BMJ Open

Comparison of Anthropometric Indices for Predicting the Risk of Metabolic Syndrome and Its Components in Chinese Adults: A Prospective Study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-016062
Article Type:	Research
Date Submitted by the Author:	24-Jan-2017

Complete List of Authors:	Wang, Haoyu; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Liu, Aihua; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Zhao, Tong; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Gong, Xun; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Pang, Tianxiao; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Zhou, Yingying; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Xiao, Yue; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Yan, Yumeng; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Fan, Chenling; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Teng, Weiping; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University

	Lai, Yaxin; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Shan, Zhongyan; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University
Primary Subject Heading:	Diabetes and endocrinology
Secondary Subject Heading:	Diagnostics, Epidemiology
Keywords:	metabolic syndrome, waist circumference, abdominal volume index, visceral adiposity index, anthropometric index

Comparison of Anthropometric Indices for Predicting the Risk of Metabolic Syndrome and Its Components in Chinese Adults: A Prospective Study

Author list and affiliations:

Haoyu Wang[1], Aihua Liu[1], Tong Zhao[1], Xun Gong[1], Tianxiao Pang[1], Yingying Zhou[1], Yue Xiao[1], Yumeng Yan[1], Chenling Fan[1], Weiping Teng[1], Yaxin Lai[1,*], Zhongyan Shan[1,*]

[1]Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University, No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China.

E-mail Addresses:

Haoyu Wang: why_endocrinology@foxmail.com

Aihua Liu: liuaihuacmu@163.com

Tong Zhao: cmu_zhaotong@163.com

Xun Gong: cmu_gx@vip.163.com

Tianxiao Pang: ptx90@163.com

Yingying Zhou: 18937856536@163.com

Yue Xiao: xy5856@126.com

Yumeng Yan: cherylyanyumeng@hotmail.com

Chenling Fan: fanchenling@126.com

Weiping Teng: twp@vip.163.com

Yaxin Lai: laiyaxin811005@126.com

Shan Zhongyan: shanzhongyan@medmail.com.cn

Corresponding author and person to whom reprint requests should be addressed:

Yaxin Lai, M.D., Ph.D.

Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases

The First Affiliated Hospital of China Medical University

No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China

Tel: +86-24-83283294

Fax: +86-24-83283294

E-mail: laiyaxin811005@126.com

Zhongyan Shan, M.D., Ph.D.

Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases

The First Affiliated Hospital of China Medical University

No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China

Tel: +86-24-83283294

Fax: +86-24-83283294

E-mail: shanzhongyan@medmail.com.cn

Running title: Anthropometric indices and Incident MetS

Authors' statement: The authors hereby confirm that neither the manuscript nor any part of it has been published or is being considered for publication elsewhere. We acknowledge that all authors participated sufficiently in the work and take public responsibility for its content.

Funding:

1. the Chinese National Natural Science Foundation (Grant: 81300645)
2. the National Science and Technology Support Program (Grant: 2009BAI80B00)

Disclosure Summary: The authors have no potential conflict of interest to declare.

Word count: 293 (Abstract); 2943 (excluding abstract, figure captions, and references)

Figures & Tables: 7

Abstract

Backgound: Our study aimed to distinguish the ability of anthropometric indices to assess the risk of metabolic syndrome (MetS) at the time of cross-section analysis and during a 4.5-year follow-up.

Setting, participants and outcome measures: Data were collected from cross-sectional and longitudinal prospective studies between 2010 and 2014. At baseline, a total of 379 individuals (198 males and 181 females) were enrolled in the study. A variety of anthropometric parameters were measured, including waist circumference (WC), body mass index (BMI), a body shape index (ABSI), abdominal volume index (AVI), body adiposity index (BAI), body roundness index (BRI), conicity index (CI), waist-to-hip ratio (WHR) and visceral adiposity index (VAI). MetS was diagnosed according to the criteria of the International Diabetes Federation. Receiver operating curve (ROC) was applied to examine the potential of the above indices at baseline to identify the status and risk of MetS.

Results: At baseline, 43.9% of males and 21.5% of females suffered from MetS. All of the anthropometric indices showed clinical significance, and VAI was superior to the other indices, as it was found to have the largest area under the ROC at the time of cross-section analysis. After a 4.5-year follow-up, 37.8% of males and 23.9% of females developed MetS. ROC analysis suggested that the strongest predictor of MetS was baseline BMI and AVI in males and females, respectively. However, no significant differences were observed between the two indices and WC. In contrast, the baseline ABSI did not predict MetS in both genders.

Conclusions: The present study indicated that these different indices derived from anthropometric parameters have different discriminatory abilities for MetS. Although WC did not have the largest AUC for diagnosing and predicting MetS, it may remain the better index of MetS status and risk

because of its simplicity and wide utilization.

Strengths and limitations of this study:

1. This is a longitudinal prospective study of the association of anthropometric indices with metabolic syndrome risk.
2. This is the first study to systematically report the different abilities of anthropometric indices in diagnosing or predicting metabolic syndrome.
3. The current study was limited to middle-aged and elderly subjects in northeast China.
4.

Keywords

Metabolic syndrome; Waist circumference; Abdominal volume index; Visceral adiposity index; Anthropometric index.

Background

Metabolic syndrome (MetS) is considered as a cluster of risk factors for cardiovascular morbidity and mortality[1], involving approximately 34% of adults based on the National Health and Nutrition Examination Survey[2]. A growing body of evidence supports the hypothesis that abdominal visceral fat plays a role in the development of MetS[3-6]. In this context, it is reasonable that central obesity is defined as a predictor of MetS.

Although the body mass index (BMI) is in widespread use, it is not an evaluation of fat distribution. Therefore, additional anthropometric indices are required to assess abdominal adipose

accumulation. Elevated waist circumference (WC) and waist-to-hip ratio (WHR) were reported to be strongly associated with central obesity and MetS[7]. Moreover, Krakauer's and Tomas' groups proposed a body shape index (ABSI) and body adiposity index (BRI), respectively, to estimate body fat distribution. However, neither of the indices above were proven to have a better correlation with cardiovascular disease compared to BMI or WC[8]. Recently, a close association of cardiometabolic risk with an alternative index, visceral adiposity index (VAI), was found[9]. However, the superiority of its predictive value versus any other indices is unclear. Abdominal volume index (AVI) is another anthropometric tool for overall volume estimation which has a strong relationship to the dysfunction of glucose metabolism, according to the author[10]. Additionally, other indices have been used, such as conicity index (CI) and body adiposity index (BAI), to improve on commonly used methods[11 12]. However, a comprehensive consensus has not been reached about the best indices for evaluating the status and risk of MetS.

Accumulating evidence has indicated the different association of these indices with MetS, and most the studies were cross-sectional. Thus, we compared the predictive ability of anthropometric indices including WC, BMI, ABSI, AVI, BAI, BRI, CI, WHR, and VAI, using a prospective study.

Methods

Study Population

To evaluate the effectiveness of anthropometric indices in predicting MetS, a community-based study was performed between 2010 and 2014 in urban Shenyang, Liaoning Province, China. Individuals with malignancy and severe liver or renal diseases were excluded. During the follow-up period, new-onset MetS subjects with a history of drugs or surgeries for weight reduction, lipid reduction, or

treatments for diabetes or hypertension during follow-up were also excluded. Finally, data from 379 participants (198 males and 181 females) aged 40-65 were selected for this study, and the average follow-up duration was 4.5 years (**Figure 1**).

This study was approved by the Ethics Committee of the First Affiliated Hospital of China Medical University, and all participants provided signed informed consent before enrollment in this study.

Data Measurement and Collection

At baseline and at the endpoint, all subjects underwent comprehensive interviews and health examinations by trained staff. A questionnaire including demographic characteristics, personal medical history, and information related to the diagnosis and treatment of MetS was completed for each participant. Based on the previous standardized protocol[13], body weight, height, waist circumference (WC), hip circumference (HC), systolic blood pressure (SBP), and diastolic blood pressure (DBP) were measured. Participants were given a standard 75-g oral glucose tolerance test (OGTT). Venous blood samples were drawn to determine fasting plasma glucose (FPG), plasma glucose 2 hours after a glucose load (2 h PG), fasting plasma insulin (FINS), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL), and low-density lipoprotein cholesterol (LDL) according to standard methods.

At baseline, all subjects had magnetic resonance imaging scans performed at the abdominal level between the 4^{th} and 5^{th} lumbar vertebrae in the prone position (FOV 42 cm×42 cm, thickness 1 cm, 6 layers, GE, USA). Subcutaneous fat area (SFA) and visceral fat area (VFA) were calculated using SLICE-O-MATIC version4.2 software (Tomovision) by two separate technicians.

Metabolic Syndrome Definition

The diagnose of MetS was diagnosed based on the International Diabetes Federation criteria, which include three or more risk characteristics[7 14], including 1.) abdominal obesity (WC≥90 cm for males, 85 cm for females), 2.) elevated TG (TG≥1.70 mmol/L), 3.) low HDL (HDL-c<1.0 mmol/L for males, <1.3 for females), 4.) high blood pressure (SBP≥130 mmHg, DBP≥85 mmHg, or a history of hypertension), or 5.) elevated plasma glucose (FPG≥5.6 mmol/L, or a diagnosis of T2DM).

Calculations

The homeostatic model assessment index for insulin resistance (HOMA-IR) was evaluated using the formula: HOMA-IR = FPG (mmol/L)×FINS (mIU/L)/22.5. The anthropometric indices, such as BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI were calculated using the following formulas:

$$BMI = \frac{Weight}{Height^2}$$

$$WHR = \frac{WC}{HC}$$

$$ABSI = \frac{WC}{BMI^{\frac{2}{3}} \times Height^{\frac{1}{2}}}$$

$$AVI = \frac{2 \times WC^2 + 0.7 \times (WC - HC)^2}{1000}$$

$$BAI = \frac{HC}{Height^{\frac{3}{2}}} - 18$$

$$BRI = 364.2 - 365.5 \times \sqrt{1 - \frac{(WC/2\pi)^2}{(0.5 \times Height)^2}}$$

$$CI = \frac{WC}{0.109 \times \sqrt{\frac{Weight}{Height}}}$$

$$VAI_{male} = (\frac{WC}{39.68} - 1.88 \times BMI) \times \frac{TG}{1.03} \times \frac{1.31}{HDL}$$

$$VAI_{female} = (\frac{WC}{36.58} - 1.89 \times BMI) \times \frac{TG}{0.81} \times \frac{1.52}{HDL}$$

Statistical Analyses

Based on the diagnosis of MetS, the subjects were assigned to MetS or non-MetS groups at baseline. Individuals without MetS at baseline were further divided into newly MetS or free-MetS groups according to whether or not they developed MetS during follow-up.

The data distribution was assessed using the Kolmogorov-Smirnov test. The variables were displayed as the mean±standard deviations, medians (interquartile range) or counts (percentages) according to their types. Univariate analyses were conducted to estimate the relative factors of MetS and its components using the *t*-test, Mann-Whitney rank sum test, Pearson's Chi-squared test, or Fisher's exact test depending on the characteristics of the data. The ability of the anthropometric indices to identify individuals with MetS was evaluated by the area under receiver operating characteristic (ROC) curves, and the new cutoff points were suggested by Youden's Index (sensitivity+specificity-1). Statistical analyses were performed using SPSS (version 23.0, IBM Corp.,

USA). MedCalc (version 16.2, MedCalc Software, Belgium) was used to analyze the ROC curves. Statistical significance was defined as $P < 0.05$ for all analyses.

Results

Baseline characteristics of the participants

At baseline, 87 (43.9%) males and 39 (21.5%) females were diagnosed with MetS. The median age of study subjects was 49.5 (45.0-55.0) for males and 47.0 (44.0-54.0) for females. Compared with the non-MetS group, subjects with MetS had significantly higher levels of SBP, DBP, FPG, 2 h PG, FIN, HbA1c, TG, LDL, HOMA-IR, SFA, and VFA, but lower levels of HDL. TC was significantly increased in males with MetS, while no significant difference was observed in females. Furthermore, all of the nine anthropometric indices, including WC, BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI, were elevated significantly in both males and females of the MetS group (**Table 1**).

In the non-MetS group, 42 (37.8%) males and 34 (23.9%) females developed MetS after 4.5-years of follow-up. Compared to the healthy controls, TG, SFA, and VFA were significantly elevated in the newly MetS group. Furthermore, females in the newly MetS group had increased baseline levels of SBP, DBP, 2 h PG, and LDL but lower levels of HDL. Considering anthropometric indices, WC, BMI, WHR, AVI, BRI, CI, and VAI were higher in males and females of the newly MetS group. The females who developed MetS had a higher baseline BAI, while no significant difference was observed between free-MetS and newly MetS in males. Additionally, there was no difference in ABSI of both males and females between the free-MetS and newly MetS groups (**Table 2**).

Comparison of the anthropometric indices for diagnosing MetS at baseline

At baseline, the areas under the ROC curves (AUCs) of all the anthropometric indices were larger than 0.5 (P<0.05), suggesting their clinical diagnostic significance for MetS (**Table 3**). Our results showed that the VAI had the largest AUC for both genders [0.85 (0.79-0.92) for males and 0.90 (0.84-0.96] for females]. The BAI [0.67 (0.59-0.75)] and ABSI [0.62 (0.52-0.72)] showed the lowest AUCs for males and females, respectively. In males, AVI, BRI, CI, and VAI had approximately the same AUCs as WC for diagnosing MetS (all P>0.05 vs. WC). However, the AUCs of BMI, WHR, ABSI, and BAI were significantly lower compared with WC for males (all P<0.05 vs. WC). In females, the AUC of VAI was significantly larger than WC, while the AUCs of ABSI, BAI, and CI were significantly lower (all P<0.05 vs. WC). The other five anthropometric indices showed no significant differences in diagnosing MetS in females (all P>0.05 vs. WC).

Comparison of the anthropometric indices for predicting MetS during follow-up

In general, the AUCs varied from 0.58 (0.49-0.68) for ABSI to 0.77 (0.68-0.85) for BMI in males and from 0.55 (0.47-0.64) for ABSI to 0.72 (0.64-0.79) for AVI in females. In addition, the AUC of ABSI was the lowest and did not differ from 0.5 in both males and females (P>0.05). Moreover, the AUC of BAI was significantly larger than 0.5 in males, while no difference from 0.5 was observed in females. All the AUCs of the other indices were greater than 0.5 (P<0.05), suggesting their clinical predictive significance for MetS. In males, the AUC of BMI did not differ significantly from WC, although BMI had the largest AUC. The other indices, including WHR, AVI, and BRI, also showed no significant differences when compared with WC. Furthermore, ABSI, BAI, CI and VAI had significantly lower AUCs than WC. In females, no significant differences were observed between WC and BMI, WHR, AVI, BAI, BRI, CI, or VAI. Moreover, ABSI had a significantly lower AUC

than WC.

Other details of all the anthropometric indices such as cutoff, sensitivity, specificity, Youden index, positive predictive value (PPV), and negative predictive value (NPV) were also reported in this study (**Table 4**).

AUCs of the anthropometric indices for predicting MetS components during follow-up

Compared with females, the morbidities of MetS, high TG and high BG in males were elevated (37.8% vs. 23.9%, 19.2% vs. 8.5%, and 24.8% vs. 14.3%, respectively) after a 4.5-year follow-up. Morbidities of the other two MetS components showed no differences between males and females (**Table S1**). Furthermore, we made comparisons of all indices in predicting MetS components (**Table 5** and **Table 6**). First, the AUCs of all the indices had predictive significance for central obesity in males, except ABSI, BAI, CI and VAI. Additionally, the AUCs of ABSI, CI and VAI were not significantly larger than 0.5 in females. The AUC of VAI was not significantly different from WC, although AVI had the largest AUC for incident central obesity in males and females. Second, none of the anthropometric indices showed significance for predicting high TG in males or females, except for BMI and VAI in males. Moreover, the AUCs of all the indices were small for predicting low HDL and high BG, and none were significantly over 0.5. Therefore, none of the indices could discriminate among both males and females with low HDL or high BG. Lastly, either BAI or VAI had an AUC less than 0.5 for high BP in males, and the AUCs of WHR, ABSI, and VAI were significantly less than 0.5 in females. Furthermore, WC and AVI had the largest AUCs for high BP in males, and no difference was observed between these two indices. In females, the AUC of AVI was the largest for high BP in females but did not differ significantly from WC.

Dicussion

A variety of investigations have evaluated the discriminatory ability of indices derived from several anthropometric parameters in MetS. Most of these studies were cross-sectional. In this study, we compared nine obesity indices, including WC, BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI, in assessing the incident risk of MetS using a 4.5-year prospective analysis. Our study indicated that some novel anthropometric indices may be insufficient for evaluating the incident risk of MetS.

At baseline, all the indices showed significant roles in diagnosing MetS, and VAI had the highest AUC value in both males and females. For the calculation of the VAI value involving WC, BMI, TG, and HDL, it is suggested that VAI might provide a broader evaluation of metabolic risk related to visceral fat dysfunction. A previous study has reported that VAI has significant advantages over WC for determining cardiometabolic risk[9], even though a study in young adults has indicated that VAI did not provide better power than WC or BMI in the assessment of visceral adiposity[15]. In our study, VAI was the best surrogate marker of MetS, especially considering the significant, excessive AUC in females.

Furthermore, we compared the AUCs of all the anthropometric indices for predicting MetS and its components. In general, ABSI was the worst predictive index for both genders. Previously, a few cross-sectional studies proved that ABSI was a weak index for MetS risk[16 17]. Our results confirmed this finding using prospective evidence. Furthermore, different from the cross-sectional study, the AUC of VAI was less than WC and even had a significant difference in males. In 2014, Chen *et al.* suggested that VAI shows a similar predictive performance for all-cause mortality to WC in ROC analysis[18], suggesting that VAI as a predictor of MetS is not superior or even equal to WC.

Additionally, BMI and AVI showed the strongest ability in the prediction of MetS for males and females, respectively. However, there was no significant difference between the two indices above and WC. Thus, WC appeared to be a more useful predictor of MetS in clinical practice for its simplicity and widespread utilization.

Our study also proposed optimal cutoff points for these anthropometric indices. An obvious difference between two genders was observed in WC, WHR, ABSI, BAI and VAI, suggesting that gender-based measures should be used in clinical practice. Notably, the present results showed that the optimal cutoff points for WC are considerably different from the cutoff points according to the guideline on prevention and treatment of metabolic dysfunction in Chinese adults[19]. Therefore, it may be optimal that decreased WC cutoffs are used in the clinical setting to select Chinese adults at high risk of incident MetS. Additionally, all the PPVs of indices were less than NPV, suggesting that the indices covered in this article were suitable for identifying individuals without a risk for MetS in a non-MetS population.

Our study further finds that the indices show different discriminatory power for different MetS components. AVI had the largest AUC for central obesity in both males and females. On the other hand, VAI of males had the highest AUC value for high TG and high BP. In females, the AUC of AVI for high BP was larger than the other indices, while no indicator showed significance in predicting high TG in females. Interestingly, the CI played only a predictive role of new-onset high BP in both genders, suggesting a worse predictive ability for MetS components. This is probably because weight dilutes the influence of height according to its formula[20]. Additionally, all the indices failed in forecasting incident low HDL and high BG, in contrast to other studies[8 9 21 22]. One possible explanation is that only a few individuals developed low HDL and high BG, and the small sample

size may impact the reliability of results. In summary, the results above suggest that the current indicators of anthropometric indices cannot provide a comprehensive prediction of metabolic risk factors. Accordingly, further study to clarify the association of anthropometric parameters with MetS components is necessary.

Several limitations of the present study should be considered. First, this study was limited to middle-aged and elderly subjects in northeast China. Hence, the applicability of these results may be limited for other populations. Second, only the baseline anthropometric parameters were used in the study, although lifestyle modification may have an impact on the chronological changes of obesity indices. However, our study aims to assess the predictive abilities of anthropometric indices at baseline in a prospective cohort. Therefore, it is likely that the anthropometric changes during follow-up period had little effect on the current results.

