Comparisons of waist circumferences measured at 4 sites[1–3]

Jack Wang, John C Thornton, Salina Bari, Bennett Williamson, Dympna Gallagher, Steven B Heymsfield, Mary Horlick, Donald Kotler, Blandine Laferrère, Laurel Mayer, F Xavier Pi-Sunyer, and Richard N Pierson Jr

ABSTRACT

Background: Waist circumference (WC) is now accepted as a practical measure of adipose tissue distribution. Four body sites for WC measurements are commonly used, as follows: immediately below the lowest ribs (WC1), the narrowest waist (WC2), the midpoint between the lowest rib and the iliac crest (WC3), and immediately above the iliac crest (WC4).

Objective: We sought to compare the magnitude and reliability of WC measured at these 4 sites in males and females.

Design: WC was measured at each site 1 time in all subjects [49 males and 62 females, aged 7–83 y, with a body mass index (in kg/m^2) of 9–43] and 3 times in a subgroup (n = 93) by one experienced observer using a heavy-duty inelastic tape. Body fat was measured in a subgroup (n = 74) with the use of dual-energy X-ray absorptiometry.

Results: The mean values of WC were WC2 < WC1 < WC3 < WC4 (P < 0.01) in females and WC2 < WC1, WC3, and WC4 (P < 0.01) in males. For all 4 sites, measurement reproducibility was high, with intraclass correlation (r) values > 0.99. WC values were significantly correlated with fatness; correlations with trunk fat were higher than correlations with total body fat in both sexes.

Conclusions: WC values at the 4 commonly used anatomic sites differ in magnitude depending on sex, are highly reproducible, and are correlated with total body and trunk adiposity in a sex-dependent manner. These observations have implications for the use of WC measurements in clinical practice and patient-oriented research. *Am J Clin Nutr* 2003;77:379–84.

KEY WORDS Central adiposity, anthropometry, body composition, body fat mass, percentage body fat, waist circumference, visceral adipose tissue

INTRODUCTION

Epidemiologic studies have clearly shown that central adiposity is highly correlated with the presence of hypertension, coronary heart disease, type 2 diabetes, and increased mortality risk (1–3). Abdominal obesity is associated with increased visceral adipose tissue (VAT) mass (4–6), and VAT is independently associated with glucose and insulin concentrations in both men and women (7–9).

Several studies found that waist circumference (WC) is more closely associated with VAT and central adiposity than is either waist-to-hip ratio or body mass index (BMI; in kg/m^2) (10–12). A recent report by Seidell et al (13) suggests that people with a small WC and large hip circumference have a lower risk of cardiovascular disease. Lean et al (14) studied 1918 adults from a general population in north Glasgow and found that WC could be used in health promotion programs to identify adults who need weight management to avoid obesity-related diseases. Booth et al (15) found that even self-reported WC estimates are useful for monitoring overweight and obesity in epidemiologic surveys.

In a guide about obesity treatment recently published by the National Institutes of Health (NIH), WC and BMI were suggested as the most available and reliable means of identifying obesity, establishing the risks related to it, and monitoring its treatment (16). The NIH guide suggests that the WC measurement be taken just above the iliac crest. However, in a literature review, we identified 14 different descriptions of the site for WC measurements (1, 3, 8, 9, 11, 12, 15, 17–23), including 1 established by the Anthropometric Standardization consensus group (19) that differs from the NIH definition of the WC site. Some methods are slightly different from the others. Overall, these sites can be organized into 4 groups defined by specific anatomic landmarks: *1*) immediately below the lowest ribs, *2*) at the narrowest waist, *3*) the midpoint between the lowest rib and iliac crest, and *4*) immediately above the iliac crest. The anatomic locations of the 4 WC sites and their abbreviations are shown in **Table 1**.

To our knowledge, there is no universally accepted method of measuring WC, and no previous attempt has been made to investigate the differences in WC measured at various sites. The purpose of the present study was to make comparisons between WC measurements at the 4 groups of sites that have been used commonly in previous studies.

