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BMJ Open Sex- and age-specific body composition indices as predictors of new-onset type 2 diabetes mellitus in Koreans: a nationwide cohort study

Min Jeong Park ⁽¹⁾, ¹ Minwoong Kang, ² Soo Yeon Jang, ¹ Ahreum Jang, ¹ Eyun Song,¹ Kyung Mook Choi ¹,¹ Sei Hyun Baik,¹ Hye Jin Yoo ¹

ABSTRACT

Objectives Hormonal and age-related differences in body composition require tailored approaches for predicting new-onset type 2 diabetes (NODM). Previous studies lacked in-depth stratified analyses. We investigate sexand age-specific body composition indices associated with NODM.

Design and setting A retrospective, nationwide, population-based cohort study.

Participants We analysed 4 058 891 adults who underwent a health examination in the year 2009 and 10-year follow-up data from the National Health Insurance Service.

Outcome measure NODM risk stratified by sex and age groups in 20-year intervals according to guartiles or per 1 SD increase in body mass index (BMI), waist circumference (WC), waist-height ratio (WHtR), visceral adiposity index (VAI), a body shape index (ABSI) and weight-adjusted waist index (WWI).

Results Among the total subjects, 625715 individuals (15.4%) developed NODM during median 10-year followup. The fourth quartile of WHtR showed the highest HR for NODM compared with the first quartile among various indices across the entire population (HR 2.54, 95% Cl 2.52 to 2.57). In men, WHtR consistently exhibited the strongest association with NODM across all age groups in analysis based on 1 SD increase; ages 20-39 years (HR 1.54, 95% CI 1.53 to 1.55), ages 40-59 years (HR 1.39, 95% CI 1.38 to 1.39), ages 60-79 years (HR 1.23, 95% CI 1.22 to 1.24). In women, the most relevant body composition index for NODM varied by age group; BMI for ages 20-39 years (HR 1.48, 95%Cl 1.47 to 1.49), WHtR for ages 40-59 years (HR 1.46, 95% CI 1.45 to 1.47) and WC for ages 60-79 vears (HR 1.23, 95%Cl 1.22 to 1.24).

Conclusion WHtR was the strongest predictor of NODM in men across all ages, while the relevant indices varied by age group in women. These findings highlight the need for sex- and age-specific body composition assessments in predicting NODM risk.

INTRODUCTION

The number of patients diagnosed with type 2 diabetes mellitus (T2DM) has been rapidly growing. In 2021, 540 million patients were diagnosed with T2DM worldwide, which

STRENGTHS AND LIMITATION OF THIS STUDY

- \Rightarrow The large-scale study using the National Health Insurance Service database represents almost the entire Korean population with 10-year longitudinal follow-up results.
- \Rightarrow Sex- and age-group-stratified risk of new-onset type 2 diabetes mellitus was estimated.
- \Rightarrow Due to the lack of laboratory data such as glycated haemoglobin or oral glucose tolerance test results, the severity of diseases could not be evaluated.
- \Rightarrow The study focused on the impact of the baseline body composition index on long-term outcomes but did not account for changes in body composition during the follow-up period.

is fivefold the number of diabetes cases in data 1980.¹ Similarly, a Korean epidemiological study reported that in 2020, 16.7% of adults ∃ \geq 30 years of old had T2DM, compared with 13.8% in 2018.² Because DM is associated with cerebro-cardiovascular complications and mortality, discovering a screening tool raining, for T2DM is important for early diagnosis. Body composition indices provide simple, rapid and inexpensive ways to evaluate risks of metabolic disease by simply measuring anthropometric parameters.

Since its development in 1932, body mass index (BMI) has been a cornerstone for measuring obesity.³ However, in 2007, research from the Framingham Heart study revealed a stronger impact of visceral adipose **G** tissue (VAT) on metabolic disease compared **g** with subcutaneous adipose tissue (SAT).⁴ VAT releases free fatty acids (FFAs), contributing to insulin resistance, whereas SAT serves as a buffer of FFAs.⁵ With the recognition of VAT's significance, alternative body composition indices, such as waist circumference (WC), waist-hip ratio (WHR) and waist-height ratio (WHtR), have been developed to highlight the hazardous metabolic effect of VAT.⁶

