

# Predicting cardiometabolic disturbances from waist-to-height ratio: findings from the Brazilian Longitudinal Study of Adult Health (ELSA-Brasil) baseline

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## Abstract

*Objective:* To evaluate the performance of waist-to-height ratio (WHtR) in predicting cardiometabolic outcomes and compare cut-off points for Brazilian adults.

*Design:* Cross-sectional study. WHtR areas under the curve (AUC) were compared with those for BMI, waist circumference (WC) and waist-to-hip ratio (WHR). The outcomes of interest were hypertension, diabetes, hypertriglycerolaemia and presence of at least two components of metabolic syndrome ( $\geq 2$  MetS). Cut-offs for WHtR were compared and validity measures were estimated for each point.

*Setting:* Teaching and research institutions in six Brazilian state capitals, 2008–2010.

*Subjects:* Women ( $n$  5026) and men ( $n$  4238) aged 35–54 years who participated in the Brazilian Longitudinal Study of Adult Health (ELSA-Brasil) at baseline.

*Results:* WHtR age-adjusted AUC ranged from 0.68 to 0.72 in men and 0.69 to 0.75 in women, with smaller AUC for hypertriglycerolaemia and the largest for  $\geq 2$  MetS. WHtR performed better than BMI for practically all outcomes; better than WHR for hypertension in both sexes; and displayed larger AUC than WC in predicting diabetes mellitus. It also offered better discriminatory power for  $\geq 2$  MetS in men; and was better than WC, but not WHR, in women. Optimal cut-off points of WHtR were 0.55 (women) and 0.54 (men), but they presented high false-negative rate compared with 0.50.

*Conclusions:* We recommend using WHtR (which performed similarly to, or better than, other available indices of adiposity) as an anthropometric index with good discriminatory power for cardiometabolic outcomes in Brazilian adults, indicating the already referenced limit of WHtR  $\geq 0.50$ .

## Keywords

Abdominal obesity  
Waist-to-height ratio  
Anthropometric indices  
Cardiometabolic outcomes  
Cross-sectional studies

Chronic non-communicable diseases are the leading cause of mortality in numerous countries and various strategies to address them have been discussed<sup>(1)</sup>. One of the main avenues is to combat obesity, in which abdominal obesity, the type most strongly associated with such diseases, has received attention from researchers owing to the greater accuracy it offers in detecting increased visceral fat, which is implicated in cardiometabolic alterations<sup>(2)</sup>.

Traditionally, abdominal obesity has been gauged by way of waist circumference (WC), either in isolation or as a ratio to hip circumference (waist-to-hip ratio, WHR)<sup>(3)</sup>.

However, given the more important inverse relationship between height and cardiometabolic disturbances<sup>(4–6)</sup>, several authors have suggested adjusting WC for height to augment its diagnostic power in comparison with other anthropometric indices for abdominal and total adiposity<sup>(7–9)</sup>. In Brazil, waist-to-height ratio (WHtR) is being indicated as a good predictor for arterial hypertension<sup>(10,11)</sup> and coronary risk<sup>(12,13)</sup>.

Some studies, however, have found in favour of using BMI<sup>(14)</sup> and WC<sup>(15)</sup>, as well as WHR<sup>(16)</sup>, for different cardiometabolic outcomes.

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Given the lack of consensus on the measure most indicated for evaluating abdominal obesity in adults, the present study aimed to answer the following questions: with what likelihood does WHtR correctly identify adult individuals with cardiometabolic alterations? Does this index offer better discriminatory power than other measures of abdominal obesity in detecting clinical outcomes in this age group? Considering the population of the Brazilian Longitudinal Study of Adult Health (ELSA-Brasil), what is the optimal cut-off point of WHtR for predicting these outcomes? Does it perform better than the main cut-off point referenced in the literature (0.50)?

