Heliyon 11 (2025) e41310

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Association of anthropometric and obesity indices with abnormal blood lipid levels in young and middle-aged adults

Xiaoling Zhou [a,b,1], Zuoli Zou [a,d,1], Ying Liu [c], Yuzhong Yan [d], Jing Wu [c,**], Geyao Zhou [a,***], Ming Li [a,e,*]

[a] School of Public Health, The Key Laboratory of Environmental Pollution Monitoring and Disease Control, Ministry of Education, Guizhou Medical University, Guiyang, 561113, China
[b] Editorial Department of Guizhou Medical Journal, Guizhou Provincial Medical Association, Guiyang, 550004, China
[c] Shanghai University of Traditional Chinese Medicine, Shanghai, China
[d] Zhoupu Hospital, Shanghai University of Medicine and Health Sciences, Shanghai, China
[e] Shanghai Dongfang Hospital, Shanghai, China

A R T I C L E I N F O

Keywords:
Obesity
Waist circumference
Body mass index
Waist to hip ratio
Blood lipids

A B S T R A C T

Introduction: Obesity is a known risk factor for dyslipidemia. We aimed to evaluate the association between nine obesity indices and various types of abnormal lipid levels in the young and middle-aged.
Methods: From July to November 2022, we distributed health survey questionnaires to the target population in the hospital and collected their biochemical and anthropometric data. Multivariate regression models and Receiver operating characteristic (ROC) curve analysis were used for data analyzing.
Results: We collected a total of 1174 complete samples. Among the five blood lipid indexes tested in this study, TG (triglyceride) is most closely related to various body measurements ($P < 0.05$). WC (Waist circumference) has the greatest risk for abnormal TG levels (OR, 2.61; $P < 0.001$) and high-density lipoprotein cholesterol (HDL-C) levels(OR, 1.96; $P < 0.001$).WHR has the greatest risk of abnormal low-density lipoprotein cholesterol (LDL-C) levels (OR, 1.35; $P < 0.05$) and non-high-density lipoprotein cholesterol levels(OR, 1.59; $P < 0.001$). ROC curve analyses revealed that all the tested variables gave the highest area under the curve (AUC) values for predicting high TG in comparison to other plasma lipid abnormalities. The AUC of WC, AVI and BMI were 0.81, 0.80 and 0.79 respectively.
Conclusion: Specific obesity-related anthropometric measurements, including WC, AVI, and WHR, show improved predictive accuracy in identifying abnormal lipid levels across diverse types. This study supports their effectiveness in early dyslipidemia screening among young and middle-aged individuals.

* Corresponding author. Shanghai Dongfang Hospital, Shanghai, China.
** Corresponding author.
*** Corresponding author.
E-mail addresses: 18212306457@163.com (X. Zhou), 1820105992@qq.com (Z. Zou), 281962466@qq.com (Y. Liu), jykwsw@126.com (Y. Yan), allydata@126.com (J. Wu), zhougeyao@gmc.edu.cn (G. Zhou), liming1070202306@163.com (M. Li).
[1] These authors have contributed equally to this work.

https://doi.org/10.1016/j.heliyon.2024.e41310
Received 8 May 2024; Received in revised form 15 December 2024; Accepted 16 December 2024
Available online 26 December 2024
2405-8440/

1. Introduction

Obesity constitutes a significant global public health concern, affecting over one-third of the world's population, with at least 60 % residing in developing countries [1]. It is well-studied that obesity is associated with a range of metabolic disorders that significantly impact cardiovascular health [2]. Dyslipidemia is an important link between obesity and the development of type 2 diabetes mellitus and cardiovascular disease (CVD) [3]. The physiological mechanisms linking obesity to dyslipidemia are intricate and involve interactions between adipose tissue dysfunction, insulin resistance, and altered lipid metabolism. However, recent evidence suggests that obesity-induced dyslipidemia is not a unique pathophysiological entity, but rather has distinct characteristics depending on many individual factors [4,5]. In line with that, in a subgroup of metabolically healthy obese (MHO) individuals, dyslipidemia is less prominent or even absent [6]. Despite a number of studies suggest that obesity and dyslipidemia are important risk factors for cardiovascular disease, different views have been proposed in recent years. For example, elevated certain lipid components (such as HDL cholesterol) may be associated with a decreased risk of atrial fibrillation. Similarly, it also reveals the 'paradox' phenomenon of obesity in patients with acute coronary syndrome, namely that a certain degree of obesity may be associated with lower mortality [7,8]. These studies indicate that we need to approach the exploration of the relationship between obesity, blood lipid levels, and diseases with greater caution and comprehensiveness.

Identifying obesity is crucial for assessing the risk of associated disorders, making it a significant health concern. However, individuals with obesity can exhibit variations in body fat distribution and associated disease risks. Consequently, current consensus recognizes that the distribution of body fat, rather than the overall amount of adipose tissue, plays a pivotal role in determining metabolic abnormalities [9]. MRI and computed tomography have been recognized as the gold standard for measuring the volume of visceral fat [10], but these two methods are not suitable for large-scale epidemiological studies due to their inconvenience and high cost [11]. Therefore, body fat is frequently estimated or reflected by a series of anthropometric indices in most studies.

Anthropometric indices used to define obesity can help in the identification of individuals or groups of people with a variety of specific health thresholds [12]. The conventional anthropometric indicators that define obesity include BMI [13], waist circumference (WC) [14], waist-height ratio (WHtR), and waist-hip ratio (WHR) [15]. Unconventional new indicators proposed in recent years include the Body Roundness Index (BRI) [16], Neck Circumference (NC), Waist-to-Weight Index (WWI), Abdominal Volume Index (AVI), and Conicity Index (CI) [17–19]. Some studies have been conducted to assess the relationship between anthropometric obesity indices and Dyslipidemia. However, the results of these studies are inconsistent. Currently, body mass index (BMI) and waist circumference (WC) are the most commonly used predictors, but BMI does not reflect body shape and fat distribution, whereas individuals with similar BMI may exhibit different levels of fitness [20–25].