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Later, more complex indices such as a body shape index (ABSI) and visceral adiposity index (VAI) were introduced, showing strong links to cardiometabolic risk and insulin sensitivity.^{7 8} The ABSI is statistically constructed metric designed to capture the metabolic impact of WC independently of height, weight and BMI, using linear least-square regression.⁷ The VAI is developed based on the fact that the harmful effect of visceral fat is related to high triglyceride (TG) and low high-density lipoprotein cholesterol (HDL-C) levels.⁹ In lipid metabolism, increased VAT leads to hypertriglyceridemia, which promotes lipoprotein remodelling and accelerates HDLchol catabolism.⁵ By incorporating the detrimental effect of a high TG/HDL-C ratio along with increased WC, VAI was formulated and has demonstrated its ability to predict metabolic disease in several studies. Furthermore, recognising the metabolic risks of sarcopenia, researchers developed the weight-adjusted waist index (WWI) to reflect low muscle mass.¹⁰ WWI was created by standardising WC with body weight. In several studies, WWI has shown a positive association with VAT and a negative association with appendicular skeletal muscle mass, making it a distinctive parameter for effectively capturing reduction in muscle mass, unlike other existing body composition.¹¹

In previous studies, some indices were investigated in terms of new-onset T2DM (NODM) development¹²; however, a comprehensive comparison of all six indices, including tailored age- and sex-related risk stratification has not been conducted. However, the increasing prevalence of sarcopenia exerts a significant impact on metabolic risk as people age. In addition, changes in body composition also differ between the sexes. Menopause causes 15-20% of additional abdominal fat accumulation, and decreasing testosterone in men induces muscle mass reduction.¹³ Therefore, we hypothesised that different body composition indices would be associated with NODM between a young muscular population and a sarcopenic older population, or between men and women. In the present study, body composition indices regarding the prediction of NODM were compared in different age and sex groups using 10-year longitudinal national comprehensive cohort data.

METHODS

Data source and study population

In the present study, claims data from the National Health Insurance Service (NHIS) database from 1 January 2004 to 31 December 2019 were used. Korea has a universal single-payer national health system, and the NHIS maintains national records of all covered inpatient and outpatient visits, procedures and prescriptions. The International Classification of Disease version 10 (ICD-10) codes were used to identify medical history and new onset of disease. The study included men and women between 20 and 80 years of age who underwent a health examination between 1 January 2009 and 31 December 2009 and satisfied the following criteria: no history of DM

(E10-14), liver disease (K70-77), pancreas disease (K85-87), pancreatectomy (E89.1) or cancer (C00-97) within 5 years or who used a glucocorticoid within 1 year from the date of health check-up at the time of data collection, all of which might affect onset of DM as a secondary cause. Participants with fasting blood glucose ≥126 mg/dL at the health examination in 2009, participants with missing and outlier values for height, weight, WC, TG and HDL-C for the calculation of anthropometric index, and subjects who were deceased at baseline were excluded. Ultimately, a total of 4 058 891 patients were included in the analysis. For the examination of body composition indices reflecting age- and sex-dependent DM risk stratification, we divided the study total population into three groups: young adults (20-39 years), middle-aged (40-59 years) and elderly (60-79 years). Individuals in their 40s and ight 50s often experience changes in body composition due to childbirth and the perimenopausal period, while those in their 60s and 70s typically face a loss of muscle mass and strength.¹⁴ The detailed study flow is shown in online supplemental figure 1. The Korea University Institutional Review Board approved this study (No. 2022GR0041) which was conducted in accordance with the Declaration of Helsinki of the World Medical Association. We were permitted to use the NHIS data by the NHIS review committee (NHIS-2022-1-704). The need for informed consent was waived because anonymous and de-identified information was used for analysis.

Definition of body composition index and variables

The characteristics of NHIS databases were presented in previous studies.¹⁵ Among various body composition parameters, six body composition indices were selected for the present study: BMI, WC, WHtR, VAI, ABSI and WWI, which have been widely studied in large cohorts. Because NHIS has no data on the hip circumference, ▶ the effect of WHR could not be analysed in this study. The body composition indices were calculated with the following equations: BMI as weight/height,^{2 3} WHtR as WC/height,^{4 6} ABSI as 1000×WC × weight^{-2/3} \times height^{5/6},¹⁶ VAI as WC/[39.68 + (1.88×BMI)] × TG/1.03×1.31/HDL (for men) and WC/[36.58 + $(1.89 \times BMI)$] × TG/0.81×1.52/HDL (for women),⁸ and WWI as WC/ $\sqrt{\text{weight.}^{17}}$ Age, sex, residential area and income percentile were obtained from the insurance eligibility database. Smoking status, alcohol consumption, regular exercise, height, weight, family history 2 of diabetes, TG and HDL-C were obtained from the health screening examination database. An area with a population >0.3 million was classified as urban. Alcohol consumption was classified as none, moderate (1-14 cups per week for men, 1–7 cups per week for women), heavy (≥ 15 cups per week for men, ≥ 8 cups per week for women) or unknown. Regular exercise was defined as none, regular (vigorous activity for ≥ 3 days or moderateintensity activity for ≥ 5 days), irregular (other activities including walking) or unknown.

