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RESEARCH ARTICLE

Abdominal Obesity Index as an Alternative Central Obesity Measurement During a Physical Examination

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Abstract:

Background:

Although BMI (body mass index) has been widely used to determine whether an individual is underweight, normal weight, overweight, or obese, its clinical usefulness for obesity study has been called into question because it does not specifically describe body fat content and distribution and has limited relevance to central obesity, which is most relevant to health risks. Although imaging techniques are used to determine central obesity, they are expensive and are thus not used in a routine physical examination of patients in medical offices.

Objective:

Developing an easy-to-use ABOI (Abdominal Obesity index) to measure central obesity during a physical examination.

Methods:

ABOI is an index utilized to assess central obesity of patients. To determine ABOI, two measurements are taken from the torso; the outer circumference of the thoracic segment, C_1, at the xiphoid process and the outer circumference of the abdominal segment, C_2, at the point of largest girth. The volume of the abdominal segment is divided by the volume of the thoracic segment to derive ABOI ($V_2/V_1 = [C_2]^2/[C_1]^2$). Thus, ABOI is the square of the ratio of the circumference of the abdominal segment to the circumference of the thoracic segment of the torso. Moreover, the ABOI does not concern total body weight, body height, or body shape (*e.g.* "apple-shaped" or "pear-shaped" body types). Instead, ABOI specifically highlights central obesity. We randomly recruited 282 subjects, ages 20-90 years, at a community health service center in Beijing, China, and determined their ABOI and BMI values.

Results:

The mean (standard deviation) BMI for the female and male subjects is, respectively, 24.24 kg/m2 (3.35) and 24.86 kg/m2 (3.25). For ABOI, mean (standard deviation) is 1.17 (0.16) and 1.01 (0.13) for females and males, respectively. There is no strict relationship between ABOI and BMI in the context of obesity as defined by high BMI values, and ABOI appears to be a more specific measure of central obesity than BMI.

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Conclusion:

ABOI is a useful and distinct independent measurement of central obesity, and ABOI (possibly in combination with the waist-to-height ratio) appears to be a more specific way to assess central obesity during a physical examination.

Keywords: Obesity, Central Obesity, Abdominal Fat, Physical examination, BMI, ABOI.

1. INTRODUCTION

Obesity has reached epidemic proportions in the developed world. According to a 2016 study, approximately 35.0% of men and 40.4% of women in the US were considered obese in 2013-2014 [1]. Obesity, and more specifically, central obesity that and refers to an excess fat deposit within the abdominal cavity, is associated with a myriad of health problems [2]. Central obesity has been linked to hypercholesterolemia, high blood pressure, type 2 diabetes, coronary artery disease, and other health concerns [3 - 9].

Although it was not originally invented as a measurement for obesity, BMI has been widely used as an easy method to determine whether individuals are underweight, normal weight, overweight or obese. BMI is calculated by dividing the body weight by the square of body height and is expressed in units of kg/m^2. According to WHO guidelines, individuals with BMI values less than 18.5 kg/m^2 are considered underweight, individuals with BMI values of 18.5-24.9 kg/m^2 are considered normal, individuals with BMI values of 25-29.9 kg/m^2 are considered overweight, and individuals with BMI values of 30 kg/m^2 or higher are considered obese. In general, individuals with BMI values in the ranges of overweight and obese are considered at increased health risks. However, BMI is neither specific nor the most sensitive parameter for measuring body fat content and distribution. For example, muscular athletes may have higher BMI due to the presence of higher amounts of muscle mass, but this should not necessarily define them as obese [10]. Furthermore, individuals with normal BMI values can in fact have high abdominal fat content and increased cardiovascular risks [7 - 9]. In recent studies, a significant number of individuals with a normal BMI are actually found to be at higher risks for cardiovascular complications based on clinical evaluations. This is most likely due to the fact that these individuals have excessive visceral fat in their abdominal cavity [7 - 9]. In contrast, although some individuals with a BMI between 30 and 35 kg/m^2 are considered to have grade-1 obesity, their BMI values are not significantly linked to a higher mortality rate [11]. Therefore, BMI alone is not a reliable way of identifying people at an increased risk for health problems associated with obesity, and thus its clinical usefulness has been called into question [12, 13].

