Visceral Adiposity Index Outperforms Conventional Anthropometric Assessments as Predictor of Diabetes Mellitus in Elderly Chinese: A Population-Based Study

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Research

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Abstract

Background

This study aimed to assess the predictive performance of diabetes (DM) by using adiposity indices compared to body mass index and waist circumference.

Methods

Among 8249 consecutive subjects who attended the Nationwide Health *Check Up* System for *Senior Citizens* between 2008 and 2018 (≥ 65 years), we examined the associations of several adiposity indices with DM risk, and further explored gender differences.

Results

Among all adiposity indicators, Chinese visceral adiposity index (CVAI) alone demonstrated the highest discriminatory ability for diabetes mellitus by area under receiver operating characteristic curves (AUC) (0.65, 0.68, and 0.66 for men, women, and all participants, respectively), regardless of gender, with optimal cut-offs set as 126.09 in men and 117.77 in women, respectively. Compared with body shape index (ABSI), CVAI was strongly associated with baseline DM (adjusted OR: 4.16 [3.35–5.17] for 4^{th} vs 1^{st} quartile groups, $P < 0.001$), which was more pronounced in elderly women ($P_{interaction} < 0.05$). Over a median of 5.25 years (IQR: 3.07–6.44 years) follow-up, Cox regression models showed higher predictive ability of CVAI rather than the ABSI. Further, this independently predicted new-onset DM (adjusted HR: 1.26, 95% CI: 1.18–1.34) and composite endpoint of new DM and death (adjusted HR: 1.17, 95% CI: 1.10–1.25, both $P < 0.001$) among those without baseline DM.

Conclusions

Our population-based data demonstrated that Chinese visceral adiposity index may serve as a superior clinical indicator of diabetes when compared with conventional anthropometric indices among elderly Chinese, especially in women.

Introduction

A higher prevalence of diabetes mellitus in the elderly population is a critical public health issue worldwide [1]. Diabetes mellitus can cause systemic organ damage, leading to cardiovascular diseases, with the prevalence being particularly high in the elderly. Diabetes in the elderly can be due to several mechanisms such as genetic background and longer life expectancy leading to decreased insulin secretion or higher insulin resistance from multiple factors (such as central obesity or metabolic syndrome) mediated by excessive visceral adipose tissue (VAT) accumulation [2,3]. Senescence per se may also trigger adverse pro-inflammatory cytokine secretions through visceral fat redistribution, leading to metabolic disorders, such as diabetes mellitus [4]. Previous studies have shown that age, gender, and ethnicity are the main determinants of body fat distribution [5], with visceral fat increased over 200% in men and 400% in women between the 3^{rd} and 7^{th} decades, respectively, due to a shift of adiposity from the peripheral to a more central truncal area [5].

Studies have demonstrated that the Asian population is at higher risk for metabolic cardiovascular diseases (such as diabetes) even in those with a lower BMI compared to whites with same baseline characteristics [6,7], leading to revisited lower BMI threshold in defining obesity for Asians [8]. Central obesity, especially abdominal VAT, has been proposed to contribute to metabolic and diabetes risk beyond the whole-body adiposity burden [9]. Recent studies have shown differences in body fat mass and distribution in the Japanese descents in Western society compared to white not fully captured by BMI alone [10]. Associations of VAT with diabetes mellitus also appeared to be stronger in South Asian men than in European men, and more so in women [11], suggesting a higher clinical impact of VAT on diabetes mellitus in South Asian women [9]. Furthermore, Asian women can have greater abdominal and visceral adiposity and are prone to higher risk of metabolic- or obesity-related diseases when compared with white women at similar BMI level.

By utilizing echocardiography, magnetic resonance imaging (MRI) and computed tomography (CT) have confirmed that the visceral adiposity as a valuable indicator mediating insulin resistance even irrespective of body mass [12,13]. Despite these advances, imaging-based clinical utilizations of visceral adiposity was largely limited due to its higher costs and technical challenges. The Chinese visceral adiposity index (CVAI) was developed to assess the presence of diabetes mellitus in the Chinese population [14]; though validation of such measures with imaging-based VAT measures and its association with diabetic risk in elderly Asians remain

largely unexplored. Alternatively, a Body Shape Index (ABSI) uses data from WC and BMI to predict fat distribution [15,16] and has been shown to be a reliable index of body fat accumulation, yet there is little data on its application in the elderly population [17].

Our study hypothesize that noninvasive clinically measurable surrogates can be helpful in identifying the body fat distribution and help predict diabetes mellitus risk. We examined the associations between CVAI, ABSI, and diabetes mellitus risk and investigated their performance in identifying diabetes mellitus compared with using BMI and WC alone to identify diabetes mellitus in the elderly population in Taiwan.