Conclusions

In conclusion, VAI is the best index for diagnosis of MetS in this cross-section. Moreover, although no obvious advantages were observed for WC, BMI and AVI are superior to the other anthropometric indices for predicting MetS in males and females, respectively. However, considering the simplicity and wide utilization, WC remains the more practical discriminator for MetS.

Abbreviations

MetS: metabolic syndrome; WC: waist circumference; BMI: body mass index; ABSI: a body shape index; AVI: abdominal volume index; BAI: body adiposity index; BRI, body roundness index; CI, conicity index; WHR: waist-to-hip ratio; VAI: visceral adiposity index; ROC: Receiver operating

curve; HC: hip circumference; SBP: systolic blood pressure; DBP: diastolic blood pressure; OGTT: 75g oral glucose tolerance test; FPG: fasting plasma glucose; 2hPG: plasma glucose 2 hours after a glucose load; FINS: fasting plasma insulin; TC: total cholesterol; TG: triglycerides; HDL: high-density lipoprotein cholesterol; LDL: low-density lipoprotein cholesterol; SFA: subcutaneous fat area; VFA: visceral fat area; HOMA-IR: the homeostatic model assessment index for insulin resistance; PPV: positive predictive value; NPV: negative predictive value.

Declarations

Acknowledgements

We thank the participants and staff at the Institute of Endocrinology of the First Affiliated Hospital of China Medical University for their involvement in this study.

Contributors

Haoyu Wang was the primary investigator, and reviewed the literatures, performed this follow-up project, collected data, analyzed results, and produced the first draft of manuscript; Aihua Liu reviewed the literature, interpreted the data, and edited the manuscript; Tong Zhao, Xun Gong, Tianxiaopang, Yingying Zhou, Yue Xiao, Yumeng Yan, and Chenlin Fan participated in this follow-up project, collected and interpreted data; Weiping Teng supervised the statistical analyses, and edited the manuscript; Zhongyan Shan supervised the statistical analyses, and produced the final version of the manuscript. All authors read and approved the final manuscript.

Funding

This work was supported by the Chinese National Natural Science Foundation (Grant: 81300645) and the National Science and Technology Support Program (Grant: 2009BAI80B00). The funders had no roles in the study design, data collection or analysis, or the presentation or publication of the results.

Competing interests

The authors declare that they have no competing interests.

Ethics approval

This study was approved by the Ethics Committee of the First Affiliated Hospital of China Medical University. Informed consent was obtained from all individual participants included in the study.

References

1. Isomaa B, Almgren P, Tuomi T, et al. Cardiovascular morbidity and mortality associated with the metabolic syndrome. *Diabetes care* 2001;24(4):683-9. doi: 10.2337/diacare.24.4.683

2. Mozumdar A, Liguori G. Persistent increase of prevalence of metabolic syndrome among U.S. adults: NHANES III to NHANES 1999-2006. *Diabetes care* 2011;34(1):216-9. doi: 10.2337/dc10-0879

3. Hwang YC, Hayashi T, Fujimoto WY, et al. Visceral abdominal fat accumulation predicts the conversion of metabolically healthy obese subjects to an unhealthy phenotype. *International journal of obesity* 2015;39(9):1365-70. doi: 10.1038/ijo.2015.75

4. Lim KI, Yang SJ, Kim TN, et al. The association between the ratio of visceral fat to thigh muscle area and metabolic syndrome: the Korean Sarcopenic Obesity Study (KSOS). *Clinical endocrinology*

2010;73(5):588-94. doi: 10.1111/j.1365-2265.2010.03841.x

5. Rothney MP, Catapano AL, Xia J, et al. Abdominal visceral fat measurement using dual-energy X-ray: association with cardiometabolic risk factors. *Obesity* 2013;21(9):1798-802. doi: 10.1002/oby.20223

6. Lee JJ, Pedley A, Hoffmann U, et al. Association of Changes in Abdominal Fat Quantity and Quality With Incident Cardiovascular Disease Risk Factors. *Journal of the American College of Cardiology* 2016;68(14):1509-21. doi: 10.1016/j.jacc.2016.06.067

7. Bao Y, Lu J, Wang C, et al. Optimal waist circumference cutoffs for abdominal obesity in Chinese. *Atherosclerosis* 2008;201(2):378-84. doi: 10.1016/j.atherosclerosis.2008.03.001

8. Chang Y, Guo X, Chen Y, et al. A body shape index and body roundness index: two new body indices to identify diabetes mellitus among rural populations in northeast China. *BMC public health* 2015;15:794. doi: 10.1186/s12889-015-2150-2

9. Amato MC, Giordano C, Galia M, et al. Visceral Adiposity Index: a reliable indicator of visceral fat function associated with cardiometabolic risk. *Diabetes care* 2010;33(4):920-2. doi: 10.2337/dc09-1825

10. Guerrero-Romero F, Rodríguez-Morán M. Abdominal volume index. an anthropometry-based index for estimation of obesity is strongly related to impaired glucose tolerance and type 2 diabetes mellitus. *Archives of Medical Research* 2003;34(5):428-32. doi: 10.1016/s0188-4409(03)00073-0

11. Bergman RN, Stefanovski D, Buchanan TA, et al. A better index of body adiposity. *Obesity* 2011;19(5):1083-9. doi: 10.1038/oby.2011.38

12. Shidfar F, Alborzi F, Salehi M, et al. Association of waist circumference, body mass index and conicity index with cardiovascular risk factors in postmenopausal women. *Cardiovascular journal of Africa* 2012;23(8):442-5. doi: 10.5830/CVJA-2012-038

13. Wang H, Lai Y, Han C, et al. The Effects of Serum ANGPTL8/betatrophin on the Risk of Developing the

Metabolic Syndrome - A Prospective Study. *Scientific reports* 2016;6:28431. doi: 10.1038/srep28431

14. Alberti KG, Eckel RH, Grundy SM, et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation* 2009;120(16):1640-5. doi: 10.1161/CIRCULATIONAHA.109.192644

15. Borruel S, Molto JF, Alpanes M, et al. Surrogate markers of visceral adiposity in young adults: waist circumference and body mass index are more accurate than waist hip ratio, model of adipose distribution and visceral adiposity index. *PloS one* 2014;9(12):e114112. doi: 10.1371/journal.pone.0114112

16. Behboudi-Gandevani S, Ramezani Tehrani F, Cheraghi L, et al. Could "a body shape index" and "waist to height ratio" predict insulin resistance and metabolic syndrome in polycystic ovary syndrome? *European journal of obstetrics, gynecology, and reproductive biology* 2016;205:110-4. doi: 10.1016/j.ejogrb.2016.08.011

17. Haghighatdoost F, Sarrafzadegan N, Mohammadifard N, et al. Assessing body shape index as a risk predictor for cardiovascular diseases and metabolic syndrome among Iranian adults. *Nutrition* 2014;30(6):636-44. doi: 10.1016/j.nut.2013.10.021

18. Chen HY, Chiu YL, Chuang YF, et al. Visceral adiposity index and risks of cardiovascular events and mortality in prevalent hemodialysis patients. *Cardiovascular diabetology* 2014;13:136. doi: 10.1186/s12933-014-0136-5

19. Adults JCfDCgoPaToDi. Chinese guidelines on prevention and treatment of dyslipidemia in adults. *Zhonghua Xin Xue Guan Bing Za Zhi* 2007;35(5):390-419.

20. Motamed N, Sohrabi M, Poustchi H, et al. The six obesity indices, which one is more compatible with metabolic syndrome? A population based study. *Diabetes & metabolic syndrome* 2016 doi: 10.1016/j.dsx.2016.08.024

21. Wang Y, He S, He J, et al. Predictive value of visceral adiposity index for type 2 diabetes mellitus: A 15-year prospective cohort study. *Herz* 2015;40 Suppl 3:277-81. doi: 10.1007/s00059-014-4175-1

22. Body Mass Index, Waist Circumference, Body Adiposity Index, and Risk for Type 2 Diabetes in Two Populations in Brazil: General and Amerindia. *PloS one* 2014 doi: 10.1371/journal.pone.0100223

Figure Caption

Figure 1. Flow graph of individual recruitment.

Tables

Table 1. Baseline characteristics of study subjects according to the MetS status at baseline.

Characteristics	Male (n=198)			Female (n=181)		
	non-MetS	MetS	*P*	non-MetS	MetS	*P*
N (%)	111 (56.1)	87 (43.9)		142 (78.5)	39 (21.5)	
Age (yr)	49.0	50.0	0.397	47.5	47.0	0.515

	(44.0-55.0)	(46.0-56.0)		(43.0-54.0)	(46.0-56.0)	
SBP (mmHg)	123.3 (117.3-131.3)	136.7 (125.3-146.7)	<0.001	116.7 (108.7-123.7)	134.0 (120.0-148.0)	<0.001
DBP (mmHg)	80.0 (85.3-73.3)	87.3 (83.3-94.0)	<0.001	76.3 (69.3-80.2)	88.7 (92.7-80.0)	<0.001
FPG (mmol/L)	5.3 (5.0-5.7)	6.1 (5.4-7.2)	<0.001	5.3 (5.0-5.5)	5.8 (5.2-7.8)	<0.001
2hPG (mmol/L)	6.3 (5.2-7.5)	9.3 (6.8-12.3)	<0.001	6.8 (5.9-7.9)	9.6 (7.8-12.6)	<0.001
FINS (mIU/L)	12.49 (9.24-17.75)	16.77 (12.87-24.63)	<0.001	15.54 (12.50-19.69)	25.05 (18.65-30.54)	<0.001
HbA1c (%)	5.7 (5.4-6.0)	6.0 (5.6-6.7)	<0.001	5.9 (5.5-6.2)	6.2 (5.7-7.2)	0.005
TC (mmol/L)	4.8 (4.3-5.3)	5.3 (4.7-5.9)	0.001	5.1 (4.5-5.5)	5.2 (4.4-5.9)	0.494
TG (mmol/L)	1.3 (0.9-1.6)	2.4 (2.0-3.6)	<0.001	1.1 (0.9-1.5)	2.4 (1.7-3.8)	<0.001
HDL (mmol/L)	1.3 (1.1-1.5)	1.1 (0.9-1.3)	<0.001	1.5 (1.3-1.8)	1.1 (1.0-1.4)	<0.001
LDL (mmol/L)	3.0 (2.6-3.5)	3.1 (2.7-3.8)	0.148	3.1 (2.6-3.6)	3.2 (2.6-3.6)	0.963
HOMA-IR	2.98 (2.23-4.46)	4.74 (3.69-6.72)	<0.001	3.79 (2.81-4.86)	6.83 (4.17-8.30)	<0.001
Current Smoking, n (%)	75(67.57)	51(58.62)	0.194	7(4.93)	1(2.56)	0.844
Alcohol Intake, n (%)	39(35.14)	41(47.13)	0.088	3(2.11)	1(2.56)	1.000
SFA (cm^2)	124.62±49.88	151.84±51.80	0.001	178.86±65.82	226.87±69.24	<0.001
VFA (cm^2)	84.40±45.85	116.39±44.40	<0.001	57.76±24.16	91.80±32.98	<0.001
WC (cm)	87.3±8.1	94.7±7.9	<0.001	80.3±8.6	89.0±7.9	<0.001
BMI (kg/m^2)	24.6±2.8	26.6±2.8	<0.001	23.9±3.0	27.1±3.4	<0.001
WHR	0.90±0.05	0.94±0.05	<0.001	0.85±0.06	0.90±0.05	<0.001
ABSI ($m^{7/6}/kg^{2/3}$)	0.0792±0.0033	0.0814±0.0034	<0.001	0.0770±0.0041	0.0784±0.0036	0.040
AVI (cm^2)	15.24 (13.48-17.03)	17.86 (16.31-20.10)	<0.001	13.10 (11.56-14.30)	15.51 (14.62-17.79)	<0.001
BAI ($0.01m^{-0.5}$)	25.84±3.01	27.33±2.68	<0.001	29.30±3.18	31.70±3.22	<0.001

BRI	3.65±0.95	4.49±0.98	<0.001	3.50±0.96	4.63±1.03	<0.001
CI ($m^{2/3}/kg^{1/2}$)	1.24±0.06	1.29±0.06	<0.001	1.20±0.07	1.25±0.06	<0.001
VAI	1.30 (0.94-1.84)	3.24 (2.17-4.63)	<0.001	1.43 (0.96-1.96)	4.30 (2.46-6.35)	<0.001

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, 2 hours after glucose-load plasma glucose; FINS, fasting plasma insulin; TC, total cholesterol; TG, triglycerides; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; SFA, subcutaneous fat area; VFA, visceral fat area; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

Table 2. Baseline characteristics of healthy subjects who developed MetS or not at follow-up.

Characteristics	Male (n=111)			Female (n=142)		
	free-MetS	newly-MetS	*P*	free-MetS	newly-MetS	*P*
N (%)	69 (62.2)	42 (37.8)		108 (76.1)	34 (23.9)	
Age (yr)	49.0 (45.0-55.5)	50.5 (41.8-55.0)	0.549	47.0 (44.0-53.0)	48.5 (42.0-56.3)	0.754

SBP (mmHg)	122.0 (114.3-132.7)	125.0 (119.3-130.7)	0.239	113.3 (105.3-122.7)	120.0 (116.5-126.8)	0.003
DBP (mmHg)	80.0 (71.7-85.7)	80.0 (77.2-85.7)	0.314	74.7 (68.0-80.0)	79.0 (76.0-82.0)	< 0.001
FPG (mmol/L)	5.3 (4.9-5.6)	5.4 (5.1-5.9)	0.149	5.3 (5.0-5.5)	5.3 (5.0-5.6)	0.274
2hPG (mmol/L)	6.2 (5.3-7.5)	6.3 (5.1-8.4)	0.584	6.6 (5.8-7.6)	7.9 (6.9-9.5)	< 0.001
FINS (mIU/L)	12.18 (8.85-16.46)	12.60 (9.92-20.42)	0.341	15.32 (12.02-19.81)	16.15 (13.33-19.38)	0.374
HbA1c (%)	5.6 (5.4-5.8)	5.7 (5.4-6.2)	0.131	5.8 (5.5-6.1)	6.1 (5.6-6.3)	0.062
TC (mmol/L)	4.7 (4.3-5.3)	4.9 (4.3-5.5)	0.302	5.1 (4.5-5.5)	5.1 (4.6-5.9)	0.426
TG (mmol/L)	1.2 (0.9-1.6)	1.4 (1.1-1.7)	0.041	1.1 (0.8-1.5)	1.3 (1.0-1.7)	0.028
HDL (mmol/L)	1.3 (1.1-1.5)	1.2 (1.1-1.4)	0.075	1.6 (1.3-1.8)	1.5 (1.3-1.7)	0.029
LDL (mmol/L)	3.0±0.8	3.2±0.9	0.286	3.1±0.8	3.4±0.9	0.033
HOMA-IR	2.89 (2.20-3.92)	3.24 (2.25-4.91)	0.171	3.62 (2.75-4.78)	4.08 (3.13-5.07)	0.128
Current Smoking, n (%)	45 (65.22)	30 (71.43)	0.498	4 (3.70)	3 (8.82)	0.358
Alcohol Intake, n (%)	22 (31.88)	17 (40.48)	0.358	3 (2.78)	0 (0.00)	1.000
SFA (cm^2)	110.19±44.09	149.19±50.11	< 0.001	169.42±61.17	207.78±71.90	0.003
VFA (cm^2)	67.70±33.78	112.83±49.98	< 0.001	54.96±23.79	66.34±23.58	0.018
WC (cm)	84.5±7.5	91.9±6.9	< 0.001	78.9±8.3	84.7±8.1	< 0.001
BMI (kg/m^2)	23.6±2.6	26.2±2.5	< 0.001	23.4±2.9	25.4±2.8	0.001
WHR	0.88±0.05	0.92±0.05	< 0.001	0.84±0.06	0.87±0.05	0.003
ABSI ($m^{7/6}/kg^{2/3}$)	0.0788±0.0030	0.0799±0.0036	0.090	0.0767±0.0038	0.0779±0.0047	0.119
AVI (cm^2)	14.18(12.89-16.23)	16.21(15.13-18.57)	< 0.001	12.46(10.91-14.18)	13.95(13.31-15.89)	< 0.001
BAI ($0.01m^{-0.5}$)	25.38±2.53	26.60±3.58	0.058	28.98±2.99	30.31±3.59	0.033

BRI	3.35±0.85	4.41±0.90	< 0.001	3.34±0.90	4.02±1.00	< 0.001
CI ($m^{2/3}/kg^{1/2}$)	1.22±0.06	1.26±0.06	0.001	1.19±0.06	1.22±0.07	0.007
VAI	1.17(0.84-1.70)	1.52(1.19-2.09)	0.009	1.35(0.86-1.83)	1.68(1.39-2.25)	0.004

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, 2 hours after glucose-load plasma glucose; FINS, fasting plasma insulin; TC, total cholesterol; TG, triglycerides; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; SFA, subcutaneous fat area; VFA, visceral fat area; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

Table 3. AUCs of anthropometric indices in diagnosing of MetS at baseline.

Indices	Male			Female		
	AUC	95%CI	*P*	AUC	95%CI	*P*

WC	0.79	(0.72-0.86)	<0.001	0.79	(0.71-0.87)	<0.001
BMI	0.73[a]	(0.65-0.80)	<0.001	0.75	(0.67-0.84)	<0.001
WHR	0.72[a]	(0.64-0.79)	<0.001	0.75	(0.67-0.83)	<0.001
ABSI	0.70[a]	(0.62-0.78)	<0.001	0.62[a]	(0.52-0.72)	0.031
AVI	0.79	(0.72-0.86)	<0.001	0.79	(0.71-0.87)	<0.001
BAI	0.67[a]	(0.59-0.75)	<0.001	0.69[a]	(0.59-0.79)	<0.001
BRI	0.76	(0.69-0.83)	<0.001	0.80	(0.71-0.88)	<0.001
CI	0.76	(0.68-0.83)	<0.001	0.73[a]	(0.64-0.82)	<0.001
VAI	0.85	(0.79-0.92)	<0.001	0.90[a]	(0.84-0.96)	<0.001

a, vs WC, $P<0.05$.

Table 4. AUCs, optimal cutoff, sensitivity, specificity, positive and negative predictive value for the anthropometric indices in ROC analysis for predicting MetS.

Anthropometric Indices	AUC (95%CI)	*P*	Cut-off	Sensitivity	Specificity	Youden Index	PPV	NPV
Male								
WC	0.76 (0.67-0.84)	<0.001	84.0	0.95	0.54	0.49	0.56	0.95
BMI	0.77 (0.68-0.85)	<0.001	24.94	0.69	0.75	0.44	0.63	0.80
WHR	0.73 (0.64-0.81)	<0.001	0.89	0.76	0.64	0.40	0.56	0.81
ABSI	0.58[a] (0.49-0.68)	0.149	0.0822	0.29	0.88	0.17	0.60	0.67
AVI	0.76 (0.67-0.84)	<0.001	14.25	0.95	0.54	0.49	0.56	0.95
BAI	0.59[a] (0.49-0.68)	0.124	27.44	0.40	0.87	0.27	0.65	0.70
BRI	0.74 (0.65-0.82)	<0.001	3.47	0.81	0.58	0.39	0.54	0.83
CI	0.67[a] (0.58-0.76)	<0.001	1.21	0.83	0.45	0.28	0.48	0.81
VAI	0.65[a] (0.55-0.74)	0.005	1.06	0.83	0.48	0.31	0.49	0.82
Female								
WC	0.71 (0.64-0.79)	<0.001	80.0	0.82	0.60	0.42	0.39	0.91
BMI	0.71 (0.63-0.78)	<0.001	25.14	0.59	0.78	0.37	0.46	0.86
WHR	0.68 (0.59-0.75)	<0.001	0.81	0.91	0.37	0.28	0.31	0.93
ABSI	0.55[a] (0.47-0.64)	0.358	0.0799	0.32	0.81	0.13	0.35	0.79

AVI	0.72 (0.64-0.79)	<0.001	13.03	0.82	0.60	0.42	0.39	0.91
BAI	0.64 (0.56-0.72)	0.013	30.38	0.53	0.74	0.27	0.39	0.83
BRI	0.71 (0.63-0.79)	<0.001	3.58	0.71	0.66	0.37	0.40	0.88
CI	0.63 (0.54-0.71)	0.020	1.23	0.44	0.81	0.25	0.42	0.82
VAI	0.66 (0.58-0.74)	0.001	1.36	0.79	0.52	0.31	0.34	0.89

a, vs WC, $P<0.05$.

