

## Comparison of body fat estimation using waist:height ratio using different 'waist' measurements in Australian adults

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The objective of the present study was to determine differences in predicting total and regional adiposity using the waist:height ratio (WHtR) calculated using different 'waist' measurements. Body composition of ninety-five males and 121 female Australian adults (aged 20 years and above) was measured using dual-energy X-ray absorptiometry. The WHtR was calculated using: (1) the narrowest point between the lower costal border and the top of the iliac crest (WHtR-W), and (2) at the level of the umbilicus (WHtR-A). Relationships between calculated WHtR and measured body composition, such as percentage body fat (%BF) and percentage trunk fat (%TF) were determined. Values obtained from WHtR-A were significantly greater than WHtR-W in both groups ( $P < 0.05$ ). While no correlation differences between WHtR-W and WHtR-A in relation to body composition variables were observed, females showed significantly lower correlation with lean mass compared with BMI. Regression analyses showed that neither WHtR had an age influence on %TF estimation. Estimated %BF and %TF were comparable for both WHtR and also with estimated values using a BMI of 25 kg/m<sup>2</sup>. Sensitivity of excess %BF and %TF increased by using WHtR-A, particularly in females. In conclusion, the umbilicus measurement may be better than using the narrowest site in the WHtR calculation, particularly in females. To improve the screening ability of the WHtR and make comparisons between studies easier there may be a need to standardise the measurement location. Further studies are recommended to confirm the findings across different ethnic groups.

**Waist:height ratio: Percentage body fat: Percentage trunk fat: Waist circumference**

Being overweight or obese is a contributing factor to the metabolic syndrome<sup>(1,2)</sup>, increases the risk of CVD, type 2 diabetes mellitus, and also a number of cancers<sup>(3–5)</sup>. Previous studies have suggested that individuals with a large accumulation of body fat in the abdominal region are at greater risk of development of the metabolic syndrome<sup>(6–8)</sup>.

Waist circumference (WC) is a clinically viable technique that has been employed to determine abdominal fat deposition<sup>(9–11)</sup>. While WC cannot provide a precise quantification of fat deposition in the region, it is time- and cost-efficient and positively correlated with visceral abdominal fat accumulation obtained from both magnetic resonance imaging and computer tomography (CT) scans<sup>(12–14)</sup>. However, because WC is an absolute value, the measurement is affected by the size of trunk which varies according to age, sex and ethnicity<sup>(15)</sup>. Although WC has been accepted by international organisations such as the International Diabetes Federation as a diagnostic criteria of metabolic complications<sup>(1)</sup>, its cut-off values are not always applicable to the entire population (for example, to children with possible metabolic syndrome risks). In addition, 'waist' circumference has a number of

different definitions, including 'the halfway point between the lower border of the ribs and the iliac crest'<sup>(10)</sup>, 'at the narrowest point between the lower costal (10th rib) border and the top of the iliac crest'<sup>(16)</sup>, and 'at the level of umbilicus' (which is more appropriately classified as the abdominal circumference (AC))<sup>(17)</sup>. The presence of multiple definitions of the WC provides for both inconsistencies in the measurement protocol and subsequent difficulty in comparisons between studies. A recent study reported that the 'waist' measurement taken at the narrowest point reflects CVD risks better compared with at the umbilicus level in females<sup>(18)</sup>. However, the study showed no significant correlation differences between 'waist' sites and the vast majority of metabolic biomarkers as well as visceral adipose tissue (VAT) obtained from CT. This indicates a further need to determine if either 'waist' site is superior to the other, in order to standardise the 'waist' measurement protocol.

As an alternative to the WC, the waist:height ratio (WHtR; waist (cm)/height (cm); also called the index of central obesity) has been suggested as a potentially useful index to determine abdominal fat deposition<sup>(19–22)</sup>. As the WHtR

**Abbreviations:** AC, abdominal circumference; %BF, percentage body fat; CT, computer tomography; DEXA, dual-energy X-ray absorptiometry; %TF, percentage trunk fat; VAT, visceral adipose tissue; WC, waist circumference; WHtR, waist:height ratio; WHtR-A, waist:height ratio using abdominal circumference; WHtR-W, WHtR using waist circumference.