Materials And Methods

Study Design and Population

This population-based study comprised 8,500 consecutive subjects who attended the Nationwide Health Check Up System for Senior Citizens between 2008 and 2018 at the Health Evaluation Center in Mackay Memorial Hospital, currently a tertiary teaching center in both the Taipei/Tamsui branch and the Taipei/New Taipei, Taiwan branch. Detailed information including medical histories for chronic illnesses, structured questionnaires for personal habits, physical examination including systolic and diastolic blood pressures, anthropometric measurements, and biochemical marker levels were obtained in all subjects participating this program. Those who had end-stage renal disease, Stage 5 (estimated glomerular filtration rate (eGFR) < 15, ml/min/1.73 m2), or those undergoing renal replacement therapy were excluded (n = 146). The presence of cardiovascular disease (CVD) history was defined as previous myocardial infarction, coronary artery disease (including elective intervention), cerebrovascular events, prior hospitalization for congestive heart failure, and peripheral arterial disease. The presence of hypertension (HTN) was defined as a previous diagnosis of disease or current medication use for HTN. Venous samples were collected by blood tests from all patients, followed by a detailed physical examination taken by the family physician. After exclusion, 8249 subjects were analyzed. Diabetes mellitus was defined as a fasting plasma glucose (FPG) $\geq$ 7.0 mmol/L, previous diagnosis of diabetes mellitus (data for which was obtained from structured questionnaire responses or from the information stored in the electronic medical record), or current use of anti-diabetic medications. Among 8249 study subjects, 1539 (18.7%) had diabetes mellitus [14]. Subjects with suspected hyperglycemia based on their fasting glucose level, though without a confirmed diagnosis of diabetes mellitus, were referred for further checkups according to the current guideline recommendations [18]. This study was approved by local ethical institutional committee (Mackay Memorial Hospital) for retrospective data analysis without informed consent of study participants (IRB No: 18MMHIS137). Informed consent was waived due to institutional review board committee regulation. All data were fully anonymized.

Anthropometric Measurements

Body weight (kg) and height (m) were measured according to standard methods. WC was measured at the middle point between the bottom of the ribcage and the uppermost border of the iliac crests at the end of exhalation with the patient in a standing position. Trained nurses used standard mercury sphygmomanometers to measure blood pressure two consecutive times at 3–5 min intervals during one visit.

Laboratory Biochemical Information

Sample collection and analysis were performed in a standard laboratory with international accreditation (ISO-15189). All subjects were requested to fast for more than 8 hours before venous blood sampling; samples were collected in a BD Vacutainer SSTTM (Becton Dickinson, Franklin Lakes, NJ, USA) sample collection tube. Sample collection and analysis principles were based on the standard requirements given in the Clinical Laboratory Standards Institute guidelines (Specimen Choice, Collection, and Handling; Approved Guideline H18-A3). FPG (via a hexokinase method); lipids including total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C); as well as uric acid (UA) were measured using a biochemical auto-analyzer (A Hitachi 7170 automatic analyzer; Hitachi Corp., Hitachinaka, Ibaraki, Japan). Quality control and instrument operation were done in accordance with standard procedures dictated by the guidelines of the Clinical Laboratory Standards Institute. Samples were assessed in triplicate, and the final values (after quality control) were confirmed to be in the linear range using an internal standard.

Assessment of Adiposity

The VAI score was calculated using the specific formula developed for the Chinese population [19]:

Men: CVAI = −267.93 + 0.68 × age + 0.03 × BMI + 4.00 × WC + 22.00 × log10 (TG) −16.32 × HDL;

Women: CVAI = −187.32 + 1.71 × Age + 4.23 × BMI + 1.12 × WC + 39.76 × log10 (TG) −11.66 × HDL.

ABSI was calculated as $WC/(BMI^{2/3} \times height^{1/2})$ and expressed in $m^{11/6}kg^{-2/3}$ [21].

BMI was calculated as weight/height squared (kg/m^2).

Clinical Follow-up

New-onset diabetes was defined as newly diagnosed diabetes, after the baseline study indexed date, in non-diabetes mellitus study participants (n = 6710) using the same clinical guidelines as used for assessing baseline diabetes mellitus. Considering that new-onset diabetes mellitus can be confounded by the high mortality rate before the development of diabetes mellitus in the elderly population, the prognostic implications of CVAI/ABSI on a composite endpoint of incident diabetes mellitus/mortality were examined

Statistical Analysis

Descriptive analyses were presented according to gender-specific quartiles of CVAI and ABSI scores to control for the well-known sexual dimorphism in body composition. The results are presented as mean (SD) and median with interquartile range (IQR: 25%–75%; given in parentheses) for normalized continuous and skewed variables, respectively. Categorical variables are expressed as numbers and percentages. One-way ANOVA or the Mann–Whitney U-test was used for comparisons of quantitative variables among groups. Chi-squared test was performed to assess differences in proportions across groups.

Partial correlations between CVAI/ABSI and three anthropometric indices and metabolic parameters adjusted for age and gender were evaluated. Multivariable logistic regression models were performed to estimate the risk of diabetes mellitus (presented as ORs and 95% CI) in relation to these indices in the three models for men and women, respectively. Receiver operating characteristic (ROC) curve analyses was used to compare the discriminative performance of CVAI and ABSI compared with BMI and WC for assessing underlying diabetes mellitus risk. A user-written command was used to calculate the Youden index for optimal clinical cut-offs of CVAI and ABSI in identifying the presence of baseline type 2 diabetes mellitus [19]. By defining the standardized unit shift of baseline age, anthropometric measures, and VAI (CVAI and ABSI), we explored the relationships among these indices with baseline diabetes mellitus risk. Cox proportional hazard regression models were constructed to explore the predictive values of CVAI/ABSI in predicting new-onset diabetes mellitus among the remaining baseline non-diabetes mellitus study participants (n = 6710), with differences in gender tested by interaction analysis (CVAI or ABSI tertiles treated as ordinal, continuous variable).

All statistical analyses were conducted using SAS software (version 9.4, SAS, Cary, NC, USA). A two-tailed statistical measure was used, with a $P < 0.05$ considered significant.