Table 5. Comparison of AUCs for anthropometric indices in predicting MetS and its components in males.

Component	Central obesity		High TG		Low HDL		High BP		High BG	
	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*
WC	0.79 (0.69-0.89)	<0.001	0.63 (0.47-0.78)	0.118	0.45 (0.31-0.59)	0.523	0.77 (0.66-0.88)	<0.001	0.57 (0.43-0.70)	0.348
BMI	0.78 (0.67-0.89)	<0.001	0.69 (0.55-0.84)	0.016	0.53 (0.39-0.68)	0.675	0.72 (0.60-0.84)	<0.001	0.58 (0.45-0.71)	0.263
WHR	0.71 (0.59-0.83)	0.002	0.61 (0.46-0.76)	0.185	0.41 (0.26-0.57)	0.286	0.75 (0.64-0.86)	<0.001	0.59 (0.46-0.72)	0.199
ABSI	0.50[a] (0.37-0.63)	0.996	0.47 (0.29-0.64)	0.665	0.37 (0.22-0.51)	0.104	0.72 (0.61-0.84)	<0.001	0.53 (0.38-0.68)	0.677
AVI	0.79 (0.69-0.89)	<0.001	0.62 (0.47-0.78)	0.123	0.45 (0.31-0.59)	0.555	0.77 (0.66-0.88)	<0.001	0.57 (0.43-0.70)	0.348
BAI	0.57[a] (0.42-0.71)	0.340	0.60 (0.43-0.77)	0.217	0.56 (0.40-0.71)	0.502	0.63[a] (0.51-0.75)	0.058	0.54 (0.40-0.68)	0.554
BRI	0.70[a] (0.58-0.82)	0.004	0.65 (0.50-0.80)	0.060	0.48 (0.34-0.61)	0.776	0.75 (0.64-0.86)	<0.001	0.58 (0.45-0.72)	0.226
CI	0.60[a]	0.139	0.54	0.604	0.39	0.181	0.76	<0.001	0.55	0.465

		(0.48-0.73)			(0.37-0.71)			(0.25-0.53)			(0.65-0.87)			(0.41-0.69)	
		0.58[a]			0.69			0.61			0.61[a]			0.56	
VAI			0.266			0.016			0.179			0.113			0.365
		(0.45-0.70)			(0.57-0.82)			(0.45-0.77)			(0.48-0.74)			(0.43-0.70)	

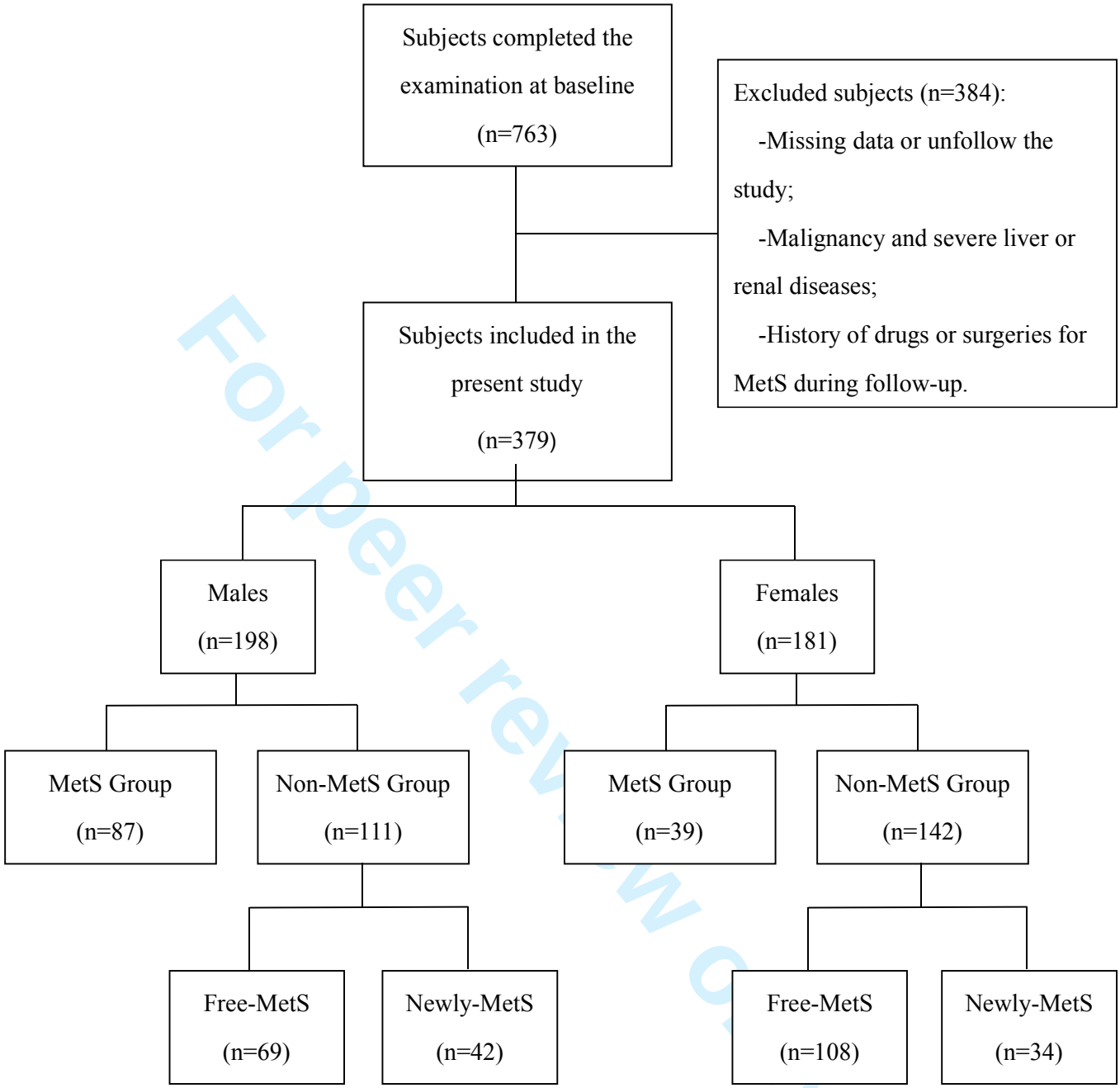
a, vs WC, $P<0.05$.

Table 6. Comparison of AUCs for anthropometric indices in predicting MetS and its components in females.

Component	Central obesity		High TG		Low HDL		High BP		High BG	
	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*
BMI	0.83 (0.75-0.92)	<0.001	0.56 (0.39-0.73)	0.563	0.64 (0.49-0.79)	0.145	0.68 (0.58-0.78)	<0.001	0.50[a] (0.35-0.65)	0.997
WC	0.82 (0.74-0.91)	<0.001	0.50 (0.32-0.67)	0.955	0.64 (0.51-0.77)	0.142	0.70 (0.61-0.80)	<0.001	0.54 (0.40-0.68)	0.584
WHR	0.65[a] (0.54-0.75)	0.021	0.39 (0.24-0.54)	0.257	0.64 (0.51-0.77)	0.145	0.60[a] (0.50-0.70)	0.066	0.62 (0.49-0.76)	0.106
ABSI	0.47[a,b] (0.36-0.59)	0.681	0.39 (0.21-0.57)	0.253	0.53 (0.35-0.71)	0.736	0.59[a] (0.49-0.69)	0.082	0.61 (0.48-0.74)	0.157
AVI	0.84 (0.75-0.92)	<0.001	0.50 (0.32-0.68)	0.981	0.64 (0.50-0.77)	0.153	0.71 (0.62-0.80)	<0.001	0.54 (0.40-0.69)	0.590
BAI	0.70[a] (0.59-0.82)	<0.001	0.58 (0.38-0.78)	0.429	0.58 (0.39-0.77)	0.413	0.61 (0.51-0.71)	0.036	0.50 (0.34-0.66)	0.990
BRI	0.77 (0.68-0.87)	<0.001	0.49 (0.31-0.67)	0.918	0.64 (0.50-0.79)	0.142	0.67[a] (0.57-0.76)	0.002	0.54 (0.39-0.69)	0.609
CI	0.58[a]	0.220	0.44	0.550	0.61	0.271	0.63[a]	0.013	0.59	0.222

	(0.47-0.69)		(0.26-0.63)		(0.44-0.77)		(0.53-0.73)		(0.46-0.73)			
	0.62[a]		0.59		0.56		0.52[a]		0.59			
VAI		0.060		0.328		0.524		0.739		0.261		
	(0.51-0.73)		(0.41-0.78)		(0.39-0.73)		(0.41-0.62)		(0.44-0.73)			

a, vs WC, $P<0.05$.



Supplement 1. Morbidities of MetS and its components during follow-up.

	Male			Female			*P*
	Free, n	Newly, n	Morbidity, %	Free, n	Newly, n	Morbidity, %	
MetS	69	42	37.8	108	34	23.9	**0.017**
Central obesity	57	31	35.2	86	30	25.9	0.148
High TG	80	19	19.2	119	11	8.5	**0.017**
Low HDL	148	16	9.8	119	11	8.5	0.703
High BP	28	59	67.8	51	82	61.7	0.352
High BG	76	25	24.8	102	17	14.3	**0.049**

TG, triglyceride; HDL, high density lipoprotein cholesterol; BP, blood pressure; BG, blood glycose.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Check
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-10
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-7
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7-8
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7
Bias	9	Describe any efforts to address potential sources of bias	9-10
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	9-10
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	6-7
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	10
		(b) Indicate number of participants with missing data for each variable of interest	10
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	10
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	10
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-12
		(*b*) Report category boundaries when continuous variables were categorized	10-12
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	10-12
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10-12
Discussion			
Key results	18	Summarise key results with reference to study objectives	13-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-15
Generalisability	21	Discuss the generalisability (external validity) of the study results	13-15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Comparison of Anthropometric Indices for Predicting the Risk of Metabolic Syndrome and Its Components in Chinese Adults: A Prospective Study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-016062.R1
Article Type:	Research
Date Submitted by the Author:	02-Jun-2017
Complete List of Authors:	Wang, Haoyu; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Liu, Aihua; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Zhao, Tong; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Gong, Xun; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Pang, Tianxiao; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Zhou, Yingying; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Xiao, Yue; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Yan, Yumeng; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Fan, Chenling; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Teng, Weiping; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University

	Lai, Yaxin; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Shan, Zhongyan; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University
Primary Subject Heading:	Diabetes and endocrinology
Secondary Subject Heading:	Diagnostics, Epidemiology
Keywords:	metabolic syndrome, waist circumference, abdominal volume index, visceral adiposity index, anthropometric index

Comparison of Anthropometric Indices for Predicting the Risk of Metabolic Syndrome and Its Components in Chinese Adults: A Prospective Study

Author list and affiliations:

Haoyu Wang[1], Aihua Liu[1], Tong Zhao[1], Xun Gong[1], Tianxiao Pang[1], Yingying Zhou[1], Yue Xiao[1], Yumeng Yan[1], Chenling Fan[1], Weiping Teng[1], Yaxin Lai[1,*], Zhongyan Shan[1,*]

[1]Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University, No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China.

E-mail Addresses:

Haoyu Wang: why_endocrinology@foxmail.com

Aihua Liu: liuaihuacmu@163.com

Tong Zhao: cmu_zhaotong@163.com

Xun Gong: cmu_gx@vip.163.com

Tianxiao Pang: ptx90@163.com

Yingying Zhou: 18937856536@163.com

Yue Xiao: xy5856@126.com

Yumeng Yan: cherylyanyumeng@hotmail.com

Chenling Fan: fanchenling@126.com

Weiping Teng: twp@vip.163.com

Yaxin Lai: laiyaxin811005@126.com

Shan Zhongyan: shanzhongyan@medmail.com.cn

Corresponding author and person to whom reprint requests should be addressed:

Yaxin Lai, M.D., Ph.D.

Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases

The First Affiliated Hospital of China Medical University

No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China

Tel: +86-24-83283294

Fax: +86-24-83283294

E-mail: laiyaxin811005@126.com

Zhongyan Shan, M.D., Ph.D.

Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases

The First Affiliated Hospital of China Medical University

No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China

Tel: +86-24-83283294

Fax: +86-24-83283294

E-mail: shanzhongyan@medmail.com.cn

Running title: Anthropometric indices and Incident MetS

Authors' statement: The authors hereby confirm that neither the manuscript nor any part of it has been published or is being considered for publication elsewhere. We acknowledge that all authors participated sufficiently in the work and take public responsibility for its content.

Funding:

1. the Chinese National Natural Science Foundation (Grant: 81300645)
2. the National Science and Technology Support Program (Grant: 2009BAI80B00)

Disclosure Summary: The authors have no potential conflict of interest to declare.

Data Sharing Statement: No additional data are available.

Word count: 317 (Abstract); 3233 (excluding abstract, figure captions, and references)

Figures & Tables: 7

Abstract

Backgound: Our study aimed to distinguish the ability of anthropometric indices to assess the risk of metabolic syndrome (MetS) during a 4.5-year follow-up.

Setting, participants and outcome measures: Data were collected from an epidemiological study between 2010 and 2014. At baseline, a total of 379 individuals (198 males and 181 females) aged from 40 to 65 were enrolled in the study. A variety of anthropometric parameters were measured and calculated, including waist circumference (WC), body mass index (BMI), a body shape index (ABSI), abdominal volume index (AVI), body adiposity index (BAI), body roundness index (BRI), conicity index (CI), waist-to-hip ratio (WHR) and visceral adiposity index (VAI). MetS was diagnosed according to the criteria of the International Diabetes Federation in 2009. Receiver Operating Characteristic (ROC) curve was applied to examine the potential of the above indices at baseline to identify the status and risk of MetS.

Results: At baseline, 43.9% of males and 21.5% of females suffered from MetS. All of the anthropometric indices showed clinical significance, and VAI was superior to the other indices, as it was found to have the largest area under the ROC curve at the time of cross-section analysis. After a 4.5-year follow-up, 37.8% of males and 23.9% of females developed MetS. ROC curve analysis suggested that the strongest predictor of MetS was baseline BMI (0.77[0.68-0.85] and 0.71[0.63-0.78] for males and females, respectively) and AVI (0.76[0.67-0.84] and 0.72[0.64-0.79] for males and females, respectively). However, no significant difference was observed between WC and the both two indices. In contrast, the baseline ABSI did not predict MetS in both genders.

Conclusions: The present study indicated that these different indices derived from anthropometric parameters have different discriminatory abilities for MetS. Although WC did not have the largest

area under the ROC curve for diagnosing and predicting MetS, it may remain the better index of MetS status and risk because of its simplicity and wide utilization.

Strengths and limitations of this study:

1. This is a longitudinal prospective study of the association of anthropometric indices with metabolic syndrome risk.
2. This is the first study to systematically report the different abilities of anthropometric indices in diagnosing or predicting metabolic syndrome.
3. The object of the present study was middle-aged and elderly subjects in northeast China, limiting the extension of the conclusion.
4. This study defined metabolic syndrome by IDF 2009 criterion. Therefore, further studies are needed to determine whether the results are consistent under different criteria.

Keywords

Metabolic syndrome; Waist circumference; Abdominal volume index; Visceral adiposity index; Anthropometric index.

Background

Metabolic syndrome (MetS), as a cluster of risk factors for cardiovascular morbidity and mortality[1], has become a major health concern in both developing and developed countries. It has been reported that more a third of adults suffer from MetS by the National Health and Nutrition Examination

Survey[2]. A growing body of evidence supports the hypothesis that abdominal visceral fat plays a role in the development of MetS[3-6]. Hence, it is reasonable that central obesity is defined as a predictor of MetS.

Body mass index (BMI) is widely used in assessing the obesity status[7], but it cannot describe the distribution of abdominal adipose tissue. Therefore, additional anthropometric indices are required to assess abdominal adipose accumulation. Elevated waist circumference (WC) and waist-to-hip ratio (WHR) were reported to be strongly associated with central obesity and MetS[8]. Moreover, Krakauer's and Tomas' groups proposed a body shape index (ABSI) and body roundness index (BRI), respectively, to estimate body fat distribution. However, neither ABSI nor BRI have been proven a more closely correlation with cardiovascular disease than BMI or WC[9]. Recently, Amato *et al*., reported an alternative anthropometric index, visceral adiposity index (VAI), that could be considered as an indicator for cardiometabolic risk[10]. However, its advantages in predicting metabolic diseases over other indices are still unclear. Abdominal volume index (AVI) is another anthropometric tool for estimating overall volume. It was hold to have an extremely closely relationship with the dysfunction of glucose metabolism[11]. Additionally, other indices have been often used in epidemiologic research, such as conicity index (CI) and body adiposity index (BAI)[12 13]. However, a comprehensive consensus has not been reached about the best indices for evaluating the status and risk of MetS.

Many studies suggest that different indicators differ in predicting disease occurrence

Accumulating evidence has suggested that the different anthropometric indices differ in determining MetS, but they are all cross-sectional. Thus, our study compared the ability in predicting MetS of WC with other anthropometric indices including BMI, ABSI, AVI, BAI, BRI, CI, WHR, and

VAI aimed at explicating the prospective differences of various anthropometric indices.

Methods

Study Population

To evaluate the effectiveness of anthropometric indices in predicting MetS, a community-based study involving 763 individuals was performed in 2010 in urban Shenyang, Liaoning Province, China. In 2014, 472 of all the participants (61.9%) were underwent the follow-up. Exclusion criteria was as following: (1) subjects missing data or unfollow the study; (2) subjects with malignancy, hepatic dysfunction, or renal diseases; (3) subjects with history of drugs or surgeries for obesity, dyslipidemia, hypertension, or diabetes at baseline or during follow-up. Finally, data from 379 participants (198 males and 181 females) aged 40-65 were selected for this study, and the average follow-up duration was 4.5 years (**Figure 1**).

This study was approved by the Ethics Committee of the First Affiliated Hospital of China Medical University, and all participants provided signed informed consent before enrollment in this study.

Data Measurement and Collection

At baseline and at the endpoint, all subjects underwent comprehensive interviews and health examinations by trained staff. A questionnaire including demographic characteristics, personal medical history, and information related to the diagnosis and treatment of MetS was completed for each participant. Based on the previous standardized protocol[14], body weight, height, waist circumference, hip circumference (HC), systolic blood pressure (SBP), and diastolic blood pressure

(DBP) were measured. Participants were given a standard 75-g oral glucose tolerance test (OGTT). Venous blood samples were drawn to determine fasting plasma glucose (FPG), plasma glucose 2 hours after a glucose load (2hPG), fasting plasma insulin (FINS), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL), and low-density lipoprotein cholesterol (LDL) according to standard methods[14 15].

At baseline, all subjects had magnetic resonance imaging (MRI) scans performed at the abdominal level between the 4th and 5th lumbar vertebrae in the prone position (FOV 42 cm×42 cm, thickness 1 cm, 6 layers, GE, USA). Subcutaneous fat area (SFA) and visceral fat area (VFA) were calculated using SLICE-O-MATIC version4.2 software (Tomovision) by two separate technicians.

Metabolic Syndrome Definition

The diagnose of MetS was based on the International Diabetes Federation criteria[16] in 2009 and Chinese-specific abdominal obesity standard[8], which means that the individual with any three or more of the five following components can be considered MetS: (1) abdominal obesity (WC≥90 cm for males, 85 cm for females); (2) elevated TG (TG≥1.70 mmol/L); (3) low HDL (HDL <1.0 mmol/L for males, <1.3 for females) ; (4) high blood pressure (SBP≥130 mmHg, DBP≥85 mmHg, or a history of hypertension) ; (5) elevated plasma glucose (FPG≥5.6 mmol/L, or a diagnosis of T2DM).