Study outcomes

The study outcome was the incidence of NODM defined by searching for either ICD-10 codes E11–14, usage of an oral hypoglycaemic agent or a fasting plasma glucose level of $\geq 126 \text{ mg/dL}$.¹⁸ The duration of follow-up was defined as the time interval between the health examination date and the date of the study outcome, death or censoring or the end of the study period (31 December 2019). We evaluated the relationship between six body composition indices-BMI, WC, WHtR, VAI, ABSI and WWI-and the onset of diabetes mellitus (NODM) over a 10-year period. These indices were compared based on their association with NODM across different 20-year age intervals and between sexes.

Statistical analysis

The baseline characteristics of the study population are presented as mean±SD for continuous variables and number (percentage) for categorical variables. The ANOVA and γ^2 test were used to compare the characteristics between men and women with different age groups and between subjects with and without T2DM. The incidence rate of NODM was calculated by dividing the number of subjects diagnosed with NODM by person-years. Cox proportional hazards regression was used to identify the association between anthropometric indices and NODM. Calculated HRs and 95% CIs were estimated based on the quartiles and 1 SD of each body composition index. To account for additional potential confounding factors at the baseline health examination, age, sex, smoking status, alcohol consumption, regular exercise, family history of diabetes, residential area and income percentile were adjusted (models 1-5). Additional adjustment with systolic blood pressure, diastolic blood pressure, TG and HDL-C was presented in online supplemental material (model 6). Not only does the VAI formula contain TG and HDL-C, but also the main purpose of our study is to estimate NODM risk by measuring body composition without laboratory tests. Hence, we presented results of models 1 through 5 in the main findings. P value <0.05 was considered statistically significant. All analyses were performed using SAS V.9.4 (SAS Institute Inc., Cary, NC, USA).

Patient and public involvement

Since this study used publicly available datasets, there was no direct patient or public involvement in the planning, execution or analysis steps. Nevertheless, we understand the value of integrating patients and public insights into research. We plan to disseminate our findings to patients and the public as valuable information for T2DM prevention.

RESULTS

Baseline characteristics of the study population and 10-year cumulative incidence of NODM

For the 10-year follow-up period, 625715 subjects were diagnosed with NODM (15.4% of the total population). The mean age of the study population was 41.9±12.2 years and 60.7% of participants were men. The incidence rate

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Figure 1 10-year incidence of T2DM stratified by 10-year age groups in (A) men and (B) women.

data of NODM for the 10-year period was 16.2% in men and 13.3% in women. When age was stratified by two decades, 10-year T2DM incidence in both men and women markedly increased almost twofold in the middle-aged group (40-59 years) compared with the young-adult group (20-39 years) (men: 14.0% in 20-39 years age group, 27.4% in 40-59 years age group; women: 10.4% in 20-39 years age group, 22.7% in 40-59 years age group; figure 1). In the elderly group, 32.9% of men and 30.7% of women progressed to T2DM during the 10-year follow-up period. The detailed baseline characteristics of men and women with age groups are presented in table 1. In obesity classification based on BMI, the percentage of obese men decreases at the ages of 60–79 years, while the percentage of obese women increases at the ages of 60-79 years. A **B**0 comparison of baseline characteristics of patients with or without incidental NODM is shown in online supplemental table 1.

Association of the guartiles of body composition indices and NODM incidence across different 20-year age intervals and between sexes

Of the various body composition indices, WHtR exhibited the highest HR for the NODM in the fourth quartile group compared with the first quartile in all models of Cox regression. NODM HR of WHtR in the fully adjusted