Results

Baseline Characteristics of the Study Population

The mean age among the 8249 study participants was 74.1 ± 7.1, and 56.4% (n = 4649) of the subjects were women (Table 1). Significant dose–response relationships were observed between higher CVAI, advanced age, larger anthropometric indices (i.e. BMI, WC), increased blood pressure, increased fasting glucose, elevated UA level, more unfavorable HDL-C/TG profiles, and worsened renal function ($P < 0.001$) in both genders. Men with higher levels of CVAI were less likely to have regular exercise, which was inversely proportional in women (both $P < 0.05$). Those with higher CVAI were more inclined to have prevalent diabetes and undergo pharmacological treatment for hyperlipidemia, leading to lower TC and LDL-C (all $P < 0.05$). Similarly, those subjects with higher ABSI presented with higher BMI/WC, increased fasting glucose, more unfavorable HDL/TG ratio, increased UA level, larger CVAI, and reduced intensity of regular exercise and tended to have baseline prevalent diabetes, irrespective of gender (both $P < 0.001$) (Table 1). Overall, women had significantly higher CVAI (118.4 ± 33.8 vs 111.0 ± 41.8) yet slightly lower ABSI (0.12 ± 0.01 vs 0.13 ± 0.01, both $P < 0.001$) compared with men.

Validation of VAI with MDCT-defined Visceral Adiposity

Data on MDCT-defined peri-cardiac and peri-aortic adiposity burden were available in 374 study subjects. A significantly positive linear correlation was observed between larger peri-cardiac fat (PCF)/peri-aortic fat (TAT) burden and larger CVAI (r = 0.825 and 0.786 for PCF and TAT, respectively. Supplemental Figure 1). However, positively attenuated correlations were observed with ABSI.

Correlation of Adiposity Measures with Diabetes and Biochemical Metabolic Profiles

Baseline prevalent diabetes mellitus was present in 19% (n = 1539) of all study participants. Those with prevalent baseline diabetes mellitus had significantly higher CVAI (132.4 ± 36.9 vs 111.2 ± 36.7) and ABSI (0.128 ± 0.017 vs 0.125 ± 0.011, both $P < 0.001$) compared with those without diabetes mellitus. Associations among CVAI/ABSI and anthropometric or metabolic profiles are shown in Supplemental Table 1. Partial correlation assessment showed that larger CVAI was positively correlated with greater BMI (r = 0.83), higher blood pressure (r = 0.17 for both systolic and diastolic blood pressure, respectively), larger WC (r = 0.90), elevated FPG levels (r = 0.25), unfavorable lipid profiles (except LDL-C), higher UA levels (r = 0.29, all $P < 0.001$) and inversely associated with HDL-C (–0.53, $P < 0.001$) after adjusting for age and gender. Correlations among ASBI and the metabolic indicators showed a similar pattern, although the coefficients were smaller compared to CVAI. No significant associations were observed between ABSI, blood pressure, TC, and LDL-C.

Association of CVAI or ABSI with DiabetesRisk

Unfavorable anthropometric measurements, lipid profile, and VAI (CVAI and ABSI) were all associated with higher baseline diabetes mellitus risk (Figure 1). Multivariable logistic regression models demonstrated increased diabetes mellitus risk across elevated CVAI or ABSI quartiles regardless of sex even after adjustment (Supplemental Table 3), with the association between CVAI and baseline diabetes being more evident in women than in men (all $P_{interaction} < 0.05$). Overall, higher ABSI was also associated with higher diabetes mellitus risk, even after adjustment in both genders. These associations were, however, less prominent than those for CVAI (adjusted OR < 2 in models). Among the four anthropometric indices, CVAI had the highest area under ROC (AUC) for baseline diabetes in men (AUC = 0.65, 95% CI: 0.62–0.67), in women (AUC = 0.68, 95% CI: 0.66–0.70), and in all participants (AUC = 0.66, 95% CI: 0.65–0.68), followed by WC (AUC: 0.63, 0.66 and 0.65 for male, female, and all subjects) and BMI (Supplemental Figure 2 A-C). However, ABSI had the lowest AUC for diabetes in men (AUC = 0.56, 95% CI: 0.54–0.58), in women (AUC = 0.57, 95% CI: 0.55–0.59), and in all subjects (AUC = 0.57, 95% CI: 0.55–0.58). CVAI alone led to a significantly increased AUC over WC and other indices regardless of gender (all Δ AUC $P < 0.05$, Supplemental Figure 2 A-C). Supplemental Table 2 shows the sensitivity, specificity, and corresponding optimal cut-off values of each index for identifying diabetes by gender. The optimal CVAI cut-off for identifying baseline diabetes mellitus was 126.09 in men and 117.77 in women.

Adiposity Measures as a Predictor of New-Onset Diabetes

Out of 6710 baseline non-diabetes mellitus subjects, 1360 developed new-onset type 2 diabetes mellitus during a median of 5.25 years (IQR: 3.07–6.44 years) follow-up. The number of mortality events recorded was 491, resulting in a composite of 1699 subjects with new-onset diabetes mellitus or death. Higher incidence rates of new-onset diabetes mellitus were observed across CVAI tertile groups (15.7%, 18.7%, and 26.4% for CAVI Q1, Q2, and Q3, respectively, $P < 0.001$) and new-onset diabetes mellitus/mortality group (19.0%, 21.5%, and 29.2% for CAVI Q1, Q2, and Q3, respectively, $P < 0.001$), with significantly higher CVAI observed in both cases (both $P < 0.05$) (Figure 2). New onset of diabetes mellitus was not statistically different across ABSI tertiles (20%, 21.1%, and 18.9% for ABSI Q1, Q2, and Q3, respectively, $P = 0.144$), nor was composite new-onset diabetes mellitus and death (22.4%, 24.2%, and 23.0% for ABSI Q1, Q2, and Q3, respectively, $P = 0.34$) (Figure 2). Higher CVAI was further independently predictive for new-onset diabetes mellitus (adjusted hazard ratio [aHR]: 1.26, 95% CI: 1.18–1.34) (Table 2) or composite new-onset diabetes mellitus/death (aHR: 1.17, 95% CI: 1.10–1.25, both $P < 0.001$) (Supplementary Table 4) in adjusted models, although these associations were non-significant when ABSI was used.