WC is a widely used measure of abdominal obesity, which reflects central obesity, a typical anthropometric parameter associated with cardiovascular diseases. Many studies have shown that WC is a better predictor of mortality risk than BMI [26,27]. However, it has limitations in distinguishing between subcutaneous and visceral fat tissue [28].It is an important consideration given the potential differences in health risks associated withWC and BMI of fat. In addition, waistto-height ratio (WHtR) and waist-to-hip ratio (WHR), as two WC-based anthropometric indices, were also frequently used and compared with BMI and WC in clinical practice. A recent study has shown that waist-to-height ratio (WHtR) is a screening tool for adult metabolic risk factors that is more advantageous than BMI and WC [29]. BRI is a new index proposed by Thomas and colleagues and based on WC and height, is a predictor of body fat percentage and visceral adiposity tissue, and its values range from 1 to 16 [16,26]. CI is based on geometric theory, that is, with the accumulation of waste fat, the body shape changes from a "cylinder" to a double "cone" [30], which can reflect the level of central obesity. Some studies still suggest that these indices provide limited information on fat distribution [31,32].

To the best of our knowledge, limited studies have specifically examined the associations between different types of blood lipid levels and obesity indices in the young and middle-aged in China. Although several studies hav e estimated and compared the predictive performances of obesity indices for Dyslipidemia in different populations [33,34], the findings were inconsistent. Hence, it is essential to evaluate whether the novel indices demonstrate superior identification of abnormal blood lipid levels in young and middle-aged individuals compared to traditional ones. In this context, the current study investigated the association between various anthropometric and obesity indicators (including NC, WC, HC, BMI, WHR, WHtR, BRI, WWI, AVI, and CI) and the occurrence of abnormal blood lipid level events (including TC, TG, HDL-C, LDL-C, and Non-HDL). The study also involved a comparative analysis of their respective risk prediction performances.

2. Methods

2.1. Study setting and participants

A cross-sectional investigation was conducted at the Physical Examination Center of Shanghai Zhoupu Hospital, enrolling 1174 participants from July 2022 to November 2022. All participants underwent physical examinations and laboratory measurements and completed standardized questionnaires. Inclusion criteria: (1) Young and middle-aged individuals aged 18 to 45; (2) Complete clinical data, including demographic information, anthropometric indicators, and blood lipid levels; (3) Signed the informed consent form, agreed to participate in the study and complete the questionnaire. Exclusion criteria:(1)With cardiovascular diseases and severe chronic illnesses; (2) Have recently used medications that may affect blood lipid levels or obesity indicators; (3) Pregnant or lactating women; (4) Individuals with incomplete data.

The contents of the questionnaires included education level, marital status, income and eating habits, etc. Written informed consent for the whole research was obtained from each participant. This study was approved by the Ethics Committee of Shanghai Zhoupu

Hospital (2022-C068-E01). The study protocol conforms to the ethical guidelines of the Declaration of Helsinki as reflected in the prior approval by the institution's human research committee.

2.2. Definitions

Abnormal blood lipid level was diagnosed by the definition of "Chinese Guidelines for Blood Lipid Management (2023) " [35]. The diagnostic criteria of blood lipid level abnormality are: TC $\geq$ 6.2 mmol/L, TG $\geq$ 2.3mmmol/L, HDL-C< 1.0 mmol/L, LDL-C$\geq$ 4.1 mmol/L and non-HDL-C$\geq$ 4.9mmmol/L. "Like meat" or "Like to eat desserts and sweet drinks" is more than three times a week were defined as having bad eating habits.The calculation formula of each obesity-related indices is shown in Table 1.

2.3. Anthropometric and laboratory measurements

At baseline time, the physical examination included measurements of height, weight, WC, hip circumference (HC), blood lipid levels, etc. WC was recorded in the midpoint between the lowest rib and the iliac crest, and HC was measured at the greater trochanter [40]. Fasting plasma glucose (GLU), TC, TG, HDL-C and LDL-Cwere quantified by an autocatalytic at the center of the hospital.

2.4. Statistical analyses

SPSS25.0 statistical software and R version 4.3.1 were used for data analysis. Mean $\pm$ standard deviation (M$\pm$SD) was reported for continuous variables and the independent-samples *t*-test was applied for comparison. Categorical variables are expressed as count (percentage), and Mann-Whitney test or Fisher's exact test analysis was used to compare differences between groups. Spearman's correlation analysis was performed to determine the relationship between the obesity-related indices and blood lipid levels. Logical regression was used to examine the risk of various obesity-related indices on the risk of blood lipid level abnormality adjusting for the relevant factors appropriately. Lastly, the AUC of obesity-related indices to predict blood lipid level abnormality was estimated by receiver operating characteristic (ROC) analyses. A two-tailed $P < 0.05$ was considered statistically significant.

3. Results

3.1. Characteristics of participants

Table 2 presents the basic characteristics of the study population, comprising 1174 research subjects divided into two groups. Of these, 908 (77.34 %) had normal blood lipid levels, while 266 (22.66 %) exhibited abnormal levels. The average age of participants was 35.02 $\pm$ 6.16 years, showing no significant difference between the two groups ($P > 0.05$). However, significant differences were observed in NC, WC, HC, BMI, WHR, WHtR, BRI, WWI, AVI, CI, education level, smoking, and drinking between the groups ($P < 0.05$), while marital status showed no significant difference ($P > 0.05$). We constructed box plots for the anthropometric and obesity indicators in both the normal and abnormal blood lipid level groups (Fig. 1). This visualization allows a direct observation of the data distribution differences for each obesity indicator between the two groups, with statistically significant distinctions ($P < 0.001$).

3.2. Correlation coefficients between anthropometric indicators and serum lipid levels

Table 3 displays the results of partial correlation analysis, revealing positive associations between NC, WC, BMI, WHR, WHtR, BRI, WWI, AVI, CI, and TC, TG, LDL-C, Non-HDL, along with negative correlations with HDL-C. Notably, HDL-C and TG exhibited the strongest correlations with each obesity measurement index ($P < 0.001$). Additionally, WHR, BMI, WC (AVI), BMI, and WC (AVI) were identified as the body measurement indicators most strongly correlated with TC, TG, HDL-C, LDL-C, and non-HDL-C.