Visceral fat deposit in the abdominal cavity can be accurately measured by Computed Tomography (CT), or Magnetic Resonance Imaging (MRI), or Dual-Energy X-ray Absorptiometry (DEXA) techniques. However, these techniques are not readily available in medical offices, costly and not cost-effective in routine physical examinations. Thus, an alternative, easy-to-use measurement for routine clinical examination for central obesity is needed. Currently, the most common easy-to-use measurement for central obesity by clinicians and researchers is the Waist-to-Hip Ratio (WHR), which can be used alone or in conjunction with BMI for indexing people with obesity and health risks [9, 14]. According to WHO guidelines [15], the waist circumference is measured at approximately the midpoint between the lower margin of the last palpable rib and the top of the iliac crest. The hip circumference is a measurement of the widest portion of the buttocks. The importance of WHR is underscored by findings showing that patients with normal BMI and high WHR have increased mortality rates when compared to patients with obesity as defined by BMI alone [9, 14]. These patients with normal BMI's, but high WHR values, also showed mortality rates higher than patients with high BMI without central obesity [9, 14]. However, WHR values may either underestimate or overestimate obesity for individuals with certain body shapes. The "pear-shaped" body type is due to a preponderance of fat in the hips and the WHR values of individuals with "pear-shaped" body type are likely to underestimate the degree of central obesity. On the other hand, the "apple-shaped" body type is typically due to a preponderance of fat in the waist. These individuals will have higher WHR values that may overestimate the degree of central obesity.

We developed ABOI as an alternative, easy-to-use measurement for central obesity. To conceptualize ABOI, the torso is viewed as a cylinder being compressed from the ventral and dorsal sides (Fig. **1**). Additionally, this cylinder is divided into a thoracic segment and an abdominal segment. The caudal base of the thoracic segment is a transverse plane bisecting the body at the xiphoid process. The caudal base of the abdominal segment is a transverse plane that bisects the body at the iliac crest. The xiphoid process is a prime point of measure for the thoracic cavity because of its location. The xiphoid process is optimal for avoiding fat deposition of the breasts. In the calculation of the volume of these cylindrical segments and for practical purposes, we can assume that the heights (h) of the thoracic segment and the abdominal segment are the same.

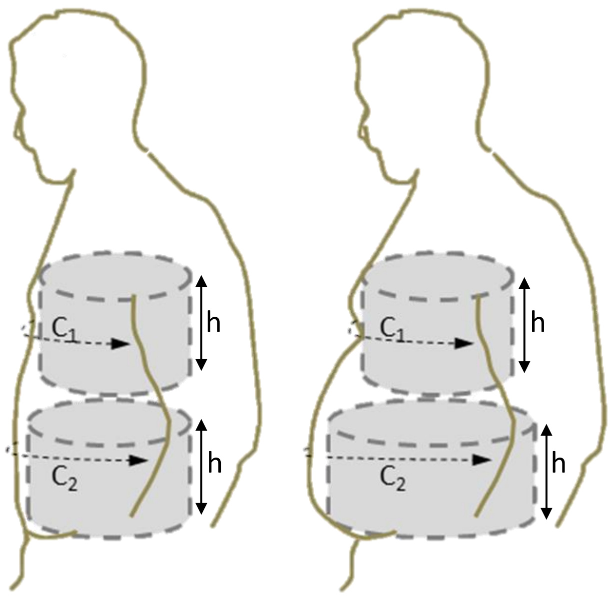

Fig. (1). Abdominal Obesity index (ABOI) and central obesity. The upper body cavity cylinder can be divided into the abdominal segment and the thoracic segment. C_1 and C_2 represent the circumferences of the thoracic segment and abdominal segment, respectively. To simplify the calculation of volumes, the heights (h) of the thoracic segment and the abdominal segment are considered the same. The volume of thoracic segment = $h \cdot 2\pi r^2$ in which r = ½C_1 and the volume of the abdominal segment = $h \cdot 2\pi r^2$ in which r = ½C_2. = ABOI = $[C_2]^2/[C_1]^2$. Generally, the larger the ABOI is, the more severe the central obesity is.