Discussion

This study assessed the associations of body adiposity indices, including CVAI and ABSI, with diabetes risk on a large scale in an elderly Chinese population. Our data showed that CVAI score strongly correlated with CT-defined visceral fat burden and tightly associated with several cardiometabolic risk profiles; however, these associations were less prominent when using ABSI. Overall, CVAI showed superior discriminatory abilities and could outperform conventional anthropometrics (such as BMI and WC) as a marker in

identifying underlying diabetes mellitus in our elderly population, especially in women, unlike ABSI. Higher CVAI further showed independent predictive values for new onset diabetes mellitus and all-cause death during mid-term follow-up.

In line with previous reports, the VAI in our current dataset, either CAVI or ABSI, showed a positive correlation with visceral fat burden. All anthropometric indices exhibited the capability of identifying baseline diabetes mellitus (all AUC > 0.5). CVAI alone yielded the highest AUC (0.66) for diabetes among all anthropometric indices, followed by WC and BMI, with ABSI exhibited the weakest association with diabetes in both genders. Although several meta-analyses comprising multiethnic populations worldwide have shown that several anthropometric measures (including VAI, BMI, and WC) were strongly associated with diabetes risk [20], CVAI as a marker of central adiposity has outperformed conventional anthropometric measures as a reliable diabetes mellitus marker in the Chinese population [14,21] and shown to successfully predict incident DM in ethnic Chinese [18,19,22] and among other races [23,24]. We further extended their findings to the elderly Chinese population. CVAI can therefore be a useful clinical adiposity surrogate for as a first-line screening tool (cut-offs of 126.09 and 117.77 for men and women, respectively) for diabetes mellitus in the elderly Chinese population when solid or more advanced biological specimens are not available. Given these associations, we postulated, by synergistically integrating information about BMI, central obesity along with lipid profiles (HDL and triglyceride), CVAI may better reflect adverse systemic effects from excessive visceral adiposity as hallmark feature for insulin resistance and diabetes in Asians [25,26].

ABSI was developed based on the United States National Health and Nutrition Examination Survey (NHANES) data (from 1999 to 2004), which provided useful health indicators from multiple ethnicities [14]. Previous reports demonstrating strong correlations between ABSI and metabolic disorders were mainly done in Caucasians [27,28]. Given the metrics of height and weight, ABSI likely provides a reflection of VAT accumulation [29], although many subsequent studies showed that ABSI was neither clinically feasible nor valid in cardiometabolic comorbidity and mortality [29-31]. In agreement with our study results, the use of ABSI failed to provide additional values beyond conventional anthropometrics among elderly Indonesians in an earlier study [32] and also failed to differentiate between excess central adiposity, incidence of metabolic abnormalities or diabetes mellitus in the multiple Asian regions [14,29,33-35]. As it has been proven, ethnic Asians are prone to metabolic abnormalities even at smaller WC and BMI measures when compared with Caucasians [36,37]. This finding, along with the fact that there is a higher genetic predisposition of TG to act as an effective predictor of diabetes mellitus in Asians [38,39], probably can explain the observed disparity between CVAI and ABSI, with the former serving as a useful marker for identifying diabetes.

Our study showed that discriminative capability of CVAI in identifying diabetes mellitus was more prominent in elderly women than in men, an indicator not seen in ABSI. Visceral adiposity has been shown to be more sensitive and is a better indicator of insulin resistance and diabetes than BMI and WC, especially in women over 45 years of age [22,23,35] as a prominent feature of metabolic abnormalities and diabetes. Though the precise reason behind some of these results remain to be clarified, this in part is hypothesized to be due to gender differences in visceral fat distribution [40] or due to the fact that women in Asia generally have greater abdominal adiposity and obesity, thus increasing related cardio-metabolic risks (i.e. HDL or TG) [9]. In this regard, CVAI can be particularly useful as an indicator of diabetes mellitus in the female population in Asia [40]. To the best of our knowledge, this work represents the first large-scale study demonstrating the clinical usefulness of CVAI as a potential screening tool of diabetes in a large-scale elderly Chinese population. The collected data provides a wealth of relevant metrics that allow us to assess the predictive power of various associations; it also gives us a set of indicators for further assessments.

Our study has several limitations. Since the study was conducted in a single center, our observations were cross-sectional. Thus, these data cannot be used to make causal inferences regarding the relationships between CVAI, ABSI, and diabetes mellitus risks. Furthermore, we did not directly measure IR, and we were unable to assess the association of CVAI/ABSI with IR directly. Finally, data on postprandial glucose levels were not available, which can lead to the underdiagnoses of some subjects with diabetes mellitus.

Conclusions

In conclusion, our study demonstrated stated that both CVAI and ABSI scores are strong and independent risk factors for diabetes mellitus among the elderly Taiwanese population. CVAI was found to be superior to WC, BMI, and ABSI and thus possesses the best predictive power for diabetes identification, based on the Youden index scores obtained in both genders (better scores in women compared with men). Our current analysis thus demonstrated that CVAI score, rather than ABSI, is better at identifying diabetes

mellitus, compared with BMI and WC measurements, in the elderly ethnic Chinese population and that it can also independently predict new-onset diabetes mellitus.