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adjusts for the height of an individual it has been suggested that the same cut-off point can be used to screen for health risks in different populations that vary in age and sex<sup>(23,24)</sup>. Previous studies using blood assays have suggested that the cut-off point of 0.5 may be appropriate to determine metabolic complications in both adults and children<sup>(21,22,25–28)</sup>. On the other hand, studies that examined a relationship between WHtR and actual body composition of the study groups are limited<sup>(22,29)</sup>. Furthermore, there has been no study that determined the impact of using different WC procedures in the calculation of the WHtR. For overweight and obese individuals who are at greater metabolic complication risks, WC using some definitions may be inappropriate as it is common to have no identifiable narrowing in their trunk. If the WHtR has the potential to be used as a universal screening method for abdominal obesity there is a need to determine the most appropriate WC site that best reflects one's body composition as indicated in percentage body fat (%BF) and abdominal fat values in each sex.

The present study aimed to compare WHtR values obtained using two commonly used WC measurement approaches and their relationships with total body and trunk fat deposition using a dataset of Australian adults whose body composition was measured by dual-energy X-ray absorptiometry (DEXA). The present study used trunk fat instead of abdominal fat or VAT. This is because trunk fat is also associated with a number of metabolic biomarkers, such as TAG and cholesterol in both adults and children<sup>(30,31)</sup>, indicating its usefulness in assessing risk of obesity-related metabolic complications associated with abdominal obesity. Also, trunk fat can be assessed by DEXA, a more convenient and economical method compared with VAT assessed using CT or magnetic resonance imaging. Therefore, clarification of the relationship between WHtR and trunk fat accumulation, as well as its association with %BF, may increase the future application of WHtR in prevention strategies.

## Methods

A body composition database of adult Australian males ( $n$  95) and females ( $n$  121) aged above 20 years was used in the present study. Participants were volunteers who participated in body composition assessment studies using DEXA at the School of Human Movement Studies, Queensland University of Technology. Overweight and obese individuals were also included if they were not medicated and had no medical history that influenced their daily lifestyle including diet and physical activity levels. Studies were approved by the Human Research Ethics Committee of Queensland University of Technology and adhered to the principles of medical research established by the National Health and Medical Research Council<sup>(32)</sup>. Each participant signed a written informed consent form in which the purpose of the study was explained and the confidentiality of results guaranteed.

### Dual-energy X-ray absorptiometry

The DEXA method is based on a three-compartment model that differentiates bone, lean and soft tissues from attenuation of two X-ray beams. The method provides consistent results with other commonly used techniques and is considered as

one of the reliable methods to estimate %BF<sup>(33–36)</sup>. Whole-body and trunk lean and fat tissues were determined using DEXA measures (DPX-L; Lunar Radiation Corp., Madison, WI, USA). All scans were analysed with ADULT software, version 3.6 (Lunar Radiation Corp.) which provides the total mass, ratio of soft tissue attenuations, and bone mineral mass for the isolated regions. The ratio of soft tissue attenuation for each region was used to divide bone mineral-free tissue of the extremities into fat and lean components. From the obtained values, fat and lean mass in the trunk region and %BF were determined. In addition, the proportion of fat in the trunk region (%TF = trunk fat/(trunk lean + trunk fat)  $\times$  100) was calculated to determine sex differences in fat accumulation pattern. All measurements were conducted at the School of Human Movement Studies, Queensland University of Technology, by an accredited technician.

### Anthropometry

Anthropometric measurements included in the analyses were height, weight and three circumferences (waist, abdominal and hip). WC was measured at the narrowest point between the lower costal border and the top of the iliac crest. AC was measured at the level of the umbilicus and the hip circumference was measured at the greatest posterior protuberance. From the anthropometric measurements, BMI and WHtR using WC (WHtR-W) and AC (WHtR-A) were calculated. In addition, hip circumference measurements were used to compare sex differences in fat distribution pattern.