3.3. Association of anthropometric indicators with different types of abnormal serum lipid levels risks

The odds ratio (OR) and 95 % confidence interval (CI) were analyzed by obesity-related Z-scores after controlling for age, sex,

Table 1
The formula of each obesity-related indices.

Indices	Formula	Reference
NC	–	–
WC	–	–
BMI	Weight (kg)/Height^2(m)	[36]
WHR	Waist circumference (cm)/Hip circumference (cm)	[5]
WHtR	Waist circumference (cm)/height (cm)	[37]
BRI	$364.2-365.5 \times [(1-((\text{Waist circumference(m)}/2\pi)/(0.5 \times \text{Height(m)})^2]^{1/2}$	[2]
WWI	$(\text{Waist circumference(m)} \times 100)/\text{Weight(m)}^{1/2}$	[38]
AVI	$[2 \times \text{Waist circumference}^2 \text{ (cm)} + 0.7 \times (\text{Waist circumference-Hip circumference})^2\text{(cm)}]/1000$	[39]
CI	$0.109^{-1} \times \text{Waist circumference(m)} \times [\text{Weight(kg)}/\text{Height(m)}]^{-1/2}$	[3]

Table 2
General characteristics of all participants.

Variables	Overall (n = 1174)	Normal(n = 908)	Abnormal (n = 266)	*P*- value
Age (years)	35.02 ± 6.16	35.10 ± 6.25	34.73 ± 5.87	0.37
Height (cm)	164.23 ± 7.20	163.62 ± 6.78	166.31 ± 8.17	<0.001
Weight (kg)	62.40 ± 11.94	60.56 ± 10.67	68.69 ± 13.78	<0.001
NC (cm)	33.28 ± 3.95	32.78 ± 3.82	34.98 ± 3.91	<0.001
WC (cm)	78.64 ± 10.19	77.03 ± 9.57	84.13 ± 10.35	<0.001
HC (cm)	95.47 ± 6.84	94.83 ± 6.63	97.66 ± 7.10	<0.001
BMI	23.04 ± 3.47	22.56 ± 3.26	24.70 ± 3.66	<0.001
WHR	0.82 ± 0.07	0.81 ± 0.07	0.86 ± 0.07	<0.001
WHtR	0.48 ± 0.06	0.47 ± 0.06	0.51 ± 0.06	<0.001
BRI	3.03 ± 1.06	2.89 ± 1.01	3.53 ± 1.071	<0.001
WWI	9.99 ± 0.79	9.93 ± 0.79	10.20 ± 0.74	<0.001
AVI	12.81 ± 3.22	12.30 ± 2.97	14.53 ± 3.43	<0.001
CI	1.17 ± 0.09	1.16 ± 0.09	1.21 ± 0.09	<0.001
TC(mmol/l)	5.02 ± 0.88	4.81 ± 0.64	5.73 ± 1.17	<0.001
TG(mmol/l)	1.30 ± 1.28	0.9884 ± 0.43752	2.38 ± 2.26	<0.001
HDL-C(mmol/l)	1.436 ± 0.31	1.4805 ± 0.27679	1.26 ± 0.36	<0.001
LDL-C(mmol/l)	3.01 ± 0.74	2.863 ± 0.59342	3.51 ± 0.96	<0.001
Non HDL-C(mmol/l)	3.59 ± 0.89	3.3317 ± 0.64573	4.47 ± 1.04	<0.001
Marital status				
Unmarried	204(17.38)	166(18.28)	38(14.29)	0.13
Married	970(82.62)	742(81.72)	228(85.71)	
Educational level, n(%)				
Junior high school and below	52(4.43)	31(3.41)	21(7.89)	0.02
Senior high school (junior college)	248(21.12)	182(20.04)	66(24.81)	
Undergraduate	824(70.19)	655(72.14)	169(63.53)	
Postgraduate	50(4.26)	40(4.41)	10(3.76)	
Smoking status, n(%)				
Yes	111(9.45)	55(6.06)	56(21.05)	<0.001
No	1063(90.55)	853(93.94)	210(78.95)	
Drink status, n(%)				
Yes	101(8.60)	56(6.17)	45(16.72)	<0.001
No	1073(91.40)	852(93.83)	221(83.08)	

education level, smoking and drinking(Fig. 2). All obesity indicators are positively correlated with abnormal TG, HDL-C and all-cause levels($P < 0.05$), but not associated with the risk of abnormal TC levels($P > 0.05$).

The WC index had the strongest association with the risk of abnormal TG level (OR, 2.53; 95%CI, 2.00–3.21). And followed by BMI (OR, 2.46; 95%CI, 1.98–3.05). Meanwhile, WC had the strongest association with the risk of abnormal HDL-C levels(OR, 1.90; 95%CI, 1.46–2.47). And followed by WHR (OR,1.88; 95%CI, 1.40–2.52). In addition,the WHR index had the strongest association with the risk of abnormal LDL-C (OR,1.32; 95%CI, 1.03–1.71) and Non-HDL-C (OR, 1.50; 95%CI, 1.15–2.00) level. Lastly, the WHR index had the strongest association with the risk of all-cause abnormal blood lipid (OR,1.75; 95%CI, 1.49–2.07). And followed by WHR (OR,1.72; 95%CI, 1.45–2.05) and AVI (OR,1.70; 95%CI, 1.45–2.00).

3.4. The predictive ability of anthropometric indicators for different types of abnormal serum lipid levels

We performed Receiver Operating Characteristic (ROC) curve analysis to examine the predictive ability of different anthropometric indicators on distinguishing individuals with abnormal lipid levels from those without (Fig. 3). WC and AVI showed the highest values for predicting all-cause blood lipid level abnormality, with an area under the curve (AUC) of 0.70. WHR, WHtR and BRI also had high AUC values of 0.78. Moreover, the AUC values of WHR, WHtR and BRI were also moderately high(0.68–0.69). The predictive capabilities of the corresponding parameters in distinguishing the participants with highTG, TC, HDL-C, LDL-C and Non-HDL-C were also analyzed. According to observations, in predicting high TG levels, including NC, WC, BMI, WHR, WHtR, BRI, AVI, and CI showed moderately high and similar AUC values (0.70–0.81). However, among these analyses, WC and AVI had the highest AUC values. Moreover, NC, WC and AVI demonstrated high predictive ability in predicting low HDL levels(0.74–0.75). The various indicators showed moderate predictive ability in predicting high TC (0.53–0.58), LDL(0.55–0.63) and non-HDL-C (0.58–0.68).