Abbreviations

ABSI: a body shape index

CT: computed tomography

CVAI: Chinese visceral adiposity index

DBP: diastolic blood pressure

eGFR, estimated glomerular filtration rate

FPG: fasting plasma glucose

HDL-C, high-density lipoprotein-cholesterol

HTN: hypertension

LDL-C, low-density lipoprotein cholesterol

MDCT: multidetector of computed tomography

PCF: peri-cardiac fat

ROC: receiver operating characteristic

SBP: systolic blood pressure

TAT: peri-aortic fat

TC: total cholesterol

TG: triglycerides

UA: uric acid

VAI: visceral adiposity index

VAT: visceral adipose tissue

WC: waist circumference

Declarations

Ethics approval and consent to participate:
This study was approved by local ethical institutional committee (Mackay Memorial Hospital) for retrospective data analysis without informed consent of study participants (IRB No: 18MMHIS137). Informed consent was waived due to institutional review board committee regulation.

Consent for publication
Not applicable.
Availability of data and materials:
All data were fully anonymized.
Competing interests:
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All authors were involved in the conceptualization of the project. MT Tsou and CL Hung were involved in the analyses and drafted the paper. All authors edited the paper. All authors have approved the final article
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Tables

Table 1. Demographic and clinical characteristics of study participants (n = 8249) across CVAI and ABSI quartiles in Taiwan

-	Men (n=3600)					Women (n=4649)				
	Q1 (< 84.47)	Q2 (84.47–111.45)	Q3 (111.45–138.01)	Q4 (≥ 138.01)		Q1 (< 94.66)	Q2 (94.66–117.87)	Q3 (117.87–141.57)	Q4 (≥ 141.57)	
-	n = 900	n = 900	n = 900	n = 900	*P*	n = 1162	n = 1163	n = 1162	n = 1162	*P*
Age, years	74.55 (7.00)	74.31 (7.06)	74.67 (7.45)	75.30 (7.25)	0.025	70.20 (5.26)	72.32 (6.14)	74.68 (6.79)	77.40 (7.09)	< 0.001
BMI, kg/m^2	21.22 (2.16)	23.63 (1.78)	25.23 (1.88)	27.80 (2.77)	< 0.001	20.81 (2.15)	23.23 (1.98)	25.03 (2.17)	28.15 (3.29)	< 0.001
SBP, mmHg	131.89 (19.99)	135.18 (18.90)	135.79 (19.05)	137.62 (18.99)	< 0.001	131.62 (20.71)	136.22 (20.16)	139.93 (20.59)	144.63 (21.53)	< 0.001
DBP, mmHg	73.24 (12.00)	75.00 (11.09)	75.67 (11.37)	76.36 (11.51)	< 0.001	71.01 (11.37)	72.86 (11.66)	74.05 (11.30)	74.75 (11.71)	< 0.001
WC, cm	75.49 (4.92)	84.10 (2.65)	89.42 (2.79)	98.42 (5.75)	< 0.001	71.90 (5.82)	78.60 (5.49)	84.07 (5.73)	92.77 (8.93)	< 0.001
FPG, mmol/l	5.62 (1.03)	5.80 (1.09)	5.94 (1.15)	6.34 (1.68)	< 0.001	5.47 (0.86)	5.71 (1.06)	6.01 (1.50)	6.40 (1.84)	< 0.001
TC, mmol/l	4.92 (0.88)	4.84 (0.91)	4.86 (0.95)	4.68 (0.87)	< 0.001	5.37 (0.87)	5.30 (0.94)	5.20 (0.94)	5.13 (0.96)	< 0.001
TG, mmol/l	0.79 (0.61–1.05)	0.99 (0.75–1.39)	1.25 (0.90–1.71)	1.41 (1.04–1.99)	< 0.001	0.79 (0.63–1.02)	1.10 (0.86–1.47)	1.32 (1.02–1.82)	1.63 (1.23–2.24)	< 0.001
HDL-C, mmol/l	1.56 (0.39)	1.30 (0.31)	1.20 (0.27)	1.08 (0.24)	< 0.001	1.83 (0.40)	1.56 (0.36)	1.42 (0.33)	1.29 (0.31)	< 0.001
LDL-C, mmol/l	2.96 (0.79)	3.01 (0.83)	3.00 (0.86)	2.85 (0.82)	< 0.001	3.15 (0.80)	3.21 (0.85)	3.13 (0.83)	3.06 (0.87)	< 0.001
UA, mg/dl	5.79 (1.27)	6.15 (1.30)	6.43 (1.45)	6.62 (1.48)	< 0.001	4.67 (1.00)	5.08 (1.08)	5.44 (1.25)	5.88 (1.45)	< 0.001
eGFR, ml/min/1.73 m^2	75.7 (20.1)	72.1 (19.2)	69.3 (19.1)	68.8 (20.5)	< 0.001	84.6 (20.1)	80.1 (20.4)	75.7 (22.1)	69.2 (21.8)	< 0.001
Smoking, n (%)	119 (13.22)	115 (12.78)	134 (14.89)	138 (15.33)	0.325	12 (1.03)	12 (1.03)	18 (1.55)	17 (1.46)	0.549
Drinking, n (%)	235 (26.11)	266 (29.56)	251 (27.89)	234 (26.00)	0.278	77 (6.63)	90 (7.74)	69 (5.94)	57 (4.91)	0.039
Exercise, n (%)	243 (27.00)	217 (24.11)	198 (22.00)	186 (20.67)	0.009	189 (16.27)	286 (24.59)	320 (27.54)	290 (24.96)	< 0.001
Diabetes, n (%)	103 (11.44)	141 (15.67)	188 (20.89)	290 (32.22)	< 0.001	80 (6.88)	141 (12.12)	245 (21.08)	351 (30.21)	< 0.001
Hyperlipidemia Tx	134 (14.9)	201 (22.3)	219 (24.3)	251 (27.9)	< 0.001	284 (24.4)	370 (31.8)	344 (29.6)	408 (35.1)	< 0.001
HTN, n (%)	108 (12.00)	115 (12.78)	146 (16.22)	125 (13.89)	0.053	121 (10.41)	183 (15.74)	218 (18.76)	215 (18.50)	< 0.001
CVD, n (%)	105 (11.67)	131 (14.56)	163 (18.11)	186 (20.67)	< 0.001	84 (7.23)	140 (12.04)	178 (15.32)	259 (22.29)	< 0.001
ABSI	0.126 (0.008)	0.131 (0.007)	0.134 (0.008)	0.138 (0.008)	< 0.001	0.118 (0.017)	0.120 (0.010)	0.122 (0.010)	0.124 (0.011)	< 0.001
-	Men (n=3600)					Women (n=4649)				