To determine ABOI, two measurements are taken from an individual in two anatomical positions. The first is the outer circumference of the thoracic segment, C_1, at the xiphoid process. The second is the outer circumference of the abdominal segment, C_2, at the point of largest girth. The volumes of both segments and the value of ABOI can then be easily calculated according to the following formulas:

$$\text{The volume of thoracic segment, } V_1 = h \cdot \pi r^2 \text{ in which } r = ½C_1 \quad \textbf{(1)}$$

$$\text{The volume of abdominal segment, } V_2 = h \cdot \pi r^2 \text{ in which } r = ½C_2 \quad \textbf{(2)}$$

$$\text{ABOI} = V_2/V_1 = [C_2]^2/[C_1]^2 \quad \textbf{(3)}$$

In individuals without central obesity, C_1 and C_2 values are more or less similar and hence their ABOI values are around 1.0. The value of C_1 of a lean individual with a wide chest and a thin waistline (*e.g.* that of a male swimmer) is most likely larger than the value of C_2, and thus, ABOI is likely to be less than 1.0. In cases of central obesity, an excess accumulation of visceral fat will result in a C_2 value larger than the C_1 value (Fig. **1**), and consequently, the ABOI value is greater than one.

The advantage of using ABOI is that it does not concern total body weight, body height, or body shape (*e.g.* “apple-shaped” or “pear-shaped” body types) according to equation (3). Instead, ABOI specifically highlights central obesity.

2. SUBJECTS AND METHODS

2.1. Participants

We received institutional approval before moving forward. Patients who came to Yuetan Community Health Service Center of Fuxing Hospital, Xicheng District, Beijing, China for routine physical examinations were asked to participate in the ABOI study. Subject age and gender were recorded. A total of 282 subjects, ages 20 to 90 years, gave their consent to participate in this study after they had been informed about purpose of this study. There were 185 female subjects (ages 23 to 88) and 97 male subjects (ages 20 to 90).

2.2. Measurements

Participants came to the health center after an overnight fast. Body weight (to the nearest 0.1 kg), height (to the nearest 0.1 cm) and BMI were determined, while the subject was standing with feet about 25-30 cm apart. To determine ABOI, the outer circumference of the thoracic segment, C_1, was measured at the xiphoid process, and the outer circumference of the abdominal segment, C_2, was measured at the point of largest girth. Each measurement was taken twice (to the nearest 0.1 cm) with a measurement tape that was snugly around the positions without compressing the underlying soft tissue. The mean value was used to determine ABOI according to the equation (3). The results were calculated, and the data was subjected to linear regression analysis. It should be noted that the C_2 value is equivalent to the waist circumference as defined by WHO [15] and thus the ratio of C_2/body height represents Waist to Height Ratio (WHR).