Table 1 Baseline character	steristics of patients	with or without inci	dent T2DM					
	Men (N=2 463 811	(Women (N=1 595 08	30)		
	Age 20–39 years	Age 40-59 years	Age 60–79 years	Ъ	Age 20–39 years	Age 40–59 years	Age 60-79 years	Ъ
Z	1 258 327	992 621	212863		563 530	826450	205100	
BMI, kg/m ²	23.9±3.2	24.0±2.8	23.4±2.8	<0.001	21.4±3.1	23.2±2.9	24.0±3.1	<0.001
Underweight	35006 (2.8)	18533 (1.9)	7902 (3.7)		72860 (12.9)	21 004 (2.5)	5474 (2.7)	
Normal	488605 (38.8)	342 039 (34.5)	85976 (40.4)		359 414 (63.8)	403581 (48.8)	71525 (34.9)	
Overweight	315404 (25.1)	284 633 (28.7)	58937 (27.7)		67955 (12.1)	201 009 (24.3)	54453 (26.6)	
Obese	419312 (33.3)	347 416 (35.0)	60048 (28.2)		63301 (11.2)	200856 (24.3)	73648 (35.9)	
Income				<0.001				<0.001
Medical aid	1073 (0.1)	698 (0.1)	487 (0.2)		722 (0.1)	1596 (0.2)	738 (0.4)	
≤30th	234504 (18.6)	160 323 (16.2)	64376 (30.2)		186337 (33.1)	264646 (32.0)	48687 (23.7)	
31st-70th	646329 (51.4)	342 703 (34.5)	72448 (34.0)		289033 (51.3)	280447 (33.9)	65071 (31.7)	
>70th	318804 (25.3)	468 547 (47.2)	74038 (34.8)		84 574 (15.0)	274104 (33.2)	88603 (43.2)	
Residency area				<0.001				<0.001
Urban	952413 (75.7)	770384 (77.6)	146653 (68.9)		446470 (79.2)	640886 (77.6)	131 129 (63.9)	
Rural	305598 (24.3)	221 942 (22.4)	66132 (31.1)		116906 (20.8)	185208 (22.4)	73891 (36.0)	
Family history of DM	95941 (7.6)	75 935 (7.7)	5822 (2.7)	<0.001	49 880 (8.9)	75913 (9.2)	8350 (4.1)	<0.001
Smoking habit				<0.001				<0.001
Never	364 532 (29.0)	263588 (26.6)	82 2 87 (38.7)		511139 (90.7)	785970 (95.1)	197 053 (96.1)	
Ex-smoker	181 767 (14.5)	261163 (26.3)	60755 (28.5)		19 931 (3.5)	11606 (1.4)	1911 (0.9)	
Current	704 877 (56.0)	462 090 (46.6)	68553 (32.2)		28 889 (5.1)	22682 (2.7)	4535 (2.2)	
Alcohol intake				<0.001				<0.001
None	314 855 (25.0)	283718 (28.6)	94373 (44.3)		298791 (53.0)	606534 (73.4)	181677 (88.6)	
Moderate	572 886 (45.5)	402 993 (40.6)	70875 (33.3)		172935 (30.7)	151 281 (18.3)	14 497 (7.1)	
Heavy	342 328 (27.2)	282280 (28.4)	42639 (20.0)		76051 (13.5)	48794 (5.9)	3793 (1.9)	
Exercise				<0.001				<0.001
None	224 755 (17.9)	204722 (20.6)	55883 (26.3)		117228 (20.8)	214703 (26.0)	67 356 (32.8)	
Irregular	826 539 (65.7)	584212 (58.9)	102 190 (48.0)		390425 (69.3)	469 541 (56.8)	101 561 (49.5)	
Regular	195 008 (15.5)	195416 (19.7)	53 336 (25.1)		50809 (9.0)	136577 (16.5)	34 821 (17.0)	
WC, cm	81.5±7.9	83.1±7.2	83.5±7.7	<0.001	70.8±7.5	75.4±7.5	80.2±7.9	<0.001
WHtR	0.5±0	0.5±0	0.5±0	<0.001	0.4±0	0.5±0.1	0.5±0.1	<0.001
ABSI	347 884.1±17515.9	357 304.7±18253.6	369 448.7±20 420.1	<0.001	337 529.8±21711.5	344 381.8±20 926.5	363 581.9±24347.6	<0.001
								Continued

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	Men (N=2 463 811				Women (N=1 595 C	80)		
	Age 20–39 years	Age 40–59 years	Age 60–79 years	٩	Age 20–39 years	Age 40–59 years	Age 60–79 years	٩
WWI	9.7±0.5	10±0.5	10.5±0.6	<0.001	9.5±0.6	10±0.7	10.8±0.8	<0.001
VAI	431 320.6±300 187.2	471 715.6±311853.9	404 461.7±255281.4	<0.001	399 669.1±257236.4	512 165.7±301 931.	2 630 556±343 916.3	<0.001
SBP, mmHg	121.9±12.2	124.2±14.3	129.7±16.3	<0.001	111.7±11.3	118.6±14.8	128.3±16.5	<0.001
DBP, mmHg	76.4±8.9	78.6±10.0	79.4±10.3	<0.001	70.1±8.4	74.0±10.1	77.9±10.2	<0.001
AST, IU/L	25.4±22.7	26.7±23.2	26.8±15.7	<0.001	19.2±11.2	22.2±16.8	24.8±14.7	<0.001
ALT, IU/L	28.9±28.1	28.2±23.6	23.7±16.9	<0.001	15.2±13.7	19.3±17.9	20.7±16.8	<0.001
FBS, mg/dL	90.5±11.1	94.7±11.7	95.8±11.9	<0.001	87.6±9.9	91.7±10.5	94.2±11.1	<0.001
eGFR	86.8±57.1	81.3±47.8	78.5±34.4	<0.001	90.0±50.0	81.8±27.3	75.8±27.1	<0.001
T-chol, mg/dL	189±34.9	199.7±36.6	194.2±37.3	<0.001	178.2±31.3	197.7±36.4	209.9±38.9	<0.001
TG, mg/dL	139.8±96.6	154.9±101.7	134.5±82.9	<0.001	82.1±47.4	104.7±62.3	132.9±72.9	<0.001
LDL-C, mg/dL	122.0 ± 302.3	117.9±72.2	115.6±60.1	<0.001	125.8±430.0	119.8±84.6	129.5±64.5	<0.001
HDL-C, mg/dL	53.1±11.9	52.3±12.1	52.7±12.6	<0.001	61.8±12.9	58.3±12.8	54.8±12.5	<0.001
Data were presented as mee ABSI, a body shape index; <i>I</i> glomerular filtration rate; FBi cholastandi TG, triducarida	an±SD or n (%). \LT, alanine aminotrans G, fasting blood glucos	ferase; AST, aspartate :e; HDL-C, high-density indev: WC, waist circu	aminotransferase; BMI y lipoprotein cholesterc	, body mas It LDL-C, lc -heicht rati	s index; DBP, diastolic t w-density lipoprotein c	olood pressure; DM, diak holesterol; SBP, systolic d weist index	blood pressure; T-chol, tot	ated al