All statistical analyses were conducted using the SPSS (version 14.0.0, 2005; SPSS, Inc., Chicago, IL, USA) statistical package. The independent  $t$  test was used to assess sex differences in body composition. Relationships between body composition obtained from DEXA and WHtR using different 'waist' values were assessed using Spearman's correlation coefficients. Observed correlation coefficients were compared using a test for equal correlations, which is a ratio that uses Fisher's  $Z$  transformation in the numerator and the square root of the sum of the variances in the denominator<sup>(37)</sup>. The generalised linear modelling analyses were conducted using %BF and %TF as dependent variables, sex as a fixed factor, BMI, WHtR using different 'waist' measures and age as covariate factors. Results were presented together with adjusted  $R^2$  ( $R^2_{\text{adj}}$ ) and standard error of estimates. In addition, cross-tabulation was conducted in order to determine sensitivities and specificities of each index using %BF and %TF values using 20% for males and 30% for females as cut-off points. The cut-off points were decided based on a previous study that stated that proliferation of adipose tissue cells begins at these values in adults<sup>(38)</sup> and a study that indicated the possible comparability between %TF and %BF of individuals<sup>(29)</sup>.

## Results

Results of body composition assessments using DEXA and anthropometry are shown in Table 1. While males were significantly ( $P < 0.01$ ) greater in body size (i.e. height and body mass) and upper-body circumferences (i.e. waist and umbilicus), females displayed significantly greater body fat deposition (%BF and %TF). Both sexes showed significant differences in WC and AC values ( $P < 0.01$ ) but females

**Table 1.** Physical characteristics of male and female subjects† (Mean values, ranges and standard deviations)

	Males (n 95)			Females (n 121)		
	Mean	Range	SD	Mean	Range	SD
Age (years)	47.1	25–64	10.5	44.2	20–64	10.9
Height (cm)	177.9	159.0–192.0	7.4	165.1*	150.0–187.0	6.1
Body mass (kg)	87.7	62.2–120.8	13.3	73.1*	47.6–111.6	13.7
BMI (kg/m <sup>2</sup> )	27.7	19.9–36.1	3.8	26.8	17.7–39.8	4.7
Waist circumference (cm)	95.4	73.2–124.0	11.0	83.0*	63.0–128.0	11.1
Abdominal circumference (cm)	98.4	78.0–128.0	10.9	89.6*	63.5–128.0	12.4
Hip circumference (cm)	104.9	81.0–123.0	7.3	106.1	78.0–133.0	10.6
WHtR-W	0.54	0.42–0.72	0.06	0.50*	0.37–0.71	0.07
WHtR-A	0.55	0.43–0.72	0.06	0.54	0.40–0.82	0.08
%BF using DEXA (%)	28.3	7.5–46.5	8.1	38.6*	19.0–55.0	8.3
%TF (%)	30.7	7.1–50.2	9.2	36.8*	15.3–53.1	9.0

WHtR-W, waist:height ratio using waist circumference; WHtR-A, waist:height ratio using abdominal circumference; %BF, percentage body fat; DEXA, dual-energy X-ray absorptiometry; %TF, percentage trunk fat.

\* Mean value is significantly different from that for males ( $P < 0.01$ ).

† For details of procedures, see Methods.

showed greater difference between the two circumferences (6.6 cm) compared with males (3.0 cm). Males also showed significantly ( $P < 0.01$ ) greater WHtR-W compared with females but no sex difference was observed in BMI or WHtR-A. In the present study 71.6% of males and 60.3% of females had BMI values equal or greater than 25 kg/m<sup>2</sup>. Also 71.6% of males and 50.4% of females had WHtR-W equal or greater than 0.5. Using WHtR-A, this proportion increased to 82.1% in males and 70.2% in females.

Table 2 presents a comparison of the WHtR values obtained from WC and AC as well as correlations between anthropometric indices (i.e. WHtR and BMI) and body composition results obtained from DEXA. A comparison of two WHtR values showed that the WHtR values calculated from AC were significantly ( $P < 0.05$ ) greater than the values for WC in both sexes and the difference was greater in females. Both BMI and WHtR using different 'waist' circumferences correlate significantly ( $P < 0.05$ ) with body composition variables in both sexes. Although no significant differences in

correlations were obtained from WHtR-A and WHtR-W in both sexes, males tended to show greater correlations using WHtR-A compared with WHtR-W and the reverse was evident in females. Males showed significant ( $P < 0.05$ ) correlation differences between BMI and WHtR only for body mass, whereas females showed significant ( $P < 0.05$ ) differences for body mass, trunk fat mass and %BF. The study also showed lower correlations with trunk and total lean mass in WHtR compared with BMI in both sexes and correlations obtained from BMI and WHtR-A were significantly ( $P < 0.05$ ) different in females (trunk lean mass:  $r_{(BMI)}$  0.499,  $r_{(WHtR-A)}$  0.276; total lean mass:  $r_{(BMI)}$  0.537,  $r_{(WHtR-A)}$  0.229). The results may indicate that WHtR is a good 'fat-sensitive' index and may be a useful screening tool.