SUBJECTS AND METHODS

Subjects

The study subjects were volunteers in various research projects in which anthropometric measurements were part of the study protocol. All subjects gave their written informed consent to participate in the research project, which was approved by the Institutional Review Board of St Luke's-Roosevelt Hospital.

[1] From the Body Composition Unit and New York Obesity Research Center, St Luke's-Roosevelt Hospital Center, Columbia University College of Physicians and Surgeons, New York.

[2] Supported in part by National Institutes of Health grant NIDDK 42518.

[3] Reprints not available. Address correspondence to J Wang, Body Composition Unit, St Luke's-Roosevelt Hospital, 1111 Amsterdam Avenue, New York, NY 10025. E-mail: jw9@columbia.edu.

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TABLE 1
The 4 sites where waist circumference was measured

Measurement sites	Comment
Immediately below the lowest rib (WC1)	
At the narrowest waist (WC2)	ASM site[1]
Midpoint between the lowest rib and the iliac crest (WC3)	WHO site[2]
Immediately above the iliac crest (WC4)	NIH and NHANES III site[3]

[1] Recommended in the *Anthropometric Standardization Reference Manual* (ASM) (19).

[2] Recommended in the World Health Organization (WHO) guidelines (14).

[3] Recommended in the National Institutes of Health (NIH) guidelines (16) and applied in the third National Health and Nutrition Examination Survey (NHANES III).

Measurements

All measurements were made while subjects were wearing a hospital gown with minimal underwear and no shoes. Weight was measured to the nearest 0.1 kg with a calibrated physician's office scale, and height was measured to the nearest 1 mm with a wall-mounted stadiometer (Holtain Ltd, Croswell, Crymych, United Kingdom). Waist circumference was measured with a heavy-duty inelastic plastic fiber tape measure (Prym-Dritz USA, Spartanburg, SC) placed directly on the skin while the subject stood balanced on both feet, with the feet touching each other and both arms hanging freely. The measurement was taken at the end of expiration. Before taking a reading, specific attention was given to placing the tape perpendicular to the long axis of the body and horizontal to the floor.

Waist circumference was measured at all 4 sites by one experienced observer, while the measurements were transcribed on a data form by a second observer. Repeat measurements were performed after one set of anthropometric measurements was completed. As the study continued, it became clear that each of the 4 sites had important technical issues that contributed both advantages and disadvantages to the evaluation of that specific location. We summarize these observations in the Discussion.

Body fat mass, percentage body fat, and percentage fat in the trunk region were measured with whole-body dual-energy X-ray absorptiometry (DPX or DPXL; GE Lunar, Madison, WI) (24). The 2 dual-energy X-ray absorptiometry systems were calibrated to each other.

Statistical methods

The hypothesis that the mean WC values at the 4 sites would be equal was tested by using repeated-measures analysis of variance. Multiple comparisons were performed with Tukey's Studentized Range (HSD) test. Separate calculations were performed for each sex. Reproducibility of the WC measurements at each site was determined by calculating the intraclass correlation coefficient for each set of measurements. Separate calculations were performed for each sex.

Linear regression methods were used to model the relation between fat values measured with dual-energy X-ray absorptiometry and WC, with separate calculations performed for each of the 4 sites. Linear regression methods were also used to study the effects of age and sex on the difference between WC measured at 2 sites. Separate calculations were performed for the differences using each pair of WC sites.

All statistical calculations were performed with SAS version 8 (SAS Institute Inc, Cary, NC) and STATA version 7.0 (STATA Corp, College Station, TX) statistical software packages for personal computers. The level of significance for all statistical tests of hypotheses was set at $P < 0.05$.

