1.80)	1.34 (1.00-1.81)	1.34 (0.99-1.80)	1.09 (0.83-1.43)	1.08 (0.82-1.42)	1.11 (0.84-1.46)
T6						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	1.14 (0.80-1.63)	1.15 (0.81-1.65)	1.17 (0.82-1.68)	0.88 (0.62-1.23)	0.90 (0.64-1.27)	0.88 (0.62-1.25)
Stable non-obese	1.03 (0.81-1.30)	1.03 (0.81-1.30)	1.02 (0.81-1.30)	0.63 (0.50-0.79)	0.63 (0.50-0.79)	0.64 (0.51-0.80)
Non-obese to obese	1.04 (0.75-1.43)	1.05 (0.76-1.44)	1.05 (0.76-1.44)	0.75 (0.55-1.02)	0.74 (0.55-1.01)	0.75 (0.55-1.02)

Model 1: adjusted for sex and age at baseline.
Model 2: adjusted for sex, age, smoking status, alcohol consumption, and physical activity.
Model 3: adjusted for sex, age, income, lifestyle factors, hypertension, dyslipidemia, family history of diabetes, and fasting plasma glucose at baseline.

(a)



(b)

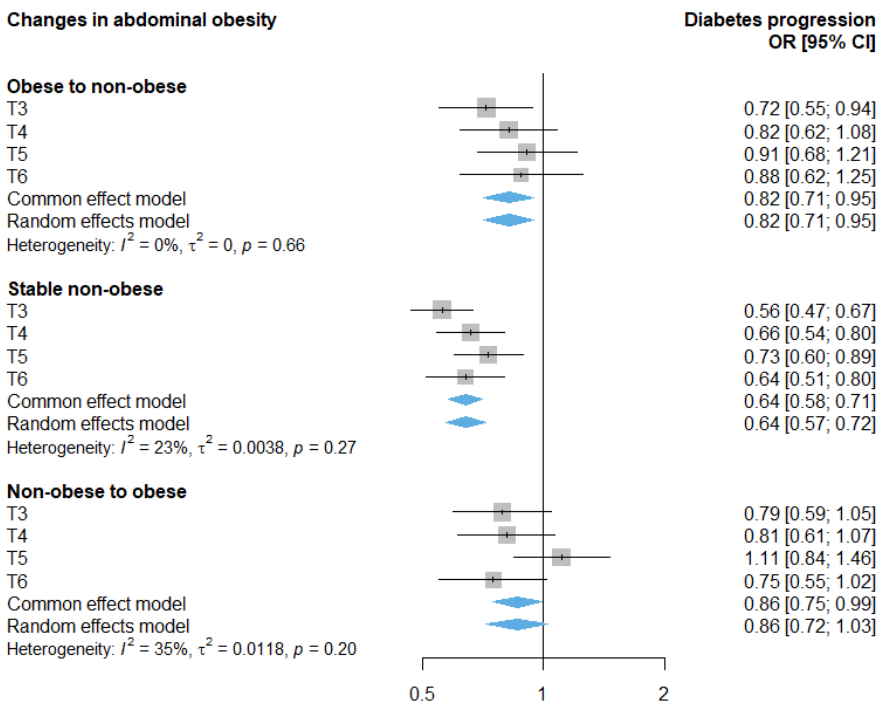


Figure 6. Forest plot of meta-analysis of changes in glycemic status by changes in abdominal obesity. (a) Reversion to normoglycemia; (b) Progression to diabetes.

Trajectory of obesity status

Detailed information on the model fitting in each follow-up time group is provided in Appendix 16 until Appendix 18. Based on the summary statistics of the trajectory of general obesity, the best model was found in the model with two latent classes in the T4 group, three latent classes in the T5 group, and four latent classes in the T6 group (Figure 7). Based on the graph, we named the trajectory as 'stable obese', 'obese to non-obese', 'stable non-obese', 'non-obese to obese', and ‘experience changes.’ According to the results from the model fitting of the trajectory of abdominal obesity, the best model was found in the model with two latent classes in the T4 group, and three latent classes in T5 and T6 group (Figure 8). Based on the graph, similar to the trajectory of general obesity, we named the trajectory as 'stable obese', 'stable non-obese', and ‘experience changes.’

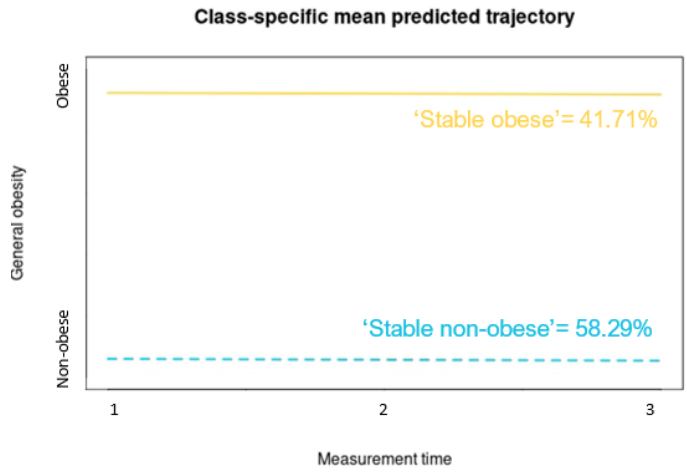
The observation used for the trajectory analysis had a large number of missing information on obesity status during the follow-up period. As presented in Appendix 19, there was 12,817 participants (41.21%) participants who had missing information on the measurement of BMI or WC. However, the result may still be robust as the latent class growth mixed modelling used in the analysis assume the missing data as missing at random.

In the trajectory of general obesity in T5 group, the graph with the purple line slightly appeared to represent trajectory from non-obese to obese, although the slope is not clear. After checking the data, this was because the participants who had changed from obese to non-obese were also included in this group, although the proportion is smaller compared with participants who changed from non-obese to obese. Therefore, the slope of the line actually represents participants who experienced changes of obesity status during the follow-up period. Because of this

reason, we named this group ‘experience changes’. The same reason goes for the trajectory of abdominal obesity with blue line in T5 and T6 groups.

Based on the results from model fitting of BMI and WC trajectories, we did not find distinct latent classes in any follow-up time group. In the summary statistics, there was no model that showed a sufficient number of participants in all latent classes (>5%) nor appropriate value of mean posterior probability (>0.70).

(a)



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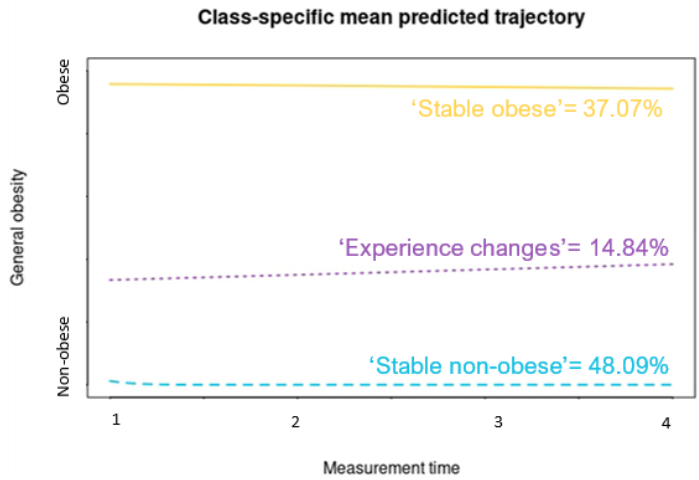


(c)

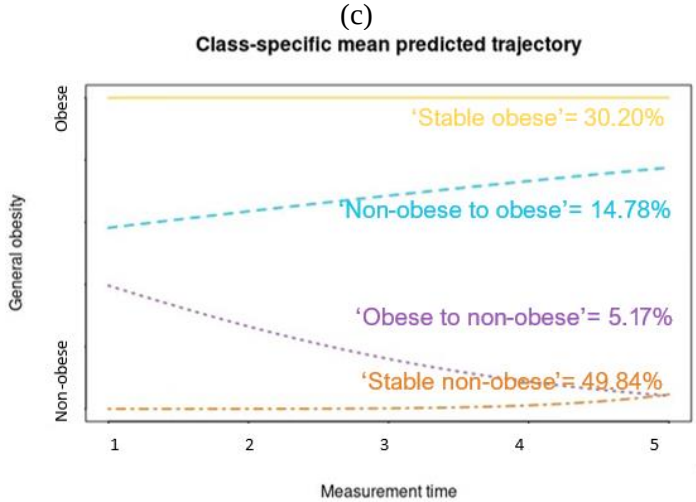
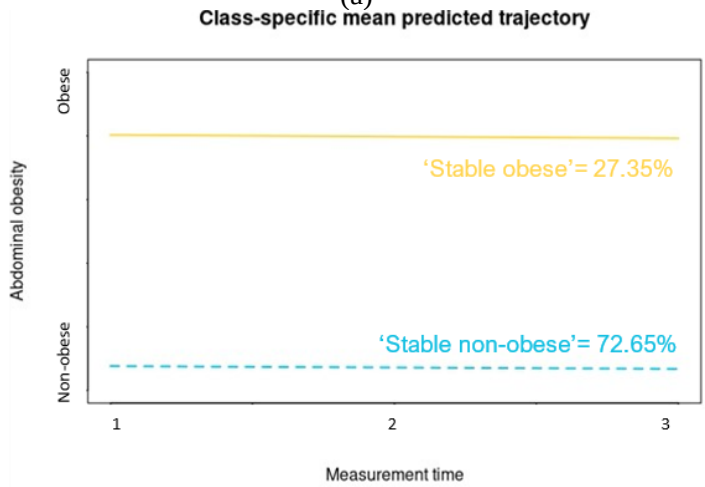


Figure 7. Trajectories of general obesity. (a) Trajectories among T4 group; (b) Trajectories among T5 group; (c) Trajectories among T6 group.

(a)



(b)

(c)

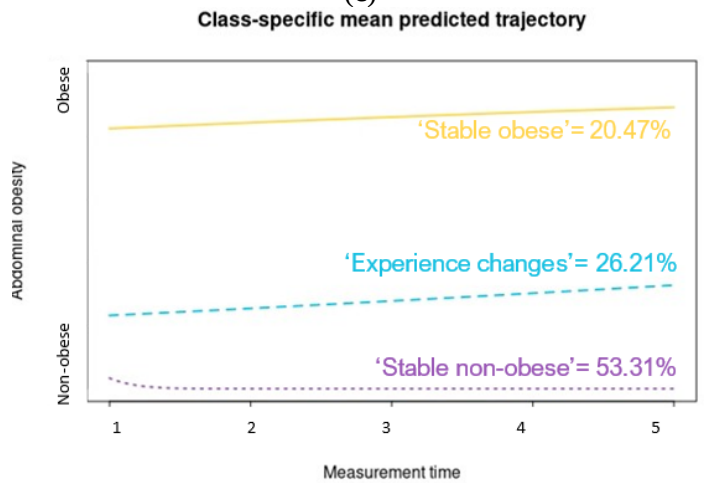


Figure 8. Trajectories of abdominal obesity. (a) Trajectories among T4 group; (b) Trajectories among T5 group; (c) Trajectories among T6 group.

Table 18 shows the distribution of the outcomes according to trajectories of both general and abdominal obesity in each follow-up time group. Consistently in all follow-up time groups, ‘stable non-obese’ showed a higher proportion of participants compared to the others. We could not combine all the participants because the types of trajectories in each follow-up time group were different. Therefore, it was more appropriate to analyze the association between the trajectory of obesity and changes in glycemic status separately in each follow-up time group.

The association between trajectory of general obesity and changes in glycemic status is presented in Table 19. Compared to ‘stable obese’ class, participants who were in ‘stable non-obese’ group were more likely to have reversion to normoglycemia (OR 1.18, 95% CI 1.04–1.34 in T4 group, OR 1.33, 95% CI 1.15–1.54 in T5 group, and OR 1.20, 95% CI 1.01–1.44 in T6 group) and less likely to have progression to diabetes (OR 0.69, 95% CI 0.61–0.78 in T4 group, OR 0.75, 95% CI 0.65–0.86 in T5 group, and OR 0.75, 95% CI 0.63–0.90 in T6 group).

The association between the trajectory of abdominal obesity and changes in glycemic status is also shown in Table 19. Compared to ‘stable obese’ class, greater odds of reversion to normoglycemia was found in the ‘stable non-obese’ class (OR 1.50, 95% CI 1.23–1.84) and ‘experience changes’ class (OR 1.34, 95% CI 1.06–1.69). Furthermore, compared with ‘stable obese’ class, ‘stable non-obese’ class was found to decrease the odds of progression to diabetes in T4 group (OR 0.66, 95% CI 0.57–0.76), T5 group (0.74, 95% CI 0.62–0.90), and T6 group (OR 0.60, 95% CI 0.49–0.73).