The relationships between body composition variables such as %BF and %TF, and anthropometric indices such as BMI and WHtR using different 'waist' measurements were determined using the generalised linear modelling analyses (Table 3). Although  $R^2_{adj}$  observed from the prediction

**Table 2.** Associations between body composition results and waist:height ratio (WHtR) and BMI of male and female subjects§ (Mean values and standard deviations for Results and Spearman's correlation coefficients)

Results	Males (n 95)						Females (n 121)					
	WHtR-W		WHtR-A		BMI (kg/m <sup>2</sup> )		WHtR-W		WHtR-A		BMI (kg/m <sup>2</sup> )	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	0.54*	0.06	0.55	0.06	27.7	3.8	0.50*	0.07	0.54	0.08	26.8	4.7
Body mass	0.704††		0.704††		0.842†		0.742††		0.671††		0.918†	
Trunk fat mass	0.849†		0.887†		0.898†		0.856††		0.802††		0.923†	
Trunk lean mass	0.298†		0.218†		0.416†		0.392†		0.276††		0.499†	
Total lean mass	0.171		0.115		0.329†		0.341†		0.229†		0.537†	
Percentage body fat	0.738†		0.821†		0.777†		0.777††		0.772††		0.868†	
Percentage of trunk fat	0.748†		0.832†		0.761†		0.830†		0.807†		0.868†	
WHtR-W	–		0.937††		0.898†		–		0.887†		0.880†	
WHtR-A	0.937†		–		0.914†		0.887††		–		0.802†	

WHtR-W, WHtR using waist circumference; WHtR-A, WHtR using abdominal circumference.

\* Mean value is significantly lower compared with that for WHtR-A ( $P < 0.01$ ).

† Significant correlation ( $P < 0.01$ ).

‡ Correlation is significantly different from the correlation obtained from BMI ( $P < 0.05$ ).

§ For details of subjects and procedures, see Table 1 and Methods.

**Table 3.** Proposed prediction equations for percentage total body fat (%BF) and percentage trunk fat (%TF) using BMI, waist:height ratio using waist circumference (WHtR-W) and WHtR using abdominal circumference (WHtR-A)\*

Independent variables	Prediction equations†	$R^2_{adj}$	SEE
BMI	%BF = $-2.519 + 1.533 \times (\text{BMI}) - 11.7 \times (\text{Sex})$	0.751	4.82
	%TF = $-11.543 + 1656 \times (\text{BMI}) - 7.849 \times (\text{Sex}) + 0.088 \times (\text{Age})$	0.691	5.31
WHtR-W	%BF = $-6.137 + 95.859 \times (\text{WHtR-W}) - 0.08 \times (\text{Age}) - 13.295 \times (\text{Sex})$	0.689	5.39
	%TF = $-16.585 + 105.987 \times (\text{WHtR-W}) - 9.647 \times (\text{Sex})$	0.654	5.62
WHtR-A	%BF = $-8.339 + 92.701 \times (\text{WHtR-A}) - 0.078 \times (\text{Age}) - 11.062 \times (\text{Sex})$	0.719	5.12
	%TF = $-18.452 + 101.636 \times (\text{WHtR-A}) - 7.163 \times (\text{Sex})$	0.680	5.41

$R^2_{adj}$ , adjusted  $R^2$ ; SEE, standard error of estimates.

\* For details of subjects and procedures, see Table 1 and Methods.