RESULTS

The study included a total of 111 subjects (49 males and 62 females) aged 7–83 y, with BMI values of 9–43. The subjects described their ethnicity as follows: 28% were African American, 15% were Asian, 35% were Caucasian, 21% were Hispanic, and 1% were other. All 111 subjects had ≥1 WC measurement at each of the 4 anatomic sites. A subgroup of 93 subjects had WC measured 3 times at each site, and 74 of these subjects had their percentage body fat measured on the same day. **Table 2** shows the physical characteristics of the entire subject group and the 2 subgroups of subjects.

The comparisons among the mean WC values at the 4 sites for each sex are shown in **Table 3**. In males, the mean of WC2 was significantly smaller than the means at the other 3 sites, which did not differ significantly from each other. In females, the mean for each site was significantly different from the other means, with WC2 < WC1 < WC3 < WC4. Age did not influence the differences between WC sites in either males or females.

The reproducibility of the WC measurements was very high for all 4 sites in both sexes (**Table 4**). The intraclass correlations were $r = 0.996$ at WC1, $r = 0.997$ at WC2, and $r = 0.998$ at WC3 and WC4 in males. In females, the correlations were $r = 0.998$ at WC2, WC3, and WC4 and $r = 0.999$ at WC1.

The results of the regression equations relating percentage body fat to WC at each site are shown in **Table 5**. There were no significant associations between WC and percentage body fat for any of the 4 WC sites in males, but there were significant relations at all 4 sites in females. The results of the regression equations relating body fat mass to WC at each site are shown in **Table 6**. WC and body fat mass were significantly correlated at all 4 sites in both sexes.

The results of the regression equations relating percentage fat in the trunk region to WC at each site are shown in **Table 7**. WC and percentage fat in the trunk region were significantly correlated at all 4 sites in both sexes. The results of the regression equations relating trunk fat mass to WC at each site are shown in **Table 8**. WC and trunk fat mass were significantly correlated at all 4 sites in both sexes.

DISCUSSION

This study indicates that WC measurements taken at the 4 commonly used measurement sites differ in magnitude from each other in a sex-dependent manner, and all are highly reproducible. WC measurements correlate significantly with body fat mass in males and females, and correlate significantly with percentage body fat in females only. The associations with trunk fat were higher than were the associations with total body fat in both sexes. The R^2 values for trunk fat mass in females ranged from 0.91 to 0.92.

Our findings suggest that WC measurements taken at the 4 sites are not all comparable, and the extent of comparability depends on the subject's sex. In both men and women, the narrowest waist circumference (ie, WC2) was significantly smaller than the WC

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TABLE 2
Subject characteristics[1]

	All Subjects		Subgroup 1[2]		Subgroup 2[3]	
	Males (n = 49)	Females (n = 62)	Males (n = 36)	Females (n = 57)	Males (n = 28)	Females (n = 46)
Age (y)						
$\bar{x}$	36.9	36.3	36.3	36.6	36.5	36.5
SD	15.8	17.9	16.3	18.4	17.5	19.4
Minimum	10.0	7.6	10.0	7.0	10.0	7.0
Maximum	83.0	76.0	83.0	76.0	83.0	76.0
Weight (kg)						
$\bar{x}$	74.0	66.4	72.8	66.2	72.9	65.4
SD	17.6	22.2	19.8	23.1	20.7	25.1
Minimum	22.2	23.0	22.2	23.0	22.2	23.0
Maximum	113.0	128.0	113.0	128.0	113.0	128.0
Height (cm)						
$\bar{x}$	171.6	158.8	169.9	158.2	168.2	158.0
SD	12.0	14.4	12.7	14.7	13.7	15.5
Minimum	130.0	116.0	130.0	116.0	130.0	116.0
Maximum	191.0	196.0	189.0	196.0	189.0	196.0
BMI (kg/m^2)						
$\bar{x}$	24.8	26.1	24.8	26.2	25.3	25.8
SD	4.5	7.5	5.1	7.8	4.9	8.4
Minimum	10.1	8.6	10.0	8.6	10.0	9.0
Maximum	32.4	42.5	32.4	42.5	32.0	43.0
Total fat (%)						
$\bar{x}$	—	—	—	—	24.3	36.7
SD	—	—	—	—	9.9	10.0
Minimum	—	—	—	—	8.6	17.5
Maximum	—	—	—	—	48.3	50.8
Trunk fat (%)						
$\bar{x}$	—	—	—	—	27.7	35.1
SD	—	—	—	—	10.8	10.2
Minimum	—	—	—	—	7.6	13.4
Maximum	—	—	—	—	45.4	49.1