### Participants and methods

The present cross-sectional study draws on the ELSA-Brasil baseline, the methodological details of which have been described elsewhere<sup>(17,18)</sup>. To summarise, the population eligible for ELSA-Brasil comprised active and retired civil servants, aged 35–74 years, from teaching and research institutions in six Brazilian state capitals (Porto Alegre, São Paulo, Rio de Janeiro, Vitória, Salvador and Belo Horizonte).

For the present study, a population aged 35–54 years was selected to gain greater age group homogeneity and in view of the low predictive power of anthropometric indices with increasing age. Individuals lacking information on any of the anthropometric measures of interest ( $n$  6) or on biochemical variables ( $n$  8) were excluded; no values were missing for blood pressure. Participants thus totalled 9264, 4238 men and 5026 women.

### Data collection procedures

At the ELSA-Brasil baseline (2008–2010), data were collected by a trained team using standardised procedures and equipment at all the ELSA-Brasil study centres<sup>(19)</sup>.

The anthropometric measures of weight, height and waist and hip circumferences were obtained using techniques recommended by Lohman *et al.*<sup>(20)</sup>, each measurement being taken only once. WC was measured at the mid-point between the lower edge of the costal arch and the iliac crest at the mid-axillary line.

Three measurements of blood pressure (BP) were taken, with the mean of the last two being used in the analyses<sup>(21)</sup>.

As part of the quality control procedures, some measurements were repeated randomly in a study sub-sample. A high intraclass correlation coefficient was found for WC (0.99), for systolic BP (0.88) and for diastolic BP (0.89), indicating good reliability in taking these measurements and thus in constructing the indicators derived from them<sup>(19)</sup>.

The following biochemical blood measurements were used in defining the clinical indicators: glucose (mg/dl), TAG (mg/dl) and HDL cholesterol (mg/dl). Laboratory samples were collected from participants after a 12 h overnight fast<sup>(22)</sup>.

### Anthropometric predictors

The anthropometric indices tested were: (i) BMI ( $\text{kg}/\text{m}^2$ ); (ii) WC (cm); (iii) WHR; and (iv) WHtR.

### Cardiometabolic outcomes

Blood pressure and blood biochemistry served to construct the following selected cardiometabolic outcomes, which were treated dichotomously (yes/no): (i) hypertension, classified as systolic BP  $\geq 140$  mmHg and/or diastolic BP  $\geq 90$  mmHg and/or use of antihypertensive medication during the two weeks prior to the test; (ii) hypertriglycerolaemia, TAG  $\geq 150$  mg/dl; and (iii) diabetes mellitus, reported as prior clinical diagnosis and/or use of medication and/or fasting glycaemia  $> 125$  mg/dl and/or 2 h post-test glycaemia  $\geq 200$  mg/dl in an oral glucose tolerance test.

The last outcome investigated was the presence of two or more components of metabolic syndrome ( $\geq 2$  MetS), out of a total four possible components: (i) BP  $\geq 130$  and/or 85 mmHg; (ii) TAG  $\geq 150$  mg/dl; (iii) HDL cholesterol  $< 40$  mg/dl (men) or  $< 50$  mg/dl (women); (iv) fasting glycaemia  $\geq 110$  mg/dl; these limits are based on the National Cholesterol Education Program Adult Treatment Panel III<sup>(23)</sup>. WC was excluded in this case, because its presence could lead to collinearity with the indicators used to evaluate abdominal fat, which also include waist measurement. The use of two or more positive components of metabolic syndrome is a diagnostic option already successfully employed by other authors<sup>(5,14,24)</sup>. It is at least as frequent a condition as the situations in isolation – if not more so – and, more importantly still, this set of components of metabolic syndrome together is of greater clinical significance.