† For males, 'Sex' = 1; for females, 'Sex' = 0.

equations using BMI were slightly higher than the values obtained from the equations using WHtR, the observed values were comparable. In addition, while %BF estimation using BMI and %TF using WHtR were only influenced by sex, %TF estimation using BMI and %BF estimation using WHtR were influenced by both sex and age of participants. Using the mean age for each sex, %BF and %TF were estimated as 24.1 and 26.1% in males and 35.8 and 33.7% in females at the BMI of 25 kg/m<sup>2</sup>. Similarly, %BF and %TF at a BMI of 30 kg/m<sup>2</sup> were 31.8 and 34.6% respectively for males and 43.5 and 42.4% respectively for females. These results indicate that %TF and %BF values were relatively consistent and it may be possible to use %TF as an indication of health risk alternative to %BF.

Comparison of prediction equations using different WHtR suggests that WHtR-A showed higher correlations in both %BF ( $R^2_{adj}$  0.689 for WHtR-W and 0.719 for WHtR-A) and %TF ( $R^2_{adj}$  0.654 for WHtR-W and 0.680 for WHtR-A). Using the WHtR cut-off point of 0.5 and average age for the study groups, %BF and %TF were estimated to be 23.3–24.7% and 25.2–26.8% respectively for males and 34.6–38.3% and 32.4–36.4% respectively in females. These estimated %BF and %TF values from the WHtR equations with the cut-off point of 0.5 were comparable with the values calculated from the equations using the BMI cut-off value of 25 kg/m<sup>2</sup>. Equations using WHtR-W estimated greater %BF and %TF values than the equations using WHtR-A in both sexes. Furthermore, proposed equations showed a tendency that estimated %TF values at given cut-off points for BMI and WHtR to be greater than %BF values in males, whereas %BF of females were estimated to be greater than %TF. This may be associated with a sex difference in body fat distribution.

In order to determine differences in sensitivity and specificity using WHtR-W and WHtR-A at the cut-off point of 0.5, and also to compare the results with BMI at different cut-off points, cross-tabulation was conducted using %BF and %TF of 20 and 30% as cut-off points for males and females, respectively (Table 4). In comparison with WHtR-W, WHtR-A showed higher sensitivity but lower specificity for both %BF and %TF regardless of sex. An increase in sensitivity by choosing WHtR-A is greater in females (difference: 21.5% for %BF and 21.3% for %TF) than their male counterparts (difference: 10.2% for %BF and 9.8% for %TF). On the other hand, changes in specificity were comparable (range 12.5–15.4%). This suggests that WHtR-A may improve screening of females with a considerable level of body fat

accumulation in general as well as in the trunk region. In comparison with BMI, WHtR-W showed comparable levels of sensitivity and specificity with the BMI using 25 kg/m<sup>2</sup> as a cut-off point in males but showed lower sensitivity and higher specificity in females. When WHtR-A was used, both groups showed greater sensitivities and lower specificities than BMI with 25 kg/m<sup>2</sup> for both %BF and %TF.

## Discussion

Previous studies have suggested that the WHtR is a useful anthropometric index to assess abdominal obesity as an alternative to WC<sup>(26,27)</sup> for individuals varying in age, sex

**Table 4.** Sensitivity and specificity of the BMI and the waist:height ratio (WHtR) at given percentage total body fat (%BF) and percentage trunk fat (%TF) in Australian males and females\*

	BMI 25 kg/m <sup>2</sup>	WHtR-W	WHtR-A
<b>Males, %BF ≤ 20.0%</b>			
TP (individuals)	66	66	74
FN (individuals)	13	13	5
TN (individuals)	14	14	12
FP (individuals)	2	2	4
Sensitivity ((TP/TP + FN) × 100)	83.5	83.5	93.7
Specificity ((TN/TN + FP) × 100)	87.5	87.5	75.0
<b>Females, %BF ≤ 30.0%</b>			
TP (individuals)	26	38	17
FN (individuals)	22	22	19
TN (individuals)	1	1	4
FP (individuals)	73.5	61.2	82.7
Sensitivity ((TP/TP + FN) × 100)	95.7	95.7	82.6
Specificity ((TN/TN + FP) × 100)	72	60	81
<b>Males, %TF ≤ 20.0%</b>			
TP (individuals)	67	67	75
FN (individuals)	15	15	7
TN (individuals)	12	12	10
FP (individuals)	1	1	3
Sensitivity ((TP/TP + FN) × 100)	81.7	81.7	91.5
Specificity ((TN/TN + FP) × 100)	92.3	92.3	76.9
<b>Females, %TF ≤ 30.0%</b>			
TP (individuals)	72	61	81
FN (individuals)	22	33	13
TN (individuals)	26	27	23
FP (individuals)	1	0	4
Sensitivity ((TP/TP + FN) × 100)	76.6	64.9	86.2
Specificity ((TN/TN + FP) × 100)	96.3	100.0	85.2