Calculations

The homeostatic model assessment index for insulin resistance (HOMA-IR) was evaluated using the formula:

$$HOMA-IR=\frac{FPG(mmol/L)\times FINS(mIU/L)}{22.5}, \quad (mmol\times mIU/L^2).$$

The anthropometric indices, such as BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI were calculated using the following formulas[10 17-20]:

$BMI = \frac{Weight}{Height^2}$,($kg^2/m$);

$WHR = \frac{WC}{HC}$;

$ABSI = \frac{WC}{BMI^{\frac{2}{3}} \times Height^{\frac{1}{2}}}$, ($m^{7/6}/kg^{2/3}$);

$AVI = \frac{2 \times WC^2 + 0.7 \times (WC - HC)^2}{1000}$, ($cm^2$)

$BAI = \frac{HC}{Height^{\frac{3}{2}}} - 18$, ($0.01 m^{-1/2}$);

$BRI = 364.2 - 365.5 \times \sqrt{1 - \frac{(WC/2\pi)^2}{(0.5 \times Height)^2}}$;

$CI = \frac{WC}{0.109 \times \sqrt{\frac{Weight}{Height}}}$, ($m^{2/3}/kg^{1/2}$);

$VAI_{male} = (\frac{WC}{39.68} - 1.88 \times BMI) \times \frac{TG}{1.03} \times \frac{1.31}{HDL}$;

$VAI_{female} = (\frac{WC}{36.58} - 1.89 \times BMI) \times \frac{TG}{0.81} \times \frac{1.52}{HDL}$.

Statistical Analyses

Based on the diagnosis of MetS, the subjects were assigned to MetS group and non-MetS group at

baseline. During follow-up, subjects in non-MetS group were further divided into newly MetS group and free-MetS group according to whether or not they developed MetS.

The data distribution was assessed using the Kolmogorov-Smirnov test. The variables were displayed as the mean±standard deviations, medians (interquartile range) or counts (percentages) according to their types. Univariate analyses were conducted to estimate the relative factors of MetS and its components using the *t*-test, Mann-Whitney rank sum test, Pearson's Chi-squared test, or Fisher's exact test depending on the characteristics of the data. Area under receiver operating characteristic (ROC) curves were calculated to evaluate the abilities of the anthropometric indices to identify MetS. And new cutoff points were suggested by Youden's Index (sensitivity+specificity-1). The ability of each anthropometric index to predict MetS was showed as areas under the ROC curves and the confidence intervals. DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the areas under the ROC curves (AUCs)[21]. Statistical analyses were performed using SPSS (version 23.0, IBM Corp., USA). MedCalc (version 16.2, MedCalc Software, Belgium) was used to analyze the ROC curves. Statistical significance was defined as $P < 0.05$ for all analyses.

Results

Baseline characteristics of the participants

After 4.5 years, 472 of all the participants (61.9%) follow-up. According to the criteria mentioned above, 198 males and 181 females were included in the present study. At baseline, 87 (43.9%) males and 39 (21.5%) females were diagnosed as MetS. The median age of study subjects was 49.5 (45.0-55.0) years for males and 47.0 (44.0-54.0) years for females. Compared with the non-MetS group, subjects with MetS had significantly higher levels of SBP, DBP, FPG, 2hPG, FINS, HbA1c,

TG, LDL, HOMA-IR, SFA, and VFA, but lower levels of HDL. TC was significantly increased in males with MetS, while no significant difference was observed in females between MetS and non-MetS. Furthermore, all of the nine anthropometric indices, including WC, BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI of the MetS group, were elevated significantly in both males and females (**Table 1**).

In the non-MetS group, 42 (37.8%) males and 34 (23.9%) females developed MetS after 4.5-years follow-up. Compared with the healthy controls, TG, SFA, and VFA were significantly elevated in the newly MetS group. Furthermore, females in the newly MetS group had higher levels of SBP, DBP, 2hPG, and LDL but lower levels of HDL at baseline. As for anthropometric indices, WC, BMI, WHR, AVI, BRI, CI, and VAI of the newly MetS group were higher in both males and females. Baseline BAI was increased in newly-MetS group for females, while no significant difference was observed between free-MetS and newly MetS in males. Additionally, ABSI did not show significant difference between the free-MetS and newly MetS groups in both males and females (**Table 2**).

Comparison of the anthropometric indices for diagnosing MetS at baseline

At baseline, the AUCs of all the anthropometric indices were larger than 0.5 (P<0.05), suggesting their diagnostic significance for MetS (**Table 3**). Our results showed that the VAI had the largest AUC for both genders (0.85 [0.79-0.92] for males and 0.90 [0.84-0.96] for females). The BAI (0.67 [0.59-0.75]) and ABSI (0.62 [0.52-0.72]) showed the lowest AUCs for males and females, respectively. In males, AVI, BRI, CI, and VAI had approximately the same AUCs as WC for diagnosing MetS (all P>0.05 vs. WC). However, the AUCs of BMI, WHR, ABSI, and BAI were significantly lower compared with WC for males (all P<0.05 vs. WC). In females, the AUC of VAI

was significantly larger than WC, while the AUCs of ABSI, BAI, and CI were significantly lower (all $P<0.05$ vs. WC). The other four anthropometric indices showed no significant difference with WC in diagnosing MetS for females (all $P>0.05$ vs. WC).

Comparison of the anthropometric indices for predicting MetS during follow-up

In general, the AUCs varied from 0.58 (0.49-0.68) for ABSI to 0.77 (0.68-0.85) for BMI in males and from 0.55 (0.47-0.64) for ABSI to 0.72 (0.64-0.79) for AVI in females. The AUC of ABSI was the lowest and did not differ from 0.5 in both males and females ($P>0.05$). Moreover, the AUC of BAI was significantly larger than 0.5 in males, while no difference from 0.5 was observed in females. All the AUCs of the other indices were greater than 0.5 ($P<0.05$), suggesting their clinical predictive significance for MetS. In males, BMI had the largest AUC, but did not differ significantly from WC. WHR, AVI, and BRI showed no significant difference with WC. Furthermore, ABSI, BAI, CI and VAI had significantly lower AUCs than WC. In females, no significant difference was observed between WC and BMI, WHR, AVI, BAI, BRI, CI, or VAI. Moreover, ABSI had a significantly lower AUC than WC.

Other details of all the anthropometric indices such as cutoff, sensitivity, specificity, Youden index, positive predictive value (PPV), and negative predictive value (NPV) were also reported in this study (**Table 4**).

AUCs of the anthropometric indices for predicting MetS components during follow-up

Compared with females, the morbidities of MetS, high TG and high blood glucose (BG) in males were elevated (37.8% vs. 23.9%, 19.2% vs. 8.5%, and 24.8% vs. 14.3%, respectively) after a

4.5-year follow-up. Morbidities of the other two MetS components showed no differences between males and females (**Table S1**). Furthermore, we made comparisons of all indices in predicting MetS components (**Table 5** and **Table 6**). Firstly, the AUCs of BMI, WHR, AVI, and BRI had predictive significances for central obesity in males, while ABSI, BAI, CI, and VAI did not. However, in females, the AUCs of ABSI, CI and VAI were not significantly larger than 0.5. In both genders, AVI had the largest AUC for incident central obesity, but did not differed significantly from WC. Second, BMI and VAI showed significances for predicting high TG in males. However, no significantly predictive value was observed in the remaining indicators for males or females. Moreover, the AUCs of all the indices were small for predicting low HDL and high BG, and none were significantly over 0.5. Therefore, none of the indices could discriminate among both males and females with low HDL or high BG. Lastly, either BAI or VAI had an AUC less than 0.5 for high blood pressure (BP) in males, and the AUCs of WHR, ABSI, and VAI were significantly less than 0.5 in females. Furthermore, WC and AVI had the largest AUCs for high BP in males, and no difference was observed between these two indices. In females, the AUC of AVI was the largest for high BP in females but did not differ significantly from WC.

Discussion

There is abundant evidence that abdominal obesity is one of the most important risk factors of metabolic diseases such as diabetes mellitus and dyslipidemia[8 22]. The abdominal visceral fat area measured by MRI is still considered the best index to evaluate the extent of abdominal obesity[23]. Our results showed that incident MetS patients had a higher baseline visceral fat area compared with non-MetS patients, confirming that abdominal visceral fat can be an excellent indicator for MetS.

However, considering the cost, safety and many other factors, it is not realistic to carry out abdominal fat screen by MRI in clinic. Therefore, accumulating studies have conducted to find a more simple and noninvasive approach to describe abdominal obesity. For a long time, a variety of investigations have evaluated the ability of indices derived from several anthropometric parameters in determining MetS. Most of these studies were cross-sectional. In this study, we compared nine obesity indices, including WC, BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI, in assessing the incident risk of MetS using a 4.5-year prospective analysis. Our study indicated that some novel anthropometric indices may be insufficient for evaluating the incident risk of MetS.

At baseline, all the indices showed significant roles in diagnosing MetS, and VAI had the highest AUC value in both males and females. For the calculation of the VAI value involving WC, BMI, TG, and HDL, it is suggested that VAI might provide a broader evaluation of metabolic risk related to visceral fat dysfunction. Previous studies had reported that VAI has significant advantages over WC for determining cardiometabolic risk[10 24 25], even though a study in young adult indicated that VAI did not provide a better efficiency of visceral adiposity assessment than WC and BMI[26]. In our study, VAI was the best surrogate marker of MetS, especially considering the significant, excessive AUC in females.

Furthermore, we compared the AUCs of all the anthropometric indices for predicting MetS and its components. In general, ABSI did not show predictive value for MetS in both genders. Previously, it was reported to be a weak indicator for MetS in a few cross-sectional studies[27 28]. This finding was confirmed by our prospective evidence. Furthermore, what was different from the cross-sectional results is that the AUC of VAI was less than WC and even had a significant difference in males. In 2014, Chen *et al.* reported that the predictive performance of VAI is similar to WC for all-cause

mortality[25], suggesting that VAI as a predictor of MetS is not superior WC. Additionally, BMI and AVI showed the strongest ability in the prediction of MetS for males and females, respectively. However, neither BMI nor AVI had any significant difference from WC. In particular, considering the simplicity and widespread utilization of WC, it appeared to be a more useful predictor of MetS in clinical practice.

Our study also proposed optimal cutoff points for these anthropometric indices. An obvious difference between two genders was observed in WC, WHR, ABSI, BAI and VAI, suggesting that gender-specific reference values should be used in clinical practice. Notably, the present results showed that the optimal cutoff point for WC are considerably different from the cutoff point according to the guideline on prevention and treatment of metabolic dysfunction in Chinese adults[29]. Therefore, it may be optimal that the decreased WC cutoff is used in the clinical setting to select Chinese adults at high risk of incident MetS. Additionally, all the PPVs of indices were less than NPVs, suggesting that the indices covered in this article were suitable for excluding the risk for MetS in a non-MetS population.

Our study further finds that the indices show different discriminatory power for different MetS components. AVI had the largest AUC for central obesity in both males and females. On the other hand, VAI of males had the highest AUC value for high TG and high BP. In females, the AUC of AVI for high BP was larger than the other indices, while no indicator showed significance in predicting high TG. Interestingly, the CI played only a predictive role of new-onset high BP in both genders, suggesting its worse predictive ability for MetS components. Some scholars believed that this is probably because weight dilutes the influence of height according to its formula[30]. Additionally, all the indices failed in forecasting incident low HDL and high BG, in contrast to other studies[9 10 24 31].

One possible explanation is that only a few individuals developed low HDL and high BG, and the small sample size may impact on the reliability of results. In summary, the results above suggest that the current indicators of anthropometric indices cannot provide a comprehensive prediction of metabolic risk factors. Accordingly, further study to clarify the association of anthropometric parameters with MetS components is necessary.

Several limitations of the present study should be considered. First, this study was limited to middle-aged and elderly subjects in northeast China. Hence, the applicability of these results may be limited for other populations. Second, only the baseline anthropometric parameters were analyzed in the study. For our study aims to assess the predictive abilities of anthropometric indices at baseline in a prospective cohort, it is likely that the anthropometric changes during follow-up period had little effect on the current results. Finally, IDF 2009 criterion was used in the present study to defined metabolic syndrome. Therefore, further studies are needed to determine whether the results are consistent under different criteria.

Conclusions

In conclusion, VAI is the best index for diagnosis of MetS. Moreover, BMI and AVI are superior to the other anthropometric indices for predicting MetS in males and females, respectively, but no obvious difference were observed between them and WC. Hence, considering the simplicity and wide utilization, WC remains the more practical discriminator for MetS.

Abbreviations

MetS: metabolic syndrome; WC: waist circumference; BMI: body mass index; ABSI: a body shape

index; AVI: abdominal volume index; BAI: body adiposity index; BRI, body roundness index; CI, conicity index; WHR: waist-to-hip ratio; VAI: visceral adiposity index; ROC: Receiver operating characteristic; AUC: areas under the ROC curve; HC: hip circumference; SBP: systolic blood pressure; DBP: diastolic blood pressure; OGTT: 75g oral glucose tolerance test; FPG: fasting plasma glucose; 2hPG: plasma glucose 2 hours after a glucose load; FINS: fasting plasma insulin; TC: total cholesterol; TG: triglycerides; HDL: high-density lipoprotein cholesterol; LDL: low-density lipoprotein cholesterol; MRI: magnetic resonance imaging; SFA: subcutaneous fat area; VFA: visceral fat area; HOMA-IR: the homeostatic model assessment index for insulin resistance; PPV: positive predictive value; NPV: negative predictive value; BG: blood glucose; BP: blood pressure.

Declarations

Acknowledgements

We thank the participants and staff at the Institute of Endocrinology of the First Affiliated Hospital of China Medical University for their involvement in this study.

Contributors

Haoyu Wang was the primary investigator, and reviewed the literatures, performed this follow-up project, collected data, analyzed results, and produced the first draft of manuscript; Aihua Liu reviewed the literature, interpreted the data, and edited the manuscript; Tong Zhao, Xun Gong, Tianxiaopang, Yingying Zhou, Yue Xiao, Yumeng Yan, and Chenlin Fan participated in this follow-up project, collected and interpreted data; Weiping Teng supervised the statistical analyses, and edited the manuscript; Yaxin Lai and Zhongyan Shan supervised the statistical analyses, and

produced the final version of the manuscript. All authors read and approved the final manuscript.

Funding

This work was supported by the Chinese National Natural Science Foundation (Grant: 81300645) and the National Science and Technology Support Program (Grant: 2009BAI80B00). The funders had no roles in the study design, data collection or analysis, or the presentation or publication of the results.

Competing interests

The authors declare that they have no competing interests.

Ethics approval

This study was approved by the Ethics Committee of the First Affiliated Hospital of China Medical University. Informed consent was obtained from all individual participants included in the study.

References

1. Isomaa B, Almgren P, Tuomi T, et al. Cardiovascular morbidity and mortality associated with the metabolic syndrome. *Diabetes care* 2001;24(4):683-9. doi: 10.2337/diacare.24.4.683

2. Mozumdar A, Liguori G. Persistent increase of prevalence of metabolic syndrome among U.S. adults: NHANES III to NHANES 1999-2006. *Diabetes care* 2011;34(1):216-9. doi: 10.2337/dc10-0879

3. Hwang YC, Hayashi T, Fujimoto WY, et al. Visceral abdominal fat accumulation predicts the conversion of metabolically healthy obese subjects to an unhealthy phenotype. *International journal of obesity*

2015;39(9):1365-70. doi: 10.1038/ijo.2015.75

4. Lim KI, Yang SJ, Kim TN, et al. The association between the ratio of visceral fat to thigh muscle area and metabolic syndrome: the Korean Sarcopenic Obesity Study (KSOS). *Clinical endocrinology* 2010;73(5):588-94. doi: 10.1111/j.1365-2265.2010.03841.x

5. Rothney MP, Catapano AL, Xia J, et al. Abdominal visceral fat measurement using dual-energy X-ray: association with cardiometabolic risk factors. *Obesity* 2013;21(9):1798-802. doi: 10.1002/oby.20223

6. Lee JJ, Pedley A, Hoffmann U, et al. Association of Changes in Abdominal Fat Quantity and Quality With Incident Cardiovascular Disease Risk Factors. *Journal of the American College of Cardiology* 2016;68(14):1509-21. doi: 10.1016/j.jacc.2016.06.067

7. Han C, Li C, Mao J, et al. High Body Mass Index Is an Indicator of Maternal Hypothyroidism, Hypothyroxinemia, and Thyroid-Peroxidase Antibody Positivity during Early Pregnancy. *Biomed Res Int* 2015;2015:351831. doi: 10.1155/2015/351831

8. Bao Y, Lu J, Wang C, et al. Optimal waist circumference cutoffs for abdominal obesity in Chinese. *Atherosclerosis* 2008;201(2):378-84. doi: 10.1016/j.atherosclerosis.2008.03.001

9. Chang Y, Guo X, Chen Y, et al. A body shape index and body roundness index: two new body indices to identify diabetes mellitus among rural populations in northeast China. *BMC public health* 2015;15:794. doi: 10.1186/s12889-015-2150-2

10. Amato MC, Giordano C, Galia M, et al. Visceral Adiposity Index: a reliable indicator of visceral fat function associated with cardiometabolic risk. *Diabetes care* 2010;33(4):920-2. doi: 10.2337/dc09-1825

11. Guerrero-Romero F, Rodriguez-Moran M. Abdominal volume index. An anthropometry-based index for estimation of obesity is strongly related to impaired glucose tolerance and type 2 diabetes mellitus. *Archives of Medical Research* 2003;34(5):428-32. doi: 10.1016/S0188-4409(03)00073-0

12. Bergman RN, Stefanovski D, Buchanan TA, et al. A better index of body adiposity. *Obesity* 2011;19(5):1083-9. doi: 10.1038/oby.2011.38

13. Shidfar F, Alborzi F, Salehi M, et al. Association of waist circumference, body mass index and conicity index with cardiovascular risk factors in postmenopausal women. *Cardiovascular journal of Africa* 2012;23(8):442-5. doi: 10.5830/CVJA-2012-038

14. Wang H, Lai Y, Han C, et al. The Effects of Serum ANGPTL8/betatrophin on the Risk of Developing the Metabolic Syndrome - A Prospective Study. *Scientific reports* 2016;6:28431. doi: 10.1038/srep28431

15. Han C, Xia X, Liu A, et al. Circulating Betatrophin Is Increased in Patients with Overt and Subclinical Hypothyroidism. *Biomed Res Int* 2016;2016:5090852. doi: 10.1155/2016/5090852

16. Alberti KG, Eckel RH, Grundy SM, et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation* 2009;120(16):1640-5. doi: 10.1161/CIRCULATIONAHA.109.192644

17. Agirbasli M, Agaoglu NB, Ergonul O, et al. Comparison of anthropometric indices in predicting metabolic syndrome components in children. *Metabolic syndrome and related disorders* 2011;9(6):453-9. doi: 10.1089/met.2011.0018

18. Zhang ZQ, Deng J, He LP, et al. Comparison of various anthropometric and body fat indices in identifying cardiometabolic disturbances in Chinese men and women. *PloS one* 2013;8(8):e70893. doi: 10.1371/journal.pone.0070893

19. Kang SH, Cho KH, Park JW, et al. Comparison of waist to height ratio and body indices for prediction of metabolic disturbances in the Korean population: the Korean National Health and Nutrition

Examination Survey 2008-2011. *BMC endocrine disorders* 2015;15:79. doi: 10.1186/s12902-015-0075-5

20. Tripolino C, Irace C, Carallo C, et al. Body fat and blood rheology: Evaluation of the association between different adiposity indices and blood viscosity. *Clinical hemorheology and microcirculation* 2017;65(3):241-48. doi: 10.3233/CH-16172

21. Delong E, Delong D, Clarke-Pearson D. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988;44(3):837-45.

22. Wang T, Ma X, Peng D, et al. Effects of Obesity Related Genetic Variations on Visceral and Subcutaneous Fat Distribution in a Chinese Population. *Scientific reports* 2016;6:20691. doi: 10.1038/srep20691

23. Hou X, Lu J, Weng J, et al. Impact of waist circumference and body mass index on risk of cardiometabolic disorder and cardiovascular disease in Chinese adults: a national diabetes and metabolic disorders survey. *PloS one* 2013;8(3):e57319. doi: 10.1371/journal.pone.0057319

24. Wang Y, He S, He J, et al. Predictive value of visceral adiposity index for type 2 diabetes mellitus: A 15-year prospective cohort study. *Herz* 2015;40 Suppl 3:277-81. doi: 10.1007/s00059-014-4175-1

25. Chen HY, Chiu YL, Chuang YF, et al. Visceral adiposity index and risks of cardiovascular events and mortality in prevalent hemodialysis patients. *Cardiovascular diabetology* 2014;13:136. doi: 10.1186/s12933-014-0136-5

26. Borruel S, Molto JF, Alpanes M, et al. Surrogate markers of visceral adiposity in young adults: waist circumference and body mass index are more accurate than waist hip ratio, model of adipose distribution and visceral adiposity index. *PloS one* 2014;9(12):e114112. doi: 10.1371/journal.pone.0114112

27. Behboudi-Gandevani S, Ramezani Tehrani F, Cheraghi L, et al. Could "a body shape index" and "waist to

height ratio" predict insulin resistance and metabolic syndrome in polycystic ovary syndrome? *European journal of obstetrics, gynecology, and reproductive biology* 2016;205:110-4. doi: 10.1016/j.ejogrb.2016.08.011

28. Haghighatdoost F, Sarrafzadegan N, Mohammadifard N, et al. Assessing body shape index as a risk predictor for cardiovascular diseases and metabolic syndrome among Iranian adults. *Nutrition* 2014;30(6):636-44. doi: 10.1016/j.nut.2013.10.021

29. Zhu J. Chinese guidelines on prevention and treatment of dyslipidemia in adults. *Zhonghua Xin Xue Guan Bing Za Zhi* 2007;35(5):390-419.