### Data analysis

The area under the receiver-operator characteristic curve (AUC) and the respective 95% confidence intervals were calculated, for men and women, for each pair of anthropometric index (BMI, WC, WHR and WHtR) and metabolic outcome of interest (hypertension, diabetes, hypertriglycerolaemia and  $\geq 2$  MetS). Then, the differences between WHtR AUC and that for each age-adjusted anthropometric index were tested<sup>(25)</sup>. AUC are summary measures of the performance of a predictive model. The larger the value of the AUC for a given outcome, the greater the model's power of discrimination. The value 1.0 indicates excellent power to discriminate between the presence or absence of the outcome and 0.5 is the limit of significance. Accordingly, the lower limit of the 95% CI should not be below 0.5<sup>(26,27)</sup>.

The cut-off points recommended in the literature for the study indices were examined for sensitivity and specificity in detecting two or more metabolic syndrome components, that is: (i) BMI  $\geq 25.0$   $\text{kg}/\text{m}^2$  and  $\geq 30.0$   $\text{kg}/\text{m}^2$ , for either sex<sup>(28)</sup>; (ii) WC  $\geq 88$  cm (men)<sup>(28)</sup> and  $\geq 102$  cm (women)<sup>(28)</sup>; (iii) WHR  $\geq 0.80$ <sup>(16)</sup> or  $\geq 0.85$ <sup>(28)</sup> (women)

and  $\geq 0.90^{(28)}$  or  $\geq 0.95^{(16)}$  (men); and (iv) WHtR  $\geq 0.50$  and  $\geq 0.60$ , for either sex<sup>(29)</sup>.

The next stage was to obtain optimal cut-off points for each anthropometric index, using two strategies. The first was to calculate the Youden index ( $J$ ) = max (sensitivity + specificity - 1), from which the point vertically furthest from the non-association AUC was identified; then, the cut-off point representing the least distance squared ( $d^2$ ) between the receiver-operator characteristic curve and the point closest to the ideal, represented by the upper left-hand corner of the AUC plot, which indicates maximum accuracy<sup>(30)</sup>.

A more detailed analysis was made of the predictive power of two different cut-off points of WHtR:  $\geq 0.50$ , for either sex<sup>(29)</sup>, and that identified in the previous analysis. The calculated statistics included sensitivity, specificity, false-positive rate, false-negative rate, test accuracy and Brier score, stratified by sex and age group.

The Brier score represents an overall measure of the model's performance and evaluates the distance between the likelihood predicted by the index in test (in this case WHtR) and the likelihood of the outcome occurring. A value of 0% agrees totally and the nearer values approach 50%, the worse the model's performance and, therefore, the less informative it is - at 50% it offers the same probability of being right or wrong. Above 50% it has no clinical significance. This score penalises false positives and false negatives less than  $R^2$  does<sup>(27)</sup>.

Lastly, the OR and respective 95% CI values were calculated between the high WHtR (classified by the different cut-off points identified) and the  $\geq 2$  MetS outcome.

The data were analysed using the statistical software packages MedCalc<sup>®</sup> version 14.1 and Stata<sup>®</sup> version 10.1.

All participants signed a declaration of free and informed consent. The present paper is the product of a subproject approved by the Ethics Committee of Brazil's Escola Nacional de Saude Pùblica (CAAE No. 44106915.2.1001.5240).

**Results**

Women made up 54% of the study population. Mean age (46.2 (SD 5.1) years;  $P=0.18$ ) was similar in both sexes, with nearly one-third of the population in each age stratum, as shown in Table 1. Table 1 also shows that mean WC and WHR were, as expected, higher in men, while BMI and WHtR (indices formulated to include height) did not differ between the sexes. All indices relating to adiposity increased linearly with age in both sexes. The increase was more marked in measures of abdominal obesity (WC, WHR and WHtR) than in BMI. In all age groups, the prevalence of the clinical outcomes was greater among men, and the outcome  $\geq 2$  MetS was twice as prevalent in men as in women.