WHtR-W, WHtR using waist circumference; WHtR-A, WHtR using abdominal circumference; TP, true positives; FN, false negatives; TN, true negatives; FP, false positives.

\* For details of subjects and procedures, see Table 1 and Methods.

and ethnicity as it adjusts for body size (i.e. height)<sup>(23)</sup>. However, no universal or standard definition of the 'waist' circumference that is appropriate to be used in the calculation of WHtR has been proposed to date. The present study was the first study that compared WHtR values using different 'waist' circumferences and determined their usefulness as a screening tool.

Defining 'waist' as the narrowest point or at the umbilicus level, the present study found differences in WHtR values in both sexes. In comparison with WHtR-W, WHtR-A was greater in both groups, indicating a significant impact of the measurement site to the WHtR value. Females showed a greater difference between AC and WC values than males, which was consistent with findings in a recent study<sup>(18)</sup>. Because the sex difference in circumference was smaller in AC compared with WC, the calculated WHtR-A was not significantly different between sexes. The observed results may indicate that WC will be affected by a sex difference in body fat distribution pattern compared with AC and therefore it is possible that WHtR using WC may fail to estimate the maximum amount of fat accumulation in the trunk region in females.

In comparison with WHtR, the BMI showed higher correlations with body mass and trunk fat mass. However, the BMI was also highly correlated with total and trunk lean mass compared with WHtR in both sexes. The results were consistent with a previous study<sup>(29)</sup>. This suggests that the WHtR is a more 'fat-sensitive' index compared with the BMI and has the potential to reduce misclassification of individuals as has been reported for BMI<sup>(39)</sup>. In addition, the present study showed that both BMI and WHtR have comparable (i.e. non-significant) correlations with %TF in both sexes. Considering the 'fat-sensitive' nature and comparable correlations for %BF using BMI, WHtR may be a useful alternative to screen for obesity, particularly in individuals with excessive fat accumulation in the trunk region.

The proposed equations that examined relationships between BMI, WHtR, %BF and %TF indicated that %TF at given BMI cut-off points (i.e. 25 and 30 kg/m<sup>2</sup>) were consistent to %BF values that were estimated at the same BMI cut-off points. The present study also showed that a WHtR cut-off point of 0.5 provided comparable %BF and %TF values to BMI estimated at the cut-off point of 25 kg/m<sup>2</sup>. These results may indicate the potential usefulness of %TF as an alternative indicator of excessive body fat accumulation. Further, although %TF is different from abdominal fat deposition or VAT accumulation by definition, it has been suggested that trunk fat is associated with metabolic biomarkers<sup>(30,31)</sup>. Considering the existing literature that provides evidence that WHtR is a useful indicator of abdominal obesity and related metabolic complications<sup>(25–27,40)</sup>, %TF may be strongly associated with abdominal visceral fat accumulation. In addition, unlike BMI, an estimation of %TF using WHtR was not influenced by age. The results were consistent with a previous study<sup>(23)</sup>, which suggested that WHtR can be applied to screening the general population across a wide age range using the same cut-off point (i.e. 0.5). Compared with BMI which needs to consider different cut-off points according to the age of participants<sup>(41)</sup>, WHtR may be a convenient option in epidemiological screening to identify individuals at risk.