4. Discussion

Anthropometric measurements are an important factor when assessing dyslipidemia levels in young and middle-aged adults. In this study, we evaluated the association between nine obesity indices and various types of abnormal lipid levels in the young and middle-aged. Previous studies have shown that the detection rate of hyperlipidemia in obese patients is significantly higher than that in normal weight individuals, and obesity is associated with blood lipid levels [41–43]. Similar results were obtained in our study, with various obesity indicators and blood lipids having a high correlation. We have found a consistent positive correlation between each body obesity measurement index and TC, TG, LDL, and non-HDL. Similarly, there is a consistent negative correlation between these

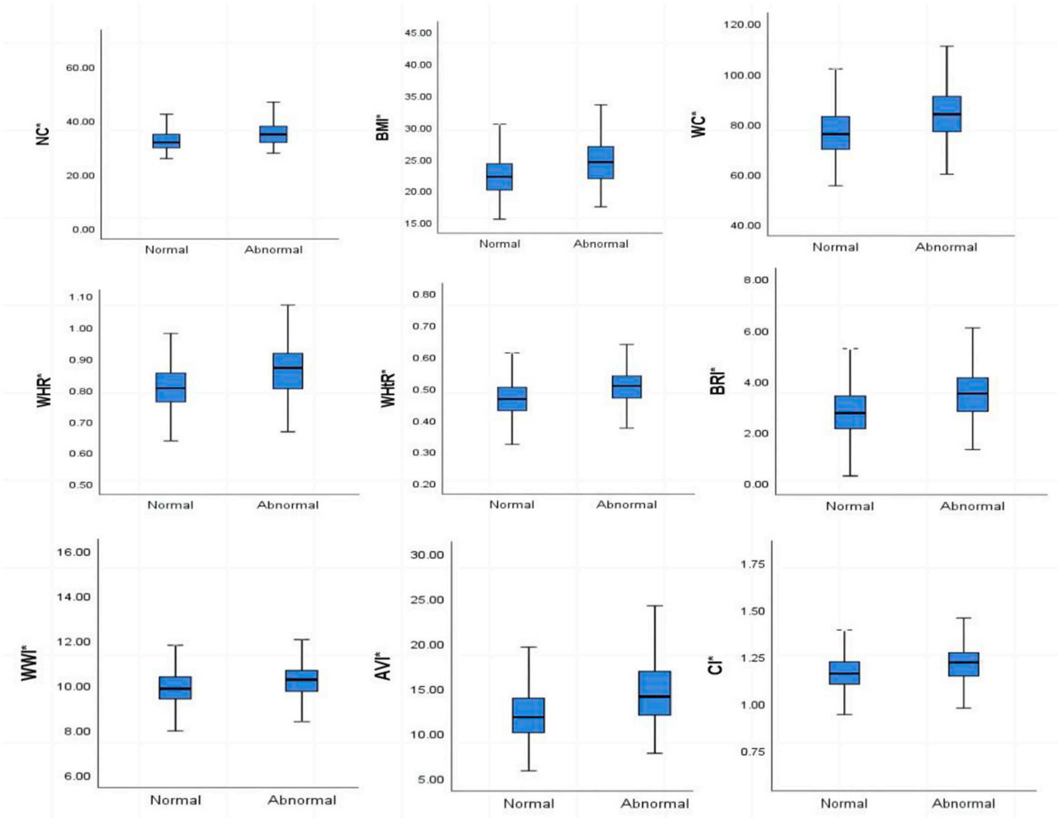

Fig. 1. Comparison of various anthropometric and metabolic parameters in Patients with abnormal and normal blood lipid levels. Box-plot representation of the values for different anthropometric/metabolic parameters in patients with abnormal and normal blood lipid levels. Dyslipidemia was defined as irregularity in the plasma levels of TC, TG, HDL, LDL, or non-HDL. Boxes represent median and interquartile range; whiskers represent minimum and maximum. Significance was determined by unpaired *t*-test. *Significant difference ($p < 0.001$).

Table 3
Correlation coefficients between anthropometric measurements and serum lipid levels.

Indices	TC	TG	HDL-C	LDL-C	Non-HDL-C
NC	0.06*	0.35**	−0.44**	0.12**	0.21**
WC	0.11**	0.44**	−0.48**	0.20**	0.28**
BMI	0.11**	0.45**	−0.47**	0.21**	0.28**
WHR	0.12**	0.39**	−0.42**	0.18**	0.27**
WHtR	0.11**	0.40**	−0.44**	0.19**	0.27**
BRI	0.11**	0.40**	−0.44**	0.19**	0.27**
WWI	0.07*	0.22**	−0.26**	0.10**	0.16**
AVI	0.11**	0.44**	−0.48**	0.20**	0.28**
CI	0.07*	0.27**	−0.32**	0.12**	0.18**

Note: TC, total cholesterol; TG, triglyceride; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; NC, Neck circumference; WC, Waist circumference; BMI, body mass index; WHR, waist-hip ratio; WHtR, waist-height ratio; BRI, Body Roundness Index; WWI, Weight adjusted waist circumference index; AVI, abdominal volume index; CI, conicity index. **$P < 0.001$,*$P < 0.05$.

measurement indices and HDL, which aligns with the findings of previous studies [44,45]. Among these blood lipids, TG and HDL exhibit the strongest association. Among them, WC, BMI and AVI are highly associated with these two types. Meanwhile, various anthropometric indicators had a positive correlation with TC.