The values of the WHtR AUC, after adjustment for age, can be seen in Table 2. They ranged from 0.68 to 0.72 in

**Table 1** Anthropometric characteristics and prevalence of metabolic disturbances, by age group, in men and women (aged 35–54 years), Brazilian Longitudinal Study of Adult Health (ELSA-Brasil) baseline, 2008–2010

	Men						Women					
	35–44 years (n 1559)		45–49 years (n 1413)		50–54 years (n 1266)		35–44 years (n 1777)		45–49 years (n 1692)		50–54 years (n 1557)	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Height (cm)	174.4	174.1, 174.7	172.9	173.3, 174.6	171.9	171.5, 172.3	160.9	160.7, 161.3	160.4	160.0, 160.6	158.8	158.5, 159.1
Weight (kg)	81.6	80.8, 82.3	81.4	80.7, 82.1	80.9	80.1, 81.7	68.2	67.5, 68.8	69.4	68.8, 70.1	69.2	68.6, 69.9 <sup>b</sup>
BMI (kg/m <sup>2</sup> )	26.7	26.5, 27.0	27.2	27.0, 27.4	27.3	27.1, 27.6	26.3	26.1, 26.5	27.0	26.7, 27.2	27.5	27.2, 27.7
WC (cm)	92.6	92.0, 93.2	94.7	94.1, 95.3	95.8	95.1, 96.4	84.0	83.5, 84.6	86.6	86.0, 87.2	88.3	87.7, 88.9
HC (cm)	100.8	100.4, 101.2	100.6	100.2, 100.9	100.3	99.9, 100.8	102.4	102.0, 102.9	103.0	102.6, 103.5	103.1	102.7, 103.6
WHR	0.92	0.91, 0.92	0.94	0.93, 0.94	0.95	0.95, 0.96	0.82	0.81, 0.82	0.84	0.83, 0.84	0.86	0.85, 0.86
WHtR	0.53	0.53, 0.54	0.55	0.54, 0.55	0.56	0.55, 0.56	0.52	0.52, 0.53	0.54	0.54, 0.55	0.56	0.55, 0.56
	n	%	n	%	n	%	n	%	n	%	n	%
Hypertension	307	19.7	430	30.4	538	42.5	223	12.5	395	23.4	490	31.5
Hypertriglycerolaemia	565	36.4	598	42.8	564	44.8	261	14.7	339	20.0	395	25.4
Diabetes	150	9.6	242	17.1	308	24.3	90	5.1	193	11.4	259	16.6
$\geq 2$ MetS	474	30.6	562	40.3	591	47.2	243	13.7	364	21.6	410	26.5

WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio;  $\geq 2$  MetS, presence of two or more components of metabolic syndrome.

**Table 2** Adjusted† area under the curve (AUC) and respective 95% CI for anthropometric predictors of metabolic disturbances in men and women (aged 35–54 years), Brazilian Longitudinal Study of Adult Health (ELSA-Brasil) baseline, 2008–2010

Anthropometric index	Hypertension		Hypertriglycerolaemia		Diabetes		≥ 2 MetS	
	AUC	95% CI	AUC	95% CI	AUC	95% CI	AUC	95% CI
<b>Men</b>	<i>n</i> 4234		<i>n</i> 4210		<i>n</i> 4236		<i>n</i> 4194	
BMI (kg/m <sup>2</sup> )	0.689	0.670, 0.706	0.665***	0.649, 0.682	0.668***	0.645, 0.691	0.709**	0.692, 0.725
WC (cm)	0.683	0.664, 0.701	0.679	0.664, 0.695	0.664***	0.641, 0.687	0.707**	0.690, 0.724
WHR	0.659***	0.641, 0.677	0.687	0.670, 0.703	0.680	0.659, 0.702	0.705**	0.689, 0.721
WHtR	0.689	0.671, 0.707	0.683	0.667, 0.700	0.689	0.667, 0.711	0.720	0.704, 0.736
<b>Women</b>	<i>n</i> 5025		<i>n</i> 5022		<i>n</i> 5026		<i>n</i> 5004	
BMI (kg/m <sup>2</sup> )	0.679**	0.661, 0.698	0.668***	0.650, 0.686	0.711***	0.688, 0.734	0.728***	0.711, 0.745
WC (cm)	0.688	0.670, 0.705	0.691	0.674, 0.708	0.722*	0.699, 0.744	0.745**	0.729, 0.761
WHR	0.674**	0.656, 0.692	0.708	0.691, 0.726	0.726	0.704, 0.749	0.749	0.733, 0.766
WHtR	0.693	0.675, 0.711	0.694	0.677, 0.711	0.730	0.708, 0.753	0.754	0.738, 0.770

WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio; ≥ 2 MetS, presence of two or more components of metabolic syndrome.

\**P* < 0.05, \*\**P* < 0.01, \*\*\**P* < 0.001 in test to differentiate between two AUC (WHtR v. other anthropometric indices).

†Adjusted for age group.

**Table 3** Reference and optimal† cut-off points for selected anthropometric indices applied in discriminating the presence of two or more components of metabolic syndrome in men and women (aged 35–54 years), Brazilian Longitudinal Study of Adult Health (ELSA-Brasil) baseline, 2008–2010

Anthropometric index	Cut-off points							
	Men ( <i>n</i> 4194)				Women ( <i>n</i> 5004)			
	Reference	Reference	<i>J</i>	<i>d</i> <sup>2</sup>	Reference	Reference	<i>J</i>	<i>d</i> <sup>2</sup>
<b>BMI (kg/m<sup>2</sup>)</b>								
Cut-off point	25.0 <sup>(28)</sup>	30.0 <sup>(28)</sup>	26.3	27.0	25.0 <sup>(28)</sup>	30.0 <sup>(28)</sup>	27.0	27.1
Sensitivity (%)	83.8	35.2	71.8	64.5	83.6	46.6	71.2	70.4
Specificity (%)	44.3	86.8	59.4	66.5	47.4	82.3	65.1	65.8
<b>WC (cm)</b>								
Cut-off point	94.0 <sup>(28)</sup>	102.0 <sup>(28)</sup>	92.1	93.1	80.0 <sup>(28)</sup>	88.0 <sup>(28)</sup>	88.3	88.3
Sensitivity (%)	67.7	36.8	74.4	70.5	91.0	69.2	68.8	68.9
Specificity (%)	63.0	86.0	57.3	61.0	39.4	69.1	69.9	69.7
<b>WHR</b>								
Cut-off point	0.90 <sup>(28)</sup>	0.95 <sup>(16)</sup>	0.92	0.94	0.80 <sup>(16)</sup>	0.85 <sup>(28)</sup>	0.85	0.85
Sensitivity (%)	87.0	58.0	76.0	67.1	91.1	72.0	71.9	71.3
Specificity (%)	41.5	72.0	56.8	64.8	37.2	67.6	67.9	68.5
<b>WHtR</b>								
Cut-off point	0.50 <sup>(29)</sup>	0.60 <sup>(29)</sup>	0.53	0.54	0.50 <sup>(29)</sup>	0.60 <sup>(29)</sup>	0.55	0.55
Sensitivity (%)	91.0	31.7	82.7	72.4	90.7	43.8	71.0	70.2
Specificity (%)	35.8	89.0	51.9	61.3	39.6	86.0	70.0	70.7

WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

†Optimal cut-off points corresponding to maximum value of the Youden index (*J*) = max (sensitivity + specificity – 1) or the least distance squared (*d*<sup>2</sup>) between the receiver-operating characteristic curve and the upper left-hand corner of the AUC plot.

men and from 0.69 to 0.75 in women, with the smallest AUC found for hypertriglycerolaemia and the largest for ≥ 2 MetS. The AUC obtained for WHtR were also compared with those of the other anthropometric indices for each clinical outcome. WHtR returned significantly larger AUC than BMI for practically all outcomes examined, except hypertension among men. WHtR performed significantly better than WHR for hypertension in both sexes and also displayed larger AUC than WC in predicting diabetes. When the ≥ 2 MetS outcome was examined, WHtR showed better discriminatory power than the other indices, although not differing from WHR in women (Table 2).