When the cut-off point of 0.5 was used, the WHtR-W estimated greater %TF values compared with the WHtR-A in both sexes. Also, WHtR-A showed slightly higher  $R^2_{adj}$  and smaller standard error of estimates in relation to %BF and %TF compared with WHtR-W. This may be simply because WHtR-W takes longer for the ratio to reach 0.5 as it uses WC measured at the narrowest point between the costal rib and iliac crest. A difference in 'waist' measurement sites in WHtR calculations also impacted on sensitivity and specificity to screen individuals with considerable fat deposition. Using %BF and %TF of 20% in males and 30% in females as cut-off points, the present study showed higher sensitivities but lower specificities using WHtR-A compared with WHtR-W in both sexes. While males showed comparable levels of sensitivity and specificity between BMI of 25 kg/m<sup>2</sup> and WHtR-W, females showed lower sensitivity in WHtR-W compared with the BMI. This suggests that the application of the WHtR-W will disadvantage females and be unable to identify those who require improvement in health status. Lower specificity in WHtR-A compared with the other indices indicated a greater risk to misclassify healthy individuals as at-risk by applying the index alone. Therefore it is recommended that WHtR-A be combined with detailed assessments, including blood assays, to avoid unnecessary medical prescriptions if using the index as a clinical diagnostic tool. However, the high sensitivity of WHtR-A indicated that it is more suitable as a general population screening tool to identify potentially at-risk individuals who should seek further assessment or be provided with advice on lifestyle modifications that do not involve medical treatment.

Although no correlation differences were found between body fat accumulation and the WHtR using WC and AC, potential benefits of using AC to calculate WHtR in females have been observed. The result was inconsistent with a previous study that suggested the usefulness of WC to assess CVD risk<sup>(18)</sup>. However, the previous study did not show significant differences between WC and AC in correlations with VAT. Because no other research has compared the appropriateness of different 'waist' circumferences for screening, it is difficult to draw definitive conclusion from these outcomes. However, the present study did show generally higher correlations with body composition variables in males and an increased 'fat-sensitive' nature of WHtR in females. Also, WHtR-A showed a considerable improvement in sensitivity in detecting at-risk individuals, particularly females, compared with WHtR-W and BMI. These results suggest that WHtR using AC may be a better option to identify at-risk Australian adults.

The present study found that WHtR values vary depending on the definition of 'waist' used. In order to optimise the screening ability of WHtR, it may be important to standardise its calculation protocol, especially the definition of the 'waist' circumference. To date, there has been a trend to accept AC as the method of choice to measure 'waist' and the cut-off points proposed from different 'waist' measurements have been listed together as a diagnostic criteria for metabolic complications<sup>(1)</sup>. However, a measurement at the umbilicus is technically a measurement of the 'abdomen' and the present findings suggest that its application may be beneficial to identify individuals at risk of obesity, particularly due to trunk fat deposition. Therefore, it is

recommended to differentiate the umbilicus circumference from other 'waist' measurements and apply it to calculate the 'abdominal:height ratio' instead of WHtR-A.

In the present study each circumference was only measured once. Therefore, it is not possible to calculate the technical error of measurement (TEM) for each site. Anthropometry is largely affected by the skill of the anthropometrist responsible for the measurements. Given that %CV (SD/mean  $\times$  100) of WC and AC were consistent in both groups (about 11% for males and about 13% for females), it is unlikely there was a considerable difference in TEM between the measured sites. However, future research should record either duplicate or triplicate measurements to enable calculation of TEM. In addition, the present study was conducted using Australian adults who were mainly Caucasians. Future research should include different ethnic groups to confirm the present findings. Furthermore, the present study was unable to clarify the impact of the measured site to the actual VAT. A previous study only used a single CT scan which was taken at the L4 pedicle and did not compare two scans that reflect each circumference site<sup>(18)</sup>. In order to elucidate the influence of measurement site on the actual VAT, it may be essential to conduct research to compare WHtR using different circumferences and VAT determined from CT scans taken at the precise level of each circumference measure.

### Conclusions

The present study showed that WHtR using different 'waist' definitions correlated highly with %TF as well as %BF in both sexes. However, the study indicated that WHtR using the umbilical measurement increases the 'fat-sensitive' nature of the index and also increases the sensitivity of identifying at-risk individuals compared with WHtR using the narrowest circumference, particularly in females. As a result, it may be better to use AC to calculate WHtR for early screening purposes in Australian adults. In order to make the index more generalisable, including being comparable between studies, standardisation of 'waist' measurement and differentiation of umbilicus measurement from other 'waist' measurements is recommended. Future research is recommended to confirm the present findings across different ethnic groups.

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