In our follow study, we analyzed the risk associations of each body measure with different types of abnormal lipid levels. Obviously, each obesity index is significantly associated with the risk of abnormal blood lipid levels of TG and HDL-C [46], but has no statistical significance with the risk of abnormal TC levels. From the perspective of abnormal blood lipid levels of TG and HDL-C, WC has the highest risk ratio, followed by BMI, WHR and AVI. From the LDL-C and non-HDL-C, the WHR index has the largest risk ratio, followed by BMI. Finally, from the perspective of overall abnormal blood lipid levels, the first is WC [47], followed by WHR and AVI, after adjusting for age, gender, education level, smoking and drinking.At present, the most commonly used indicators for evaluating visceral

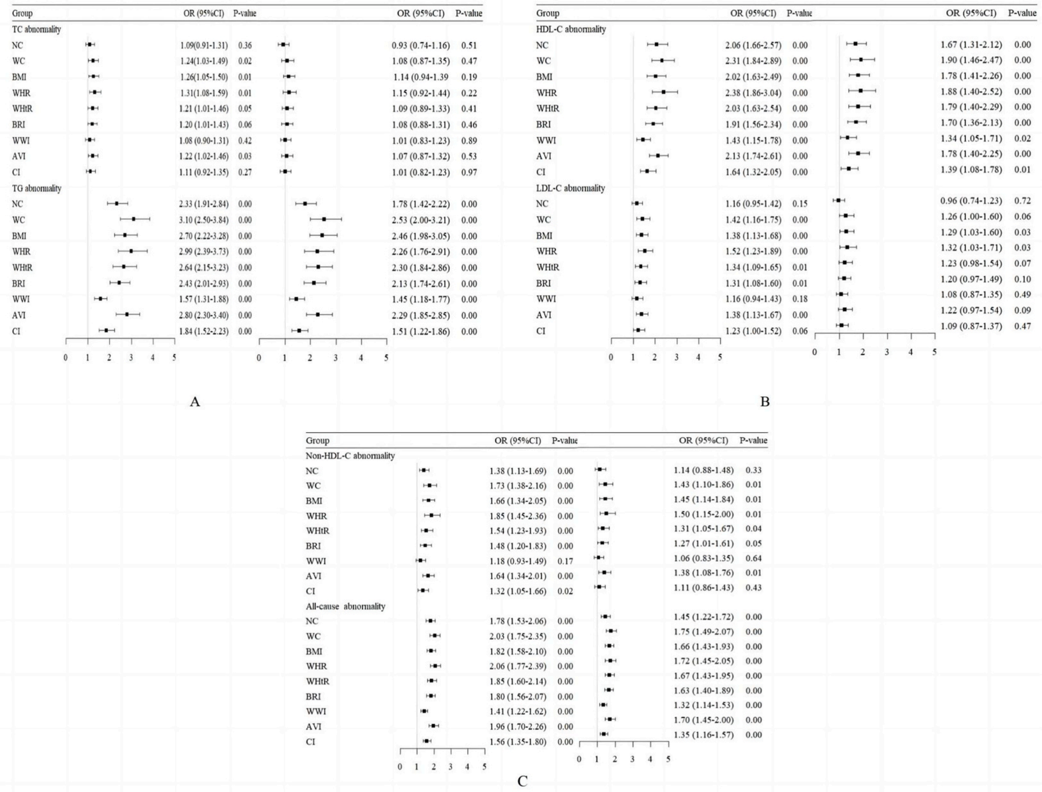

Fig. 2. (ABC).The OR values of various anthropometric/metabolic variables and the absence or presence of different forms of dyslipidemia. Bar graphs represent the values for area under the curves from receiver operating characteristic (ROC) curve analysis to determine the predictivecapability of different anthropometric/metabolic parameters for identification of a overall dyslipidemia (irregularity in the plasma levels of TC, TG, HDL, LDL, or non-HDL). Abbreviations: WC,Waist circumference; BMI, body mass index; WHR, Waist-hip ratio; WHtR, Waist height ratio; BRI, Body roundness index; WWI, Weight adjusted waist circumference index; AVI, Abdominal volume index; CI,Cone Index.

fat are BMI and WC [44–46].This study found that AVI is a special and novel indicator for assessing abnormal blood lipid levels in young and middle-aged people, which is a significant finding.

We also investigated the effectiveness of using anthropometric and adiposity measures to detect abnormal lipid levels.The WC, WHR, and AVI indicators have good discriminatory abilities for identifying abnormal blood lipid levels in both men and women among the 9 obesity measurement indicators including NC, WC, BMI, WHR, WHtR, BRI, WWI, AVI, and CI. WC performed well in identifying high-TG, which can be defined as an "excellent" indicator ($0.8 \leq AUC < 0.9$) according to the criteria of Hosmer and Lemesow [48].

There are some limitations to the study. Firstly, the study uses a cross-sectional design, which means that we can only observe correlations between variables and cannot infer causation. Secondly, while the study controlled for common confounders such as age, sex, diet, and exercise, there is still the possibility of other potential confounders that were not accounted for. This may affect our understanding of the relationship between the indicators and abnormal lipid levels.Thirdly, the binary cut-off value is used for lipids, but lipids are continuous variables, which may cause some errors. The study was limited to a population in a specific region, so generalizations to other geographic regions may have some limitations. Results may vary from region to region due to differences in factors such as diet, lifestyle and genetic background.To address these limitations and to more fully assess the role of anthropometric and obesity measures in detecting abnormal lipid levels in young and middle-aged adults, larger, multicenter, multi-year studies are warranted, taking into account more potential confounders, and populations of different ages and geographic regions.