Table 18. Distribution of outcome according to trajectory of obesity in each follow-up time group

	Total N (%)	Control (Prediabetes persistence) N (%)	Case 1 (Reversion to normoglycemia) N (%)	Case 2 (Progression to diabetes) N (%)
Trajectory of general obesity				
T4				
Stable obese	3574 (41.71)	1162 (40.87)	1012 (35.60)	1400 (49.24)
Stable non-obese	4955 (58.29)	1681 (59.13)	1831 (64.40)	1443 (50.76)
T5				
Stable obese	2343 (37.07)	777 (36.88)	639 (30.33)	927 (44.00)
Stable non-obese	3040 (48.09)	1017 (48.27)	1141 (54.15)	882 (41.86)
Experience changes	938 (14.84)	313 (14.86)	327 (15.52)	298 (14.14)
T6				
Stable obese	1226 (30.20)	396 (29.27)	356 (26.31)	474 (35.03)
Obese to non-obese	210 (5.17)	78 (5.76)	61 (4.51)	71 (5.25)
Stable non-obese	2023 (49.84)	672 (49.67)	742 (54.84)	609 (45.01)
Non-obese to obese	600 (14.78)	207 (15.3)	194 (14.34)	199 (14.71)
Trajectory of abdominal obesity				
T4				
Stable obese	2333 (27.35)	726 (25.54)	649 (22.83)	958 (33.7)
Stable non-obese	6196 (72.65)	2117 (74.46)	2194 (77.17)	1885 (66.3)
T5				
Stable obese	886 (14.02)	304 (14.43)	218 (10.35)	364 (17.28)
Stable non-obese	4052 (64.10)	1361 (64.59)	1468 (69.67)	1223 (58.04)
Experience changes	1383 (21.88)	442 (20.98)	421 (19.98)	520 (24.68)
T6				
Stable obese	831 (20.47)	237 (17.52)	247 (18.26)	347 (25.65)
Stable non-obese	2164 (53.31)	746 (55.14)	783 (57.87)	635 (46.93)
Experience changes	1064 (26.21)	334 (24.69)	323 (23.87)	371 (27.42)

Table 19. Odds ratios for changes in glycemic status by trajectory of obesity in each follow-up time group

	Reversion to normoglycemia OR (95% CI)			Progression to diabetes OR (95% CI)		
	Model 1	Model 2	Model 1	Model 2	Model 2	Model 3
Trajectory of general obesity						
T4						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Stable non-obese	1.20 (1.06-1.36)	1.19 (1.05-1.35)	1.18 (1.04-1.34)	0.69 (0.61-0.78)	0.68 (0.60-0.77)	0.69 (0.61-0.78)
T5						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Stable non-obese	1.34 (1.16-1.54)	1.34 (1.16-1.54)	1.33 (1.15-1.54)	0.76 (0.66-0.87)	0.75 (0.65-0.86)	0.75 (0.65-0.86)
Experience changes	1.20 (0.98-1.46)	1.20 (0.98-1.47)	1.20 (0.98-1.46)	0.82 (0.67-1.00)	0.82 (0.68-1.00)	0.82 (0.67-1.00)
T6						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Obese to non-obese	0.87 (0.60-1.25)	0.87 (0.61-1.26)	0.88 (0.61-1.27)	0.76 (0.54-1.08)	0.77 (0.54-1.09)	0.76 (0.53-1.08)
Stable non-obese	1.23 (1.03-1.46)	1.21 (1.01-1.44)	1.20 (1.01-1.44)	0.76 (0.64-0.90)	0.74 (0.62-0.88)	0.75 (0.63-0.90)
Non-obese to obese	1.05 (0.82-1.33)	1.04 (0.82-1.33)	1.04 (0.82-1.33)	0.81 (0.64-1.02)	0.80 (0.63-1.02)	0.81 (0.64-1.03)
Trajectory of abdominal obesity						
T4						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Stable non-obese	1.12 (0.97-1.30)	1.12 (0.97-1.30)	1.11 (0.96-1.28)	0.66 (0.57-0.75)	0.65 (0.57-0.75)	0.66 (0.57-0.76)
T5						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Stable non-obese	1.48 (1.21-1.81)	1.49 (1.22-1.81)	1.50 (1.23-1.84)	0.76 (0.63-0.91)	0.76 (0.63-0.91)	0.74 (0.62-0.90)
Experience changes	1.32 (1.05-1.66)	1.32 (1.05-1.66)	1.34 (1.06-1.69)	0.96 (0.78-1.19)	0.97 (0.78-1.20)	0.95 (0.77-1.18)
T6						
Stable obese	Reference	Reference	Reference	Reference	Reference	Reference
Stable non-obese	1.01 (0.83-1.25)	1.02 (0.83-1.25)	1.00 (0.81-1.23)	0.58 (0.48-0.71)	0.58 (0.48-0.71)	0.60 (0.49-0.73)

	Reversion to normoglycemia OR (95% CI)			Progression to diabetes OR (95% CI)		
	Model 1	Model 2	Model 1	Model 2	Model 2	Model 3
Experience changes	0.84 (0.67-1.06)	0.85 (0.67-1.07)	0.84 (0.67-1.06)	0.69 (0.55-0.85)	0.69 (0.55-0.86)	0.70 (0.56-0.87)

Model 1: adjusted for sex and age at baseline.

Model 2: adjusted for sex, age, smoking status, alcohol consumption, and physical activity.

Model 3: adjusted for sex, age, income, lifestyle factors, hypertension, dyslipidemia, family history of diabetes, and fasting plasma glucose at baseline.

3. Discussion

3.1 Summary and Discussion of Findings

Findings of the first study showed that most participants (60.1%) maintained their blood glucose within the prediabetes range in four years of median follow-up. Among the rest of the participants, there were more people who had reversion to normoglycemia (31.8%) than those who had progression to diabetes (8.2%). The prevalence of prediabetes glycemic status and its change varied depending on the indicator, but nevertheless, a previous study reported similar results to our study, suggesting a larger proportion of people had their glycemic status back to normoglycemia than progressing to diabetes if following the ADA criteria (10).

Older adults were observed to be less likely to have diabetes progression in the first study, and also less likely to have reversion to normoglycemia (not significant) which suggests that older people are more likely to remain in a prediabetes state instead of experiencing changes in glycemic status. This is supported by findings from previous studies that indicated conversion of diabetes progression was lower compared to that of prediabetes persistence among older adults, defined by any of the HbA1c value and FPG (48).

Participants with higher educational attainment were likely to have reversion to normoglycemia and less likely to have progression to diabetes in the first study. Furthermore, the results from stratified analysis by sex showed that the significant association with reversion to normoglycemia was only observed in women. Although it is unclear, the difference may be due to the influence of

education on the reversion of normoglycemia, which may be confounded by the adherence to a healthy lifestyle. Particularly in the first study, education was only found to be associated with modifiable factors score in women (Appendix 10). This then may lead to the disparate association of education with reversion to normoglycemia reversion between men and women.

In the first study, among all the considered modifiable factors, obesity, heavy alcohol consumption, hypertension, and dyslipidemia were associated with lower odds of prediabetes reversion to normoglycemia. On the other hand, obesity, current smoking, and hypertension were observed to increase the odds of diabetes progression. Similar to our findings, high BMI and WC-defined abdominal obesity were found to be inversely related to reversion to normoglycemia (14, 28, 32) and positively related to diabetes progression (32,33). People with hypertension were less likely to have reversion to normoglycemia and more likely to have progression to diabetes in the first study, which is consistent with a previous study that reported a lower likelihood of reversion to normoglycemia in people with hypertension, using the same definition of glycemic status as the current study (10). Furthermore, similar to our finding, other studies reported that hypertension in individuals with prediabetes increased the risk of developing type 2 diabetes (49,50), especially those whose HbA1c levels at baseline were higher (50).

Engaging in a healthy lifestyle is well-known to be advantageous in preventing and delaying disease progression, including in lowering the risk of diabetes (51,52). Correspondingly, this study also indicated that individuals with more healthy or favorable modifiable factors were less likely to have diabetes progression from prediabetes. Furthermore, those who adhered to more favorable modifiable factors were also more likely to have reversion to normoglycemia.

Either using abdominal obesity or BMI to represent the obesity factor in the scoring component, the results are consistent. Therefore, using any of the two factors may be appropriate in evaluating the modifiable factors in order to promote normoglycemia reversion and prevent diabetes progression of individuals with prediabetes.

The results from the analyses in the second study showed that participants who changed from general obese or abdominal obese state to non-obese state were more likely to go back to normoglycemia. Additionally, participants who changed from with to without abdominal obesity were less likely to have progression to diabetes. Participants who maintained having no general obesity and no abdominal obesity were more likely to go back to normoglycemia and less likely to have diabetes progression. Similarly, in the trajectory analysis, participants with a trajectory of stable non-obese, both general and abdominal, were more likely to have normoglycemia reversion and less likely to have diabetes progression. Furthermore, those who changed from non-obese to obese showed lower odds of developing diabetes. These findings indicated that for people without obesity, whether it is general or abdominal obesity, maintaining this condition may be helpful in returning the glycemic status from prediabetes to normal and preventing from going to diabetes. For people with obesity, reducing BMI or WC may also give a similar advantage in changing the prediabetes glycemic status to normal.

Some prior studies have reported their findings on the associations between BMI and WC values and changes in glycemic status (15,53-55). A study by Modi et al (2021) concluded that reduced BMI was associated with regression of prediabetes or diabetes (53). Another study also reported similar results, with HbA1c as the marker to define glycemic status, suggesting that every reduction of

1 kg/m^2 of BMI was related to the reversion to normoglycemia (15). Furthermore, other studies suggested that an increased in WC was associated with diabetes risk in people with prediabetes (54,55) Although not exactly having the same exposure, (i.e., these studies used BMI and WC as continuous variables as the exposure, while this study used the obesity status as the exposure) their findings are in line with that of our study.

The evaluation of the longitudinal trajectory of BMI and WC by using a similar method to this study and its association with diabetes risk has been established by prior studies (27,28). However, those studies were conducted among the general population. To the best of our knowledge, this is the first study to observe the association between the trajectory of obesity status and changes in prediabetes to normoglycemia and diabetes, in binary variable.

Regarding the trajectory analysis, using BMI and WC in their continuous form instead of transforming to the categorical variable is more common. In our study, we tried to examine these markers in both binary and continuous variables as both types have their advantages (56). However, we only found distinct latent classes for the binary variables. We argue that using binary may be favored because BMI and WC cutoff points for obesity are well-established and widely used in research, guidelines, and clinical practices. Therefore, categorizing BMI and WC may be easier in terms of interpretability in the present study. In our study, participants have various follow-up durations, so we had to separately perform trajectory modeling in each follow-up time group. With this method, it was challenging to do pooled analysis of all participants because the type of trajectories were too varied making combining all the participants as one according to the trajectories were not possible.

Although BMI has been commonly used as an anthropometric measure to reflect body composition for a long time, other indices, including WC, may also be as important in explaining health outcomes and mortality (57). Some suggested that, compared with general obesity, abdominal obesity was associated more with morbidity, including diabetes (41,42,58). Additionally, previous studies reported that WC was found to have a slightly higher value of area under the curve in the receiver operating characteristics curve analysis compared with BMI, indicating that it might be better in identifying diabetes (59,60). Particularly in our study, changes in abdominal obesity might explain the risk of diabetes progression from prediabetes better compared to BMI-defined obesity as all the categories were associated with diabetes progression.

3.2 Strength and Limitations

The strength of the first study is that it was based on a large prospective study representing the Korean population and included the scoring analysis of modifiable factors for normoglycemia reversion from prediabetes. However, this study had some limitations. First, a large number of participants from the original study was excluded due to the low follow-up rate from Phase II (50.6%). However, we confirmed that those with follow-up and without follow-up data are not different in terms of the measured characteristics critical to this study. Second, there is a possibility of information bias as some data were collected using a self-report questionnaire. Third, the role of the medication in the glycemic status change could not be evaluated because there was no information regarding medication type taken by participants. However, people with a history of diabetes

were not included as the study participants and this has minimized the possible effect of diabetes medication use in altering glycemic status change. Fourth, the glycemic status in this study was only defined only by two parameters, which are FPG and HbA1c, not including the oral glucose tolerance test results because it was not conducted in the original cohort study; therefore, there could be other individuals with prediabetes that were not included.

The strength of the second study is that it was based on a large cohort database and nationally represents the Korean population that contains longitudinal data of the participants. Thus, it allowed this study to analyze the changes in obesity status and also trajectory analysis using repeated measurements. To the best of our knowledge, this is the first study to see the changes in obesity status and trajectory of obesity status among individuals with prediabetes and evaluate their association with the changes in glycemic status in the same study population. The limitation of this study is that, first, this study could not define the glycemic status using markers other than FPG due to the unavailability of biomarkers in the original study. Thus, there were probably prediabetes cases that were not discovered. Second, the associations of changes in obesity and the shifts in prediabetes appeared to be different across the follow-up time group. Further study is warranted to confirm whether the duration of changes in the obesity status affect the reversion or progression of prediabetes. Third, NHIS-HEALS did not assess detailed information on some modifiable factors, such as the amount and type of alcohol consumption, amount of cigarette that has been consumed, and diet quality. Therefore, we could not observe the association between baseline modifiable factors among the study population and the changes in glycemic status comprehensively. Fourth, we could only include a less complex model in the

analysis of trajectory by not including any covariate, other than measurement time, in the model. This was due to the convergence issue as a more complex model often failed to converge.