	Q1 (< 0.1261)	Q2 (0.1261–0.1322)	Q3 (0.1322–0.1379)	Q4 (≥ 0.1379)		Q1 (< 0.1137)	Q2 (0.1137–0.1199)	Q3 (0.1199–0.1267)	Q4 (≥ 0.1267)	
-	n = 900	n = 900	n = 900	n = 900	*P*	n = 1162	n = 1162	n = 1163	n = 1162	*P*
Age, years	74.91 (7.09)	74.92 (7.15)	74.06 (6.92)	74.94 (7.58)	0.022	73.42 (6.67)	73.05 (6.58)	73.20 (6.83)	74.93 (7.34)	< 0.001
BMI, Kg/m2	24.12 (3.31)	24.64 (3.04)	24.67 (3.34)	24.46 (3.23)	0.001	24.64 (3.83)	24.39 (3.56)	24.21 (3.39)	23.98 (3.72)	< 0.001
SBP, mmHg	134.90 (19.90)	134.74 (19.22)	136.35 (19.17)	134.50 (19.04)	0.170	139.16 (22.30)	137.64 (21.54)	137.30 (20.48)	138.30 (20.77)	0.161
DBP, mmHg	74.11 (11.50)	74.48 (10.95)	76.17 (11.99)	75.50 (11.63)	< 0.001	73.33 (11.97)	73.13 (11.27)	72.71 (11.39)	73.51 (11.72)	0.380
WC, cm	79.85 (8.00)	85.56 (7.23)	88.92 (8.21)	93.11 (8.45)	< 0.001	75.14 (8.17)	79.64 (7.97)	83.18 (8.14)	89.38 (10.28)	< 0.001
FPG, mmol/l	5.76 (1.07)	5.84 (1.07)	5.97 (1.27)	6.13 (1.63)	< 0.001	5.72 (1.13)	5.90 (1.42)	5.93 (1.41)	6.04 (1.64)	< 0.001
TC, mmol/l	4.85 (0.87)	4.87 (0.92)	4.81 (0.88)	4.78 (0.94)	0.101	5.27 (0.91)	5.29 (0.93)	5.24 (0.96)	5.21 (0.93)	0.195
TG, mmol/l	0.95 (0.70–1.40)	1.10 (0.78–1.53)	1.11 (0.80–1.58)	1.16 (0.82–1.66)	< 0.001	1.06 (0.80–1.49)	1.16 (0.82–1.62)	1.20 (0.88–1.70)	1.25 (0.90–1.76)	< 0.001
HDL-C, mmol/l	1.36 (0.39)	1.31 (0.36)	1.25 (0.34)	1.22 (0.31)	< 0.001	1.60 (0.42)	1.54 (0.39)	1.49 (0.38)	1.48 (0.41)	< 0.001
LDL-C, mmol/l	2.96 (0.79)	2.98 (0.83)	2.95 (0.83)	2.94 (0.86)	0.760	3.14 (0.79)	3.16 (0.85)	3.14 (0.86)	3.11 (0.85)	0.426
UA, mg/dl	6.13 (1.36)	6.24 (1.37)	6.20 (1.39)	6.40 (1.50)	0.006	5.13 (1.26)	5.30 (1.28)	5.32 (1.27)	5.36 (1.33)	0.001
eGFR, ml/min/1.73 m^2	71.3 (19.9)	71.3 (19.2)	72.0 (19.8)	71.1 (20.7)	0.76	77.9 (21.2)	78.1 (21.1)	76.9 (22.1)	76.7 (23.1)	0.02
Smoking, n (%)	107 (11.89)	119 (13.22)	135 (15.00)	145 (16.11)	0.050	9 (0.77)	14 (1.20)	14 (1.20)	22 (1.89)	0.114
Drinking, n (%)	211 (23.44)	253 (28.11)	244 (27.11)	278 (30.89)	0.005	70 (6.02)	74 (6.37)	72 (6.19)	77 (6.63)	0.942
Exercise, n (%)	259 (28.78)	233 (25.89)	188 (20.89)	164 (18.22)	< 0.001	334 (28.74)	250 (21.51)	227 (19.52)	274 (23.58)	< 0.001
Diabetes, n (%)	151 (16.78)	151 (16.78)	197 (21.89)	223 (24.78)	< 0.001	152 (13.08)	194 (16.70)	205 (17.63)	266 (22.89)	< 0.001
Hyperlipidemia Tx	199 (21.1)	213 (23.6)	204 (22.0)	189 (22.8)	0.6	400 (30.9)	329 (29.0)	357 (31.1)	320 (29.9)	0.67
HTN, n (%)	138 (15.33)	130 (14.44)	113 (12.56)	113 (12.56)	0.218	210 (18.07)	174 (14.97)	188 (16.17)	165 (14.20)	0.059
CVD, n (%)	137 (15.22)	155 (17.22)	132 (14.67)	161 (17.89)	0.190	179 (15.40)	158 (13.60)	157 (13.50)	167 (14.37)	0.527
CVAI	80.93 (37.22)	105.64 (33.47)	119.72 (36.68)	137.75 (37.43)	< 0.001	109.70 (33.84)	114.92 (32.36)	119.67 (31.45)	129.33 (34.19)	< 0.001