The analysis stratified by age group (data not shown) showed that, for all the anthropometric indices tested, AUC values diminished with age. However, loss of

predictive power was greater for men after 50 years of age. WHtR maintained reasonably informative AUC values, i.e. good predictive power, in all age strata, with values greater than 0.69 for men and 0.74 for women (from age 50 to 54 years). Among women, WHtR and WHR performed equally well after age 50 years, while WC and BMI showed a more marked decline.

Sensitivity and specificity values at different cut-off points for the anthropometric indices were compared for the ≥ 2 MetS outcome (Table 3). Many of the cut-off points observed in our study were higher than those previously identified in the literature. The exceptions to this were WC in men and, in some cases, WC and WHR in women.

To evaluate discriminatory characteristics, validity measures were calculated for the classic cut-off of WHtR

**Table 4** Validity measures of waist-to-height ratio (WHtR) cut-off points and OR and 95% CI for presence of two or more components of metabolic syndrome ( $\geq 2$  MetS), by sex and age, Brazilian Longitudinal Study of Adult Health (ELSA-Brasil) baseline, 2008–2010

Categories	Validity measures of WHtR cut-off points						$\geq 2$ MetS		
	SENS (%)	SPEC (%)	FPR (%)	FNR (%)	Accuracy (%)	Brier score	% within WHtR $\geq 0.50$	OR	95% CI
Men aged 35–49 years ( <i>n</i> 2942)									
WHtR $\geq 0.50$	90.0	38.4	61.6	10.0	56.5	0.43	44.2	5.6	4.5, 7.0
WHtR $\geq 0.54$	70.0	64.7	35.3	30.4	66.4	0.33	52.0	4.2	3.6, 4.9
Men aged 50–54 years ( <i>n</i> 1252)									
WHtR $\geq 0.50$	93.1	28.4	71.6	6.9	58.9	0.42	53.8	5.3	3.7, 7.6
WHtR $\geq 0.54$	74.0	54.0	46.0	26.1	63.4	0.36	59.0	3.3	2.6, 4.2
Women aged 35–49 years ( <i>n</i> 3455)									
WHtR $\geq 0.50$	90.0	44.1	55.9	10.0	52.2	0.48	25.5	7.1	5.4, 9.3
WHtR $\geq 0.55$	69.0	71.6	28.4	31.0	71.1	0.28	34.1	5.6	4.7, 6.8
Women aged 50–54 years ( <i>n</i> 1549)									
WHtR $\geq 0.50$	91.7	28.4	71.6	8.3	45.2	0.55	31.6	4.4	3.0, 6.4
WHtR $\geq 0.55$	75.4	61.2	38.8	24.6	65.0	0.35	41.1	4.8	3.7, 6.2

SENS, sensitivity; SPEC, specificity; FPR, false-positive rate; FNR, false-negative rate; % within WHtR  $\geq 0.50$ , prevalence of two or more components of metabolic syndrome in subjects with WHtR  $\geq 0.50$ .

( $\geq 0.50$ ) and the optimal cut-off points identified ( $\geq 0.54$  for men and  $\geq 0.55$  for women), as shown in Table 4. The first cut-off achieved greater sensitivity, with substantial false-positive rate and higher Brier score.

## Discussion

WHtR showed good predictive power to identify metabolic disturbances in isolation or jointly, returning AUC close to or greater than 0.70 for all the outcomes, particularly for predicting the presence of two or more components of metabolic syndrome ( $\geq 2$  MetS).

In the present study, the WHtR AUC ranged from 0.68 to 0.72 in men and from 0.69 to 0.75 in women. AUC equal to or greater than 0.7 were identified in meta-analyses by Browning *et al.*<sup>(31)</sup> and Ashwell *et al.*<sup>(8)</sup>, highlighting diabetes and metabolic syndrome.