4. Conclusions

The present study observed associations between some modifiable factors and reversion to normoglycemia, as well as progression to diabetes among people with prediabetes. The results showed that more than half of the participants remained in prediabetes glycemic status. Most of the remaining participants had a reversion to normoglycemia, and this was found to be affected by obesity status, alcohol consumption, and the presence of hypertension and dyslipidemia. The rest of the participants developed diabetes and this progression was influenced by obesity status, smoking status, and the presence of hypertension. Having more favorable modifiable factors was associated with a higher probability of returning to normoglycemia and a lower probability of progression to type 2 diabetes.

Among people with prediabetes and non-obese, those who maintained being in a normal range of BMI and WC were more likely to have their blood glucose returned to normal range and less likely to have progression to diabetes. As for individuals with prediabetes who have general or abdominal obesity, the change to a non-obese state may be associated with normoglycemia reversion.

Findings from this study can be used as grounds to encourage the public, especially individuals with prediabetes, to engage in a healthier lifestyle and pay attention to some modifiable factor conditions. Furthermore, it may be used to encourage them to manage their weight and body composition, blood pressure, and lipid profiles to promote glycemic status reversion to the normal range and prevent diabetes progression. Further evaluation regarding other modifiable factors that were not included in this study and using a more comprehensive analysis may be

important. With the increase of studies about modifiable factors and prediabetes glycemic status changes, it is expected that there will be more evidence that can be useful in the management of blood glucose or glycemic status and prevent more complications from hyperglycemia.

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초록

연구 배경

세계적으로 당뇨병 전 단계 유병률이 증가하고 있는 추세이다. 당뇨병 전 단계는 제2형 당뇨병 및 기타 질병의 위험 증가와 관련이 있지만, 정상 혈당으로 되돌아갈 가능성도 있기 때문에 중요한 단계로 여겨진다. 따라서 당뇨병 전 단계에서 혈당 변화의 요인을 파악하는 것은 중요하며, 본 연구는 당뇨병 전 단계 성인에서 교정 가능한 위험 요인과 정상 혈당으로 변화 또는 당뇨병으로 진행의 연관성을 규명하고자 하였다.

연구 방법

연구 1

본 연구는 Health Examinees-Gem (HEXA-G) 자료를 활용하여 당뇨병 전 단계 성인 10,358 명을 분석에 포함하였다. 체질량 지수, 복부 비만, 흡연 상태, 신체 활동, 음주, 식사의 질, 고혈압, 이상지질혈증과 같은 교정 가능한 요인을 포함하여 교정 가능한 요인 점수를 계산하였다. 다항 로지스틱회귀모형(multinomial logistic regression)을 활용하여 포함된 교정 가능한 요인 및 점수와 혈당변화와의 연관성을 평가하였다.

연구 2

본 연구는 국민건강보험 건강검진DB 자료(National Health Insurance Service-National Health Screening Cohort, NHIS-HEALS)를 활용하여 공복혈

당지수를 기반으로 당뇨병 전 단계 성인을 정의하였으며, 2번 이상의 반복 측정된 체질량지수와 허리둘레 정보가 있는 31,104명을 포함하여 코호트 내 환자-대조군 연구 디자인(nested case-control study)를 사용했다. 체질량지수 기반의 비만과 허리둘레로 정의한 복부 비만을 모든 시점에서 확인하고, baseline시점부터 결과 측정 시점전까지의 비만 상태 변화를 평가하여 이를 노출로 설정했다. 또한, 종단 데이터에서 latent class trajectory modeling 분석을 활용하여 비만과 복부 비만의 궤적을 유형화하였다. 로지스틱회귀모형(multinomial logistic regression)을 활용하여 각 유형과 혈당 변화의 관계를 평가하였다.

연구 결과

연구 1

4년(범위 1~7년)의 중앙값 추적 관찰 기간 이후, 31.8%의 대상자가 정상 혈당으로 되돌아갔고, 8.1%는 제2형 당뇨병으로 진행되었다. BMI ≥ 25kg/m2 (OR 0.71 [95% CI 0.63-0.79]), 복부 비만(0.76 [0.68-0.86]), 과음(0.74 [0.60-0.91]), 고혈압 (0.71 [0.64-0.79]), 이상지질혈증 (0.78 [0.70-0.85])은 정상 혈당으로 변화의 가능성을 낮추는 것으로 밝혀졌다. BMI ≥25 kg/m2(1.58 [1.29-1.94]), 복부 비만(1.31 [1.11-1.55]), 현재 흡연 상태(1.43 [1.07-1.91]), 고혈압(1.26 [1.07-1.49])은 2형 당뇨병 진행 가능성을 높이는 것으로 확인되었다. 또한, 더 나은 교정 가능한 요인을 많이 가질수록 정상 혈당으로 변화의 가능성이 높아지고 (1.46 [1.30-1.64]), 제 2형 당뇨병 진행의 가능성이 (0.62 [0.49-0.77]) 낮아지는 것이 나타났다.

연구 2

기반의 비만 평가에서는 'stable obese' 그룹에 비해 'obese to non-obese' (OR 1.22 [1.04-1.43]) 및 'stable non-obese' (OR 1.17 [1.08-1.26]) 그룹에서 정상 혈당으로 복귀할 확률이 더 높았다. 또한, 'stable non-obese' 그룹 (OR 0.69 [0.64-0.75])과 'non-obese to obese' 그룹 (OR 0.73 [0.63-0.84]) 은 'stable obese' 그룹에 비해 당뇨병 진행 가능성이 낮았다. 복부비만의 변화를 평가한 결과에서, 'obese to non-obese' 및 'stable non-obese' 그룹은 'stable obese' 그룹에 비해 정상혈당으로 복귀할 확률이 높았고 (각각 OR 1.22, [1.06-1.41] 및 1.71, [1.06-1.30]), 당뇨병으로 진행될 확률은 낮았다 (각각OR 0.82 [0.71-0.94 및 0.65 [0.59-0.71]). 각 추적 기간 그룹에서 일반 및 복부 비만 상태의 궤적에 대해 2~4개의 잠재적 클래스가 확인되었다. 모든 그룹에서 'stable non-obese' 궤적은 'stable obese' 클래스에 비해 정상 혈당으로 되돌아갈 가능성이 더 높았고 당뇨병으로 진행될 가능성이 더 낮았다.

결론

본 연구에서는 일부 교정 가능한 요인이 당뇨병 전 단계의 혈당 상태 변화에 영향을 미치는 것으로 밝혀졌다. 또한, 교정 가능한 요인이 많을수록 정상 혈당으로 돌아갈 가능성이 높아지고 당뇨병으로 진행될 가능성이 낮아지는 것을 확인하였다. 또한, 비만이 아닌 대상자가 지속적으로 정상 BMI와 WC를 유지하고 복부 비만인 대상자가 복부 비만 아닌 상태로 변화하는 것은 정상 혈당으로 복귀할 가능성이 높아지고 당뇨병 진행 가능성이 감소하는 것으로 밝혀졌다. 이에 따라 당뇨병 전 단계 성인은

체중, 혈압, 및 혈중 지질을 잘 관리하고, 흡연 및 과음과 같은 건강에 해로운 습관을 피하는 것을 제안하였다.

“본 논문 작성자는 한국정부초청장학금 (Global Korea Scholarship)을 지원받은 장학생임”

Appendix

Appendix 1. Comparison of participants in the HEXA-G study recruited from Phase I and Phase II (adopted from Nabila *et al.,* Diabetes Care. 2023)

	Phase I N (%)	Phase II N (%)	Standardized difference
Total	26915 (41.7)	37570 (58.7)	
Sex			0.017
Men	9033 (33.6)	12644 (33.7)	
Women	17882 (66.4)	24926 (66.3)	
Age			0.305
40-49	9493 (35.3)	11523 (30.7)	
50-59	11158 (41.5)	16032 (42.7)	
60-69	6264 (23.3)	10015 (26.7)	
Education			
Middle school or less	8341 (31.6)	11508 (30.9)	0.065
High school	10766 (40.8)	15383 (41.3)	
College or above	7259 (27.5)	10333 (27.8)	
BMI			0.190
Underweight	389 (1.4)	619 (1.6)	
Normal	10031 (37.3)	14111 (37.6)	
Overweight	7778 (28.9)	10394 (27.7)	
Obese	8676 (32.3)	12412 (33.1)	
Abdominal obesity			0.132
No	20136 (75.5)	29045 (77.4)	
Yes	6543 (24.5)	8476 (22.6)	
Smoking Status			0.040
Never Smoker	20131 (75.5)	27316 (73.1)	
Former Smoker	3852 (14.4)	6053 (16.2)	
Current Smoker	2677 (10.0)	3975 (10.6)	
Physical Activity			0.022
No Exercise	11922 (47.9)	16422 (44.1)	
<150	3326 (13.4)	4444 (11.9)	
≥150	9639 (38.7)	16398 (44.0)	
Alcohol Consumption			0.058
Non-Drinkers	15933 (59.7)	20790 (55.7)	
Light Drinkers	7107 (26.6)	10880 (29.2)	
Moderate Drinkers	1857 (7.0)	2822 (7.6)	
Heavy Drinkers	1792 (6.7)	2801 (7.5)	
DQI-K Score			0.009
Good Diet Quality	12648 (47.7)	17857 (48.2)	
Poor Diet Quality	13854 (52.3)	19201 (51.8)	
Hypertension			0.135
No	19495 (72.7)	26640 (71.0)	
Yes	7315 (27.3)	10886 (29.0)	
Dyslipidemia			0.235
No	18011 (66.9)	24012 (63.9)	
Yes	8904 (33.1)	13558 (36.1)	
Family history of diabetes			0.029
No	22260 (83.5)	29653 (79.5)	
Yes	4395 (16.5)	7662 (20.5)	

Standardized differences were calculated without including missing values. Standardized difference >0.2 indicates an imbalance between the groups.

Appendix 2. Comparison of participants in the HEXA-G study recruited from Phase II with and without follow-up (adopted from Nabila *et al.*, Diabetes Care. 2023)

	Without follow-up data N (%)	With follow-up data N (%)	Standardized difference
Total	36684 (49.4)	37570 (50.6)	
Sex			0.015
Men	12599 (34.3)	12644 (33.7)	
Women	24085 (65.7)	24926 (66.3)	
Age			0.177
40-49	14263 (38.9)	11523 (30.7)	
50-59	14273 (38.9)	16032 (42.7)	
60-69	8148 (22.2)	10015 (26.7)	
Education			0.036
Middle school or less	11000 (30.3)	11508 (30.9)	
High school	14675 (40.4)	15383 (41.3)	
College or above	10681 (29.4)	10333 (27.8)	
BMI			0.032
Underweight	787 (2.1)	653 (1.7)	
Normal	13946 (38.0)	14111 (37.6)	
Overweight	9954 (27.1)	10394 (27.7)	
Obese	11997 (32.7)	12412 (33.0)	
Abdominal obesity			0.006
No	28275 (77.1)	29045 (77.3)	
Yes	8409 (22.9)	8525 (22.7)	
Smoking Status			0.125
Never Smoker	25785 (70.7)	27316 (73.1)	
Former Smoker	5332 (14.6)	6053 (16.2)	
Current Smoker	5371 (14.7)	3975 (10.6)	
Physical Activity			0.102
No Exercise	17679 (48.5)	16422 (44.1)	
<150	4503 (12.4)	4444 (11.9)	
≥150	14239 (39.1)	16398 (44.0)	
Alcohol Consumption			0.073
Non-Drinkers	19275 (52.9)	20790 (55.7)	
Light Drinkers	10786 (29.6)	10880 (29.2)	
Moderate Drinkers	3174 (8.7)	2822 (7.6)	
Heavy Drinkers	3214 (8.8)	2801 (7.5)	
DQI-K Score			0.042
Good Diet Quality	20687 (57.0)	21900 (59.1)	
Poor Diet Quality	15592 (43.0)	15158 (40.9)	
Hypertension			0.009
No	26135 (71.2)	26609 (70.8)	
Yes	10549 (28.8)	10961 (29.2)	
Dyslipidemia			0.021
No	23751 (64.8)	23956 (63.9)	
Yes	12875 (35.2)	13558 (36.1)	
Family history of diabetes			0.003
No	29037 (79.6)	29653 (79.5)	
Yes	7441 (20.4)	7662 (20.5)	

Standardized differences were calculated without including missing values. Standardized difference >0.2 indicates an imbalance between the groups.