3. RESULTS

Fig. (**2**) shows the distributions of BMI and ABOI in correlation with ages for both female and male participants. The mean BMI for females is 24.24 kg/m^2 with a standard deviation of 3.35; the mean BMI of males is 24.86 kg/m^2 with a standard deviation of 3.25. The mean ABOI for females is 1.17 with a standard deviation of 0.16; the mean ABOI of males is 1.01 with a standard deviation of 0.13. Thus, the mean ABOI of females is approximately 10% larger than that of males. Based on the *p* values, there is no significant correlation between age and BMI or age and ABOI in males (Fig. **2**), but there does appear to be an age-associated increase in both BMI and ABOI in the female participants, especially those ages 50 or older (Fig. **2**). This aging-associated increase in ABOI of our female participants is in agreement with a recently published study, which used DEXA scan analysis to show an increase in fat mass and central obesity associated with menopause in a significant number of Chinese women [16]. Given that a BMI of 24.0-24.9 kg/m^2 was associated with the lowest health risks for Chinese women and men ages 40 years or older [17], and the mean ABOI values of female and male subjects were 1.17 and 1.01, respectively (Fig. **2**), we also grouped female and male participants into different age groups for statistical analysis. Group 1: BMI less than 25 kg/m^2 and ABOI less than the mean ABOI value; Group 2: BMI less than 25 kg/m^2 and ABOI larger than the mean ABOI value; Group 3: BMI larger than 25 kg/m^2 and ABOI less than the mean ABOI value; Group 4: BMI larger than 25 kg/m^2 and ABOI larger than the mean ABOI value. All young female subjects (ages 23-38), except one, have BMI less than 25 kg/m^2 and ABOI less than the mean value (Fig. **3A**). The exceptional subject has a BMI of 30 kg/m^2 and has severe central obesity and thus a rather large ABOI value of 1.89. Based on their ABOI and BMI values, the female subjects ages 40 or older can be divided into 4 groups (Figs. **3B**, **C**, **D**). The male subjects, young and old, can also be divided into different age groups (Fig. **4**). Overall, the variable scattering of points in Figs. (**3** and **4**) clearly indicate that there is no strict relationship between ABOI and BMI values. Furthermore, when we looked at the ABOI values of both female and male participants with obesity, as defined by a BMI value greater than or equal to 30 kg/m^2, we found no strict relationship between BMI and ABOI (Table **1**). These results collectively indicate that ABOI and BMI are independent from each other, as expected by their mathematic presentations.

Table 1. ABI of Individuals with obesity as defined by BMI>30 kg/m^2.

Female				Male			
Subject	Age (years)	BMI (kg/m^2)	ABOI	Subject	Age (years)	BMI (kg/m^2)	ABOI
1	33	30	1.89	1	52	30	1.00
2	55	30	1.11	2	62	30	1.02
3	63	30	1.33	3	64	30	1.34
4	63	30	1.30	4	68	30	1.22
5	68	30	1.06	5	67	31	0.95
6	78	31	1.27	6	83	31	1.10
7	77	31	1.23	7	67	32	1.04
8	54	32	0.98	8	62	32	1.09
9	56	32	1.27	9	77	34	1.17
10	60	33	1.14	-	-	-	-
11	68	33	1.27	-	-	-	-
12	51	38	1.35	-	-	-	-