ABSI, a body shape index; BMI, body mass index; CVAI, Chinese visceral adiposity index; DBP, diastolic blood pressure; DM, diabetes mellitus; eGFR, estimated glomerular filtration rate; FPG, fasting plasma glucose; HDL-C, high density lipoprotein cholesterol; HTN,

hypertension; Hyperlipidemia Tx, pharmacological treatment for hyperlipidemia; LDL-C, low density lipoprotein cholesterol; SBP, systolic blood pressure; SD< standard deviation; TC, total cholesterol; TG, Triglyceride; UA, uric acid; WC, waist circumference.

Data are mean (SD) or median (interquartile range), unless otherwise stated.

Table 2. Uni- and multivariate Cox models in predicting new-onset diabetes by CVAI and ABSI tertiles among study population without baseline diabetes (n = 6710).

	Unadjusted	**Multivariate Model 1**	**Multivariate Model 2**	**Multivariate Model 3**
Visceral adiposity index (CVAI)	**HRs (95% CI)**			
All (per 1-standard unit increment)	1.30 (1.23–1.38)***	1.29 (1.22–1.37)***	1.30 (1.23–1.37)***	1.26 (1.18–1.34)***
CVAI Tertiles				
Q1	1 (Reference)	1 (Reference)	1 (Reference)	1 (Reference)
Q2	1.20 (1.04–1.37)*	1.19 (1.03–1.37)*	1.17 (1.02–1.35)*	1.13 (0.97–1.31)
Q3	1.77 (1.56–2.03)***	1.75 (1.53–2.00)***	1.73 (1.51–1.98)***	1.60 (1.37–1.86)***
$P_{interaction}$ *for sex*	0.08	0.13	0.19	0.32
	Un-Adjusted	**Multi-variate Model 1**	**Multi-variate Model 2**	**Multi-variate Model 3**
Body shape index (ABSI)	**HR (95% CI)**			
All (per 1-standard unit increment)				
ABSI Tertiles	0.98 (0.93–1.05)	0.96 (0.90–1.02)	0.96 (0.91–1.02)	0.96 (0.90–1.03)
Q1	1 (Reference)	1 (Reference)	1 (Reference)	1 (Reference)
Q2	1.03 (0.91–1.17)	1.02 (0.90–1.16)	1.06 (0.93–1.21)	1.13 (0.97–1.31)
Q3	0.94 (0.82–1.07)	0.92 (0.81–1.06)	1.00 (0.88–1.15)	0.99 (0.84–1.16)
$P_{interaction}$ *for sex*	0.40	0.52	0.72	0.84

HRs and 95% CI of the CVAI and ABSI.

Model 1: Adjusted for age; Model 2: Adjusted for age, smoking, alcohol drinking, and exercise; Model 3: Adjusted for model 2 and TC, SBP, DBP, and UA.

ABSI, a body shape index; CVAI, Chinese visceral adiposity index; DBP, diastolic blood pressure; SBP, systolic blood pressure; TC, total cholesterol; UA, uric acid.