model was 2.54 (95% CI 2.52 to 2.57) followed by WC, BMI, VAI, WWI and ABSI with HRs of 2.54, 2.52, 2.31, 2.19, 1.78 and 1.18, respectively (table 2). When we further adjusted for systolic blood pressure, diastolic blood pressure, TG and HDL, which are directly influenced by anthropometric parameters, WHtR still showed the highest HR for NODM among all body composition indices (online supplemental table 2).

Subgroup analysis was performed to examine the best body composition indices associated with NODM in different sex and 20-year interval age groups. As shown in figure 2A, in men, WHtR had the highest HR for NODM across all age groups compared with other indices. The impact of the body composition indices on NODM was most significant in men aged 20-39 years, showing a gradual reduction in HR with ageing. However, in women, the effect of body composition indices on NODM was the greatest in the middle-aged group (ages 40-59 years), with HR values numerically higher than those in both young-adult women (ages 20-39 years) and elderly women (ages 60-79 years) (figure 2B). Similar to men, the WHtR had the highest HR for NODM in women, except in the elderly group.

Association of 1 SD increment of body composition indices with NODM across different 20-year age interval groups and sex groups

In the regression analysis based on quartiles of indices, HRs of NODM were markedly increased in the fourth quartile of indices compared with risk increments observed in the second and third quartiles. To avoid overestimating the association between NODM and the body composition indices, which might occur due to high correlations observed in the fourth quartile, we also evaluated the association between NODM and a 1 SD increase in each index. The relative risk of NODM with a 1 SD increase of body composition indices in each sex and age group is shown in figure 3A,B. In men, WHtR had the highest HR across all age groups with 54% increased risk in young adults, 39% in middle-aged and 23% in the elderly per 1 SD increase, showing a sequential decrease in HR values as age increased (figure 3A and online supplemental table 3). Conversely, in women, differential indices showed the highest risk of NODM with a 1 SD increase in each age group; BMI had the highest HR in young adults, WHtR in middle-aged subjects and WC in the elderly. The association of indices related to WC and WHtR remained significant up to middle age but diminished in older age groups (figure 3B and online supplemental table 3).

DISCUSSION

The present research included a nationwide cohort database and found that a distinct body composition index adequately predicted the risk of 10-year NODM in different age and sex groups. The incidence of NODM increased twofold from the young-adult group to the middle-aged group. WHtR was strongly associated with

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NODM in men across all age groups. In women, BMI in young adults (ages 20–30 years), WHtR in middle-aged (ages 40–50 years) and WC in the elderly (ages 60–70 years) showed a strong association with NODM based on 1 SD increase of each index. In men, the influence of body composition indices on NODM was the greatest in the young-adult group, with a sequential decrease as age increased. In women, the significant effect of body composition indices was maintained in the middle-aged group but showed a decreased impact in the elderly group. Although the predictive power of the body composition index for NODM was not generally high, we emphasise that consistent application of BMI for assessing metabolic risk in all age and sex groups should be avoided. Since Bray and Popkin warned of a crisis of diabetes incidence in 2014, ¹⁹ the prevalence of T2DM rapidly grew worldwide increasing the number of individuals with T2DM every year. In addition to traditional risk factors for T2DM such as obesity, age, ethnicity and familial history of DM, frequent exposure to highly processed food and a sedentary lifestyle warrants periodic screening for T2DM mediate glycaemic control after the onset of DM was shown important for the reduction of vascular complica-tions and mortality.²⁰ The legacy effect evidenced in this study emphasises the significance of early detection and management of DM. BMI has been used as an easy and rapid method to screen DM risk and evaluate the degree of obesity. To compensate for the limitations of BMI in rapid method to screen DM risk and evaluate the degree **6** of obesity. To compensate for the limitations of BMI in ŧ discriminating between visceral and subcutaneous fat, WC, WHtR and ABSI were suggested.⁴⁶⁷ Laboratory data such as TG and HDL-C were adopted in the VAI equation,⁸ and the development of WWI was used to discrimi- $\mathbf{\overline{a}}$ nate between muscle and fat mass.¹¹