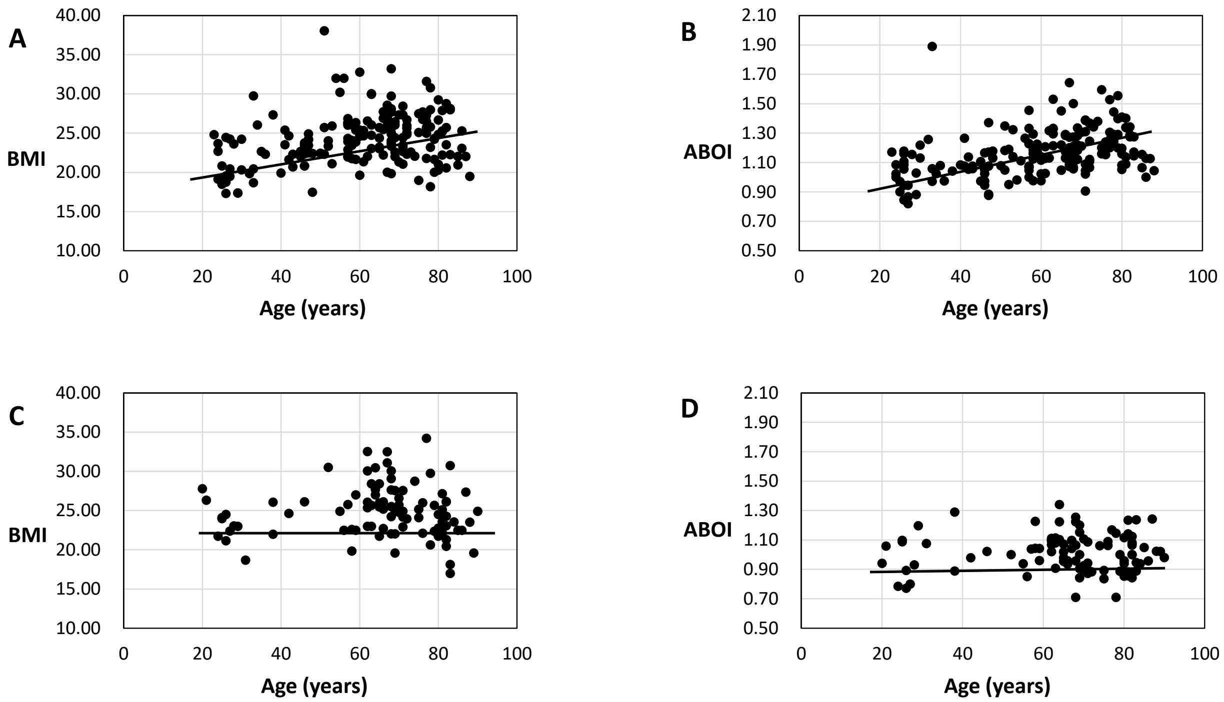

Fig. (2). BMI and ABOI of female and male subjects of different ages. The ages of female subjects in this study were 23-88 years and the ages of male subjects 20-90 years. **A**) Female BMI vs age with mean BMI of 24.14 and a standard deviation of 3.35 (r^2 = 0.106, $p < 0.001$). **B**) Female ABOI vs age with mean ABOI of 1.17 and a standard deviation of 0.16 (r^2 = 0.162, $p < 0.001$). **C**) Male BMI vs age with mean BMI of 24.86 and a standard deviation of 3.25 (r^2 = 0.0001, $p < 0.726$). **D**) Male ABOI vs age with mean ABOI of 1.01 and a standard deviation of 0.13 (r^2 = 0.003, p = 0.670).