Appendix 3. Comparison of participants in the HEXA-G study recruited from Phase II with complete and incomplete information on FPG and HbA1c (adopted from Nabila *et al.*, Diabetes Care. 2023)

	With complete information on both markers		With incomplete information on any markers		Standardized difference
	N	(%)	N	(%)	
Total	10,529	(28.0)	27,041	(72.0)	
Sex					0.048
Men	3717	(35.3)	8927	(33.0)	
Women	6812	(64.7)	18114	(67.0)	
Age					0.096
40-49	3566	(33.9)	7957	(29.4)	
50-59	4264	(40.5)	11768	(43.5)	
60-69	2699	(25.6)	7316	(27.1)	
Education					0.134
Middle school or less	3540	(34.4)	7968	(29.6)	
High school	4299	(41.7)	11084	(41.2)	
College or above	2462	(23.9)	7871	(29.2)	
BMI					0.033
Underweight	148	(1.4)	471	(1.7)	
Normal	3892	(37.0)	10219	(37.8)	
Overweight	2935	(27.9)	7459	(27.6)	
Obese	3537	(33.6)	8875	(32.8)	
Abdominal obesity					0.019
No	8073	(76.8)	20972	(77.6)	
Yes	2432	(23.2)	6044	(22.4)	
Smoking Status					0.076
Never Smoker	7428	(71.7)	19888	(73.7)	
Former Smoker	1647	(15.9)	4406	(16.3)	
Current Smoker	1282	(12.4)	2693	(10.0)	
Physical Activity					0.014
No Exercise	4588	(44.5)	11834	(43.9)	
<150	1239	(12.0)	3205	(11.9)	
≥150	4485	(43.5)	11913	(44.2)	
Alcohol Consumption					0.044
Non-Drinkers	5611	(54.3)	15179	(56.3)	
Light Drinkers	3078	(29.8)	7802	(28.9)	
Moderate Drinkers	817	(7.9)	2005	(7.4)	
Heavy Drinkers	831	(8.0)	1970	(7.3)	
DQI-K Score					0.001
Good Diet Quality	7693	(76.1)	20516	(76.1)	
Poor Diet Quality	2416	(23.9)	6433	(23.9)	
Hypertension					0.010
No	7494	(71.3)	19146	(70.9)	
Yes	3012	(28.7)	7874	(29.1)	
Dyslipidemia					0.047
No	6900	(65.5)	17112	(63.3)	
Yes	3629	(34.5)	9929	(36.7)	
Family history of diabetes					0.103
No	8518	(80.9)	21135	(78.2)	
Yes	1816	(17.2)	5846	(21.6)	

Standardized differences were calculated without including missing values. Standardized difference >0.2 indicates an imbalance between the groups.

Appendix 4. Baseline glycemic status of participants with complete information on FPG and HbA1c levels (adopted from Nabila *et al.*, Diabetes Care. 2023)

		Did not report history of diagnosed with DM by physicians			Reported history of diagnosed with DM by physicians		
		Normoglycemia by FPG	Prediabetes by FPG	Diabetes by FPG	Normoglycemia by FPG	Prediabetes by FPG	Diabetes by FPG
Did not report history of diagnosed with DM by physicians	Normoglycemia by HbA1c	13713	**1491**	28			
	Prediabetes by HbA1c	**6349**	**2518**	109			
	Diabetes by HbA1c	135	434	350			
Reported history of diagnosed with DM by physicians	Normoglycemia by HbA1c				49	35	6
	Prediabetes by HbA1c				152	295	86
	Diabetes by HbA1c				123	407	761

The number of included participants is marked with bold text. Participants who did not report history of diagnosed with DM by physicians and their glycemic status were in prediabetes defined by HbA1c, prediabetes defined by FPG, or prediabetes defined by both markers are considered as individuals with prediabetes and included in the analysis of this study.

Appendix 5. Odds ratios of reversion to normoglycemia stratified by sex and heterogeneity test results (adopted from Nabila *et al.*, Diabetes Care. 2023)

Variables	Men				Women				P-value	I^2
	Total N (%)	Prediabetes persistence N (%)	Reversion to normoglycemia N (%)	Reversion to normoglycemia OR 95% CI	Total N (%)	Prediabetes persistence N (%)	Reversion to normoglycemia N (%)	Reversion to normoglycemia OR 95% CI		
N	3545	2216 (62.5)	943 (26.6)		6813	4006 (58.8)	2350 (34.5)			
Sociodemographic factors										
Age										
40-49	792 (22.3)	480 (21.7)	226 (24.0)	Reference	1389 (20.4)	704 (17.6)	584 (24.9)	Reference		
50-59	1444 (40.7)	930 (42.0)	360 (38.2)	0.96 (0.77-1.19)	3418 (50.2)	2056 (51.3)	1144 (48.7)	0.91 (0.78-1.06)	0.69	0%
60-69	1309 (36.9)	806 (36.4)	357 (37.9)	1.08 (0.86-1.36)	2006 (29.4)	1246 (31.1)	622 (26.5)	0.93 (0.78-1.11)	0.31	2%
Education										
Middle school or less	750 (21.3)	456 (20.7)	205 (21.8)	Reference	2663 (39.3)	1672 (41.9)	784 (33.5)	Reference		
High school	1328 (37.6)	818 (37.1)	371 (39.5)	1.10 (0.88-1.39)	2798 (41.3)	1606 (40.3)	1003 (42.9)	1.23 (1.07-1.41)	0.42	0%
College or above	1450 (41.1)	931 (42.2)	364 (38.7)	0.90 (0.71-1.15)	1318 (19.4)	708 (17.8)	551 (23.6)	1.43 (1.21-1.70)	<0.01	89%
Income										
<200	920 (26.4)	567 (26.1)	258 (27.6)	Reference	2294 (34.5)	1368 (35.1)	747 (32.6)	Reference		
200-399	1603 (46.1)	993 (45.8)	432 (46.3)	0.97 (0.79-1.20)	2951 (44.4)	1761 (45.1)	1003 (43.7)	0.87 (0.76-1.00)	0.40	0%
≥400	957 (27.5)	610 (28.1)	244 (26.1)	0.97 (0.76-1.24)	1397 (21.0)	772 (19.8)	544 (23.7)	0.99 (0.84-1.18)	0.89	0%
Modifiable factors										
BMI (kg/m^2)										
<18.5	34 (1.0)	20 (0.9)	13 (1.4)	1.09 (0.51-2.36)	100 (1.5)	48 (1.2)	51 (2.2)	1.05 (0.68-1.63)	0.93	0%
18.5 - 22.9	828 (23.4)	505 (22.8)	261 (27.7)	Reference	2477 (36.4)	1321 (33.0)	1048 (44.6)	Reference		
23 - 24.9	1048 (29.6)	669 (30.2)	290 (30.8)	0.87 (0.70-1.08)	1863 (27.4)	1132 (28.3)	617 (26.3)	0.77 (0.67-0.89)	0.36	0%
≥25	1631 (46.1)	1020 (46.1)	379 (40.2)	0.84 (0.68-1.03)	2368 (34.8)	1502 (37.5)	633 (26.9)	0.68 (0.59-0.78)	0.09	65%
Abdominal obesity										
No	2403 (67.9)	1487 (67.2)	700 (74.2)	Reference	5187 (76.2)	2951 (73.7)	1936 (82.5)	Reference		
Yes	1138 (32.1)	727 (32.8)	243 (25.8)	0.81 (0.68-0.97)	1620 (23.8)	1052 (26.3)	412 (17.5)	0.76 (0.65-0.87)	0.58	0%
Smoking status										
Never smokers	833 (23.5)	519 (23.5)	230 (24.4)	Reference	6596 (97.0)	3874 (96.9)	2288 (97.5)	Reference		
Former smokers	1663 (47.0)	1073 (48.5)	432 (45.9)	0.95 (0.78-1.17)	80 (1.2)	53 (1.3)	22 (0.9)	0.62 (0.36-1.09)	0.16	48%
Current smokers	1042 (29.5)	620 (28.0)	280 (29.7)	0.98 (0.78-1.24)	122 (1.8)	69 (1.7)	36 (1.5)	0.96 (0.61-1.52)	0.94	0%

Variables	Men				Women				P-value	I^2
	Total N (%)	Prediabetes persistence N (%)	Reversion to normoglycemia N (%)	Reversion to normoglycemia OR 95% CI	Total N (%)	Prediabetes persistence N (%)	Reversion to normoglycemia N (%)	Reversion to normoglycemia OR 95% CI		
Smoking pack-year										
Never smokers	833 (23.7)	519 (23.6)	230 (24.5)	Reference	6596 (97.1)	3874 (97.0)	2288 (97.6)	Reference		
Light smokers	1393 (39.6)	872 (39.7)	389 (41.4)	1.03 (0.83-1.27)	185 (2.7)	110 (2.8)	53 (2.3)	0.79 (0.54-1.14)	0.22	34%
Moderate smokers	991 (28.2)	618 (28.1)	251 (26.7)	0.91 (0.72-1.15)	11 (.2)	7 (.2)	4 (.2)	1.38 (0.35-5.43)	0.56	0%
Heavy smokers	300 (8.5)	187 (8.5)	69 (7.3)	0.91 (0.65-1.29)	1 (.0)	1 (.0)	0 (.0)	-		
Physical activity										
No exercise	1418 (40.1)	883 (40.0)	384 (40.9)	Reference	3157 (46.5)	1831 (45.9)	1108 (47.3)	Reference		
<150min/week	408 (11.6)	252 (11.4)	113 (12.0)	1.03 (0.79-1.35)	769 (11.3)	444 (11.1)	270 (11.5)	0.95 (0.78-1.15)	0.63	0%
≥150min/week	1706 (48.3)	1074 (48.6)	442 (47.1)	1.00 (0.83-1.19)	2864 (42.2)	1716 (43.0)	966 (41.2)	0.93 (0.83-1.06)	0.51	0%
Alcohol consumption										
Non-drinkers	966 (27.3)	582 (26.3)	273 (29.1)	Reference	4975 (73.3)	2945 (73.8)	1707 (72.9)	Reference		
Light drinkers	1351 (38.2)	842 (38.1)	377 (40.1)	1.00 (0.82-1.22)	1493 (22.0)	847 (21.2)	546 (23.3)	1.05 (0.91-1.20)	0.69	0%
Moderate drinkers	568 (16.1)	359 (16.2)	147 (15.7)	0.85 (0.66-1.10)	171 (2.5)	108 (2.7)	52 (2.2)	0.83 (0.57-1.21)	0.92	0%
Heavy drinkers	649 (18.4)	428 (19.4)	142 (15.1)	0.76 (0.58-0.98)	149 (2.2)	89 (2.2)	38 (1.6)	0.74 (0.48-1.13)	0.92	0%
Diet quality										
Good diet quality	1817 (51.4)	1164 (52.7)	446 (47.4)	Reference	3525 (52.0)	2058 (51.6)	1232 (52.6)	Reference		
Poor diet quality	1715 (48.6)	1044 (47.3)	494 (52.6)	0.80 (0.68-0.94)	3256 (48.0)	1929 (48.4)	1108 (47.4)	0.99 (0.88-1.11)	0.03	78%
Hypertension										
No	2115 (59.8)	1290 (58.3)	624 (66.2)	Reference	4765 (70.0)	2677 (66.9)	1823 (77.6)	Reference		
Yes	1424 (40.2)	923 (41.7)	318 (33.8)	0.76 (0.63-0.90)	2043 (30.0)	1326 (33.1)	526 (22.4)	0.69 (0.60-0.79)	0.38	0%
Dyslipidemia										
No	1861 (52.5)	1150 (51.9)	539 (57.2)	Reference	3907 (57.3)	2166 (54.1)	1527 (65.0)	Reference		
Yes	1684 (47.5)	1066 (48.1)	404 (42.8)	0.84 (0.71-0.99)	2906 (42.7)	1840 (45.9)	823 (35.0)	0.76 (0.67-0.85)	0.32	0%
Other factors										
Family history of diabetes										
No	2903 (82.1)	1835 (83.1)	788 (83.7)	Reference	5153 (75.8)	2975 (74.4)	1888 (80.5)	Reference		
Yes	632 (17.9)	374 (16.9)	154 (16.3)	1.10 (0.88-1.37)	1647 (24.2)	1023 (25.6)	458 (19.5)	0.73 (0.64-0.84)	<0.01	89%
Baseline FPG (mean ± SD)	98.9 ± 10.2	99.6 ± 9.4	94.5 ± 9.8	0.93 (0.92-0.94)	94.5 ± 9.8	95.7 ± 9.1	90.6 ± 9.1	0.92 (0.91-0.92)	NA	NA

Variables	Men				Women				P-value	I^2
	Total N (%)	Prediabetes persistence N (%)	Reversion to normoglycemia		Total N (%)	Prediabetes persistence N (%)	Reversion to normoglycemia			
			N (%)	OR 95% CI			N (%)	OR 95% CI		
Baseline HbA1c (mean ± SD)	5.8 ± 0.3	5.8 ± 0.3	5.7 ± 0.2	0.80 (0.77-0.82)	5.8 ± 0.2	5.9 ± 0.2	5.7 ± 0.2	0.69 (0.67-0.71)	<0.01	98%

P-value from Cochran's Q test <0.1 or I^2 from Higgin's I^2 test >50% implied that there is a significant difference by the stratified factor. OR, adjusted odds ratio adjusted for age (continuous), education, income, baseline FPG (continuous), baseline HbA1c (continuous), and family history of diabetes. FPG, fasting plasma glucose; DQI-K, diet quality index for Koreans. The income is in Korean 10.000 won. Abdominal obesity was defined as a waist circumference ≥ 90 cm for men and ≥ 85 cm for women. Smoking pack-year was grouped into light (0, 1–20 pack-year), moderate (20.1–40 pack-year), and heavy smokers (>40 pack-year). Alcohol consumption was categorized into light (<0.1–19.9 g/day for men and 0.1–9.9 g/day for women), moderate (20–39.9 g/day for men and 10–19.9 g/day for women), or heavy drinkers (≥40 g/day for men and ≥20 g/day for women). Diet quality was considered good if the DQI-K score was 0–3 and poor if the score was 4–9.