In several studies, a comparison of new indices to BMI for DM screening has been reported. In a Chinese study ≥ that included 8121 subjects aged 35-60 years, WHtR was reported as more effective than BMI or WC for T2DM prediction.²¹ In the meta-analysis of 31 studies, WHtR was significantly associated with T2DM compared with BMI in both men and women.²² In another meta-analysis including 22 prospective studies, WHtR and WC showed <u>0</u> similar predictability for DM and were superior to BMI.²³ Furthermore, Saberi-Karimian et al reported that WC predicted T2DM development better than BMI, ABSI, WHtR and WHR in their prospective study with 9354 subjects.²⁴ In a study that included 3461 Chinese participants, VAI was reported as an effective index for DM & prediction compared with WC, WHtR and BMI.²⁵ Differences in study results might be due to the heterogeneity of the study populations and characteristics. Unlike previous studies, risk stratification was performed in the present study with subjects of different ages and sex because they may have different metabolic risks and body composition.

Based on the study results, in women, age had a significant effect on body composition index that is most relevant to incidental DM. Women experience significant changes in hormones and body composition during pregnancy,

	D%CI OT INUUNI ACTOS	s quartiles or boo	ly composition inc	alces in total popula	ation			
	T2DM (N=625715)	Person-years	Incidence rate	Model 1	Model 2	Model 3	Model 4	Model 5
BMI								
Q1 (n=1 005 153)	91517	9 827 735.2	9.3			t	-	1
Q2 (n=1 016 249)	128239	9 778 783.8	13.1	1.41 (1.40–1.42)	1.21 (1.20–1.22)	1.22 (1.21–1.23)	1.22 (1.21–1.23)	1.22 (1.21–1.23)
Q3 (n=1 038 875)	171369	9 788 956.5	17.5	1.88 (1.87–1.90)	1.52 (1.50-1.53)	1.53 (1.52–1.55)	1.52 (1.51–1.54)	1.54 (1.52–1.55)
Q4 (n=998614)	234590	9 031 690.8	26.0	2.80 (2.78–2.82)	2.30 (2.28–2.31)	2.31 (2.29–2.33)	2.29 (2.27–2.31)	2.31 (2.29–2.33)
P for linear trend				< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
WC								
Q1 (n=965392)	78371	9 534 939.2	8.2	-	-	-	-	F
Q2 (n=1 100 752)	138929	10 600 570.5	13.1	1.60 (1.58–1.61)	1.36 (1.35-1.37)	1.35 (1.34–1.37)	1.35 (1.34–1.36)	1.35 (1.34–1.36)
Q3 (n=1 034 301)	176385	9 698 250.5	18.2	2.22 (2.20–2.24)	1.77 (1.75–1.79)	1.76 (1.74–1.77)	1.75 (1.73–1.76)	1.76 (1.74–1.78)
Q4 (n=958446)	232 030	8 593 406.1	27.0	3.30 (3.27–3.32)	2.55 (2.53-2.57)	2.52 (2.50-2.55)	2.51 (2.48–2.53)	2.52 (2.50–2.54)
P for linear trend				< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
WHtR								
Q1 (n=1 014 803)	73 264	10 069 987.3	7.3	-	-	-	-	t
Q2 (n=1 015 850)	117355	9 843 068.3	11.9	1.64 (1.63–1.66)	1.35 (1.34–1.37)	1.35 (1.34–1.36)	1.34 (1.33–1.35)	1.35 (1.33–1.36)
Q3 (n=1 011 915)	171833	9 499 797.5	18.1	2.49 (2.47–2.51)	1.80 (1.79–1.82)	1.79 (1.78–1.81)	1.78 (1.76–1.80)	1.79 (1.77–1.81)
Q4 (n=1 016 323)	263 263	9 014 313.2	29.2	4.03 (4.00-4.06)	2.58 (2.55–2.60)	2.56 (2.54–2.58)	2.54 (2.52–2.56)	2.54 (2.52–2.57)
P for linear trend				< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
VAI								
Q1 (n=1 014 722)	100 176	9 894 725.8	10.1	-	-	-	-	-
Q2 (n=1 014 723)	125 088	9 780 992.2	12.8	1.26 (1.25–1.27)	1.23 (1.22–1.24)	1.22 (1.21–1.23)	1.22 (1.21–1.23)	1.22 (1.21–1.23)
Q3 (n=1 014 723)	163 206	9 584 646.6	17.0	1.68 (1.67–1.70)	1.56 (1.55–1.57)	1.53 (1.52–1.54)	1.53 (1.51–1.54)	1.53 (1.52–1.54)
Q4 (n=1 014 723)	237 245	9 166 801.7	25.9	2.56 (2.54–2.58)	2.27 (2.25–2.28)	2.20 (2.18–2.21)	2.18 (2.17–2.20)	2.19 (2.17–2.21)
P for linear trend				< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
ABSI								
Q1 (n=1 014 710)	110242	9 903 776.6	11.1	-	-	-	-	1
Q2 (n=1 014 752)	138228	9 741 236.9	14.2	1.28 (1.27–1.29)	1.09 (1.08–1.10)	1.08 (1.07–1.09)	1.08 (1.07–1.09)	1.09 (1.08–1.09)
Q3 (n=1 014 964)	166 745	9 559 615.0	17.4	1.57 (1.56–1.58)	1.16 (1.15–1.17)	1.15 (1.14–1.16)	1.15 (1.14–1.16)	1.16 (1.15–1.17)
Q4 (n=1 014 465)	210500	9 222 537.8	22.8	2.06 (2.04–2.07)	1.20 (1.19–1.21)	1.18 (1.17–1.19)	1.19 (1.18–1.20)	1.18 (1.17–1.19)
P for linear trend				< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
IWWI								
Q1 (n=1 011 717)	86064	9 994 386.9	8.6	-	-	-	-	÷
								Continued