Figures

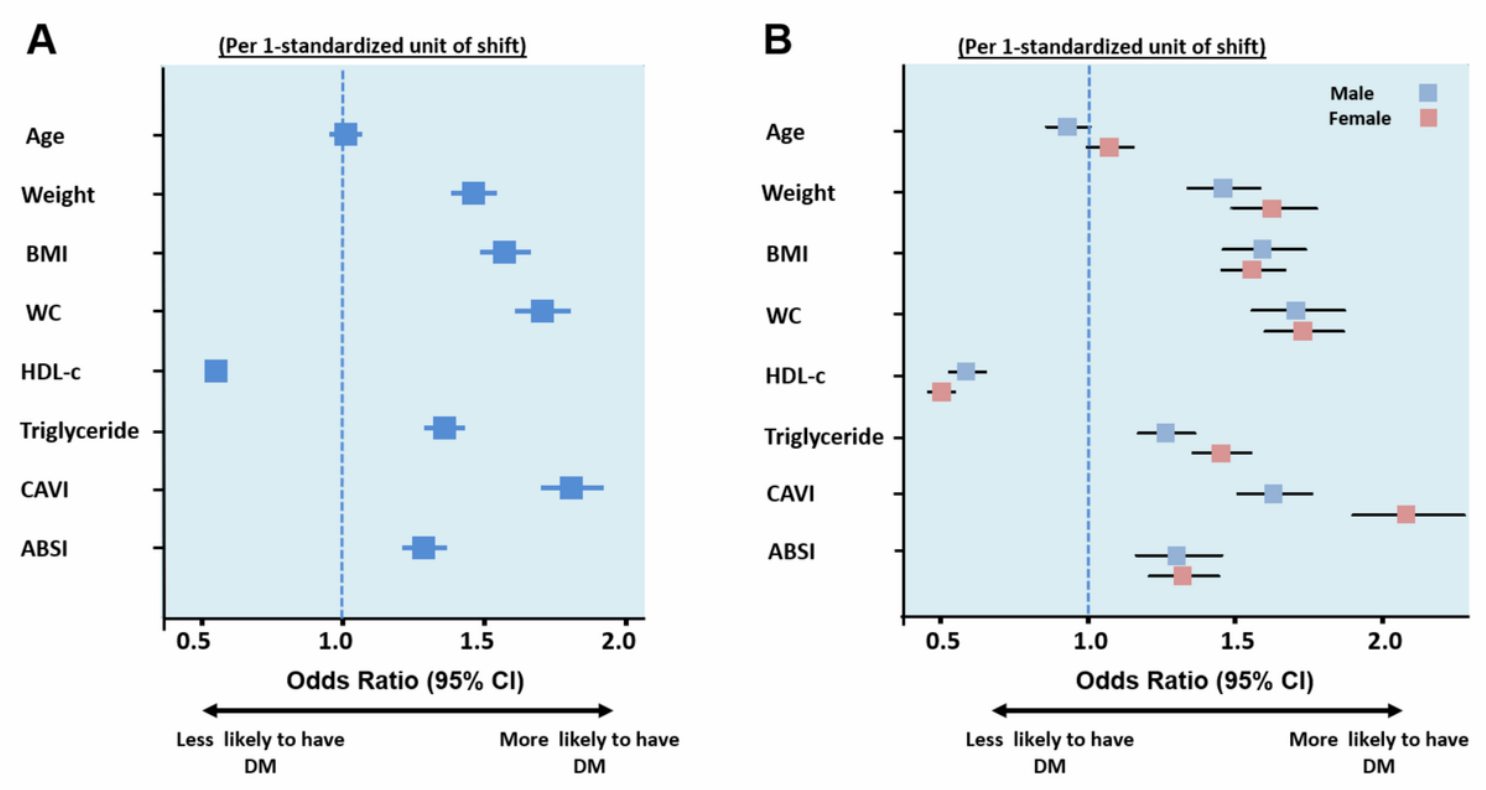

Figure 1

Univariate models in identifying baseline diabetes risk using age, various anthropometric or VAI indices (A) and sex differences (B). P interaction by sex < 0.05, in age, HDL, TG, and CVAI. CVAI, Chinese visceral adiposity index; HDL, high-density lipoprotein; TG, triglyceride; VAI, visceral adiposity index.

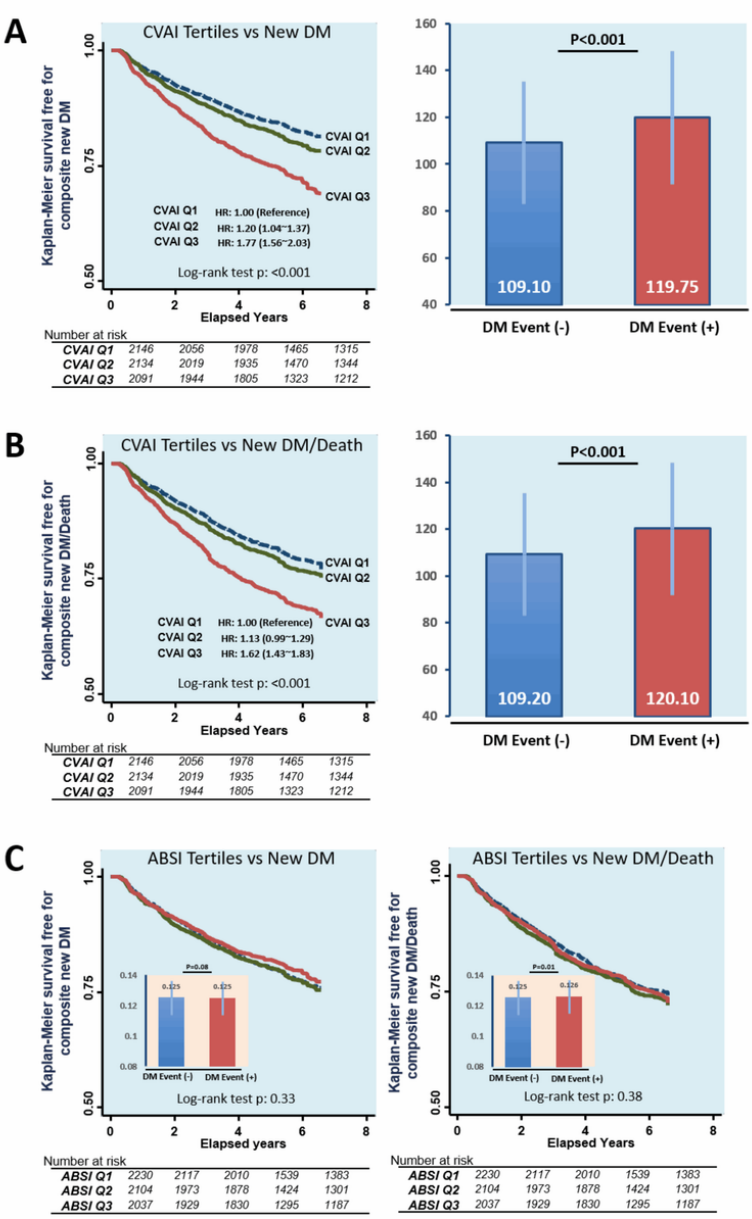

Figure 2

Kaplan–Meier survival curves of new-onset DM or a composite of new-onset DM/death across CVAI (A and B)/ABSI (C) tertile groups and difference of CVAI/ABSI between those who with or without events. CVIA, Chinese visceral adiposity index; ABSI, a Body Shape Index; DM, diabetes mellitus.

Supplementary Files

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- SupplementaryMaterials.docx