5. Conclusion

This study evaluated the ability of various obesity body measurement indicators to identify and diagnose abnormalities in different blood lipid levels in young and middle-aged people. Among them, WC, AVI, and WHR showed higher predictive accuracy in identifying different types of abnormal lipid levels. This study adds evidence on the ability of each body measurement index to identify and assess different types of dyslipidemia in young and middle-aged people, and provides theoretical support for the effectiveness of early screening for abnormal blood lipid levels. However, the validity of these indicators needs further verification in larger-scale studies

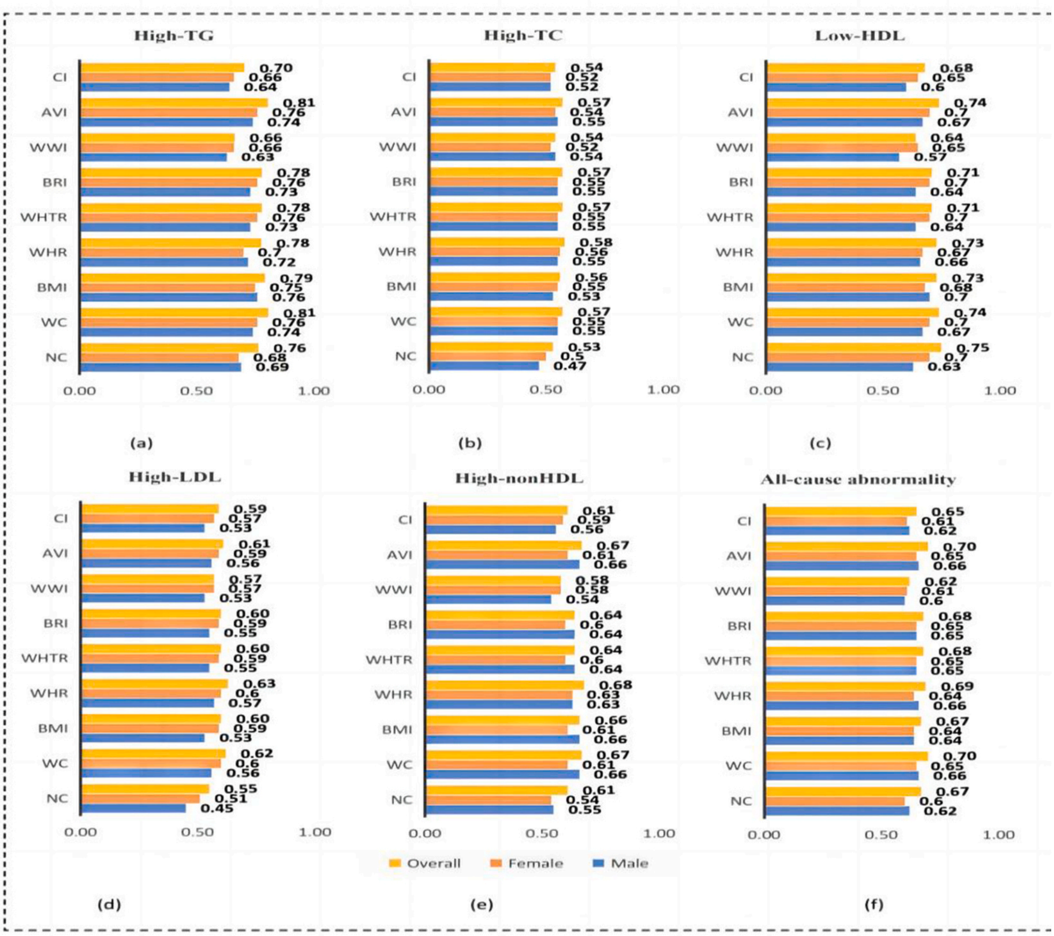

Fig. 3. The capability of various anthropometric/metabolic variables to predict the absence or presence of different forms of dyslipidemia. Bar graphs represent the values for area under the curves from receiver operating characteristic (ROC) curve analysis to determine the predictivecapability of different anthropometric/metabolic parameters for identification of a overall dyslipidemia (irregularity in the plasma levels of TC, TG, HDL, LDL, or non-HDL). Abbreviations: WC,Waist circumference; BMI, body mass index; WHR, Waist-hip ratio; WHtR, Waist height ratio; BRI, Body roundness index; WWI, Weight adjusted waist circumference index; AVI, Abdominal volume index; CI,Cone Index.

with more rigorous designs. In future research, we will explore a wider range of combinations of anthropometric indicators to better distinguish different body compositions and their associated health risks.

Funding

This work was supported by Shanghai Pudong New Area Health Commission Research Project and Research project of Clinical Research Center of Shanghai Health Medical University (Grant numbers [PW2021A-69] and [22MC2022002]). The funding bodies had no role in the study design, data collection, analysis, interpretation of data, or writing the manuscript.

CRediT authorship contribution statement

Xiaoling Zhou: Writing – original draft, Data curation, Conceptualization. **Zuoli Zou:** Writing – original draft, Data curation. **Ying Liu:** Investigation, Data curation. **Yuzhong Yan:** Supervision, Methodology, Conceptualization. **Jing Wu:** Writing – review & editing, Methodology, Conceptualization. **Geyao Zhou:** Supervision, Conceptualization. **Ming Li:** Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e41310.