Appendix 6. Odds ratios of progression to diabetes stratified by sex and heterogeneity test results (adopted from Nabila *et al.*, Diabetes Care. 2023)

Variables	Men				Women				P-value	I^2
	Total N (%)	Prediabetes persistence N (%)	Progression to diabetes		Total N (%)	Prediabetes persistence N (%)	Progression to diabetes			
			N (%)	OR 95% CI			N (%)	OR 95% CI		
N	3545	2216 (62.5)	386 (10.9)		6813	4006 (58.8)	457 (6.7)			
Sociodemographic factors										
Age										
40-49	792 (22.3)	480 (21.7)	86 (22.3)	Reference	1389 (20.4)	704 (17.6)	101 (22.1)	Reference		
50-59	1444 (40.7)	930 (42.0)	154 (39.9)	0.68 (0.49-0.94)	3418 (50.2)	2056 (51.3)	218 (47.7)	0.51 (0.38-0.68)	0.19	41%
60-69	1309 (36.9)	806 (36.4)	146 (37.8)	0.72 (0.51-1.01)	2006 (29.4)	1246 (31.1)	138 (30.2)	0.43 (0.31-0.61)	0.04	77%
Education										
Middle school or less	750 (21.3)	456 (20.7)	89 (23.2)	Reference	2663 (39.3)	1672 (41.9)	207 (45.5)	Reference		
High school	1328 (37.6)	818 (37.1)	139 (36.3)	0.72 (0.51-1.00)	2798 (41.3)	1606 (40.3)	189 (41.5)	0.92 (0.72-1.17)	0.24	28%
College or above	1450 (41.1)	931 (42.2)	155 (40.5)	0.70 (0.50-0.98)	1318 (19.4)	708 (17.8)	59 (13.0)	0.57 (0.40-0.82)	0.42	0%
Income (10.000 won)										
<200	920 (26.4)	567 (26.1)	95 (25.3)	Reference	2294 (34.5)	1368 (35.1)	179 (40.0)	Reference		
200-399	1603 (46.1)	993 (45.8)	178 (47.3)	1.04 (0.77-1.42)	2951 (44.4)	1761 (45.1)	187 (41.8)	0.80 (0.63-1.03)	0.20	39%
≥400	957 (27.5)	610 (28.1)	103 (27.4)	1.10 (0.77-1.57)	1397 (21.0)	772 (19.8)	81 (18.1)	0.83 (0.59-1.15)	0.25	24%
Modifiable factors										
BMI (kg/m^2)										
<18.5	34 (1.0)	20 (0.9)	1 (0.3)	0.52 (0.06-4.17)	100 (1.5)	48 (1.2)	1 (0.2)	0.40 (0.05-3.00)	0.86	0%
18.5 - 22.9	828 (23.4)	505 (22.8)	62 (16.1)	Reference	2477 (36.4)	1321 (33.0)	108 (23.7)	Reference		
23 - 24.9	1048 (29.6)	669 (30.2)	89 (23.2)	1.04 (0.71-1.52)	1863 (27.4)	1132 (28.3)	114 (25.0)	1.04 (0.77-1.40)	1.00	0%
≥25	1631 (46.1)	1020 (46.1)	232 (60.4)	1.69 (1.22-2.35)	2368 (34.8)	1502 (37.5)	233 (51.1)	1.53 (1.18-1.99)	0.64	0%
Abdominal obesity										
No	2403 (67.9)	1487 (67.2)	216 (56.3)	Reference	5187 (76.2)	2951 (73.7)	300 (65.8)	Reference		
Yes	1138 (32.1)	727 (32.8)	168 (43.8)	1.40 (1.10-1.79)	1620 (23.8)	1052 (26.3)	156 (34.2)	1.24 (0.99-1.56)	0.48	0%
Smoking status										
Never smokers	833 (23.5)	519 (23.5)	84 (21.9)	Reference	6596 (97.0)	3874 (96.9)	434 (95.2)	Reference		
Former smokers	1663 (47.0)	1073 (48.5)	158 (41.1)	0.89 (0.65-1.21)	80 (1.2)	53 (1.3)	5 (1.1)	0.96 (0.36-2.55)	0.88	0%
Current smokers	1042 (29.5)	620 (28.0)	142 (37.0)	1.39 (1.00-1.93)	122 (1.8)	69 (1.7)	17 (3.7)	1.68 (0.91-3.10)	0.59	0%

Variables	Men				Women				P-value	I^2
	Total N (%)	Prediabetes persistence N (%)	Progression to diabetes		Total N (%)	Prediabetes persistence N (%)	Progression to diabetes			
			N (%)	OR 95% CI			N (%)	OR 95% CI		
Smoking pack-year										
Never smokers	833 (23.7)	519 (23.6)	84 (22.0)	Reference	6596 (97.1)	3874 (97.0)	434 (95.2)	Reference		
Light smokers	1393 (39.6)	872 (39.7)	132 (34.6)	0.92 (0.67-1.27)	185 (2.7)	110 (2.8)	22 (4.8)	1.60 (0.95-2.72)	0.08	67%
Moderate smokers	991 (28.2)	618 (28.1)	122 (31.9)	1.21 (0.87-1.69)	11 (.2)	7 (.2)	0 (.0)	-		
Heavy smokers	300 (8.5)	187 (8.5)	44 (11.5)	1.27 (0.81-2.00)	1 (.0)	1 (.0)	0 (.0)	-		
Physical activity										
No regular exercise	1418 (40.1)	883 (40.0)	151 (39.3)	Reference	3157 (46.5)	1831 (45.9)	218 (47.9)	Reference		
<150min/week	408 (11.6)	252 (11.4)	43 (11.2)	1.08 (0.72-1.62)	769 (11.3)	444 (11.1)	55 (12.1)	1.06 (0.76-1.50)	0.95	0%
≥150min/week	1706 (48.3)	1074 (48.6)	190 (49.5)	1.05 (0.81-1.37)	2864 (42.2)	1716 (43.0)	182 (40.0)	0.91 (0.72-1.14)	0.42	0%
Alcohol consumption										
Non-drinkers	966 (27.3)	582 (26.3)	111 (28.9)	Reference	4975 (73.3)	2945 (73.8)	323 (70.8)	Reference		
Light drinkers	1351 (38.2)	842 (38.1)	132 (34.4)	0.83 (0.61-1.13)	1493 (22.0)	847 (21.2)	100 (21.9)	0.99 (0.76-1.29)	0.40	0%
Moderate drinkers	568 (16.1)	359 (16.2)	62 (16.1)	1.02 (0.70-1.48)	171 (2.5)	108 (2.7)	11 (2.4)	0.73 (0.36-1.46)	0.40	0%
Heavy drinkers	649 (18.4)	428 (19.4)	79 (20.6)	1.01 (0.71-1.44)	149 (2.2)	89 (2.2)	22 (4.8)	1.92 (1.12-3.30)	0.05	74%
Diet quality										
Good diet quality	1817 (51.4)	1164 (52.7)	207 (53.9)	Reference	3525 (52.0)	2058 (51.6)	235 (51.8)	Reference		
Poor diet quality	1715 (48.6)	1044 (47.3)	177 (46.1)	1.08 (0.85-1.37)	3256 (48.0)	1929 (48.4)	219 (48.2)	0.97 (0.78-1.20)	0.51	0%
Hypertension										
No	2115 (59.8)	1290 (58.3)	201 (52.3)	Reference	4765 (70.0)	2677 (66.9)	265 (58.1)	Reference		
Yes	1424 (40.2)	923 (41.7)	183 (47.7)	1.16 (0.91-1.49)	2043 (30.0)	1326 (33.1)	191 (41.9)	1.34 (1.07-1.68)	0.40	0%
Dyslipidemia										
No	1861 (52.5)	1150 (51.9)	172 (44.6)	Reference	3907 (57.3)	2166 (54.1)	214 (46.8)	Reference		
Yes	1684 (47.5)	1066 (48.1)	214 (55.4)	1.19 (0.93-1.51)	2906 (42.7)	1840 (45.9)	243 (53.2)	1.18 (0.95-1.46)	0.96	0%
Other factors										
Family history of diabetes										
No	2903 (82.1)	1835 (83.1)	280 (72.9)	Reference	5153 (75.8)	2975 (74.4)	290 (63.6)	Reference		
Yes	632 (17.9)	374 (16.9)	104 (27.1)	1.53 (1.28-1.82)	1647 (24.2)	1023 (25.6)	166 (36.4)	1.46 (1.17-1.83)	0.75	0%
Baseline FPG (mean ± SD)	98.9 ± 10.2	99.6 ± 9.4	106.0 ± 10.7	1.07 (1.05-1.08)	94.5 ± 9.8	95.7 ± 9.1	103.2 ± 10.8	1.08 (1.06-1.09)	0.16	48%

Variables	Men				Women				P-value	I^2
	Total N (%)	Prediabetes persistence N (%)	Progression to diabetes		Total N (%)	Prediabetes persistence N (%)	Progression to diabetes			
			N (%)	OR 95% CI			N (%)	OR 95% CI		
Baseline HbA1c (mean ± SD)	5.8 ± 0.3	5.8 ± 0.3	6.0 ± 0.3	1.37 (1.31-1.44)	5.8 ± 0.2	5.9 ± 0.2	6.1 ± 0.3	1.37 (1.31-1.43)	1.00	0%

P-value from Cochran's Q test <0.1 or I^2 from Higgin's I^2 test >50% implied that there is a significant difference by the stratified factor. OR, adjusted odds ratio adjusted for age (continuous), education, income, baseline FPG (continuous), baseline HbA1c (continuous), and family history of diabetes. FPG, fasting plasma glucose; DQI-K, diet quality index for Koreans. The income is in Korean 10.000 won. Abdominal obesity was defined as a waist circumference ≥ 90 cm for men and ≥ 85 cm for women. Smoking pack-year was grouped into light (0, 1–20 pack-year), moderate (20.1–40 pack-year), and heavy smokers (>40 pack-year). Alcohol consumption was categorized into light (<0.1–19.9 g/day for men and 0.1–9.9 g/day for women), moderate (20–39.9 g/day for men and 10–19.9 g/day for women), or heavy drinkers (≥40 g/day for men and ≥20 g/day for women). Diet quality was considered good if the DQI-K score was 0–3 and poor if the score was 4–9.