30. Motamed N, Sohrabi M, Poustchi H, et al. The six obesity indices, which one is more compatible with metabolic syndrome? A population based study. *Diabetes & metabolic syndrome* 2016 doi: 10.1016/j.dsx.2016.08.024

31. Alvim Rde O, Mourao-Junior CA, de Oliveira CM, et al. Body mass index, waist circumference, body adiposity index, and risk for type 2 diabetes in two populations in Brazil: general and Amerindian. *PloS one* 2014;9(6):e100223. doi: 10.1371/journal.pone.0100223

Figure Caption

Figure 1. Flow graph of individual recruitment.

Tables

Table 1. Baseline characteristics of study subjects according to the MetS status at baseline.

Characteristics	Male (n=198)			Female (n=181)		
	non-MetS	MetS	*P*	non-MetS	MetS	*P*
N (%)	111 (56.1)	87 (43.9)		142 (78.5)	39 (21.5)	
Age (yr)	49.0 (44.0-55.0)	50.0 (46.0-56.0)	0.397	47.5 (43.0-54.0)	47.0 (46.0-56.0)	0.515
SBP (mmHg)	123.3 (117.3-131.3)	136.7 (125.3-146.7)	<0.001	116.7 (108.7-123.7)	134.0 (120.0-148.0)	<0.001
DBP (mmHg)	80.0 (85.3-73.3)	87.3 (83.3-94.0)	<0.001	76.3 (69.3-80.2)	88.7 (92.7-80.0)	<0.001
FPG (mmol/L)	5.3 (5.0-5.7)	6.1 (5.4-7.2)	<0.001	5.3 (5.0-5.5)	5.8 (5.2-7.8)	<0.001
2hPG (mmol/L)	6.3 (5.2-7.5)	9.3 (6.8-12.3)	<0.001	6.8 (5.9-7.9)	9.6 (7.8-12.6)	<0.001
FINS (mIU/L)	12.49 (9.24-17.75)	16.77 (12.87-24.63)	<0.001	15.54 (12.50-19.69)	25.05 (18.65-30.54)	<0.001
HbA1c (%)	5.7 (5.4-6.0)	6.0 (5.6-6.7)	<0.001	5.9 (5.5-6.2)	6.2 (5.7-7.2)	0.005
TC (mmol/L)	4.8 (4.3-5.3)	5.3 (4.7-5.9)	0.001	5.1 (4.5-5.5)	5.2 (4.4-5.9)	0.494
TG (mmol/L)	1.3 (0.9-1.6)	2.4 (2.0-3.6)	<0.001	1.1 (0.9-1.5)	2.4 (1.7-3.8)	<0.001
HDL (mmol/L)	1.3 (1.1-1.5)	1.1 (0.9-1.3)	<0.001	1.5 (1.3-1.8)	1.1 (1.0-1.4)	<0.001
LDL (mmol/L)	3.0 (2.6-3.5)	3.1 (2.7-3.8)	0.148	3.1 (2.6-3.6)	3.2 (2.6-3.6)	0.963
HOMA-IR	2.98 (2.23-4.46)	4.74 (3.69-6.72)	<0.001	3.79 (2.81-4.86)	6.83 (4.17-8.30)	<0.001
Current Smoking, n (%)	75(67.57)	51(58.62)	0.194	7(4.93)	1(2.56)	0.844
Alcohol Intake, n (%)	39(35.14)	41(47.13)	0.088	3(2.11)	1(2.56)	1.000
SFA (cm^2)	124.62±49.88	151.84±51.80	0.001	178.86±65.82	226.87±69.24	<0.001
VFA (cm^2)	84.40±45.85	116.39±44.40	<0.001	57.76±24.16	91.80±32.98	<0.001

WC (cm)	87.3±8.1	94.7±7.9	<0.001	80.3±8.6	89.0±7.9	<0.001
BMI (kg/m^2)	24.6±2.8	26.6±2.8	<0.001	23.9±3.0	27.1±3.4	<0.001
WHR	0.90±0.05	0.94±0.05	<0.001	0.85±0.06	0.90±0.05	<0.001
ABSI (m$^{7/6}$/kg$^{2/3}$)	0.0792±0.0033	0.0814±0.0034	<0.001	0.0770±0.0041	0.0784±0.0036	0.040
AVI (cm^2)	15.24 (13.48-17.03)	17.86 (16.31-20.10)	<0.001	13.10 (11.56-14.30)	15.51 (14.62-17.79)	<0.001
BAI (0.01m$^{-0.5}$)	25.84±3.01	27.33±2.68	<0.001	29.30±3.18	31.70±3.22	<0.001
BRI	3.65±0.95	4.49±0.98	<0.001	3.50±0.96	4.63±1.03	<0.001
CI (m$^{2/3}$/kg$^{1/2}$)	1.24±0.06	1.29±0.06	<0.001	1.20±0.07	1.25±0.06	<0.001
VAI	1.30 (0.94-1.84)	3.24 (2.17-4.63)	<0.001	1.43 (0.96-1.96)	4.30 (2.46-6.35)	<0.001

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, 2 hours after glucose-load plasma glucose; FINS, fasting plasma insulin; TC, total cholesterol; TG, triglycerides; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; SFA, subcutaneous fat area; VFA, visceral fat area; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

Data was presented in the form of mean±standard deviation, median (interquartile range) or counts (percentages), depending on its type. All adiposity and cardiometabolic risk factors between groups with and without MetS were compared using an independent *t*-test, Mann-Whitney rank sum test, Pearson's Chi-squared test, or Fisher's exact test according to the characteristics of the data.

Table 2. Baseline characteristics of healthy subjects who developed MetS or not at follow-up.

Characteristics	Male (n=111)			Female (n=142)		
	free-MetS	newly-MetS	*P*	free-MetS	newly-MetS	*P*
N (%)	69 (62.2)	42 (37.8)		108 (76.1)	34 (23.9)	
Age (yr)	49.0 (45.0-55.5)	50.5 (41.8-55.0)	0.549	47.0 (44.0-53.0)	48.5 (42.0-56.3)	0.754
SBP (mmHg)	122.0 (114.3-132.7)	125.0 (119.3-130.7)	0.239	113.3 (105.3-122.7)	120.0 (116.5-126.8)	0.003
DBP (mmHg)	80.0 (71.7-85.7)	80.0 (77.2-85.7)	0.314	74.7 (68.0-80.0)	79.0 (76.0-82.0)	< 0.001
FPG (mmol/L)	5.3 (4.9-5.6)	5.4 (5.1-5.9)	0.149	5.3 (5.0-5.5)	5.3 (5.0-5.6)	0.274
2hPG (mmol/L)	6.2 (5.3-7.5)	6.3 (5.1-8.4)	0.584	6.6 (5.8-7.6)	7.9 (6.9-9.5)	< 0.001
FINS (mIU/L)	12.18 (8.85-16.46)	12.60 (9.92-20.42)	0.341	15.32 (12.02-19.81)	16.15 (13.33-19.38)	0.374
HbA1c (%)	5.6 (5.4-5.8)	5.7 (5.4-6.2)	0.131	5.8 (5.5-6.1)	6.1 (5.6-6.3)	0.062
TC (mmol/L)	4.7 (4.3-5.3)	4.9 (4.3-5.5)	0.302	5.1 (4.5-5.5)	5.1 (4.6-5.9)	0.426
TG (mmol/L)	1.2 (0.9-1.6)	1.4 (1.1-1.7)	0.041	1.1 (0.8-1.5)	1.3 (1.0-1.7)	0.028
HDL (mmol/L)	1.3 (1.1-1.5)	1.2 (1.1-1.4)	0.075	1.6 (1.3-1.8)	1.5 (1.3-1.7)	0.029
LDL (mmol/L)	3.0±0.8	3.2±0.9	0.286	3.1±0.8	3.4±0.9	0.033
HOMA-IR	2.89 (2.20-3.92)	3.24 (2.25-4.91)	0.171	3.62 (2.75-4.78)	4.08 (3.13-5.07)	0.128
Current Smoking, n (%)	45 (65.22)	30 (71.43)	0.498	4 (3.70)	3 (8.82)	0.358
Alcohol Intake, n (%)	22 (31.88)	17 (40.48)	0.358	3 (2.78)	0 (0.00)	1.000
SFA (cm^2)	110.19±44.09	149.19±50.11	< 0.001	169.42±61.17	207.78±71.90	0.003
VFA (cm^2)	67.70±33.78	112.83±49.98	< 0.001	54.96±23.79	66.34±23.58	0.018
WC (cm)	84.5±7.5	91.9±6.9	< 0.001	78.9±8.3	84.7±8.1	< 0.001
BMI (kg/m^2)	23.6±2.6	26.2±2.5	< 0.001	23.4±2.9	25.4±2.8	0.001
WHR	0.88±0.05	0.92±0.05	< 0.001	0.84±0.06	0.87±0.05	0.003

ABSI ($m^{7/6}/kg^{2/3}$)	0.0788±0.0030	0.0799±0.0036	0.090	0.0767±0.0038	0.0779±0.0047	0.119
AVI (cm^2)	14.18(12.89-16.23)	16.21(15.13-18.57)	< 0.001	12.46(10.91-14.18)	13.95(13.31-15.89)	< 0.001
BAI ($0.01m^{-0.5}$)	25.38±2.53	26.60±3.58	0.058	28.98±2.99	30.31±3.59	0.033
BRI	3.35±0.85	4.41±0.90	< 0.001	3.34±0.90	4.02±1.00	< 0.001
CI ($m^{2/3}/kg^{1/2}$)	1.22±0.06	1.26±0.06	0.001	1.19±0.06	1.22±0.07	0.007
VAI	1.17(0.84-1.70)	1.52(1.19-2.09)	0.009	1.35(0.86-1.83)	1.68(1.39-2.25)	0.004

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, 2 hours after glucose-load plasma glucose; FINS, fasting plasma insulin; TC, total cholesterol; TG, triglycerides; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; SFA, subcutaneous fat area; VFA, visceral fat area; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

Data was presented in the form of mean±standard deviation, median (interquartile range) or counts (percentages), depending on its type. All adiposity and cardiometabolic risk factors between groups with and without MetS were compared using an independent *t*-test, Mann-Whitney rank sum test, Pearson's Chi-squared test, or Fisher's exact test according to the characteristics of the data.

Table 3. AUCs of anthropometric indices in diagnosing of MetS at baseline.

Indices	Male			Female		
	AUC	95%CI	*P*	AUC	95%CI	*P*
WC	0.79	(0.72-0.86)	<0.001	0.79	(0.71-0.87)	<0.001
BMI	0.73[a]	(0.65-0.80)	<0.001	0.75	(0.67-0.84)	<0.001
WHR	0.72[a]	(0.64-0.79)	<0.001	0.75	(0.67-0.83)	<0.001
ABSI	0.70[a]	(0.62-0.78)	<0.001	0.62[a]	(0.52-0.72)	0.031
AVI	0.79	(0.72-0.86)	<0.001	0.79	(0.71-0.87)	<0.001
BAI	0.67[a]	(0.59-0.75)	<0.001	0.69[a]	(0.59-0.79)	<0.001
BRI	0.76	(0.69-0.83)	<0.001	0.80	(0.71-0.88)	<0.001
CI	0.76	(0.68-0.83)	<0.001	0.73[a]	(0.64-0.82)	<0.001
VAI	0.85	(0.79-0.92)	<0.001	0.90[a]	(0.84-0.96)	<0.001

Abbreviations: WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, *P* is less than 0.05

Table 4. AUCs, optimal cutoff, sensitivity, specificity, positive and negative predictive value for the anthropometric indices in ROC analysis for predicting MetS.

Anthropometric Indices	AUC (95%CI)	*P*	Cut-off	Sensitivity	Specificity	Youden Index	PPV	NPV
Male								
WC	0.76 (0.67-0.84)	<0.001	84.0	0.95	0.54	0.49	0.56	0.95
BMI	0.77 (0.68-0.85)	<0.001	24.94	0.69	0.75	0.44	0.63	0.80
WHR	0.73 (0.64-0.81)	<0.001	0.89	0.76	0.64	0.40	0.56	0.81
ABSI	0.58[a] (0.49-0.68)	0.149	0.0822	0.29	0.88	0.17	0.60	0.67
AVI	0.76 (0.67-0.84)	<0.001	14.25	0.95	0.54	0.49	0.56	0.95
BAI	0.59[a] (0.49-0.68)	0.124	27.44	0.40	0.87	0.27	0.65	0.70
BRI	0.74 (0.65-0.82)	<0.001	3.47	0.81	0.58	0.39	0.54	0.83
CI	0.67[a] (0.58-0.76)	<0.001	1.21	0.83	0.45	0.28	0.48	0.81
VAI	0.65[a] (0.55-0.74)	0.005	1.06	0.83	0.48	0.31	0.49	0.82
Female								
WC	0.71 (0.64-0.79)	<0.001	80.0	0.82	0.60	0.42	0.39	0.91
BMI	0.71 (0.63-0.78)	<0.001	25.14	0.59	0.78	0.37	0.46	0.86
WHR	0.68 (0.59-0.75)	<0.001	0.81	0.91	0.37	0.28	0.31	0.93
ABSI	0.55[a] (0.47-0.64)	0.358	0.0799	0.32	0.81	0.13	0.35	0.79

AVI	0.72 (0.64-0.79)	<0.001	13.03	0.82	0.60	0.42	0.39	0.91
BAI	0.64 (0.56-0.72)	0.013	30.38	0.53	0.74	0.27	0.39	0.83
BRI	0.71 (0.63-0.79)	<0.001	3.58	0.71	0.66	0.37	0.40	0.88
CI	0.63 (0.54-0.71)	0.020	1.23	0.44	0.81	0.25	0.42	0.82
VAI	0.66 (0.58-0.74)	0.001	1.36	0.79	0.52	0.31	0.34	0.89

Abbreviations: AUC, area under curve; PPV, positive predictive value; NPV, negative predictive value; WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, P is less than 0.05

Table 5. Comparison of AUCs for anthropometric indices in predicting MetS components in males.

Component	Central obesity		High TG		Low HDL		High BP		High BG	
	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*
WC	0.79 (0.69-0.89)	<0.001	0.63 (0.47-0.78)	0.118	0.45 (0.31-0.59)	0.523	0.77 (0.66-0.88)	<0.001	0.57 (0.43-0.70)	0.348
BMI	0.78 (0.67-0.89)	<0.001	0.69 (0.55-0.84)	0.016	0.53 (0.39-0.68)	0.675	0.72 (0.60-0.84)	<0.001	0.58 (0.45-0.71)	0.263
WHR	0.71 (0.59-0.83)	0.002	0.61 (0.46-0.76)	0.185	0.41 (0.26-0.57)	0.286	0.75 (0.64-0.86)	<0.001	0.59 (0.46-0.72)	0.199
ABSI	0.50[a] (0.37-0.63)	0.996	0.47 (0.29-0.64)	0.665	0.37 (0.22-0.51)	0.104	0.72 (0.61-0.84)	<0.001	0.53 (0.38-0.68)	0.677
AVI	0.79 (0.69-0.89)	<0.001	0.62 (0.47-0.78)	0.123	0.45 (0.31-0.59)	0.555	0.77 (0.66-0.88)	<0.001	0.57 (0.43-0.70)	0.348
BAI	0.57[a] (0.42-0.71)	0.340	0.60 (0.43-0.77)	0.217	0.56 (0.40-0.71)	0.502	0.63[a] (0.51-0.75)	0.058	0.54 (0.40-0.68)	0.554
BRI	0.70[a] (0.58-0.82)	0.004	0.65 (0.50-0.80)	0.060	0.48 (0.34-0.61)	0.776	0.75 (0.64-0.86)	<0.001	0.58 (0.45-0.72)	0.226
CI	0.60[a]	0.139	0.54	0.604	0.39	0.181	0.76	<0.001	0.55	0.465

	(0.48-0.73)		(0.37-0.71)		(0.25-0.53)		(0.65-0.87)		(0.41-0.69)			
	0.58[a]		0.69		0.61		0.61[a]		0.56			
VAI		0.266		0.016		0.179		0.113		0.365		
	(0.45-0.70)		(0.57-0.82)		(0.45-0.77)		(0.48-0.74)		(0.43-0.70)			

Abbreviations: TG, triglycerides; HDL, high density lipoprotein cholesterol; BP, blood pressure; BG, blood glucose; AUC, area under curve; WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, P is less than 0.05

Table 6. Comparison of AUCs for anthropometric indices in predicting MetS components in females.