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Table 2 Continued								
	T2DM (N=625715)	Person-years	Incidence rate	Model 1	Model 2	Model 3	Model 4	Model 5
Q2 (n=1 021 449)	126085	9 868 208.8	12.8	1.49 (1.47–1.50)	1.25 (1.24–1.26)	1.25 (1.23–1.26)	1.24 (1.23–1.25)	1.25 (1.23–1.26)
Q3 (n=1 011 449)	170662	9 503 139.9	18.0	2.09 (2.07–2.11)	1.51 (1.50–1.52)	1.50 (1.49–1.51)	1.50 (1.48–1.51)	1.50 (1.49–1.51)
Q4 (n=1 014 276)	242 904	9 061 430.7	26.8	3.12 (3.10–3.15)	1.81 (1.79–1.82)	1.79 (1.77–1.80)	1.79 (1.77–1.80)	1.78 (1.76–1.79)
P for linear trend				< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Model 1: Unadjusted. Model 2: Adjusted for a Model 3: Adjusted for a Model 4: Adjusted for a Model 5: Adjusted for a ABSI, A body shape inc WHtR, waist-heidht ratii	ge and sex. ge, sex, smoking habit, a ge, sex, smoking habit, a ge, sex, smoking habit, a lex; BMI, body mass indt, ex.WVI, weicht-adiusted	alcohol drinking and alcohol drinking, ph alcohol drinking, ph acs, DM, diabetes rr waist index.	d physical activity. lysical activity and fa lysical activity, family neilitus; NODM, new.	amily history of DM. / history of DM, incor -onset T2DM; T2DM,	ne percentile and resi type 2 diabetes melli	idence area. tus; VAI, visceral adip	osity index; WC, wai	st circumference;

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childbirth and menopause. Cho et al showed weight gain in women during the perinatal period mostly resulted from visceral fat deposition,²⁶ and in other studies, the number of parity was positively associated with abdominal obesity.²⁷ Furthermore, in previous research, fat mass volume doubled, and lean mass decreased at the start of menopause with the reduction in oestrogen level.²⁷ In several studies, body fat distribution was shown to change from the extremities to the trunk during the perimenopausal period.²⁸ These undesirable body composition changes are strongly associated with cardiometabolic disease risks, increasing incidence of DM, dyslipidaemia and cardiovascular disease in postmenopausal women.²⁹ Therefore, the significant increase of DM incidence in women in the 40–59 years age group compared with **8** the 20–39 years age group in the present study was likely because women undergo a decrease in oestrogen in their **g** mid-to-late 40s and 50s. Regarding the body composition index associated with DM, we demonstrated that every 1 SD increase in BMI exhibited the strongest HR for NODM in the young women; however, in the middle-aged women, that of WHtR showed the highest HR for NODM. This result may be due to visceral fat accumulation and uses related undesirable body compositional changes after women experience pregnancy and delivery through their 40s and menopause in their 50s.