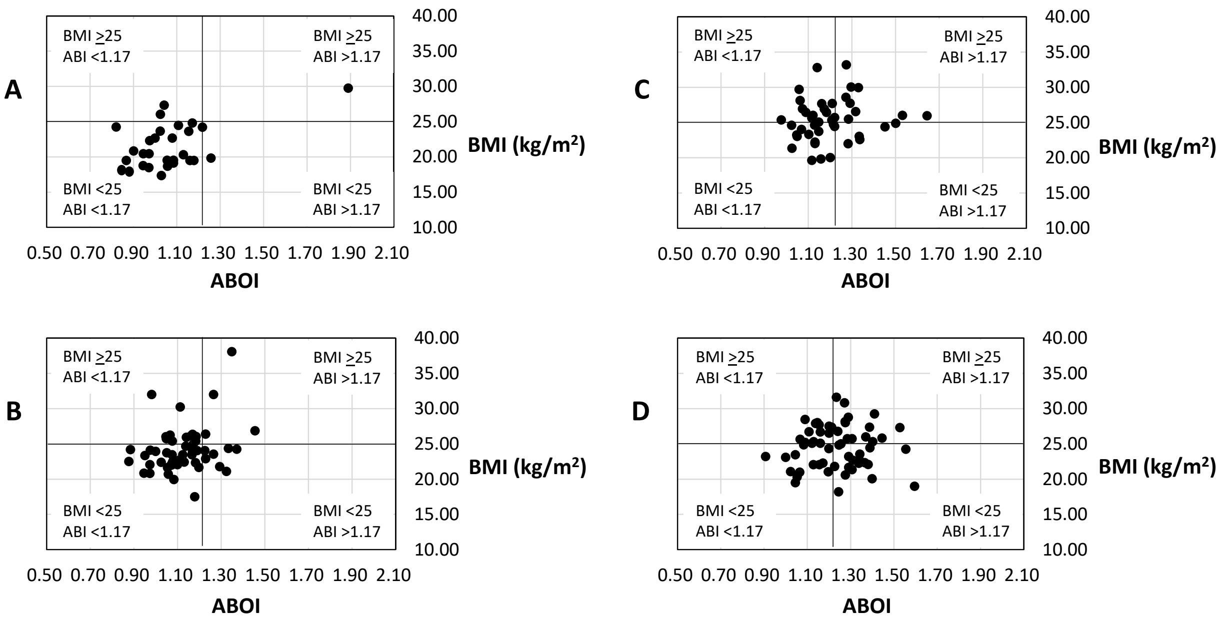

Fig. (3). ABOI versus BMI of female subjects of different age groups. The ABOI values of subjects are plotted against their BMI values. The mean ABOI of the entire female cohort was 1.17 (the position is marked by the vertical line) according to the data in Fig. (**2**). BMI higher than 25 was considered high and unhealthy. **A**) Ages 23-38 years (p = 0.0036). **B**) Ages 40-59 years (p value = 0.064). **C**) Ages 60-69 (p = 0.260). **D**) Ages 70-88 years (p = 0.732).

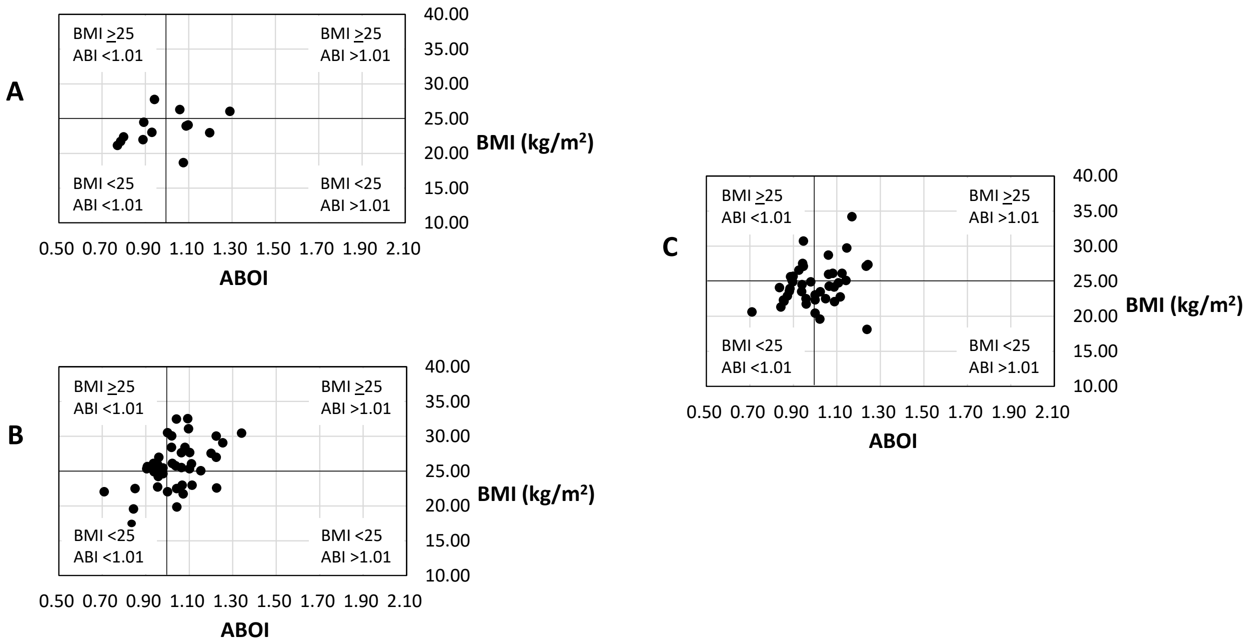

Fig. (4). ABOI versus BMI of male subjects of different age groups. The ABOI values of subjects are plotted against their BMI values. The mean ABOI of the entire male cohort was 1.01.