Component	Central obesity		High TG		Low HDL		High BP		High BG	
	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*
BMI	0.83 (0.75-0.92)	<0.001	0.56 (0.39-0.73)	0.563	0.64 (0.49-0.79)	0.145	0.68 (0.58-0.78)	<0.001	0.50[a] (0.35-0.65)	0.997
WC	0.82 (0.74-0.91)	<0.001	0.50 (0.32-0.67)	0.955	0.64 (0.51-0.77)	0.142	0.70 (0.61-0.80)	<0.001	0.54 (0.40-0.68)	0.584
WHR	0.65[a] (0.54-0.75)	0.021	0.39 (0.24-0.54)	0.257	0.64 (0.51-0.77)	0.145	0.60[a] (0.50-0.70)	0.066	0.62 (0.49-0.76)	0.106
ABSI	0.47[a] (0.36-0.59)	0.681	0.39 (0.21-0.57)	0.253	0.53 (0.35-0.71)	0.736	0.59[a] (0.49-0.69)	0.082	0.61 (0.48-0.74)	0.157
AVI	0.84 (0.75-0.92)	<0.001	0.50 (0.32-0.68)	0.981	0.64 (0.50-0.77)	0.153	0.71 (0.62-0.80)	<0.001	0.54 (0.40-0.69)	0.590
BAI	0.70[a] (0.59-0.82)	<0.001	0.58 (0.38-0.78)	0.429	0.58 (0.39-0.77)	0.413	0.61 (0.51-0.71)	0.036	0.50 (0.34-0.66)	0.990
BRI	0.77 (0.68-0.87)	<0.001	0.49 (0.31-0.67)	0.918	0.64 (0.50-0.79)	0.142	0.67[a] (0.57-0.76)	0.002	0.54 (0.39-0.69)	0.609
CI	0.58[a]	0.220	0.44	0.550	0.61	0.271	0.63[a]	0.013	0.59	0.222

	(0.47-0.69)		(0.26-0.63)		(0.44-0.77)		(0.53-0.73)		(0.46-0.73)			
	0.62[a]		0.59		0.56		0.52[a]		0.59			
VAI		0.060		0.328		0.524		0.739		0.261		
	(0.51-0.73)		(0.41-0.78)		(0.39-0.73)		(0.41-0.62)		(0.44-0.73)			

Abbreviations: TG, triglycerides; HDL, high density lipoprotein cholesterol; BP, blood pressure; BG, blood glucose; AUC, area under curve; WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, P is less than 0.05

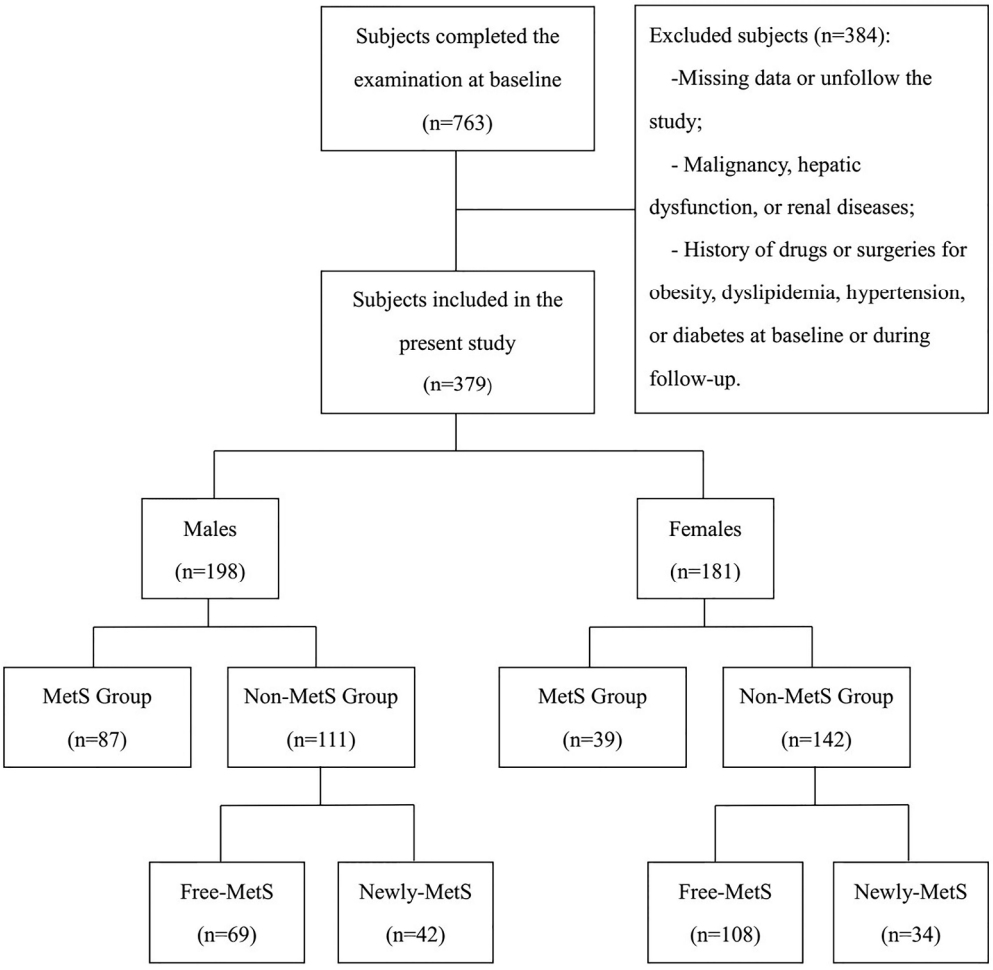


Figure 1. Flow graph of individual recruitment.

313x304mm (300 x 300 DPI)

Supplement 1. Morbidities of MetS and its components during follow-up.

	Male			Female			*P*
	Free, n	Newly, n	Morbidity, %	Free, n	Newly, n	Morbidity, %	
MetS	69	42	37.8	108	34	23.9	0.017
Central obesity	57	31	35.2	86	30	25.9	0.148
High TG	80	19	19.2	119	11	8.5	0.017
Low HDL	148	16	9.8	119	11	8.5	0.703
High BP	28	59	67.8	51	82	61.7	0.352
High BG	76	25	24.8	102	17	14.3	0.049

TG, triglyceride; HDL, high density lipoprotein cholesterol; BP, blood pressure; BG, blood glycose.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Check
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 4-5
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4-5
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6-10
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-7
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7-8
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8
Bias	9	Describe any efforts to address potential sources of bias	9-10
Study size	10	Explain how the study size was arrived at	6-7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	10
		(*c*) Explain how missing data were addressed	7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	7
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	11
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	10
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	10
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-13
		(*b*) Report category boundaries when continuous variables were categorized	11-13
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-13
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	13-16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-16
Generalisability	21	Discuss the generalisability (external validity) of the study results	13-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Comparison of Anthropometric Indices for Predicting the Risk of Metabolic Syndrome and Its Components in Chinese Adults: A Prospective, Longitudinal Study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-016062.R2
Article Type:	Research
Date Submitted by the Author:	24-Jul-2017
Complete List of Authors:	Wang, Haoyu; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Liu, Aihua; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Zhao, Tong; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Gong, Xun; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Pang, Tianxiao; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Zhou, Yingying; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Xiao, Yue; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Yan, Yumeng; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Fan, Chenling; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Teng, Weiping; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University

	Lai, Yaxin; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University Shan, Zhongyan; Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University
Primary Subject Heading:	Diabetes and endocrinology
Secondary Subject Heading:	Diagnostics, Epidemiology
Keywords:	metabolic syndrome, waist circumference, abdominal volume index, visceral adiposity index, anthropometric index, body mass index

Comparison of Anthropometric Indices for Predicting the Risk of Metabolic Syndrome and Its Components in Chinese Adults: A Prospective, Longitudinal Study

Author list and affiliations:

Haoyu Wang[1], Aihua Liu[1], Tong Zhao[1], Xun Gong[1], Tianxiao Pang[1], Yingying Zhou[1], Yue Xiao[1], Yumeng Yan[1], Chenling Fan[1], Weiping Teng[1], Yaxin Lai[1,*], Zhongyan Shan[1,*]

[1]Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases, The First Affiliated Hospital of China Medical University, China Medical University, No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China.

E-mail Addresses:

Haoyu Wang: why_endocrinology@foxmail.com

Aihua Liu: liuaihuacmu@163.com

Tong Zhao: cmu_zhaotong@163.com

Xun Gong: cmu_gx@vip.163.com

Tianxiao Pang: ptx90@163.com

Yingying Zhou: 18937856536@163.com

Yue Xiao: xy5856@126.com

Yumeng Yan: cherylyanyumeng@hotmail.com

Chenling Fan: fanchenling@126.com

Weiping Teng: twp@vip.163.com

Yaxin Lai: laiyaxin811005@126.com

Shan Zhongyan: shanzhongyan@medmail.com.cn

Corresponding author and person to whom reprint requests should be addressed:

Yaxin Lai, M.D., Ph.D.

Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases

The First Affiliated Hospital of China Medical University

No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China

Tel: +86-24-83283294

Fax: +86-24-83283294

E-mail: laiyaxin811005@126.com

Zhongyan Shan, M.D., Ph.D.

Department of Endocrinology and Metabolism, Institute of Endocrinology, Liaoning Provincial Key Laboratory of Endocrine Diseases

The First Affiliated Hospital of China Medical University

No. 155 Nanjing North Street, Shenyang, Liaoning 110001, China

Tel: +86-24-83283294

Fax: +86-24-83283294

E-mail: shanzhongyan@medmail.com.cn

Running title: Anthropometric indices and Incident MetS

Authors' statement: The authors hereby confirm that neither the manuscript nor any part of it has been published or is being considered for publication elsewhere. We acknowledge that all authors participated sufficiently in the work and take public responsibility for its content.

Funding:

1. the Chinese National Natural Science Foundation (Grant: 81300645)
2. the National Science and Technology Support Program (Grant: 2009BAI80B00)

Disclosure Summary: The authors have no potential conflict of interest to declare.

Data Sharing Statement: No additional data are available.

Word count: 299 (Abstract); 3332 (excluding abstract, figure captions, and references)

Figures & Tables: 7

Abstract

OBJECTIVES: Our study aimed to distinguish the ability of anthropometric indices to assess the risk of metabolic syndrome (MetS).

DESIGN: Prospective cohort study.

SETTING: Shenyang, China.

PARTICIPANTS: A total of 379 residents aged between 40 and 65 were enrolled. 253 of them were free of MetS, and had been followed up for 4.5 years.

METHODS: At baseline, all the participants underwent a thorough medical examination. A variety of anthropometric parameters were measured and calculated, including waist circumference (WC), body mass index (BMI), a body shape index (ABSI), abdominal volume index (AVI), body adiposity index (BAI), body roundness index (BRI), conicity index (CI), waist-to-hip ratio (WHR) and visceral adiposity index (VAI). After 4.5-year follow-up, we re-examined whether participants were suffering from MetS. A receiver operating characteristic (ROC) curve was applied to examine the potential of the above indices to identify the status and risk of MetS.

OUTCOMES: Occurrence of MetS.

RESULTS: At baseline, 33.2% participants suffered from MetS. All of the anthropometric indices showed clinical significance, and VAI was superior to the other indices as it was found to have the largest area under the ROC curve. After a 4.5-year follow-up, 37.8% of males and 23.9% of females developed MetS. ROC curve analysis suggested that baseline BMI was the strongest predictor of MetS for males (0.77[0.68-0.85]), and AVI was the strongest for females(0.72[0.64-0.79]). However, no significant difference was observed between WC and both indices. In contrast, the baseline ABSI did not predict MetS in both genders.

CONCLUSIONS: The present study indicated that these different indices derived from anthropometric parameters have different discriminatory abilities for MetS. Although WC did not have the largest area under the ROC curve for diagnosing and predicting MetS, it may remain a better index of MetS status and risk because of its simplicity and wide utilization.

Strengths and limitations of this study:

1. This is the first study to systematically report different abilities of anthropometric indices in diagnosing or predicting metabolic syndrome.
2. The prospective design is a strength of this study. Some previous reports have been limited by their design (cross-sectional).
3. The participants in the present study were middle-aged and elderly in northeast China, which limits the applicability of the conclusions to other populations.
4. This study defined metabolic syndrome using IDF 2009 criteria. Therefore, further studies are needed to determine whether the results are consistent under different criteria.

Keywords

Metabolic syndrome; Waist circumference; Abdominal volume index; Visceral adiposity index; Anthropometric index; Body mass index.

Background

Metabolic syndrome (MetS), as a cluster of risk factors for cardiovascular morbidity and mortality[1], has become a major health concern in both developing and developed countries. It has been reported that more than a third of adults suffer from MetS by the National Health and Nutrition Examination Survey[2]. A growing body of evidence supports the hypothesis that abdominal visceral fat plays a role in the development of MetS[3-6]. Hence, it is reasonable that central obesity is defined as a predictor of MetS.

Body mass index (BMI) is widely used in assessing the obesity status[7], but it cannot describe the distribution of abdominal adipose tissue. Therefore, additional anthropometric indices are required to assess abdominal adipose accumulation. Elevated waist circumference (WC) and waist-to-hip ratio (WHR) were reported to be strongly associated with central obesity and MetS[8]. Moreover, Krakauer's and Tomas' groups proposed a body shape index (ABSI) and body roundness index (BRI), respectively, to estimate body fat distributions. However, neither ABSI nor BRI have been shown to be more closely correlated with cardiovascular disease than BMI or WC[9]. Recently, Amato *et al*., reported an alternative anthropometric index, i.e., visceral adiposity index (VAI), that could be considered as an indicator for cardiometabolic risk[10]. However, its advantages in predicting metabolic diseases over other indices are still unclear. The abdominal volume index (AVI) is another anthropometric tool for estimating overall volume. It is thought to have an extremely close relationship with the dysfunction of glucose metabolism[11]. Additionally, other indices have often been used in epidemiologic research, such as the conicity index (CI) and body adiposity index (BAI)[12 13]. However, a comprehensive consensus has not been reached about the best indices for evaluating the status and risk of MetS.

Accumulating evidence has suggested that different anthropometric indices differ in determining MetS, but they are all cross-sectional. Thus, our study compared the ability to predict MetS of WC with other anthropometric indices including BMI, ABSI, AVI, BAI, BRI, CI, WHR and VAI to explicate the prospective differences in various anthropometric indices.

Methods

Study Population

To evaluate the effectiveness of anthropometric indices in predicting MetS, a community-based prospective cohort was established in 2010 in urban Shenyang, Liaoning Province, China. All 763 residents of the community aged between 40 and 65 were recruited. Exclusion criteria were as follows: (1) participants with a history of drugs or surgeries for obesity, dyslipidaemia, hypertension, or diabetes at baseline or during follow-up; (2) participants with malignancy, hepatic dysfunction, or renal diseases. According to the above criteria, 379 participants were ultimately selected for this study. At baseline, 253 of them (111 males and 142 females) did not suffer from MetS, and underwent a 4.5-year follow-up (**Figure 1**).

This study was approved by the Ethics Committee of the First Affiliated Hospital of China Medical University, and all participants provided signed informed consent before enrolment in this study.

Data Measurement and Collection

At baseline and at the endpoint, all participants underwent comprehensive interviews and health examinations by trained staff. A questionnaire, including demographic characteristics, personal

medical history, and information related to the diagnosis and treatment of MetS, was completed for each participant. Based on the previous standardized protocol[14], body weight, height, waist circumference, hip circumference (HC), systolic blood pressure (SBP), and diastolic blood pressure (DBP) were measured. Participants were given a standard 75-g oral glucose tolerance test (OGTT). Venous blood samples were drawn to determine fasting plasma glucose (FPG), plasma glucose for 2 hours after a glucose load (2hPG), fasting plasma insulin (FINS), total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL), and low-density lipoprotein cholesterol (LDL) according to standard methods[14 15].

At baseline, all participants had magnetic resonance imaging (MRI) scans performed at the abdominal level between the 4th and 5th lumbar vertebrae in the prone position (FOV 42 cm×42 cm, thickness 1 cm, 6 layers, GE, USA). The subcutaneous fat area (SFA) and visceral fat area (VFA) were calculated using SLICE-O-MATIC version 4.2 software (Tomovision) by two separate technicians.

Metabolic Syndrome Definition

The diagnosis of MetS was based on the International Diabetes Federation criteria[16] in 2009 and Chinese-specific abdominal obesity standard[8], which means that the individual with any three or more of the five following components were considered to have MetS: (1) abdominal obesity (WC≥ 90 cm for males, 85 cm for females); (2) elevated TG (TG≥1.70 mmol/L); (3) low HDL (HDL <1.0 mmol/L for males, <1.3 for females); (4) high blood pressure (SBP≥130 mmHg, DBP≥85 mmHg, or a history of hypertension); and (5) elevated plasma glucose (FPG≥5.6 mmol/L, or a diagnosis of T2DM).

Calculations

The homeostatic model assessment index for insulin resistance (HOMA-IR) was evaluated using the following formula:

HOMA-IR = FPG (mmol/L) × FINS (mIU/L)/22.5

The anthropometric indices, such as BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI were calculated using the following formulas[10 17-20]:

BMI = Weight (kg)/ Height^2 (m);

WHR = WC (cm)/ HC (cm);

ABSI = WC (m)/ [BMI$^{2/3}$ (kg/m^2) × Height$^{1/2}$ (m)];

AVI = [2×WC^2 (cm)+0.7×(WC-HC)^2 (cm)]/1000;

BAI = [HC (m)/Height$^{2/3}$ (m)]-18;

BRI = 364.2-365.5× [1-π^{-2}×WC^2 (m)×Height^{-2} (m)]$^{1/2}$;

CI = 0.109^{-1}×WC (m)× [Weight (kg)/Height (m)]$^{-1/2}$;

VAI_{male} = [WC (cm)/39.68-1.88×BMI (kg/m^2)] × [TG (mmol/L)/1.03] × [1.31/HDL (mmol/L)];

VAI_{female} = [WC (cm)/36.58-1.89×BMI (kg/m^2)] × [TG (mmol/L)/0.81] × [1.52/HDL (mmol/L)];

Statistical Analyses

Based on the diagnosis of MetS, the participants were assigned to the MetS or non-MetS group at baseline. During follow-up, participants in the non-MetS group were further divided into the newly-MetS group and free-MetS group according to whether they developed MetS.

The data distribution was assessed using the Kolmogorov-Smirnov test. The variables were displayed as the mean±standard deviation, median (interquartile range) or count (percentage)

according to their types. Univariate analyses were conducted to estimate the relative factors of MetS and its components using a *t*-test, Mann-Whitney rank sum test, Pearson's Chi-squared test, or Fisher's exact test depending on the characteristics of the data. The area under receiver operating characteristic (ROC) curves was calculated to evaluate the abilities of the anthropometric indices to identify MetS. New cut-off points were suggested by Youden's Index (sensitivity+specificity-1). The ability of each anthropometric index to predict MetS was shown as areas under the ROC curves and the confidence intervals. DeLong, Delong, and Clarke-Pearson's nonparametric approach was used to compare the areas under the ROC curves (AUCs)[21]. Statistical analyses were performed using SPSS (version 23.0, IBM Corp., USA). MedCalc (version 16.2, MedCalc Software, Belgium) was used to analyse the ROC curves. Statistical significance was defined as $P < 0.05$ for all analyses.

Results

Baseline characteristics of the participants

According to the criteria mentioned above, 379 residents (198 males and 181 females) were included in the present study. 253 of them were free of MetS, and received follow-up. According to the criteria mentioned above, 198 males and 181 females were included in the present study. At baseline, 87 (43.9%) males and 39 (21.5%) females were diagnosed as having MetS. The median age of study participants was 49.5 (45.0-55.0) years for males and 47.0 (44.0-54.0) years for females. Compared with the non-MetS group, participants with MetS had significantly higher levels of SBP, DBP, FPG, 2hPG, FINS, HbA1c, TG, LDL, HOMA-IR, SFA, and VFA, but lower levels of HDL. TC was significantly increased in males with MetS, while no significant difference was observed in females between MetS and non-MetS. Furthermore, all of the nine anthropometric indices, including WC,

BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI, of the MetS group were elevated significantly in both males and females (**Table 1**).

In the non-MetS group, 42 (37.8%) males and 34 (23.9%) females developed MetS after the 4.5-year follow-up. Compared with the healthy controls, TG, SFA, and VFA were significantly elevated in the newly-MetS group. Furthermore, females in the new MetS group had higher levels of SBP, DBP, 2hPG, and LDL but lower levels of HDL at baseline. For anthropometric indices, WC, BMI, WHR, AVI, BRI, CI, and VAI of the newly-MetS group were higher in both males and females. Baseline BAI was increased in the newly-MetS group for females, while no significant difference was observed between the free-MetS group and newly-MetS group in males. Additionally, ABSI did not show a significant difference between the free-MetS and newly-MetS groups in both males and females (**Table 2**).

Comparison of the anthropometric indices for diagnosing MetS at baseline

At baseline, the AUCs of all the anthropometric indices were larger than 0.5 (P<0.05), suggesting their diagnostic significance for MetS (**Table 3**). Our results showed that the VAI had the largest AUC for both genders (0.85 [0.79-0.92] for males and 0.90 [0.84-0.96] for females). The BAI (0.67 [0.59-0.75]) and ABSI (0.62 [0.52-0.72]) showed the lowest AUCs for males and females, respectively. In males, AVI, BRI, CI, and VAI had approximately the same AUCs as WC for diagnosing MetS (all P>0.05 vs. WC). However, the AUCs of BMI, WHR, ABSI, and BAI were significantly lower compared with WC for males (all P<0.05 vs. WC). In females, the AUC of VAI was significantly larger than WC, while the AUCs of ABSI, BAI, and CI were significantly lower (all P<0.05 vs. WC). The other four anthropometric indices showed no significant differences with WC

in diagnosing MetS for females (all P>0.05 vs. WC).