However, in men, the WHtR had the closest relationship with NODM across all age groups. In numerous literađ tures, WHtR was shown superior to BMI for DM predictext tion.^{23 25} The reason why WHtR is better than BMI for DM prediction is due to the inclusion of visceral obesity in the WHtR index. Visceral adiposity induces insulin resistance, dysregulation of adipokines and malfunction of adipocytes, resulting in NODM.³⁰ However, the reason WHtR is ∃ better than WC for NODM prediction remains unknown although several theories have been suggested. A plausible explanation is short stature, which is largely due to training, genetic factors and might affect visceral obesity, insulin resistance, and vulnerability to metabolic diseases.³¹ In addition, because WHtR adjusts for the effect of height and on WC, it reflects a different body fat distribution and muscle mass based on individual height.¹³ simi

Notably, in the young-adult group, the BMI of women and WHtR of men had the highest HRs for NODM with a 1 SD increase, indicating body composition associated with NODM differs between sexes. Women store excess fat first Inol in a metabolically healthy fat region such as subcutaneous fat and lower extremities and then in VAT, whereas men predominantly accumulate fat more rapidly in VAT.³² For women, the importance of VAT starts to appear in the postpartum and perimenopausal period. The present study showed that WHtR was significantly associated with the risk of NODM, especially in young-adult men with a sequential decrease with ageing; however, in women, the clinically significant effect of WHtR for NODM was obvious around the perimenopausal period. Considering the emerging trend in early-onset DM leading to higher incidence of microvascular and macrovascular





Figure 2 HRs of T2DM across quartiles of body composition indices according to 20-year age group in men (A) and women (B). BMI, body mass index; T2DM, type 2 diabetes mellitus; WC, waist circumference; WHtR, waist-height ratio.



Figure 3 HR of new-onset T2DM in a fully adjusted model according to a 1 SD increase of anthropometric indices stratified by 20-year age groups in men (A) and women (B). ABSI, a body shape index; BMI, body mass index; NOFM, new-onset T2DM; T2DM, type 2 diabetes mellitus; VAI, visceral adiposity index; WC, waist circumference; WHtR, waist-height ratio; WWI, weight-adjusted waist index.

complications, intervention that reverses or reduces abdominal obesity, especially in young-adult men and perimenopausal women, is critical.

The present study had several limitations. Because claims data from NHIS were analysed, subjects were included and excluded based on ICD-10 codes that clinicians reported to the insurance service. Although we attempted to exclude subjects with secondary causes of DM, including related diseases or medication, some undefined cases may have been inadvertently included or excluded. Due to the absence of data on the dose and duration of glucocorticoid use, we exclude all individuals who prescribed glucocorticoid within 1 year. Also, patients using other medications that could affect the development of DM, such as statin, antipsychotics or antiretrovirals, were not excluded. Due to the absence of information on eating habits in our database, we were unable to adjust the effect of diet habits in analysis. Furthermore, due to the lack of laboratory data such as glycated haemoglobin or oral glucose tolerance test results, the severity of diseases could not be evaluated. In

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addition, any causal relationship could not be evaluated due to the intrinsic restriction of observational studies. Additionally, although we performed receiver operating characteristics analysis to compare the predictive power of each body composition index, the onset of DM in the elderly tend to be multifactorial beyond the effect of body composition, resulting in a decrease in the area under the curve with increasing age. This reduction in predictive power was insufficient to compare the superiority of the indices, so we did not proceed to the pairwise comparison of indices. Finally, because only data of Koreans were included, age- and sex-stratified DM risk should be evalu-ated in different ethnicities. However, this is the first and most recent large-scale study in which significant body composition indices for NODM were compared using 8 a 10-year longitudinal follow-up NHIS database representing almost the entire Korean population. Subjects with probable secondary causes for DM were excluded, and multiple variables were adjusted that could affect the onset of DM to examine the effect of body composition indices on NODM incidence.

Conclusion

WHtR in men of all age groups, BMI, WHtR and WC in young-adult, middle-aged and elderly women, respectively, had the strongest association with the 10-year incidence of NODM in the Korean population. Applying an age- and sex-specific body composition index is important to appropriately screen for the risk of NODM. Because the incidence of NODM significantly increased in the middleaged group in both men and women, active surveillance for NODM risk by measuring WC and height is necessary for effective prevention.

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Competing interests None declared.

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

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by The Korea University Institutional Review Board (No. 2022GR0041). The study was conducted in accordance with the Declaration of Helsinki of the World Medical Association. The need for informed consent was waived because anonymous and de-identified information was used for analysis.

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