Given that WHtR is clearly a better risk indicator than BMI for hypertension, diabetes and dyslipidemia in different ethnic populations, including East Asians [18 - 21], we calculated the WHtR of our subjects using the ratio of C_2/body height. The mean WHtR for the females is 0.61 with a standard deviation of 0.054; the mean WHtR of the males is 0.56 with a standard deviation of 0.057. We next plotted the WHtR values against the ABOI values. The results showed that the R^2 value for WHtR versus ABOI in the female cohort was 0.2831 with a less than 0.01 p-value, suggesting a statistically significant 28% correlation between WHtR and ABOI. The R^2 value for WHtR versus ABOI in the male cohort was 0.4628 with a less than 0.01 p-value, suggesting a statistically significant 46% correlation between WHtR and ABOI. These results showed that correlation between WHtR and ABOI is not 100% and varies with gender. However, future studies involving a much larger population are required for a definitive conclusion. Since it was estimated that the optimal WHtR cut-off value is 0.5 [18 - 21], and the mean ABOI values of the female and male subjects in our study were 1.17 and 1.01, respectively (Fig. **2**), our subjects were easily categorized into two main sub-groups according to their WHtR and ABOI values: those with larger than 0.5 WHtR and above mean ABOI and those with larger than 0.5 WHtR and below the mean ABOI (Fig. **5**). These results suggest that combined use of WHtR and ABOI may be clinically useful for stratifying and indexing patients into subgroups.

4. DISCUSSION

Pertinent to the clinical potential of ABOI is a recent finding showing that BMI is a poor measurement of obesity in the elderly, due to an age-associated increase in fat mass and decrease in muscle mass [22]. Although ABOI alone does not concern an individual's total body weight and muscle mass, our study suggests that ABOI may be a particularly useful and distinct independent measurement of central obesity in elderly female and male subjects (Figs. **3** and **4**). Unfortunately, the number of elderly subjects in this study is rather small, and while the above assertion makes sense theoretically, a stronger assertion cannot be made without a larger dataset.

It is interesting to note that there is a statistically significant correlation between ABOI and WHtR and that the correlation varies according to gender (Fig. **5**). It has been demonstrated in different ethnic populations, including adult Chinese populations, that WHtR larger than 0.5 is a risk factor for hypertension and diabetes [18 - 21]. Therefore, it is interesting to note that very few subjects in our cohort have a WHtR smaller than 0.5 (Fig. **5**). Unfortunately, we did not have information about specific health stats, such as hypertension, diabetes and dyslipidemia, of the subjects. However, our subjects fall into two main groups: those with larger than 0.5 WHtR and above mean ABOI and those with larger than 0.5 WHtR and below the mean ABOI (Fig. **5**). Nevertheless, future studies are needed to assess the clinical usefulness of combining WHtR and ABOI to stratify and index individuals into subgroups for the assessment of their risks for cardiovascular diseases, diabetes, and dyslipidemia.

In the future, we would like to validate the relationship between ABOI and central obesity by comparing the ABOI values of individuals with visceral fat quantification using imaging modalities. In addition, we would like to investigate the relationship between visceral fat content and both ABOI and WHtR, as well as the combined use of ABOI and WHtR as a tool for indexing individuals to predict health risks. Moreover, we would like to carry out longitudinal prospective cohort studies to assess the predictive values of ABOI, ABOI in relation to BMI, and ABOI in relation to WHtR on risks for type 2 diabetes, cardiovascular diseases, and overall morbidity and mortality. Such studies will allow the determination of more precise upper cut-off values of ABOI and WHtR for central obesity and health risks and mortality.