Comparison of the anthropometric indices for predicting MetS during follow-up

In general, the AUCs varied from 0.58 (0.49-0.68) for ABSI to 0.77 (0.68-0.85) for BMI in males and from 0.55 (0.47-0.64) for ABSI to 0.72 (0.64-0.79) for AVI in females. The AUC of ABSI was the lowest and did not differ from 0.5 in both males and females (P>0.05). Moreover, the AUC of BAI was significantly larger than 0.5 in males, while no difference from 0.5 was observed in females. All the AUCs of the other indices were greater than 0.5 (P<0.05), suggesting their clinical predictive significance for MetS. In males, BMI had the largest AUC but did not differ significantly from WC. WHR, AVI, and BRI showed no significant difference with WC. Furthermore, ABSI, BAI, CI and VAI had significantly lower AUCs than WC. In females, no significant difference was observed between WC and BMI, WHR, AVI, BAI, BRI, CI, or VAI. Moreover, ABSI had a significantly lower AUC than WC.

Other details of all the anthropometric indices such as cut-off, sensitivity, specificity, Youden index, positive predictive value (PPV), and negative predictive value (NPV) were also reported in this study (**Table 4**).

AUCs of the anthropometric indices for predicting MetS components during follow-up

Compared with females, the morbidities of MetS, high TG and high blood glucose (BG) in males were elevated (37.8% vs. 23.9%, 19.2% vs. 8.5%, and 24.8% vs. 14.3%, respectively) after a 4.5-year follow-up. Morbidities of the other two MetS components showed no differences between males and females (**Table S1**). Furthermore, we made comparisons of all indices in predicting MetS

components (**Table 5** and **Table 6**). First, the AUCs of BMI, WHR, AVI, and BRI had predictive significances for central obesity in males, while ABSI, BAI, CI, and VAI did not. However, in females, the AUCs of ABSI, CI and VAI were not significantly larger than 0.5. In both genders, AVI had the largest AUC for incident central obesity, but did not differ significantly from WC. Second, BMI and VAI showed significances for predicting high TG in males. However, no significantly predictive value was observed in the remaining indicators for males or females. Moreover, the AUCs of all the indices were small for predicting low HDL and high BG, and none were significantly over 0.5. Therefore, none of the indices could discriminate among both males and females with low HDL or high BG. Lastly, either BAI or VAI had an AUC less than 0.5 for high blood pressure (BP) in males, and the AUCs of WHR, ABSI, and VAI were significantly less than 0.5 in females. Furthermore, WC and AVI had the largest AUCs for high BP in males, and no difference was observed between these two indices. In females, the AUC of AVI was the largest for high BP in females but did not differ significantly from WC.

Discussion

There is abundant evidence that abdominal obesity is one of the most important risk factors of metabolic diseases such as diabetes mellitus and dyslipidaemia[8 22]. The abdominal visceral fat area measured by MRI is still considered the best index to evaluate the extent of abdominal obesity[23]. Our results showed that incident MetS patients had a higher baseline visceral fat area compared with non-MetS patients, confirming that abdominal visceral fat can be an excellent indicator for MetS. However, considering the cost, safety and many other factors, it is not realistic to carry out abdominal fat screening with MRI in the clinic. Therefore, accumulating studies have been

conducted to find a more simple and non-invasive approach to describe abdominal obesity. For a long time, a variety of investigations have evaluated the ability of indices derived from several anthropometric parameters in determining MetS. Most of these studies were cross-sectional. In this study, we compared nine obesity indices, including WC, BMI, WHR, ABSI, AVI, BAI, BRI, CI, and VAI, in assessing the incident risk of MetS using a 4.5-year prospective analysis. Our study indicated that some novel anthropometric indices may be insufficient for evaluating the incident risk of MetS.

At baseline, all the indices showed significant roles in diagnosing MetS, and VAI had the highest AUC value in both males and females. For calculation of the VAI value involving WC, BMI, TG, and HDL, it is suggested that VAI might provide a broader evaluation of metabolic risk related to visceral fat dysfunction. Previous studies have reported that VAI has significant advantages over WC for determining cardiometabolic risk[10 24 25], even though a study in young adults indicated that VAI did not provide better efficiency of visceral adiposity assessment than WC and BMI[26]. In our study, VAI was the best surrogate marker of MetS, especially considering the significant, excessive AUC in females.

Furthermore, we compared the AUCs of all the anthropometric indices for predicting MetS and its components. In general, ABSI did not show a predictive value for MetS in both genders. Previously, ABSI was reported to be a weak indicator for MetS in a few cross-sectional studies[27 28]. This finding was confirmed by our prospective evidence. Furthermore, what was different from the cross-sectional results is that the AUC of VAI was less than WC and even had a significant difference in males. In 2014, Chen *et al.* reported that the predictive performance of VAI is similar to WC for all-cause mortality[25], suggesting that VAI as a predictor of MetS is not superior to WC. Additionally, BMI and AVI showed the strongest ability in the prediction of MetS for males and females,

respectively. However, neither BMI nor AVI had any significant difference from WC. In particular, considering the simplicity and widespread utilization of WC, it appeared to be a more useful predictor of MetS in clinical practice.

Our study also proposed optimal cut-off points for these anthropometric indices. An obvious difference between two genders was observed in WC, WHR, ABSI, BAI and VAI, suggesting that gender-specific reference values should be used in clinical practice. Notably, the present results showed that the optimal cut-off point for WC are considerably different from the cut-off point according to the guidelines on the prevention and treatment of metabolic dysfunction in Chinese adults[29]. Therefore, it may be optimal that the decreased WC cut-off is used in the clinical setting to select Chinese adults at high risk of incident MetS. Additionally, all the PPVs of indices were less than NPVs, suggesting that the indices covered in this article were suitable for excluding the individuals with high risk for MetS from a non-MetS population.

Our study further found that the indices show different discriminatory power for different MetS components. AVI had the largest AUC for central obesity in both males and females. On the other hand, the VAI of males had the highest AUC value for high TG and high BP. In females, the AUC of AVI for high BP was larger than the other indices, while no indicator showed significance in predicting high TG. Interestingly, the CI played only a predictive role for new-onset high BP in both genders, suggesting its worse predictive ability for MetS components. Some scholars have suggested that this is probably because weight dilutes the influence of height according to its formula[30]. Additionally, all the indices failed in forecasting incident low HDL and high BG, in contrast to other studies[9 10 24 31]. One possible explanation is that only a few individuals developed low HDL and high BG, and the small sample size may impact on the reliability of results. In summary, the results above

suggest that the current indicators of anthropometric indices cannot provide a comprehensive prediction of metabolic risk factors. Accordingly, further study to clarify the association of anthropometric parameters with MetS components is necessary.

Several limitations of the present study should be considered. First, this study was limited to middle-aged and elderly participants in northeast China. Hence, the applicability of these results may be limited for other populations. Second, only the baseline anthropometric parameters were analysed in the study. For our study aims to assess the predictive abilities of anthropometric indices at baseline in a prospective cohort, it is likely that the anthropometric changes during the follow-up period had little effect on the current results. Finally, IDF 2009 criteria were used in the present study to define metabolic syndrome. Therefore, further studies are needed to determine whether the results are consistent under different criteria.

Conclusions

In conclusion, VAI is the best index for the diagnosis of MetS. Moreover, BMI and AVI are superior to the other anthropometric indices for predicting MetS in males and females, respectively, but no obvious differences were observed between them and WC. Hence, considering the simplicity and wide utilization, WC remains the more practical discriminator for MetS.

Abbreviations

MetS: metabolic syndrome; WC: waist circumference; BMI: body mass index; ABSI: a body shape index; AVI: abdominal volume index; BAI: body adiposity index; BRI, body roundness index; CI, conicity index; WHR: waist-to-hip ratio; VAI: visceral adiposity index; ROC: Receiver operating

characteristic; AUC: areas under the ROC curve; HC: hip circumference; SBP: systolic blood pressure; DBP: diastolic blood pressure; OGTT: 75 g oral glucose tolerance test; FPG: fasting plasma glucose; 2hPG: plasma glucose for 2 hours after a glucose load; FINS: fasting plasma insulin; TC: total cholesterol; TG: triglycerides; HDL: high-density lipoprotein cholesterol; LDL: low-density lipoprotein cholesterol; MRI: magnetic resonance imaging; SFA: subcutaneous fat area; VFA: visceral fat area; HOMA-IR: the homeostatic model assessment index for insulin resistance; PPV: positive predictive value; NPV: negative predictive value; BG: blood glucose; BP: blood pressure.

Declarations

Acknowledgements

We thank the participants and staff at the Institute of Endocrinology of the First Affiliated Hospital of China Medical University for their involvement in this study.

Contributors

Haoyu Wang was the primary investigator, and reviewed the literatures, performed the follow-up project, collected data, analysed results, and produced the first draft of manuscript; Aihua Liu reviewed the literature, interpreted the data, and edited the manuscript; Tong Zhao, Xun Gong, Tianxiaopang, Yingying Zhou, Yue Xiao, Yumeng Yan, and Chenlin Fan participated in this follow-up project, collected and interpreted data; Weiping Teng supervised the statistical analyses, and edited the manuscript; Yaxin Lai and Zhongyan Shan supervised the statistical analyses, and produced the final version of the manuscript. All authors read and approved the final manuscript.

Funding

This work was supported by the Chinese National Natural Science Foundation (Grant: 81300645) and the National Science and Technology Support Program (Grant: 2009BAI80B00). The funders had no roles in the study design, data collection or analysis, or the presentation or publication of the results.

Competing interests

The authors declare that they have no competing interests.

Ethics approval

This study was approved by the Ethics Committee of the First Affiliated Hospital of China Medical University. Informed consent was obtained from all individual participants included in the study.

References

1. Isomaa B, Almgren P, Tuomi T, et al. Cardiovascular morbidity and mortality associated with the metabolic syndrome. *Diabetes care* 2001;24(4):683-9. doi: 10.2337/diacare.24.4.683
2. Mozumdar A, Liguori G. Persistent increase of prevalence of metabolic syndrome among U.S. adults: NHANES III to NHANES 1999-2006. *Diabetes care* 2011;34(1):216-9. doi: 10.2337/dc10-0879
3. Hwang YC, Hayashi T, Fujimoto WY, et al. Visceral abdominal fat accumulation predicts the conversion of metabolically healthy obese subjects to an unhealthy phenotype. *International journal of obesity* 2015;39(9):1365-70. doi: 10.1038/ijo.2015.75
4. Lim KI, Yang SJ, Kim TN, et al. The association between the ratio of visceral fat to thigh muscle area and metabolic syndrome: the Korean Sarcopenic Obesity Study (KSOS). *Clinical endocrinology* 2010;73(5):588-94. doi: 10.1111/j.1365-2265.2010.03841.x
5. Rothney MP, Catapano AL, Xia J, et al. Abdominal visceral fat measurement using dual-energy X-ray: association with cardiometabolic risk factors. *Obesity* 2013;21(9):1798-802. doi: 10.1002/oby.20223
6. Lee JJ, Pedley A, Hoffmann U, et al. Association of Changes in Abdominal Fat Quantity and Quality With Incident Cardiovascular Disease Risk Factors. *Journal of the American College of Cardiology* 2016;68(14):1509-21. doi: 10.1016/j.jacc.2016.06.067
7. Han C, Li C, Mao J, et al. High Body Mass Index Is an Indicator of Maternal Hypothyroidism, Hypothyroxinemia, and

Thyroid-Peroxidase Antibody Positivity during Early Pregnancy. *Biomed Res Int* 2015;2015:351831. doi: 10.1155/2015/351831

8. Bao Y, Lu J, Wang C, et al. Optimal waist circumference cutoffs for abdominal obesity in Chinese. *Atherosclerosis* 2008;201(2):378-84. doi: 10.1016/j.atherosclerosis.2008.03.001
9. Chang Y, Guo X, Chen Y, et al. A body shape index and body roundness index: two new body indices to identify diabetes mellitus among rural populations in northeast China. *BMC public health* 2015;15:794. doi: 10.1186/s12889-015-2150-2
10. Amato MC, Giordano C, Galia M, et al. Visceral Adiposity Index: a reliable indicator of visceral fat function associated with cardiometabolic risk. *Diabetes care* 2010;33(4):920-2. doi: 10.2337/dc09-1825
11. Guerrero-Romero F, Rodriguez-Moran M. Abdominal volume index. An anthropometry-based index for estimation of obesity is strongly related to impaired glucose tolerance and type 2 diabetes mellitus. *Archives of Medical Research* 2003;34(5):428-32. doi: 10.1016/S0188-4409(03)00073-0
12. Bergman RN, Stefanovski D, Buchanan TA, et al. A better index of body adiposity. *Obesity* 2011;19(5):1083-9. doi: 10.1038/oby.2011.38
13. Shidfar F, Alborzi F, Salehi M, et al. Association of waist circumference, body mass index and conicity index with cardiovascular risk factors in postmenopausal women. *Cardiovascular journal of Africa* 2012;23(8):442-5. doi: 10.5830/CVJA-2012-038
14. Wang H, Lai Y, Han C, et al. The Effects of Serum ANGPTL8/betatrophin on the Risk of Developing the Metabolic Syndrome - A Prospective Study. *Scientific reports* 2016;6:28431. doi: 10.1038/srep28431
15. Han C, Xia X, Liu A, et al. Circulating Betatrophin Is Increased in Patients with Overt and Subclinical Hypothyroidism. *Biomed Res Int* 2016;2016:5090852. doi: 10.1155/2016/5090852
16. Alberti KG, Eckel RH, Grundy SM, et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. *Circulation* 2009;120(16):1640-5. doi: 10.1161/CIRCULATIONAHA.109.192644
17. Agirbasli M, Agaoglu NB, Ergonul O, et al. Comparison of anthropometric indices in predicting metabolic syndrome components in children. *Metabolic syndrome and related disorders* 2011;9(6):453-9. doi: 10.1089/met.2011.0018
18. Zhang ZQ, Deng J, He LP, et al. Comparison of various anthropometric and body fat indices in identifying cardiometabolic disturbances in Chinese men and women. *PloS one* 2013;8(8):e70893. doi: 10.1371/journal.pone.0070893
19. Kang SH, Cho KH, Park JW, et al. Comparison of waist to height ratio and body indices for prediction of metabolic disturbances in the Korean population: the Korean National Health and Nutrition Examination Survey 2008-2011. *BMC endocrine disorders* 2015;15:79. doi: 10.1186/s12902-015-0075-5
20. Tripolino C, Irace C, Carallo C, et al. Body fat and blood rheology: Evaluation of the association between different adiposity indices and blood viscosity. *Clinical haemorheology and microcirculation* 2017;65(3):241-48. doi: 10.3233/CH-16172
21. Delong E, Delong D, Clarke-Pearson D. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988;44(3):837-45.
22. Wang T, Ma X, Peng D, et al. Effects of Obesity Related Genetic Variations on Visceral and Subcutaneous Fat Distribution in a Chinese Population. *Scientific reports* 2016;6:20691. doi: 10.1038/srep20691
23. Hou X, Lu J, Weng J, et al. Impact of waist circumference and body mass index on risk of cardiometabolic disorder and cardiovascular disease in Chinese adults: a national diabetes and metabolic disorders survey. *PloS one*

2013;8(3):e57319. doi: 10.1371/journal.pone.0057319
24. Wang Y, He S, He J, et al. Predictive value of visceral adiposity index for type 2 diabetes mellitus: A 15-year prospective cohort study. *Herz* 2015;40 Suppl 3:277-81. doi: 10.1007/s00059-014-4175-1
25. Chen HY, Chiu YL, Chuang YF, et al. Visceral adiposity index and risks of cardiovascular events and mortality in prevalent haemodialysis patients. *Cardiovascular diabetology* 2014;13:136. doi: 10.1186/s12933-014-0136-5
26. Borruel S, Moulto JF, Alpanes M, et al. Surrogate markers of visceral adiposity in young adults: waist circumference and body mass index are more accurate than waist hip ratio, model of adipose distribution and visceral adiposity index. *PloS one* 2014;9(12):e114112. doi: 10.1371/journal.pone.0114112
27. Behboudi-Gandevani S, Ramezani Tehrani F, Cheraghi L, et al. Could "a body shape index" and "waist to height ratio" predict insulin resistance and metabolic syndrome in polycystic ovary syndrome? *European journal of obstetrics, gynaecology, and reproductive biology* 2016;205:110-4. doi: 10.1016/j.ejogrb.2016.08.011
28. Haghighatdoost F, Sarrafzadegan N, Mohammadifard N, et al. Assessing body shape index as a risk predictor for cardiovascular diseases and metabolic syndrome among Iranian adults. *Nutrition* 2014;30(6):636-44. doi: 10.1016/j.nut.2013.10.021
29. Zhu J. Chinese guidelines on prevention and treatment of dyslipidaemia in adults. *Zhonghua Xin Xue Guan Bing Za Zhi* 2007;35(5):390-419.
30. Motamed N, Sohrabi M, Poustchi H, et al. The six obesity indices, which one is more compatible with metabolic syndrome? A population based study. *Diabetes & metabolic syndrome* 2016 doi: 10.1016/j.dsx.2016.08.024
31. Alvim Rde O, Mourao-Junior CA, de Oliveira CM, et al. Body mass index, waist circumference, body adiposity index, and risk for type 2 diabetes in two populations in Brazil: general and Amerindian. *PloS one* 2014;9(6):e100223. doi: 10.1371/journal.pone.0100223

Figure Caption

Figure 1. Flow graph of individual recruitment.

Tables

Table 1. Baseline characteristics of study subjects according to the MetS status at baseline.

Characteristics	Male (n=198)			Female (n=181)		
	non-MetS	MetS	*P*	non-MetS	MetS	*P*
N (%)	111 (56.1)	87 (43.9)		142 (78.5)	39 (21.5)	
Age (yr)	49.0 (44.0-55.0)	50.0 (46.0-56.0)	0.397	47.5 (43.0-54.0)	47.0 (46.0-56.0)	0.515
SBP (mmHg)	123.3 (117.3-131.3)	136.7 (125.3-146.7)	<0.001	116.7 (108.7-123.7)	134.0 (120.0-148.0)	<0.001
DBP (mmHg)	80.0 (85.3-73.3)	87.3 (83.3-94.0)	<0.001	76.3 (69.3-80.2)	88.7 (92.7-80.0)	<0.001
FPG (mmol/L)	5.3 (5.0-5.7)	6.1 (5.4-7.2)	<0.001	5.3 (5.0-5.5)	5.8 (5.2-7.8)	<0.001
2hPG (mmol/L)	6.3 (5.2-7.5)	9.3 (6.8-12.3)	<0.001	6.8 (5.9-7.9)	9.6 (7.8-12.6)	<0.001
FINS (mIU/L)	12.49 (9.24-17.75)	16.77 (12.87-24.63)	<0.001	15.54 (12.50-19.69)	25.05 (18.65-30.54)	<0.001
HbA1c (%)	5.7 (5.4-6.0)	6.0 (5.6-6.7)	<0.001	5.9 (5.5-6.2)	6.2 (5.7-7.2)	0.005
TC (mmol/L)	4.8 (4.3-5.3)	5.3 (4.7-5.9)	0.001	5.1 (4.5-5.5)	5.2 (4.4-5.9)	0.494
TG (mmol/L)	1.3 (0.9-1.6)	2.4 (2.0-3.6)	<0.001	1.1 (0.9-1.5)	2.4 (1.7-3.8)	<0.001
HDL (mmol/L)	1.3 (1.1-1.5)	1.1 (0.9-1.3)	<0.001	1.5 (1.3-1.8)	1.1 (1.0-1.4)	<0.001
LDL (mmol/L)	3.0 (2.6-3.5)	3.1 (2.7-3.8)	0.148	3.1 (2.6-3.6)	3.2 (2.6-3.6)	0.963
HOMA-IR	2.98 (2.23-4.46)	4.74 (3.69-6.72)	<0.001	3.79 (2.81-4.86)	6.83 (4.17-8.30)	<0.001
Current Smoking, n (%)	75(67.57)	51(58.62)	0.194	7(4.93)	1(2.56)	0.844
Alcohol Intake, n (%)	39(35.14)	41(47.13)	0.088	3(2.11)	1(2.56)	1.000
SFA (cm^2)	124.62±49.88	151.84±51.80	0.001	178.86±65.82	226.87±69.24	<0.001
VFA (cm^2)	84.40±45.85	116.39±44.40	<0.001	57.76±24.16	91.80±32.98	<0.001

WC (cm)	87.3±8.1	94.7±7.9	<0.001	80.3±8.6	89.0±7.9	<0.001
BMI (kg/m^2)	24.6±2.8	26.6±2.8	<0.001	23.9±3.0	27.1±3.4	<0.001
WHR	0.90±0.05	0.94±0.05	<0.001	0.85±0.06	0.90±0.05	<0.001
ABSI (m$^{7/6}$/kg$^{2/3}$)	0.0792±0.0033	0.0814±0.0034	<0.001	0.0770±0.0041	0.0784±0.0036	0.040
AVI (cm^2)	15.24 (13.48-17.03)	17.86 (16.31-20.10)	<0.001	13.10 (11.56-14.30)	15.51 (14.62-17.79)	<0.001
BAI (0.01m$^{-0.5}$)	25.84±3.01	27.33±2.68	<0.001	29.30±3.18	31.70±3.22	<0.001
BRI	3.65±0.95	4.49±0.98	<0.001	3.50±0.96	4.63±1.03	<0.001
CI (m$^{2/3}$/kg$^{1/2}$)	1.24±0.06	1.29±0.06	<0.001	1.20±0.07	1.25±0.06	<0.001
VAI	1.30 (0.94-1.84)	3.24 (2.17-4.63)	<0.001	1.43 (0.96-1.96)	4.30 (2.46-6.35)	<0.001

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, plasma glucose for 2 hours after a glucose load; FINS, fasting plasma insulin; TC, total cholesterol; TG, triglycerides; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; SFA, subcutaneous fat area; VFA, visceral fat area; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

Data was presented in the form of mean ± standard deviation, median (interquartile range) or counts (percentages), depending on its type. All adiposity and cardiometabolic risk factors between groups with and without MetS were compared using an independent *t*-test, Mann-Whitney rank sum test, Pearson's Chi-squared test, or Fisher's exact test according to the characteristics of the data.