References

[1] M. Blüher, Metabolically healthy obesity, Endocr. Rev. 41 (3) (2020) bnaa004, https://doi.org/10.1210/endrev/bnaa004.
[2] M. Blüher, Obesity: global epidemiology and pathogenesis, Nat. Rev. Endocrinol. 15 (5) (2019) 288–298, https://doi.org/10.1038/s41574-019-0176-8.
[3] A.J. Berberich, R.A. Hegele, A modern approach to dyslipidemia, Endocr. Rev. 43 (4) (2022) 611–653, https://doi.org/10.1210/endrev/bnab037.
[4] A. Hussain, J. Lian, R. Watts, et al., Attenuation of obesity-induced hyperlipidemia reduces tumor growth, Biochim. Biophys. Acta Mol. Cell Biol. Lipids 1867 (4) (2022) 159124, https://doi.org/10.1016/j.bbalip.2022.159124.
[5] H.E. Bays, P.P. Toth, P.M. Kris-Etherton, et al., Obesity, adiposity, and dyslipidemia: a consensus statement from the National Lipid Association, J Clin Lipidol 7 (4) (2013) 304–383, https://doi.org/10.1016/j.jacl.2013.04.001.
[6] J.B. Moore, Non-alcoholic fatty liver disease: the hepatic consequence of obesity and the metabolic syndrome, Proc. Nutr. Soc. 69 (2) (2010) 211–220, https://doi.org/10.1017/S0029665110000030.
[7] M.İ. Hayıroğlu, F. Şaylık, T. Çınar, et al., Meta-analysis of the current research on the relationship between blood lipid levels and the occurrence of atrial fibrillation, Heart Lung Circ. 32 (10) (2023) 1158–1166, https://doi.org/10.1016/j.hlc.2023.08.006.
[8] F. Şaylık, T. Çınar, M.İ. Hayıroğlu, Effect of the obesity paradox on mortality in patients with acute coronary syndrome: a comprehensive meta-analysis of the literature, Balkan Med. J. 40 (2) (2023) 93–103, https://doi.org/10.4274/balkanmedj.galenos.2022.2022-11-56.
[9] C. Walton, B. Lees, D. Crook, M. Worthington, I.F. Godsland, J.C. Stevenson, Body fat distribution, rather than overall adiposity, influences serum lipids and lipoproteins in healthy men independently of age, Am. J. Med. 99 (5) (1995) 459–464, https://doi.org/10.1016/s0002-9343(99)80220-4.
[10] R. Ross, Advances in the application of imaging methods in applied and clinical physiology, Acta Diabetol. 40 (Suppl 1) (2003) S45–S50, https://doi.org/10.1007/s00592-003-0025-y.
[11] Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults–the evidence report. National institutes of health [published correction appears in obes res 1998 nov;6(6):464], Obes. Res. 6 (Suppl 2) (1998) 51S–209S.
[12] S.A. Mohanty, S. Woolhandler, D.U. Himmelstein, D.H. Bor, Diabetes and cardiovascular disease among Asian Indians in the United States, J. Gen. Intern. Med. 20 (5) (2005) 474–478, https://doi.org/10.1111/j.1525-1497.2005.40294.x.
[13] J. Yang, F. Wang, J. Wang, et al., Using different anthropometric indices to assess prediction ability of type 2 diabetes in elderly population: a 5 year prospective study, BMC Geriatr. 18 (1) (2018) 218, https://doi.org/10.1186/s12877-018-0912-2. Published 2018 Sep. 17.
[14] K.G. Alberti, P. Zimmet, J. Shaw, Metabolic syndrome–a new world-wide definition. A consensus statement from the international diabetes federation, Diabet. Med. 23 (5) (2006) 469–480, https://doi.org/10.1111/j.1464-5491.2006.01858.x.
[15] C. Nishida, G.T. Ko, S. Kumanyika, Body fat distribution and noncommunicable diseases in populations: overview of the 2008 WHO expert consultation on waist circumference and waist-hip ratio, Eur. J. Clin. Nutr. 64 (1) (2010) 2–5, https://doi.org/10.1038/ejcn.2009.139.
[16] D.M. Thomas, C. Bredlau, A. Bosy-Westphal, et al., Relationships between body roundness with body fat and visceral adipose tissue emerging from a new geometrical model, Obesity 21 (11) (2013) 2264–2271, https://doi.org/10.1002/oby.20408.
[17] N. Motamed, D. Perumal, F. Zamani, et al., Conicity index and waist-to-hip ratio are superior obesity indices in predicting 10-year cardiovascular risk among men and women, Clin. Cardiol. 38 (9) (2015) 527–534, https://doi.org/10.1002/clc.22437.
[18] N.Y. Krakauer, J.C. Krakauer, A new body shape index predicts mortality hazard independently of body mass index, PLoS One 7 (7) (2012) e39504, https://doi.org/10.1371/journal.pone.0039504.
[19] T. Alirezaei, H. Soori, R. Irilouzadian, H. Najafimehr, Novel anthropometric indices as screening tools for obesity: a study on healthy Iranians, J Nutr Metab 2023 (2023) 6612411, https://doi.org/10.1155/2023/6612411. Published 2023 Oct 3.
[20] A. Elagizi, S. Kachur, C.J. Lavie, et al., An overview and update on obesity and the obesity paradox in cardiovascular diseases, Prog. Cardiovasc. Dis. 61 (2) (2018) 142–150, https://doi.org/10.1016/j.pcad.2018.07.003.
[21] C. Chandramouli, W.T. Tay, N.S. Bamadhaj, et al., Association of obesity with heart failure outcomes in 11 Asian regions: a cohort study, PLoS Med. 16 (9) (2019) e1002916, https://doi.org/10.1371/journal.pmed.1002916. Published 2019 Sep. 24.
[22] E.A. Silveira, N. Kliemann, M. Noll, N. Sarrafzadegan, C. de Oliveira, Visceral obesity and incident cancer and cardiovascular disease: an integrative review of the epidemiological evidence, Obes. Rev. 22 (1) (2021) e13088, https://doi.org/10.1111/obr.13088.
[23] S.B. Heymsfield, R. Scherzer, A. Pietrobelli, C.E. Lewis, C. Grunfeld, Body mass index as a phenotypic expression of adiposity: quantitative contribution of muscularity in a population-based sample, Int. J. Obes. 33 (12) (2009) 1363–1373, https://doi.org/10.1038/ijo.2009.184.
[24] C.N. Lumeng, A.R. Saltiel, Inflammatory links between obesity and metabolic disease, J. Clin. Invest. 121 (6) (2011) 2111–2117, https://doi.org/10.1172/JCI57132.
[25] P.T. Katzmarzyk, T.V. Barreira, D.M. Harrington, A.E. Staiano, S.B. Heymsfield, J.M. Gimble, Relationship between abdominal fat and bone mineral density in white and African American adults, Bone 50 (2) (2012) 576–579, https://doi.org/10.1016/j.bone.2011.04.012.
[26] D.R. Brenner, K. Tepylo, K.M. Eny, L.E. Cahill, A. El-Sohemy, Comparison of body mass index and waist circumference as predictors of cardiometabolic health in a population of young Canadian adults, Diabetol Metab Syndr 2 (1) (2010) 28, https://doi.org/10.1186/1758-5996-2-28. Published 2010 May 12.
[27] H. Petursson, J.A. Sigurdsson, C. Bengtsson, T.I. Nilsen, L. Getz, Body configuration as a predictor of mortality: comparison of five anthropometric measures in a 12 year follow-up of the Norwegian HUNT 2 study, PLoS One 6 (10) (2011) e26621, https://doi.org/10.1371/journal.pone.0026621.
[28] T. Qiao, T. Luo, H. Pei, et al., Association between abdominal obesity indices and risk of cardiovascular events in Chinese populations with type 2 diabetes: a prospective cohort study, Cardiovasc. Diabetol. 21 (1) (2022) 225, https://doi.org/10.1186/s12933-022-01670-x. Published 2022 Nov 1.
[29] M. Ashwell, P. Gunn, S. Gibson, Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis, Obes. Rev. 13 (3) (2012) 275–286, https://doi.org/10.1111/j.1467-789X.2011.00952.x.
[30] N.Y. Krakauer, J.C. Krakauer, A new body shape index predicts mortality hazard independently of body mass index, PLoS One 7 (7) (2012) e39504, https://doi.org/10.1371/journal.pone.0039504.
[31] L.M. Donini, E. Poggiogalle, Balzo V. Del, et al., How to estimate fat mass in overweight and obese subjects, Internet J. Endocrinol. 2013 (2013) 285680, https://doi.org/10.1155/2013/285680.
[32] M.J. Müller, M. Lagerpusch, J. Enderle, B. Schautz, M. Heller, A. Bosy-Westphal, Beyond the body mass index: tracking body composition in the pathogenesis of obesity and the metabolic syndrome, Obes. Rev. 13 (Suppl 2) (2012) 6–13, https://doi.org/10.1111/j.1467-789X.2012.01033.x.
[33] Su Yingya, Epidemic characteristics of obesity and relationship between obesity measurement indexes and dyslipidemia in rural adults in Haining city, Chinese Journal of Health Inspection 27 (16) (2017) 2389–2392.
[34] Jian Su, Quanyong Xiang, Shurong Lu, et al., Relationship between adult obesity measurement indicators and the prevalence of dyslipidemia in Jiangsu Province, Health Research 44 (5) (2015) 827831, https://doi.org/10.19813/j.cnki.weishengyanjiu.2015.05.026.
[35] Zengwu Wang, Jing Liu, Li Jianjun, et al., Chinese blood lipid management guidelines (2023), Chinese Journal of Circulation 38 (3) (2023) 237–271.
[36] J.H. Butt, M.C. Petrie, P.S. Jhund, et al., Anthropometric measures and adverse outcomes in heart failure with reduced ejection fraction: revisiting the obesity paradox, Eur. Heart J. 44 (13) (2023) 1136–1153, https://doi.org/10.1093/eurheartj/ehad083.