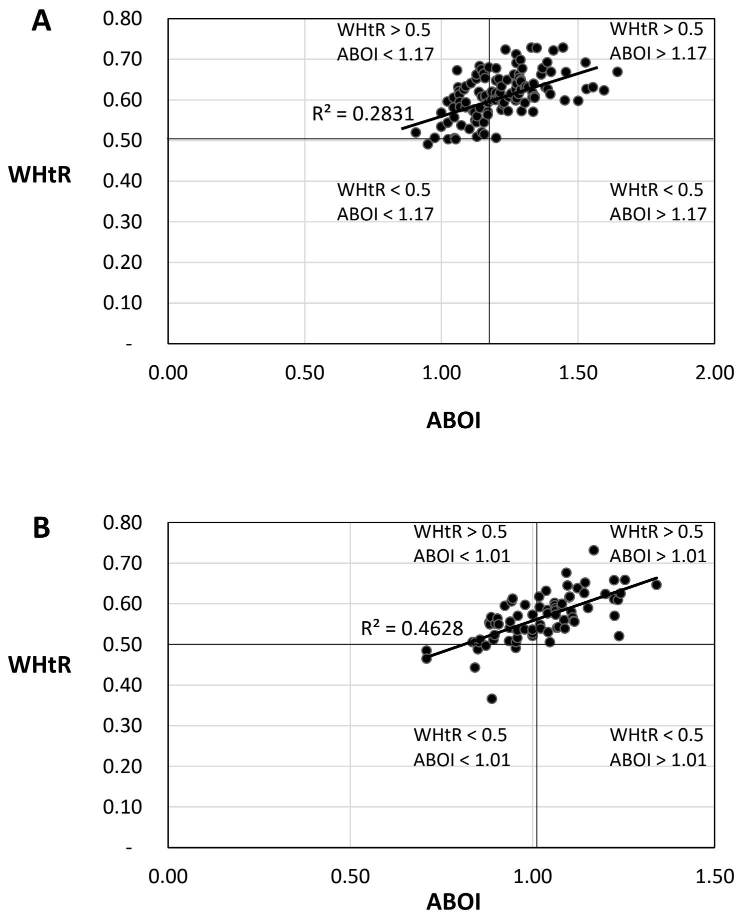

Fig. (5). ABOI *versus* WHtR of female and male subjects. The ABOI versus WHtR in (**A**) females and (**B**) males. The R^2 values are shown in the graphs and the p value for both (A) and (B) is < 0.01. The mean ABOI of the entire female cohort was 1.17 (the position is marked by the vertical black line) according to the data in Fig. (**2**). The mean ABOI of the entire male cohort was 1.01 (the position is marked by the vertical black line) according to (Fig. **2**).

One limitation of ABOI is that it is likely to underestimate central obesity in individuals with severe obesity. For these individuals, fat accumulation is more than likely to have progressed beyond the abdomen into the thoracic region, resulting in an increase in not only C_2 but also C_1 and thus a misleading ABOI value. However, such individuals should still have an ABOI that is significantly larger than 1.0, given that the rib cage should limit how much the expansion of the thoracic volume can take place. Perhaps in these individuals, an excessively large C_2 measurement by itself is enough evidence to show central obesity. The second limitation is a lack of direct visceral fat measurement using imaging techniques due to a lack of funds. Currently, we are seeking funds to use imaging techniques, such as Dual Energy X-ray Absorptiometry Scan (DEXA) and Magnetic Resonance Imaging (MRI), to quantitatively study the relationship between ABOI and visceral fat content in individuals [5, 6, 10, 23]. The third limitation of our study lies in the size of study population. We regard our calculations with our data set to be preliminary in nature, primarily focused on supporting the mathematical logic behind the concept of ABOI and the distinctness of the measurement from BMI rather than attempting to show clinical correlates. That said, we recognize the inherent limitations of using an ethnically homogenous population from a limited area in China. Particularly since there have been several studies demonstrating a difference in body build and muscularity in individuals of Chinese descent that has a significant effect on BMI measurements and BMI's effectiveness as a clinical tool in these populations [24, 25]. In the future, we would like to acquire ABOI data from a more ethnically diverse population and ideally include clinical correlates over time.

CONCLUSION

In comparison to BMI, ABOI appears to be a more specific way to assess central obesity of patients during a routine physical examination, and moreover, the combined use of ABOI and WHtR may be more useful for indexing patients for central obesity and predicting health risks. We hope that other investigators will include ABOI measurements in their investigations on central obesity, helping to assess ABOI's clinical value and utility.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Institutional approval from Yuetan Community Health Service Center of Fuxing Hospital, Xicheng District, Beijing, China was received.

HUMAN AND ANIMAL RIGHTS

Animals did not participate in this research. All human research procedures followed were in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2008.

CONSENT FOR PUBLICATION

Relevant data from each patient were obtained and recorded on special form.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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