Table 2. Baseline characteristics of healthy subjects who developed MetS or not at follow-up.

Characteristics	Male (n=111)			Female (n=142)		
	free-MetS	newly-MetS	*P*	free-MetS	newly-MetS	*P*
N (%)	69 (62.2)	42 (37.8)		108 (76.1)	34 (23.9)	
Age (yr)	49.0 (45.0-55.5)	50.5 (41.8-55.0)	0.549	47.0 (44.0-53.0)	48.5 (42.0-56.3)	0.754
SBP (mmHg)	122.0 (114.3-132.7)	125.0 (119.3-130.7)	0.239	113.3 (105.3-122.7)	120.0 (116.5-126.8)	0.003
DBP (mmHg)	80.0 (71.7-85.7)	80.0 (77.2-85.7)	0.314	74.7 (68.0-80.0)	79.0 (76.0-82.0)	< 0.001
FPG (mmol/L)	5.3 (4.9-5.6)	5.4 (5.1-5.9)	0.149	5.3 (5.0-5.5)	5.3 (5.0-5.6)	0.274
2hPG (mmol/L)	6.2 (5.3-7.5)	6.3 (5.1-8.4)	0.584	6.6 (5.8-7.6)	7.9 (6.9-9.5)	< 0.001
FINS (mIU/L)	12.18 (8.85-16.46)	12.60 (9.92-20.42)	0.341	15.32 (12.02-19.81)	16.15 (13.33-19.38)	0.374
HbA1c (%)	5.6 (5.4-5.8)	5.7 (5.4-6.2)	0.131	5.8 (5.5-6.1)	6.1 (5.6-6.3)	0.062
TC (mmol/L)	4.7 (4.3-5.3)	4.9 (4.3-5.5)	0.302	5.1 (4.5-5.5)	5.1 (4.6-5.9)	0.426
TG (mmol/L)	1.2 (0.9-1.6)	1.4 (1.1-1.7)	0.041	1.1 (0.8-1.5)	1.3 (1.0-1.7)	0.028
HDL (mmol/L)	1.3 (1.1-1.5)	1.2 (1.1-1.4)	0.075	1.6 (1.3-1.8)	1.5 (1.3-1.7)	0.029
LDL (mmol/L)	3.0±0.8	3.2±0.9	0.286	3.1±0.8	3.4±0.9	0.033
HOMA-IR	2.89 (2.20-3.92)	3.24 (2.25-4.91)	0.171	3.62 (2.75-4.78)	4.08 (3.13-5.07)	0.128
Current Smoking, n (%)	45 (65.22)	30 (71.43)	0.498	4 (3.70)	3 (8.82)	0.358
Alcohol Intake, n (%)	22 (31.88)	17 (40.48)	0.358	3 (2.78)	0 (0.00)	1.000
SFA (cm^2)	110.19±44.09	149.19±50.11	< 0.001	169.42±61.17	207.78±71.90	0.003
VFA (cm^2)	67.70±33.78	112.83±49.98	< 0.001	54.96±23.79	66.34±23.58	0.018
WC (cm)	84.5±7.5	91.9±6.9	< 0.001	78.9±8.3	84.7±8.1	< 0.001
BMI (kg/m^2)	23.6±2.6	26.2±2.5	< 0.001	23.4±2.9	25.4±2.8	0.001
WHR	0.88±0.05	0.92±0.05	< 0.001	0.84±0.06	0.87±0.05	0.003

ABSI ($m^{7/6}/kg^{2/3}$)	0.0788±0.0030	0.0799±0.0036	0.090	0.0767±0.0038	0.0779±0.0047	0.119
AVI (cm^2)	14.18(12.89-16.23)	16.21(15.13-18.57)	< 0.001	12.46(10.91-14.18)	13.95(13.31-15.89)	< 0.001
BAI ($0.01m^{-0.5}$)	25.38±2.53	26.60±3.58	0.058	28.98±2.99	30.31±3.59	0.033
BRI	3.35±0.85	4.41±0.90	< 0.001	3.34±0.90	4.02±1.00	< 0.001
CI ($m^{2/3}/kg^{1/2}$)	1.22±0.06	1.26±0.06	0.001	1.19±0.06	1.22±0.07	0.007
VAI	1.17(0.84-1.70)	1.52(1.19-2.09)	0.009	1.35(0.86-1.83)	1.68(1.39-2.25)	0.004

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, plasma glucose for 2 hours after a glucose load; FINS, fasting plasma insulin; TC, total cholesterol; TG, triglycerides; HDL, high density lipoprotein cholesterol; LDL, low density lipoprotein cholesterol; SFA, subcutaneous fat area; VFA, visceral fat area; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

Data was presented in the form of mean ± standard deviation, median (interquartile range) or counts (percentages), depending on its type. All adiposity and cardiometabolic risk factors between groups with and without MetS were compared using an independent *t*-test, Mann-Whitney rank sum test, Pearson's Chi-squared test, or Fisher's exact test according to the characteristics of the data.

Table 3. AUCs of anthropometric indices in diagnosing of MetS at baseline.

Indices	Male			Female		
	AUC	95%CI	*P*	AUC	95%CI	*P*
WC	0.79	(0.72-0.86)	<0.001	0.79	(0.71-0.87)	<0.001
BMI	0.73[a]	(0.65-0.80)	<0.001	0.75	(0.67-0.84)	<0.001
WHR	0.72[a]	(0.64-0.79)	<0.001	0.75	(0.67-0.83)	<0.001
ABSI	0.70[a]	(0.62-0.78)	<0.001	0.62[a]	(0.52-0.72)	0.031
AVI	0.79	(0.72-0.86)	<0.001	0.79	(0.71-0.87)	<0.001
BAI	0.67[a]	(0.59-0.75)	<0.001	0.69[a]	(0.59-0.79)	<0.001
BRI	0.76	(0.69-0.83)	<0.001	0.80	(0.71-0.88)	<0.001
CI	0.76	(0.68-0.83)	<0.001	0.73[a]	(0.64-0.82)	<0.001
VAI	0.85	(0.79-0.92)	<0.001	0.90[a]	(0.84-0.96)	<0.001

Abbreviations: WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, *P* is less than 0.05

Table 4. AUCs, optimal cutoff, sensitivity, specificity, positive and negative predictive value for the anthropometric indices in ROC analysis for predicting MetS.

Anthropometric Indices	AUC (95%CI)	*P*	Cut-off	Sensitivity	Specificity	Youden Index	PPV	NPV
Male								
WC	0.76 (0.67-0.84)	<0.001	84.0	0.95	0.54	0.49	0.56	0.95
BMI	0.77 (0.68-0.85)	<0.001	24.94	0.69	0.75	0.44	0.63	0.80
WHR	0.73 (0.64-0.81)	<0.001	0.89	0.76	0.64	0.40	0.56	0.81
ABSI	0.58[a] (0.49-0.68)	0.149	0.0822	0.29	0.88	0.17	0.60	0.67
AVI	0.76 (0.67-0.84)	<0.001	14.25	0.95	0.54	0.49	0.56	0.95
BAI	0.59[a] (0.49-0.68)	0.124	27.44	0.40	0.87	0.27	0.65	0.70
BRI	0.74 (0.65-0.82)	<0.001	3.47	0.81	0.58	0.39	0.54	0.83
CI	0.67[a] (0.58-0.76)	<0.001	1.21	0.83	0.45	0.28	0.48	0.81
VAI	0.65[a] (0.55-0.74)	0.005	1.06	0.83	0.48	0.31	0.49	0.82
Female								
WC	0.71 (0.64-0.79)	<0.001	80.0	0.82	0.60	0.42	0.39	0.91
BMI	0.71 (0.63-0.78)	<0.001	25.14	0.59	0.78	0.37	0.46	0.86
WHR	0.68 (0.59-0.75)	<0.001	0.81	0.91	0.37	0.28	0.31	0.93
ABSI	0.55[a] (0.47-0.64)	0.358	0.0799	0.32	0.81	0.13	0.35	0.79

AVI	0.72 (0.64-0.79)	<0.001	13.03	0.82	0.60	0.42	0.39	0.91
BAI	0.64 (0.56-0.72)	0.013	30.38	0.53	0.74	0.27	0.39	0.83
BRI	0.71 (0.63-0.79)	<0.001	3.58	0.71	0.66	0.37	0.40	0.88
CI	0.63 (0.54-0.71)	0.020	1.23	0.44	0.81	0.25	0.42	0.82
VAI	0.66 (0.58-0.74)	0.001	1.36	0.79	0.52	0.31	0.34	0.89

Abbreviations: AUC, area under curve; PPV, positive predictive value; NPV, negative predictive value; WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, P is less than 0.05

Table 5. Comparison of AUCs for anthropometric indices in predicting MetS components in males.

Component	Central obesity		High TG		Low HDL		High BP		High BG	
	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*
WC	0.79 (0.69-0.89)	<0.001	0.63 (0.47-0.78)	0.118	0.45 (0.31-0.59)	0.523	0.77 (0.66-0.88)	<0.001	0.57 (0.43-0.70)	0.348
BMI	0.78 (0.67-0.89)	<0.001	0.69 (0.55-0.84)	0.016	0.53 (0.39-0.68)	0.675	0.72 (0.60-0.84)	<0.001	0.58 (0.45-0.71)	0.263
WHR	0.71 (0.59-0.83)	0.002	0.61 (0.46-0.76)	0.185	0.41 (0.26-0.57)	0.286	0.75 (0.64-0.86)	<0.001	0.59 (0.46-0.72)	0.199
ABSI	0.50[a] (0.37-0.63)	0.996	0.47 (0.29-0.64)	0.665	0.37 (0.22-0.51)	0.104	0.72 (0.61-0.84)	<0.001	0.53 (0.38-0.68)	0.677
AVI	0.79 (0.69-0.89)	<0.001	0.62 (0.47-0.78)	0.123	0.45 (0.31-0.59)	0.555	0.77 (0.66-0.88)	<0.001	0.57 (0.43-0.70)	0.348
BAI	0.57[a] (0.42-0.71)	0.340	0.60 (0.43-0.77)	0.217	0.56 (0.40-0.71)	0.502	0.63[a] (0.51-0.75)	0.058	0.54 (0.40-0.68)	0.554
BRI	0.70[a] (0.58-0.82)	0.004	0.65 (0.50-0.80)	0.060	0.48 (0.34-0.61)	0.776	0.75 (0.64-0.86)	<0.001	0.58 (0.45-0.72)	0.226
CI	0.60[a]	0.139	0.54	0.604	0.39	0.181	0.76	<0.001	0.55	0.465

	(0.48-0.73)		(0.37-0.71)		(0.25-0.53)		(0.65-0.87)		(0.41-0.69)			
	0.58[a]		0.69		0.61		0.61[a]		0.56			
VAI		0.266		0.016		0.179		0.113		0.365		
	(0.45-0.70)		(0.57-0.82)		(0.45-0.77)		(0.48-0.74)		(0.43-0.70)			

Abbreviations: TG, triglycerides; HDL, high density lipoprotein cholesterol; BP, blood pressure; BG, blood glucose; AUC, area under curve; WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, P is less than 0.05

Table 6. Comparison of AUCs for anthropometric indices in predicting MetS components in females.

Component	Central obesity		High TG		Low HDL		High BP		High BG	
	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*	AUC (95%CI)	*P*
BMI	0.83 (0.75-0.92)	<0.001	0.56 (0.39-0.73)	0.563	0.64 (0.49-0.79)	0.145	0.68 (0.58-0.78)	<0.001	0.50[a] (0.35-0.65)	0.997
WC	0.82 (0.74-0.91)	<0.001	0.50 (0.32-0.67)	0.955	0.64 (0.51-0.77)	0.142	0.70 (0.61-0.80)	<0.001	0.54 (0.40-0.68)	0.584
WHR	0.65[a] (0.54-0.75)	0.021	0.39 (0.24-0.54)	0.257	0.64 (0.51-0.77)	0.145	0.60[a] (0.50-0.70)	0.066	0.62 (0.49-0.76)	0.106
ABSI	0.47[a] (0.36-0.59)	0.681	0.39 (0.21-0.57)	0.253	0.53 (0.35-0.71)	0.736	0.59[a] (0.49-0.69)	0.082	0.61 (0.48-0.74)	0.157
AVI	0.84 (0.75-0.92)	<0.001	0.50 (0.32-0.68)	0.981	0.64 (0.50-0.77)	0.153	0.71 (0.62-0.80)	<0.001	0.54 (0.40-0.69)	0.590
BAI	0.70[a] (0.59-0.82)	<0.001	0.58 (0.38-0.78)	0.429	0.58 (0.39-0.77)	0.413	0.61 (0.51-0.71)	0.036	0.50 (0.34-0.66)	0.990
BRI	0.77 (0.68-0.87)	<0.001	0.49 (0.31-0.67)	0.918	0.64 (0.50-0.79)	0.142	0.67[a] (0.57-0.76)	0.002	0.54 (0.39-0.69)	0.609
CI	0.58[a]	0.220	0.44	0.550	0.61	0.271	0.63[a]	0.013	0.59	0.222

	(0.47-0.69)		(0.26-0.63)		(0.44-0.77)		(0.53-0.73)		(0.46-0.73)			
	0.62[a]		0.59		0.56		0.52[a]		0.59			
VAI		0.060		0.328		0.524		0.739		0.261		
	(0.51-0.73)		(0.41-0.78)		(0.39-0.73)		(0.41-0.62)		(0.44-0.73)			

Abbreviations: TG, triglycerides; HDL, high density lipoprotein cholesterol; BP, blood pressure; BG, blood glucose; AUC, area under curve; WC, waist circumference; BMI, body mass index; WHR, waist-to-hip ratio; ABSI, a body shape index; AVI, abdominal volume index; BAI, body adiposity index; BRI, body roundness index; CI, conicity; VAI, visceral adiposity index.

DeLong. Delong. Clarke-Pearson's nonparametric approach was used to compare the AUCs of indices.

a, compared with the AUC of waist circumference, P is less than 0.05

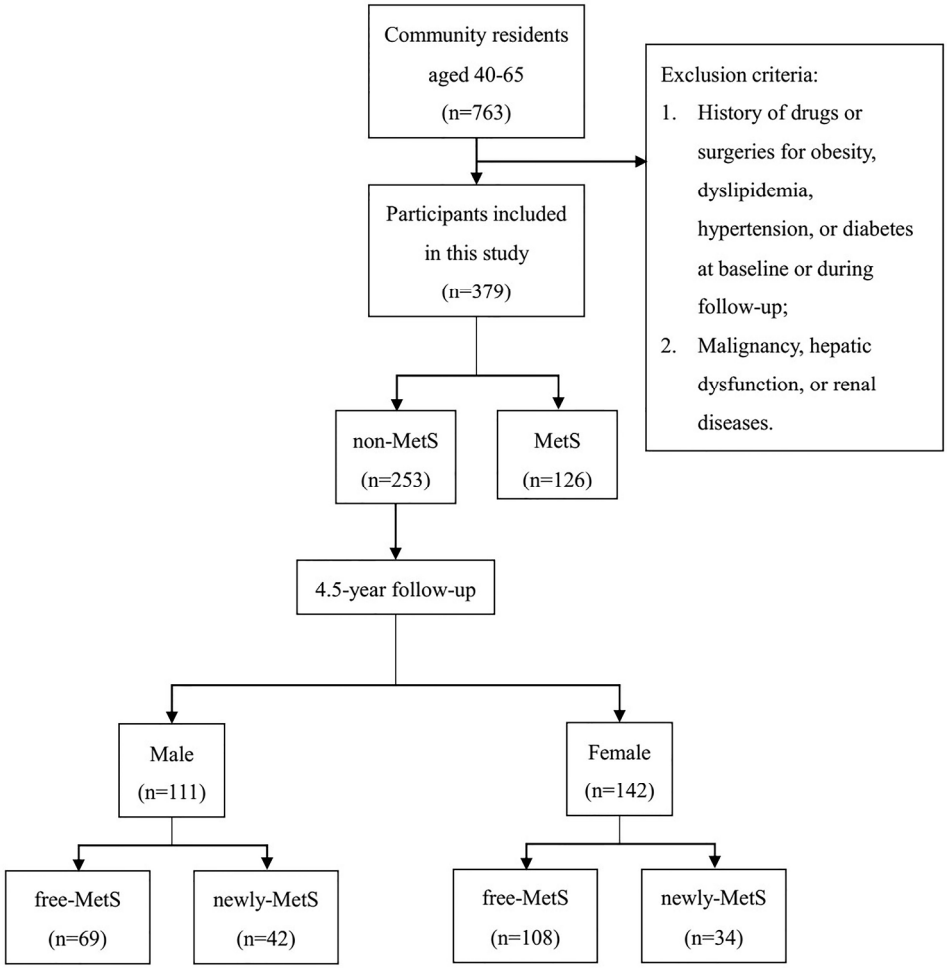


Figure 1. Flow graph of individual recruitment.

308x304mm (300 x 300 DPI)

Supplement 1. Morbidities of MetS and its components during follow-up.

	Male			Female			*P*
	Free, n	Newly, n	Morbidity, %	Free, n	Newly, n	Morbidity, %	
MetS	69	42	37.8	108	34	23.9	0.017
Central obesity	57	31	35.2	86	30	25.9	0.148
High TG	80	19	19.2	119	11	8.5	0.017
Low HDL	148	16	9.8	119	11	8.5	0.703
High BP	28	59	67.8	51	82	61.7	0.352
High BG	76	25	24.8	102	17	14.3	0.049

TG, triglyceride; HDL, high density lipoprotein cholesterol; BP, blood pressure; BG, blood glycose.

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Check
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 4
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	4-5
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	7-10
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	7-8
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NA
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-9
Bias	9	Describe any efforts to address potential sources of bias	9-10
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	9-10
		(*c*) Explain how missing data were addressed	7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	7
		(*e*) Describe any sensitivity analyses	NA

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	10
		(b) Give reasons for non-participation at each stage	10
		(c) Consider use of a flow diagram	10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	11
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	10
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	10
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-13
		(*b*) Report category boundaries when continuous variables were categorized	11-13
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-13
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11-13
Discussion			
Key results	18	Summarise key results with reference to study objectives	13-16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15-16
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-16
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-16
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.