For the same outcomes, similar WHtR AUC were observed for Iranian men (0.65 to 0.72), but were lower for Iranian women (0.63 to 0.69), with higher values for  $\geq 2$  MetS in both sexes<sup>(32)</sup>. Studies have also found smaller AUC values for these same disturbances in China, ranging from 0.57 to 0.67 for men and from 0.60 to 0.67 for women<sup>(14)</sup>. In Turkey, findings were similar to those of the present study for the different outcomes examined, especially regarding the  $\geq 2$  MetS outcome, returning AUC of 0.70 and 0.76, respectively, for men and women<sup>(24)</sup>.

Few studies in Brazil have used receiver-operator characteristic curves to measure and compare the performance of WHtR with other anthropometric indices<sup>(11–14)</sup>. Even using other outcomes, studies in Bahia State to identify coronary risk using the Framingham score found important WHtR AUC values for men (0.76)<sup>(12)</sup> and women (0.74)<sup>(13)</sup>. Vasques *et al.*<sup>(15)</sup> examined insulin resistance in male workers at a public university in Minas Gerais and found a WHtR AUC of 0.70. In Alagoas, in a

female population-based study, Caminha *et al.*<sup>(11)</sup> observed AUC equal to 0.73 when evaluating hypertension. Despite the different outcomes and populations, there are similarities in the values encountered for AUC, attesting to the predictive power of the WHtR indicator.

WHtR performed better than the other anthropometric indices, although not differing substantially from WHR for women.

WHtR performed better than BMI for practically all outcomes examined, in both men and women, which is corroborated by the meta-analyses of Lee *et al.*<sup>(7)</sup>, Ashwell *et al.*<sup>(8)</sup> and Savva<sup>(9)</sup>. The use of WC instead of weight to construct the indicator (WHtR) brings gains for identifying individuals with higher levels of abdominal fat, despite normal BMI levels<sup>(33)</sup>. It is widely recognised that the strongest association is between visceral fat and chronic diseases, compared with overweight<sup>(2,3)</sup>. In addition, it is advantageous to use two rather than three measures, and only one anthropometric indicator for the evaluation of obesity in the adult population, rather than BMI and waist, separately.

In men, WHtR was observed to outperform the other anthropometric indices in predictive power, although the differences from WC and WHR were less substantial in women. The expected presence of increased body fat in women's thighs and buttocks makes WHR also an important tool in evaluating the extent of body fat in women.

Using the same outcome ( $\geq 2$  MetS), Mirmiran *et al.*<sup>(32)</sup> found higher AUC for WHtR compared with other anthropometric indices. Similarly, in Turkey, WHtR achieved the best discriminatory power in adults of both sexes, always better than WHR<sup>(24)</sup>.

The predictive power of anthropometric indices generally declines with age, which can be explained by the alterations in body composition that take place in both

sexes. Among the women particularly, onset of menopause entails lower oestrogen production and increased abdominal adiposity as compared with the hip region<sup>(2)</sup>. The rather insignificant alterations in hip circumference measurements with advancing age found among participants in the ELSA-Brasil study point to a certain maintenance of subcutaneous adipose tissue, which is associated with lesser cardiovascular risk than intraabdominal or visceral adipose tissue<sup>(34)</sup>. That fact may explain why WHR was just as valid as WHtR in predicting cardiometabolic outcomes in women even after age 50 years, with both indicators managing to predict the occurrence of  $\geq 2$  MetS accurately. Nevertheless, height would have the advantage, in addition to being self-reported, of being a more routine measurement in health research and services and less inconvenient for the individual examined.

It is noteworthy that ethnic differences among populations have more direct implications for WC, which shows quite different cut-off points by sex and ethnicity<sup>(35)</sup>. In this case, WHtR offers the advantage of having very close or identical cut-off points for men and women.