Appendix 7. Analysis of the odds ratio of glycemic status change by excluding participants with follow-up surveys of less than three years (adopted from Nabila *et al.*, Diabetes Care. 2023)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
		N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Sociodemographic factors						
Sex						
Men	3138 (34.8)	1963 (36.2)	814 (28.7)	Reference	361 (46.7)	Reference
Women	5892 (65.2)	3462 (63.8)	2018 (71.3)	1.29 (1.15-1.45)	412 (53.3)	0.66 (0.55-0.79)
Age (Mean ± SD)	55.3 ± 7.5	55.6 ± 7.3	54.6 ± 7.7	1.00 (0.99-1.01)	55.5 ± 7.6	0.98 (0.96-0.99)
Age						
40-49	1938 (21.5)	1059 (19.5)	701 (24.8)	Reference	178 (23.0)	Reference
50-59	4257 (47.1)	2621 (48.3)	1297 (45.8)	0.94 (0.83-1.08)	339 (43.9)	0.59 (0.47-0.74)
60-69	2835 (31.4)	1745 (32.2)	834 (29.4)	1.01 (0.87-1.18)	256 (33.1)	0.57 (0.44-0.73)
Education						
Middle school or less	3009 (33.5)	1880 (34.8)	863 (30.6)	Reference	266 (34.6)	Reference
High school	3526 (39.2)	2074 (38.4)	1151 (40.8)	1.24 (1.09-1.41)	301 (39.2)	0.85 (0.69-1.05)
College or above	2451 (27.3)	1444 (26.8)	806 (28.6)	1.26 (1.09-1.47)	201 (26.2)	0.70 (0.55-0.90)
Income						
<200	2792 (31.7)	1679 (31.8)	867 (31.3)	Reference	246 (32.7)	Reference
200-399	3924 (44.6)	2379 (45.1)	1211 (43.7)	0.87 (0.77-0.99)	334 (44.4)	0.90 (0.74-1.11)
≥400	2087 (23.7)	1220 (23.1)	694 (25.0)	0.98 (0.84-1.14)	173 (23.0)	0.95 (0.74-1.22)
Modifiable factors						
BMI (kg/m^2)						
<23	2916 (32.3)	1605 (29.6)	1162 (41.0)	Reference	149 (19.4)	Reference
≥23	6105 (67.7)	3815 (70.4)	1669 (59.0)	0.74 (0.66-0.82)	621 (80.6)	1.43 (1.16-1.75)
BMI (kg/m^2)						
<18.5	109 (1.2)	54 (1.0)	54 (1.9)	1.14 (0.75-1.73)	1 (.1)	0.30 (0.04-2.24)
18.5 - 22.9	2807 (31.1)	1551 (28.6)	1108 (39.1)	Reference	148 (19.2)	Reference
23 - 24.9	2543 (28.2)	1572 (29.0)	779 (27.5)	0.78 (0.68-0.88)	192 (24.9)	1.10 (0.86-1.41)
≥25	3562 (39.5)	2243 (41.4)	890 (31.4)	0.71 (0.63-0.80)	429 (55.7)	1.60 (1.29-1.99)
Abdominal Obesity						
No	6537 (72.5)	3827 (70.6)	2242 (79.2)	Reference	468 (60.8)	Reference
Yes	2483 (27.5)	1593 (29.4)	588 (20.8)	0.79 (0.70-0.89)	302 (39.2)	1.27 (1.07-1.51)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
		N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Smoking Status						
Never smokers	6441 (71.5)	3815 (70.5)	2156 (76.2)	Reference	470 (61.0)	Reference
Former smokers	1530 (17.0)	989 (18.3)	388 (13.7)	0.98 (0.81-1.20)	153 (19.9)	0.95 (0.71-1.28)
Current smokers	1042 (11.6)	610 (11.3)	285 (10.1)	1.03 (0.83-1.27)	147 (19.1)	1.48 (1.09-2.01)
Smoking pack-year						
Never smokers	6441 (71.7)	3815 (70.7)	2156 (76.3)	Reference	470 (61.2)	Reference
Light smokers	1379 (15.3)	850 (15.8)	383 (13.6)	1.03 (0.84-1.25)	146 (19.0)	1.10 (0.82-1.47)
Moderate smokers	896 (10.0)	557 (10.3)	227 (8.0)	0.99 (0.78-1.25)	112 (14.6)	1.31 (0.94-1.83)
Heavy smokers	272 (3.0)	173 (3.2)	59 (2.1)	0.97 (0.68-1.40)	40 (5.2)	1.29 (0.81-2.05)
Physical Activity						
No Regular Exercise	4011 (44.6)	2387 (44.2)	1287 (45.6)	Reference	337 (43.8)	Reference
<150min/week	1046 (11.6)	616 (11.4)	342 (12.1)	0.99 (0.84-1.17)	88 (11.4)	1.02 (0.78-1.35)
≥150min/week	3942 (43.8)	2403 (44.5)	1195 (42.3)	0.94 (0.85-1.05)	344 (44.7)	1.02 (0.85-1.22)
Alcohol Consumption						
Non-Drinkers	5121 (56.9)	3025 (56.0)	1709 (60.5)	Reference	387 (50.3)	Reference
Light Drinkers	2521 (28.0)	1511 (28.0)	790 (28.0)	0.98 (0.87-1.11)	220 (28.6)	0.94 (0.76-1.16)
Moderate Drinkers	652 (7.2)	412 (7.6)	173 (6.1)	0.84 (0.67-1.05)	67 (8.7)	1.02 (0.73-1.42)
Heavy Drinkers	705 (7.8)	458 (8.5)	151 (5.3)	0.72 (0.57-0.90)	96 (12.5)	1.30 (0.96-1.75)
Diet Quality						
Good Diet Quality	4702 (52.3)	2830 (52.4)	1462 (51.8)	Reference	410 (53.4)	Reference
Poor Diet Quality	4293 (47.7)	2574 (47.6)	1361 (48.2)	0.95 (0.86-1.06)	358 (46.6)	1.04 (0.88-1.23)
Hypertension						
No	5999 (66.5)	3463 (63.9)	2103 (74.3)	Reference	433 (56.2)	Reference
Yes	3020 (33.5)	1956 (36.1)	727 (25.7)	0.71 (0.64-0.80)	337 (43.8)	1.25 (1.05-1.48)
Dyslipidemia						
No	5030 (55.7)	2903 (53.5)	1774 (62.6)	Reference	353 (45.7)	Reference
Yes	4000 (44.3)	2522 (46.5)	1058 (37.4)	0.78 (0.71-0.87)	420 (54.3)	1.17 (0.99-1.39)
Other factors						
Family history of diabetes						
No	7002 (77.7)	4188 (77.4)	2296 (81.2)	Reference	518 (67.3)	Reference
Yes	2010 (22.3)	1225 (22.6)	533 (18.8)	0.83 (0.74-0.95)	252 (32.7)	1.53 (1.27-1.83)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
		N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Baseline FPG (mean ± SD)	95.4 ± 10.2	96.5 ± 9.3	90.8 ± 9.3	0.92 (0.91-0.93)	104.1 ± 10.8	1.08 (1.07-1.09)
Baseline HbA1c (mean ± SD)	5.8 ± 0.2	5.9 ± 0.3	5.7 ± 0.2	0.73 (0.72-0.75)	6.0 ± 0.3	1.37 (1.33-1.42)

OR, adjusted odds ratio adjusted for age (continuous), education, income, baseline FPG (continuous), baseline HbA1c (continuous), and family history of diabetes. FPG, fasting plasma glucose; DQI-K, diet quality index for Koreans. The income is in Korean 10.000 won. Abdominal obesity was defined as a waist circumference ≥ 90 cm for men and ≥ 85 cm for women. Smoking pack-year was grouped into light (0, 1–20 pack-year), moderate (20.1–40 pack-year), and heavy smokers (>40 pack-year). Alcohol consumption was categorized into light (<0.1–19.9 g/day for men and 0.1–9.9 g/day for women), moderate (20–39.9 g/day for men and 10–19.9 g/day for women), or heavy drinkers (≥40 g/day for men and ≥20 g/day for women). Diet quality was considered good if the DQI-K score was 0–3 and poor if the score was 4–9.

Appendix 8. Analysis of the odds ratio of changes in glycemic status among individuals with prediabetes defined by FPG (adopted from Nabila *et al.*, Diabetes Care. 2023)

Variables	Total	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
	N (%)	N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Sociodemographic factors						
Sex						
Men	2715 (46.8)	1630 (48.5)	608 (42.7)	Reference	477 (47.0)	Reference
Women	3082 (53.2)	1729 (51.5)	816 (57.3)	1.23 (1.07-1.41)	537 (53.0)	1.10 (0.94-1.29)
Age (mean ± SD)	55.5±7.5	55.6±7.4	55.1±7.8	0.99 (0.98-1.00)	55.6±7.6	0.99 (0.98-1.00)
Age						
40–49	1287 (22.2)	714 (21.3)	345 (24.2)	Reference	228 (22.5)	Reference
50–59	2594 (44.7)	1519 (45.2)	631 (44.3)	0.86 (0.73-1.02)	444 (43.8)	0.78 (0.63-0.95)
60–69	1916 (33.1)	1126 (33.5)	448 (31.5)	0.82 (0.68-0.98)	342 (33.7)	0.77 (0.61-0.96)
Education						
Middle school or less	1899 (33.0)	1085 (32.5)	444 (31.4)	Reference	370 (36.7)	Reference
High school	2344 (40.7)	1322 (39.6)	627 (44.4)	1.26 (1.07-1.48)	395 (39.2)	0.84 (0.69-1.01)
College or above	1517 (26.3)	934 (28.0)	341 (24.2)	1.06 (0.87-1.29)	242 (24.0)	0.74 (0.59-0.92)
Income (10.000 won)						
<200	1843 (32.8)	1036 (31.8)	481 (34.8)	Reference	326 (33.4)	Reference
200–399	2497 (44.5)	1450 (44.5)	609 (44.0)	0.86 (0.74-1.01)	438 (44.9)	0.99 (0.82-1.20)
≥400	1276 (22.7)	770 (23.6)	294 (21.2)	0.79 (0.65-0.96)	212 (21.7)	0.97 (0.77-1.23)
Modifiable factors						
BMI (kg/m^2)						
<23 kg/m^2	1592 (27.5)	872 (26.0)	519 (36.4)	Reference	201 (19.8)	Reference
≥23 kg/m^2	4203 (72.5)	2486 (74.0)	905 (63.6)	0.65 (0.57-0.75)	812 (80.2)	1.37 (1.14-1.65)
BMI (kg/m^2)						
<18.5 kg/m^2	55 (.9)	30 (.9)	22 (1.5)	1.29 (0.73-2.30)	3 (.3)	0.45 (0.13-1.52)
18.5–22.9 kg/m^2	1537 (26.5)	842 (25.1)	497 (34.9)	Reference	198 (19.5)	Reference
23–24.9 kg/m^2	1599 (27.6)	962 (28.6)	394 (27.7)	0.75 (0.63-0.89)	243 (24.0)	1.03 (0.82-1.29)
≥25 kg/m^2	2604 (44.9)	1524 (45.4)	511 (35.9)	0.60 (0.51-0.70)	569 (56.2)	1.55 (1.27-1.89)
Abdominal obesity						
No	3944 (68.1)	2291 (68.2)	1086 (76.3)	Reference	567 (56.0)	Reference
Yes	1850 (31.9)	1067 (31.8)	337 (23.7)	0.69 (0.60-0.80)	446 (44.0)	1.66 (1.42-1.94)

Variables	Total	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
	N (%)	N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Smoking status						
Never smokers	3609 (62.5)	2068 (61.7)	926 (65.3)	Reference	615 (61.0)	Reference
Former smokers	1374 (23.8)	845 (25.2)	304 (21.4)	0.99 (0.79-1.23)	225 (22.3)	1.05 (0.81-1.36)
Current smokers	796 (13.8)	439 (13.1)	188 (13.3)	1.18 (0.93-1.50)	169 (16.7)	1.41 (1.07-1.86)
Smoking pack-year						
Never smokers	3609 (62.7)	2068 (62.0)	926 (65.4)	Reference	615 (61.3)	Reference
Light smokers	1162 (20.2)	703 (21.1)	270 (19.1)	1.04 (0.83-1.29)	189 (18.8)	1.05 (0.81-1.37)
Moderate smokers	737 (12.8)	424 (12.7)	172 (12.2)	1.15 (0.89-1.48)	141 (14.1)	1.29 (0.96-1.74)
Heavy smokers	246 (4.3)	141 (4.2)	47 (3.3)	0.97 (0.66-1.41)	58 (5.8)	1.55 (1.04-2.30)
Physical activity						
No regular exercise	2448 (42.5)	1405 (42.0)	602 (42.6)	Reference	441 (43.8)	Reference
<150min/week	675 (11.7)	405 (12.1)	154 (10.9)	0.92 (0.74-1.14)	116 (11.5)	0.96 (0.75-1.23)
≥150min/week	2641 (45.8)	1533 (45.9)	658 (46.5)	1.07 (0.93-1.23)	450 (44.7)	0.92 (0.78-1.09)
Alcohol consumption						
Non-drinkers	2817 (48.8)	1608 (48.0)	728 (51.4)	Reference	481 (47.8)	Reference
Light drinkers	1687 (29.2)	963 (28.8)	422 (29.8)	1.02 (0.87-1.19)	302 (30.0)	0.99 (0.82-1.20)
Moderate drinkers	566 (9.8)	334 (10.0)	136 (9.6)	0.98 (0.77-1.25)	96 (9.5)	0.91 (0.68-1.22)
Heavy drinkers	701 (12.1)	443 (13.2)	130 (9.2)	0.75 (0.59-0.95)	128 (12.7)	0.85 (0.65-1.11)
Diet quality						
Good diet quality	4373 (76.2)	2523 (75.8)	1082 (77.0)	Reference	768 (76.4)	Reference
Poor diet quality	1365 (23.8)	804 (24.2)	324 (23.0)	0.94 (0.80-1.09)	237 (23.6)	0.96 (0.80-1.14)
Hypertension						
No	3463 (59.8)	1947 (58.0)	959 (67.4)	Reference	557 (55.0)	Reference
Yes	2330 (40.2)	1410 (42.0)	464 (32.6)	0.69 (0.60-0.80)	456 (45.0)	1.03 (0.88-1.20)
Dyslipidemia						
No	3110 (53.6)	1792 (53.3)	858 (60.3)	Reference	460 (45.4)	Reference
Yes	2687 (46.4)	1567 (46.7)	566 (39.7)	0.78 (0.68-0.88)	554 (54.6)	1.32 (1.14-1.54)
Other factors						
Family history of diabetes						
No	4461 (77.3)	2581 (77.1)	1158 (81.7)	Reference	722 (71.6)	Reference
Yes	1312 (22.7)	766 (22.9)	259 (18.3)	0.74 (0.63-0.87)	287 (28.4)	1.25 (1.05-1.49)

Variables	Total	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
	N (%)	N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Baseline FPG (mean ± SD)	106.8 ± 6.2	106.3 ± 5.6	104.6 ± 5.0	0.94 (0.93-0.95)	111.4 ± 7.3	1.12 (1.11-1.13)

OR, adjusted odds ratio adjusted for age (continuous), education, income, baseline FPG (continuous), and family history of diabetes. FPG, fasting plasma glucose; DQI-K, diet quality index for Koreans. The income is in Korean 10.000 won. Abdominal obesity was defined as a waist circumference ≥ 90 cm for men and ≥ 85 cm for women. Smoking pack-year was grouped into light (0, 1–20 pack-year), moderate (20.1–40 pack-year), and heavy smokers (>40 pack-year). Alcohol consumption was categorized into light (<0.1–19.9 g/day for men and 0.1–9.9 g/day for women), moderate (20–39.9 g/day for men and 10–19.9 g/day for women), or heavy drinkers (≥40 g/day for men and ≥20 g/day for women). Diet quality was considered good if the DQI-K score was 0–3 and poor if the score was 4–9.