[37] T.M. Quadros, A.P. Gordia, R.C. Silva, L.R. Silva, Predictive capacity of anthropometric indicators for dyslipidemia screening in children and adolescents, J. Pediatr. 91 (5) (2015) 455–463, https://doi.org/10.1016/j.jped.2014.11.006.

[38] K. Kulik-Kupka, M. Jabczyk, J. Nowak, P. Jagielski, B. Hudzik, B. Zubelewicz-Szkodzińska, Fetuin-A and its association with anthropometric, atherogenic, and biochemical parameters and indices among women with polycystic ovary syndrome, Nutrients 14 (19) (2022) 4034, https://doi.org/10.3390/nu14194034. Published 2022 Sep. 28.

[39] F. Xie, Y. Pei, Q. Zhou, D. Cao, Y. Wang, Comparison of obesity-related indices for identifying nonalcoholic fatty liver disease: a population-based cross-sectional study in China, Lipids Health Dis. 20 (1) (2021) 132, https://doi.org/10.1186/s12944-021-01560-3. Published 2021 Oct 10.

[40] Y.L. Chen, P. An, A.P. Wang, et al., Discussion on neck circumference and risk of hyperuricemia, Journal of PLA Medical College 41 (4) (2020), 324-328 +332.

[41] Jiangyun Wang, Jiaxiang Fan, Jie Yang, et al., Analysis of annual changes in blood glucose, lipids, and blood pressure among physical examination population and related factors, Agricultural Reclamation Medicine 45 (1) (2023) 39–44.

[42] Chunmei Gong, Shiqiang Sun, Jichang Zhou, et al., Correlation analysis of body mass index with blood pressure, blood lipid, blood glucose and serum uric acid in 3235 healthy subjects, Prevention and Control of chronic Diseases in China 23 (11) (2015 J) 839–842.

[43] Baohua Bian, Correlation analysis of blood lipids, blood glucose and serum uric acid levels in a university staff and workers, Mod. Prev. Med. (9) (2006) 1573–1574.

[44] Yingya Su, The epidemiological characteristics of adult obesity in rural areas of haining city and the relationship between obesity measurement indexes and blood lipid abnormalities, Chin. J. Health Lab. Technol. 27 (16) (2017) 2389–2392.

[45] Li Linzhong, Hu Xiaoqi, Chaohui Cui, et al., A study on the relationship between obesity-related indicators and blood lipid levels in 9-10-year-old children in urban areas of Beijing, Chin. J. Epidemiol. 28 (8) (2007) 734–737.

[46] Song Lin, Juhong Lu, Hui Song, et al., Relationship between obesity and lipid metabolism among children and adolescents in Yinchuan City, Health Research 43 (5) (2014) 779–783, https://doi.org/10.19813/j.cnki.weishengyanjiu.2014.05.014.

[47] Jian Su, Quanyong Xiang, Shurong Lu, et al., Relationship between adult obesity measurement indicators and the prevalence of dyslipidemia in Jiangsu Province, Health Research 44 (5) (2015) 827–831.

[48] L.Y. ian, S.X. Guo, R.L. Ma, et al., Comparison of obesity-related indicators for identifying metabolic syndrome among normal-weight adults in rural Xinjiang, China, BMC Publ. Health 22 (1) (2022) 1730, https://doi.org/10.1186/s12889-022-14122-8. Published 2022 Sep. 12.