The choice of a cut-off point should be based more on the objectives of health care, than on statistical criteria, properly. The optimal cut-off points originating from the ELSA-Brasil population differed from those suggested by the literature, particularly for BMI<sup>(28)</sup> and WHtR<sup>(31)</sup>. The latter points were established based on the balance between sensitivity and specificity, resulting in 0.55 for females and 0.54 for males.

In Brazil, these values had already been identified by Almeida *et al.*<sup>(13)</sup> to discriminate high coronary risk in women, with sensitivity and specificity of 68 and 66%, respectively. For this same outcome, Haun *et al.*<sup>(12)</sup> suggested slightly lower cut-off points (0.52 for men and 0.53 for women), and classified individuals with 68% sensitivity in both sexes and specificity of 64% for men and 58% for women. Caminha *et al.*<sup>(11)</sup> found the optimal cut-off equal to 0.54 for women in Alagoas State.

For the same outcome ( $\geq 2$  MetS), suggested cut-off points vary considerably for different populations. In the population of Iran<sup>(32)</sup>, the cut-off point for men coincides with the finding of the present study (0.54), but is much higher for women (0.59), due to high prevalence of female obesity. In China, where BMI measurements are around 23.0 kg/m<sup>2</sup>, the cut-off points are 0.51 (men) and 0.53 (women)<sup>(14)</sup>; in Turkey, where mean BMI levels are high (28.3 kg/m<sup>2</sup> for men and 30.2 kg/m<sup>2</sup> for women), the proposed cut-offs are 0.58 and 0.59, respectively<sup>(36)</sup>. And in the USA, Bohr *et al.*<sup>(37)</sup> proposed the cut-off point of 0.58 to predict metabolic syndrome in young American adults (24 to 34 years).

High mean BMI and WC, in both sexes, were observed in ELSA-Brasil, which explains the higher optimal cut-off points of WHtR identified, since these indices are highly correlated, but with different predictive ability.

In present study, the cut-off for WHtR proposed internationally for both sexes<sup>(29,31)</sup> (0.50) obtained high sensitivity (about 90%). When applied in populations with high prevalence of obesity (as in the case of ELSA-Brasil<sup>(18)</sup>), more sensitive cut-off points inflate the number of false positives. However, this is not a problem for actions in public health, in which we are interested in the early detection of individuals at risk or in subclinical stages of diabetes or CVD, like impaired glucose tolerance or dyslipidaemia. (Higher WHtR cut-off points reduced the prevalence of abdominal obesity in the population, in some strata by almost half – as among women up to 50 years of age – increasing by three or four times the number of false negatives, failing to detect a possible onset of metabolic disease.)

Therefore, the poor specificity presented by the 0.50 cut-off point does not compromise its use, since the cost the health care of these diseases will probably be much higher than the inclusion of false-positive individuals in new screening tests, such as BP measurement and laboratory tests<sup>(38)</sup>, or health education promotion.

Despite the intrinsic limitations on causality in cross-sectional designs, it is valid to claim that the substantial number of individuals in the ELSA-Brasil population afforded the present study greater statistical power, contributing not just better precision in estimating AUC, but also permitting analysis adjusted for possible confounders and observation of the desired effect in different sex and age strata.

Information quality assurance and control measures were also taken at all stages of data collection<sup>(19)</sup>, minimising errors or flaws very common in multicentre studies involving large numbers of actors.

Although widely used in diagnostic studies to compare the power of different predictors, the AUC is an insufficient measure of discrimination to evaluate the predictive model completely. In addition, we used the Brier score, a robust methodology for analysis of validity<sup>(39)</sup> and, in the present study, the values corroborated the consistency of the results, highlighting the internal validity of the anthropometric indicator tested.

In conclusion, we propose to include WHtR, which had good discriminatory power for important cardiometabolic outcomes and performed similarly to, or better than, other available indices of adiposity, as an anthropometric index in the monitoring of nutritional status of the Brazilian adult population, assuming the cut-off of 0.50 as more sensitive and indicated for actions in public health.

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