Appendix 9. Analysis of associations between modifiable factors score and glycemic status change using BMI in the components (adopted from Nabila *et al.,* Diabetes Care. 2023)

Variables	Total N (%)	Events at follow-up				
		Prediabetes persistence	Reversion to normoglycemia		Progression to diabetes	
		N (%)	N (%)	OR 95% CI	N (%)	OR 95% CI
Modifiable factors score (continuous, mean ± SD)	4.2 ± 1.3	4.1 ± 1.3	4.5 ± 1.3	1.16 (1.11-1.20)	3.7 ± 1.3	0.87 (0.82-0.93)
Modifiable factors category						
Unfavorable group	2981 (29.0)	1918 (31.1)	711 (21.8)	Reference	352 (42.1)	Reference
Intermediate group	2875 (28.0)	1772 (28.7)	857 (26.3)	1.22 (1.07-1.39)	246 (29.4)	0.88 (0.72-1.07)
Favorable group	4413 (43.0)	2481 (40.2)	1693 (51.9)	1.52 (1.35-1.71)	239 (28.6)	0.69 (0.57-0.84)
Number of modifiable factors score						
0	35 (.3)	25 (.4)	4 (.1)	0.33 (0.11-1.01)	6 (.7)	1.33 (0.49-3.60)
1	176 (1.7)	108 (1.8)	33 (1.0)	0.76 (0.49-1.18)	35 (4.2)	1.77 (1.11-2.82)
2	791 (7.7)	515 (8.3)	185 (5.7)	0.83 (0.67-1.02)	91 (10.9)	1.07 (0.80-1.44)
3	1979 (19.3)	1270 (20.6)	489 (15.0)	0.83 (0.71-0.96)	220 (26.3)	1.11 (0.89-1.38)
4	2875 (28.0)	1772 (28.7)	857 (26.3)	Reference	246 (29.4)	Reference
5	2681 (26.1)	1560 (25.3)	948 (29.1)	1.15 (1.01-1.30)	173 (20.7)	0.85 (0.68-1.06)
6	1423 (13.9)	765 (12.4)	600 (18.4)	1.38 (1.19-1.60)	58 (6.9)	0.67 (0.49-0.93)
7	309 (3.0)	156 (2.5)	145 (4.4)	1.52 (1.16-1.97)	8 (1.0)	0.49 (0.23-1.05)

BMI was included and replaced abdominal obesity from the main analysis. BMI ≥23 kg/m2 was scored 0 and <23 kg/m^2 was scored 1. OR, adjusted odds ratio adjusted for age (continuous), education, income, baseline FPG (continuous), baseline HbA1c, and family history of diabetes. All modifiable factors score is the sum of BMI, smoking status, physical activity, alcohol consumption, diet quality, hypertension, and dyslipidemia scores. All factors score was divided into three groups based on tertiles scores. Scores of 0–3 were categorized as unfavorable, 4 as intermediate, and 5–7 as favorable.

Appendix 10. Distribution of sociodemographic factors based on modifiable factors score group (adopted from Nabila *et al.*, Diabetes Care. 2023)

Sociodemographic factors	Total		Modifiable factors score						
			Unfavorable group		Intermediate group		Favorable group		
	N	(%)	N	(%)	N	(%)	N	(%)	P-value
Men									
Age									<0.001
40-49	788	(22.4)	511	(24.9)	161	(19.0)	116	(18.8)	
50-59	1433	(40.7)	844	(41.1)	351	(41.4)	238	(38.5)	
60-69	1297	(36.9)	697	(34.0)	336	(39.6)	264	(42.7)	
Education									0.059
Middle school or less	743	(21.2)	455	(22.3)	181	(21.4)	107	(17.3)	
High school	1319	(37.6)	776	(38.0)	305	(36.0)	238	(38.5)	
College or above	1446	(41.2)	812	(39.7)	361	(42.6)	273	(44.2)	
Income									0.842
<200	910	(26.3)	536	(26.6)	211	(25.2)	163	(26.6)	
200-399	1598	(46.2)	934	(46.4)	390	(46.7)	274	(44.8)	
≥400	952	(27.5)	542	(26.9)	235	(28.1)	175	(28.6)	
Women									
Age									<0.001
40-49	1382	(20.5)	372	(15.2)	490	(22.3)	520	(24.8)	
50-59	3392	(50.3)	1217	(49.7)	1102	(50.1)	1073	(51.1)	
60-69	1976	(29.3)	861	(35.1)	609	(27.7)	506	(24.1)	
Education									<0.001
Middle school or less	2639	(39.2)	1125	(46.1)	808	(36.8)	706	(33.7)	
High school	2778	(41.3)	926	(37.9)	932	(42.5)	920	(43.9)	
College or above	1313	(19.5)	390	(16.0)	454	(20.7)	469	(22.4)	
Income									<0.001
<200	2273	(34.5)	964	(40.5)	726	(33.7)	583	(28.3)	
200-399	2928	(44.4)	1001	(42.0)	952	(44.2)	975	(47.3)	
≥400	1393	(21.1)	416	(17.5)	474	(22.0)	503	(24.4)	

P-value was calculated using the Chi-Square test. Income is in Korean 10.000 won.

Appendix 11. Distribution of outcomes according to follow-up time group and age category

Measurement time	Age group	All			Men			Women		
		Control (PD)	Case 1 (NG)	Case 2 (DM)	Control (PD)	Case 1 (NG)	Case 2 (DM)	Control (PD)	Case 1 (NG)	Case 2 (DM)
Second measurement	≤50	7949	8212	1961	6013	5258	**1534**	1936	2954	**427**
	51-55	6671	6527	1950	4729	4088	**1431**	1942	2439	**519**
	56-60	5593	5184	1837	3367	2812	**1188**	2226	2372	**649**
	>60	6214	5935	2462	3713	3198	**1400**	2501	2737	**1062**
	Total	26427	25858	8210	17822	15356	5553	8605	10502	2657
Third measurement	≤50	4743	2919	1054	3634	1985	**805**	1109	934	**249**
	51-55	3861	2400	936	2743	1575	**673**	1118	825	**263**
	56-60	3235	1940	851	1963	1124	**505**	1272	816	**346**
	>60	3515	2456	1224	2038	1334	**649**	1477	1122	**575**
	Total	15354	9715	4065	10378	6018	2632	4976	3697	1433
Fourth measurement	≤50	3282	1204	841	2547	834	**639**	735	370	**202**
	51-55	2595	1077	663	1833	724	**454**	762	353	**209**
	56-60	1568	673	435	975	420	**266**	593	253	**169**
	>60	3006	1337	904	1719	750	**500**	1287	587	**404**
	Total	10451	4291	2843	7074	2728	1859	3377	1563	984
Fifth measurement	≤50	2282	632	606	1788	**451**	466	494	181	**140**
	51-55	1722	568	454	1201	401	**322**	521	167	**132**
	56-60	1599	518	504	994	315	**309**	605	203	**195**
	>60	1898	646	558	1101	349	**305**	797	297	**253**
	Total	7501	2364	2122	5084	1516	1402	2417	848	720
Sixth measurement	≤50	1680	401	446	1306	**301**	345	374	**100**	101
	51-55	1247	319	389	887	**219**	263	360	**100**	126
	56-60	1146	289	325	708	185	**180**	438	**104**	145
	>60	1305	349	398	755	**203**	228	550	**146**	170
	Total	5378	1358	1558	3656	908	1016	1722	450	542

PD, prediabetes persistence; NG, reversion to normoglycemia; DM, progression to diabetes. Data with bold font indicate the total number of matched participants

Appendix 12. Distribution of matched participants based on age and sex in each measurement

Measurement time	Age group	Men			Women			All			Total
		Control (PD)	Case 1 (NG)	Case 2 (DM)	Control (PD)	Case 1 (NG)	Case 2 (DM)	Control (PD)	Case 1 (NG)	Case 2 (DM)	
Second measurement	≤50	1534	1534	1534	427	427	427	1961	1961	1961	
	51-55	1431	1431	1431	519	519	519	1950	1950	1950	
	56-60	1188	1188	1188	649	649	649	1837	1837	1837	
	>60	1400	1400	1400	1062	1062	1062	2462	2462	2462	
	Total	5553	5553	5553	2657	2657	2657	8210	8210	8210	24630
Third measurement	≤50	805	805	805	249	249	249	1054	1054	1054	
	51-55	673	673	673	263	263	263	936	936	936	
	56-60	505	505	505	346	346	346	851	851	851	
	>60	649	649	649	575	575	575	1224	1224	1224	
	Total	2632	2632	2632	1433	1433	1433	4065	4065	4065	12195
Fourth measurement	≤50	639	639	639	202	202	202	841	841	841	
	51-55	454	454	454	209	209	209	663	663	663	
	56-60	266	266	266	169	169	169	435	435	435	
	>60	500	500	500	404	404	404	904	904	904	
	Total	1859	1859	1859	984	984	984	2843	2843	2843	8529
Fifth measurement	≤50	451	451	451	140	140	140	591	591	591	
	51-55	322	322	322	132	132	132	454	454	454	
	56-60	309	309	309	195	195	195	504	504	504	
	>60	305	305	305	253	253	253	558	558	558	
	Total	1387	1387	1387	720	720	720	2107	2107	2107	6321
Sixth measurement	≤50	301	301	301	100	100	100	401	401	401	
	51-55	219	219	219	100	100	100	319	319	319	
	56-60	180	180	180	104	104	104	284	284	284	
	>60	203	203	203	146	146	146	349	349	349	
	Total	903	903	903	450	450	450	1353	1353	1353	4059

PD, prediabetes persistence; NG, reversion to normoglycemia; DM, progression to diabetes. Data with bold font indicate the total number of matched participants.

Appendix 13. Distribution of outcomes among matched participants

	Prediabetes persistence N (%)	Reversion to normoglycemia N (%)	Progression to diabetes N (%)	Total N (%)
All	10368	10368	10368	31104
Follow-up time group				
T3 (2012-2013)	4065 (39.21)	4065 (39.21)	4065 (39.21)	12195 (39.21)
T4 (2014-2015)	2843 (27.42)	2843 (27.42)	2843 (27.42)	8529 (27.42)
T5 (2016-2017)	2107 (20.32)	2107 (20.32)	2107 (20.32)	6321 (20.32)
T6 (2018-2019)	1353 (13.05)	1353 (13.05)	1353 (13.05)	4059 (13.05)

Appendix 14. Distribution of outcome according to changes in general obesity in each follow-up time group

	Total N (%)	Control (Prediabetes persistence) N (%)	Case 1 (Reversion to normoglycemia) N (%)	Case 2 (Progression to diabetes) N (%)
T3				
Stable obese	4433 (50.66)	1672 (52.12)	1525 (55.27)	1236 (44.40)
Obese to non-obese	521 (5.95)	197 (6.14)	166 (6.02)	158 (5.68)
Stable non-obese	3279 (37.47)	1145 (35.69)	914 (33.13)	1220 (43.82)
Non-obese to obese	518 (5.92)	194 (6.05)	154 (5.58)	170 (6.11)
Missing	3444	857	1306	1281
T4				
Stable obese	2988 (50.34)	1122 (51.66)	1049 (55.62)	817 (43.50)
Obese to non-obese	379 (6.38)	139 (6.40)	114 (6.04)	126 (6.71)
Stable non-obese	2163 (36.44)	769 (35.41)	585 (31.02)	809 (43.08)
Non-obese to obese	406 (6.84)	142 (6.54)	138 (7.32)	126 (6.71)
Missing	2593	671	957	965
T5				
Stable obese	2189 (48.69)	822 (39.01)	771 (36.59)	596 (28.29)
Obese to non-obese	358 (7.96)	134 (6.36)	115 (5.46)	109 (5.17)
Stable non-obese	1634 (36.34)	601 (28.52)	416 (19.74)	617 (29.28)
Non-obese to obese	315 (7.01)	104 (4.94)	112 (5.32)	99 (4.7)
Missing	1825	446	693	686
T6				
Stable obese	1502 (48.34)	543 (40.13)	535 (39.54)	424 (31.34)
Obese to non-obese	296 (9.53)	102 (7.54)	94 (6.95)	100 (7.39)
Stable non-obese	1118 (35.98)	409 (30.23)	313 (23.13)	396 (29.27)
Non-obese to obese	191 (6.15)	64 (4.73)	61 (4.51)	66 (4.88)
Missing	952	235	350	367

Appendix 15. Distribution of outcome according to changes in abdominal obesity in each follow-up time group

	Total N (%)	Control (Prediabetes persistence) N (%)	Case 1 (Reversion to normoglycemia) N (%)	Case 2 (Progression to diabetes) N (%)
T3				
Stable obese	5378 (61.46)	2047 (63.81)	1813 (65.71)	1518 (54.53)
Obese to non-obese	776 (8.87)	276 (8.60)	232 (8.41)	268 (9.63)
Stable non-obese	1732 (19.79)	568 (17.71)	464 (16.82)	700 (25.14)
Non-obese to obese	865 (9.88)	317 (9.88)	250 (9.06)	298 (10.70)
Missing	3444	857	1306	1281
T4				
Stable obese	3617 (60.93)	1361 (62.66)	1220 (64.69)	1036 (55.17)
Obese to non-obese	583 (9.82)	206 (9.48)	178 (9.44)	199 (10.60)
Stable non-obese	1118 (18.83)	394 (18.14)	280 (14.85)	444 (23.64)
Non-obese to obese	618 (10.41)	211 (9.71)	208 (11.03)	199 (10.60)
Missing	2593	671	957	965
T5				
Stable obese	2661 (59.19)	979 (46.46)	930 (44.14)	752 (35.69)
Obese to non-obese	502 (11.17)	172 (8.16)	139 (6.6)	191 (9.07)
Stable non-obese	864 (19.22)	327 (15.52)	198 (9.4)	339 (16.09)
Non-obese to obese	469 (10.43)	183 (8.69)	147 (6.98)	139 (6.6)
Missing	1825	446	693	686
T6				
Stable obese	1846 (59.41)	695 (51.37)	620 (45.82)	531 (39.25)
Obese to non-obese	396 (12.75)	141 (10.42)	127 (9.39)	128 (9.46)
Stable non-obese	575 (18.51)	187 (13.82)	162 (11.97)	226 (16.7)
Non-obese to obese	290 (9.33)	95 (7.02)	94 (6.95)	101 (7.46)
Missing	952	235	350	367

Appendix 16. Model fitting for the trajectory of obesity among participants in T4 group

Parameter	Number of class(es)	Log-likelihood	AIC	BIC	% of participants per class	Mean posterior probabilities	% of posterior probabilities > 70%
General obesity							
	1	-14190	28387	28408			
	2	**-10090**	**20192**	**20234**	**41.90 / 58.10**	**0.96 / 0.97**	**96.19 / 96.51**
	3	-10082	20182	20246	37.01 / 4.08 / 58.90	0.73 / 0.76 / 0.96	67.47 / 49.71 / 95.18
Abdominal obesity							
	1	-12588	25183	25204			
	2	**-10655**	**21323**	**21365**	**27.35 / 72.65**	**0.91 / 0.93**	**93.87 / 93.51**
	3	-10649	21315	21379	29.82 / 25.33 / 44.86	0.89 / 0.51 / 0.54	86.12 / 12.5 / 7.53
	4	-10648	21320	21405	29.25 / 4.88 / 50.70 / 15.17	0.81 / 0.39 / 0.53 / 0.54	79.68 / 0 / 0 / 20.87
Body mass index (continuous)							
Linear	1	-39410	78833	78882			
	2	-39410	78840	78910	49.07 / 50.93	0.52 / 0.51	0 / 0
	3	-39410	78845	78937	40.80 / 20.83 / 38.36	0.36 / 0.35 / 0.35	0.03 / 0 / 0
Waist circumference (continuous)							
Linear	1	-65843	131700	131749			
	2	-65812	131644	131714	98.23 / 1.77	0.96 / 0.68	97.82 / 39.07
	3	-65812	131649	131741	94.99 / 2.93 / 2.08	0.74 / 0.22 / 0.04	73.38 / 4.80 / 43.50

AIC, Akaike information criterion; BIC, the Bayesian information criterion; The selected model is highlighted in bold characters.

Appendix 17. Model fitting for the trajectory of obesity among participants in T5 group

Parameter	Number of class(es)	Log-likelihood	AIC	BIC	% of participants per class	Mean posterior probabilities	% of posterior probabilities > 70%
General obesity							
	1	-13635	27276	27296			
	2	-9163	18339	18379	44.61 / 55.39	0.95 / 0.98	91.24 / 100
	3	**-9066**	**18150**	**18210**	**37.07 / 48.09 / 14.84**	**0.92 / 0.88 / 0.85**	**91.25 / 100 / 78.46**
	4	-9061	18147	18228	14.93 / 32.37 / 3.62 / 49.07	0.85 / 0.82 / 0.63 / 0.53	79.45 / 89.93 / 31.44 / 0
Abdominal obesity							
	1	-12155	24317	24337			
	2	-9885	19781	19822	31.42 / 68.58	0.91 / 0.95	90.74 / 98.48
	3	**-9842**	**19704**	**19765**	**14.02 / 21.88 / 64.10**	**0.70 / 0.79 / 0.90**	**63.09 / 66.59 / 88.62**
	4	-9830	19683	19764	24.24 / 4.33 / 54.79 / 16.64	0.83 / 0.50 / 0.78 / 0.79	72.52 / 0 / 85.82 / 73.38
Body mass index (continuous)							
Linear	1	-35947	71908	71955			
	2	-35947	71914	71981	46.11 / 50.89	0.52 / 0.52	0 / 0
	3	-35741	71508	71595	0.81 / 98.42 / 0.78	0.80 / 0.99 / 0.85	72.55 / 99.53 / 73.47
Waist circumference (continuous)							
Linear	1	-62116	124245	124293			
	2	-62116	124252	124319	31.21 / 68.79	0.52 / 0.53	0 / 0
	3	-62061	124149	124237	0.38 / 98.91 / 0.71	0.73 / 0.98 / 0.74	45.83 / 99.10 / 55.56

AIC, Akaike information criterion; BIC, the Bayesian information criterion; The selected model is highlighted in bold characters.

Appendix 18. Model fitting for the trajectory of obesity among participants in T6 group

Parameter	Number of class(es)	Log-likelihood	AIC	BIC	% of participants per class	Mean posterior probabilities	% of posterior probabilities > 70%
General obesity							
	1	-10926	21858	21877			
	2	-6799	13611	13649	43.02 / 56.98	0.97 / 0.98	95.25 / 99.35
	3	-6660	13339	13395	36.88 / 14.19 / 48.93	0.93 / 0.85 / 0.92	94.72 / 81.60 / 98.39
	4	**-6647**	**13319**	**13395**	**30.20 / 14.78 / 5.17 / 49.84**	**0.83 / 0.90 / 0.78 / 0.90**	**92.66 / 86.83 / 71.43 / 98.27**
Abdominal obesity							
	1	-9569	19144	19162			
	2	-7609	15231	15268	30.97 / 69.03	0.91 / 69.03	85.84 / 96.54
	3	**-7534**	**15087**	**15143**	**20.47 / 26.21 / 53.31**	**0.87 / 0.85 / 0.81**	**81.83 / 71.62 / 87.29**
	4	-7520	15065	15141	17.20 / 15.10 / 57.08 / 10.62	0.77 / 0.68 / 0.79 / 0.71	68.19 / 51.22 / 83.00 / 55.45
	5	-7516	15062	15157	12.37 / 16.85 / 13.50 / 4.41 / 52.87	0.72 / 0.68 / 0.76 / 0.58 / 0.72	55.38 / 45.47 / 62.41 / 0 / 74.14
Body mass index (continuous)							
Linear	1	-27688	55390	55434			
	2	-27584	55189	55252	0.17 / 99.83	0.96 / 0.99	100 / 99.98
	3	-27546	55117	55199	0.12 / 97.76 / 2.12	0.99 / 0.98 / 0.72	100 / 98.61 / 52.33
Quadratic	1	-27635	55303	55404			
	2	-27315	54669	54795	36.39 / 63.61	0.69 / 0.74	44.96 / 60.19
	3	-27314	54676	54828	15.77 / 24.39 / 59.84	0.60 / 0.63 / 0.53	20.31 / 26.36 / 0.37
	4	-27315	54685	54862	0.07 / 38.88 / 20.55 / 40.50	0.44 / 0.57 / 0.40 / 0.40	0 / 18.76 / 0 / 0.18
Waist circumference (continuous)							
Linear	1	-49285	98585	98629			
	2	-49285	98591	98653	47.33 / 52.67	0.52 / 0.52	0 / 0
	3	-49260	98546	98628	4.36 / 92.49 / 3.15	0.73 / 0.87 / 0065	53.67 / 90.89 / 32.03
	4	-49234	98500	98601	1.82 / 0.89 / 95.98 / 1.31	079 / 0.74 / 0.93 / 0.67	45.95 / 55.56 / 95.56 / 33.96
Quadratic	1	-49334	98700	98801			
	2	-49183	98406	98532	0.71 / 99.29	0.80 / 0.99	75.86 / 99.63

AIC, Akaike information criterion; BIC, the Bayesian information criterion; The selected model is highlighted in bold characters.

Appendix 19. Comparison of distribution of participants with full measurement data, missing data at any time point, and with missing data at the last measurement

	All participants N (%)	Participants with complete measurement data N (%)	Participants with incomplete measurement data N (%)	Participants with missing data at the measurement time before outcome N (%)
	31104	18287	12817	8814
Sex				
Men	20343 (65.40)	12705 (69.48)	7638 (59.59)	5236 (59.41)
Women	10761 (34.60)	5582 (30.52)	5179 (40.41)	3578 (40.59)
Age (years)				
(Mean (SD))	56.63 (7.94)	55.38 (7.99)	58.40 (7.51)	58.55 (7.71)
≤50	8661 (27.85)	6118 (33.46)	2543 (19.84)	1740 (19.74)
51-55	7116 (22.88)	4899 (26.79)	2217 (17.3)	1523 (17.28)
56-60	6222 (20.00)	3821 (20.89)	2401 (18.73)	1742 (19.76)
>60	9105 (29.27)	3449 (18.86)	5656 (44.13)	3809 (43.22)
Income				
Low	7593 (24.41)	4264 (23.32)	3329 (25.97)	2337 (26.51)
Middle	11674 (37.53)	6494 (35.51)	5180 (40.42)	3518 (39.91)
High	11837 (38.06)	7529 (41.17)	4308 (33.61)	2959 (33.57)
Follow-up time				
T3 (2012-2013)	12195 (39.21)	8751 (47.85)	3444 (26.87)	3444 (39.07)
T4 (2014-2015)	8529 (27.42)	4814 (26.32)	3715 (28.98)	2593 (29.42)
T5 (2016-2017)	6321 (20.32)	2962 (16.2)	3359 (26.21)	1825 (20.71)
T6 (2018-2019)	4059 (13.05)	1760 (9.62)	2299 (17.94)	952 (10.8)
Smoking status				
Never	19113 (63.71)	10928 (59.76)	8185 (63.86)	5617 (63.73)
Former	4820 (16.07)	3039 (16.62)	1781 (13.9)	1170 (13.27)
Current	6065 (20.22)	3635 (19.88)	2430 (18.96)	1740 (19.74)
Missing	1106	685	421	287
Alcohol consumption				
Non-drinker	14814 (48.20)	8049 (44.01)	6765 (52.78)	4682 (53.12)
Drinker	15922 (51.80)	10023 (54.81)	5899 (46.02)	4031 (45.73)
Missing	368	215	153	101
Physical activity				
No regular exercise	10879 (35.27)	6237 (34.11)	4642 (36.22)	3260 (36.99)
Regular exercise	19965 (64.73)	11895 (65.05)	8070 (62.96)	5486 (62.24)
Missing	260	155	105	68
Hypertension				
No	21544 (69.26)	12943 (70.78)	8601 (67.11)	5931 (67.29)
Yes	9560 (30.74)	5344 (29.22)	4216 (32.89)	2883 (32.71)
Dyslipidemia				
No	23037 (74.06)	13908 (76.05)	9129 (71.23)	6286 (71.32)
Yes	8067 (25.94)	4379 (23.95)	3688 (28.77)	2528 (28.68)
Family history of diabetes				
No	12674 (40.75)	6530 (35.71)	6144 (47.94)	4160 (47.2)
Yes	18430 (59.25)	11757 (64.29)	6673 (52.06)	4654 (52.8)
FPG at baseline				
(mean (SD))	108.95 (6.72)	109.02 (6.69)	108.84 (6.76)	108.99 (6.91)
BMI (kg/m^2)				
(Mean (SD))	24.60 (2.82)	24.60 (2.77)	24.59 (2.89)	24.60 (2.94)
<18.5	313 (1.01)	164 (0.90)	149 (1.16)	114 (1.29)
18.5-23.4	8387 (26.96)	4889 (26.73)	3498 (27.29)	2434 (27.62)
23.4-24.9	8910 (28.65)	5322 (29.10)	3588 (27.99)	2396 (27.18)
25.0-29.9	12368 (39.76)	7267 (39.74)	5101 (39.80)	3516 (39.89)
≥30	1126 (3.62)	645 (3.53)	481 (3.75)	354 (4.02)

	All participants N (%)	Participants with complete measurement data N (%)	Participants with incomplete measurement data N (%)	Participants with missing data at the measurement time before outcome N (%)
Waist circumference (Mean (SD))	84.11 (7.72)	84.18 (7.60)	84.01 (7.89)	84.04 (8.00)
Abdominal obesity				
No	21802 (70.09)	12979 (70.97)	8823 (68.84)	6043 (68.56)
Yes	9302 (29.91)	5308 (29.03)	3994 (31.16)	2771 (31.44)

FPG, fasting plasma glucose, BMI, body mass index; Income was categorized according to the type of insurance (low: type 1-4, middle: type 5-8, and high: type 9-10); P-value was calculated by Chi-square for categorical variables and by One-way ANOVA for continuous variable.