[1] There was only one significant difference: the males in subgroup 2 were shorter than the other males ($P < 0.05$).
[2] Studied to assess waist circumference measurement reproducibility at each of the 4 sites in each sex.
[3] Studied to determine correlations between waist circumference measured at each of the 4 sites and body fat in each sex.

values at the other 3 sites. However, the other 3 sites were not significantly different from each other in males. In females, they were significantly different from each other. Thus, the 4 WC measurement sites are not interchangeable, and between-study comparisons are valid only if the same measurement site was used in both studies.

The results also indicate that the reliability coefficients for WC measured at each of the 4 sites are better than 0.99. Because the replicated measurements were taken on the same day for each subject, it is not surprising that the observed reliabilities are higher than are corresponding results reported in other studies in which the replicated measurements were taken on different days (11, 25).

Measurement location

Historically, the locations for WC measurements have varied, ranging from anatomic landmarks to the subject's self-preferred clothing waistline. In a literature search, we found 14 different descriptions of the WC measurement site (1, 3, 8, 9, 11, 12, 17–23). All 14 sites are within the region from the tenth rib to the iliac crest. The 14 sites were grouped into the 4 locations described in the present report. These 4 groups include 3 sites recommended in national and international guidelines: the narrowest waist (WC2), as suggested in the Anthropometric Standardization Report (19); the midpoint between the lowest rib and the iliac crest (WC3), as suggested in the World Health Organization Guidelines; and immediately above the iliac crest

TABLE 3
Comparisons among waist circumference measurements at the 4 sites for each sex[1]

Measurement site	Value
Males (n = 49)	
WC1	898.3 ± 128.1^b
WC2	887.8 ± 123.2^a
WC3	903.3 ± 128.5^b
WC4	902.9 ± 125.8^b
Females (n = 62)	
WC1	841.5 ± 157.7^b
WC2	828.2 ± 150.8^a
WC3	855.5 ± 157.6^c
WC4	873.7 ± 154.7^d

[1] $\bar{x}$ ± SD. For each sex, values with different superscript letters are significantly different, $P = 0.01$ (Tukey's studentized range (HSD) test). WC1, immediately below the lowest rib; WC2, at the narrowest waist; WC3, midpoint between the lowest rib and the iliac crest; WC4, immediately above the iliac crest.

TABLE 4
Reproducibility of waist circumference measurements at the 4 sites for each sex[1]

Measurement site	$\bar{x}$	Within-subject variation	Between-subject variation	Intraclass correlation (r)	CV
	mm	*mm*	*mm*		
Males (n = 36)					
WC1	901.2	9.1	136.8	0.996	1.008
WC2	891.6	7.1	131.7	0.997	0.796
WC3	907.5	6.6	137.7	0.998	0.724
WC4	908.2	5.7	136.4	0.998	0.625
Females (n = 57)					
WC1	845.0	5.6	161.5	0.999	0.667
WC2	831.8	6.4	154.0	0.998	0.773
WC3	861.4	7.8	162.7	0.998	0.911
WC4	877.7	6.8	161.6	0.998	0.773

[1] WC1, immediately below the lowest rib; WC2, at the narrowest waist; WC3, midpoint between the lowest rib and the iliac crest; WC4, immediately above the iliac crest.

(WC4), as recommended in the NIH Guidelines (16) and as applied in the third National Health and Nutrition Examination Survey. As our investigation advanced, several technical issues arose with regard to each site, as described below.

WC1

We did not experience any difficulties in locating the site below the lowest rib in all subjects, even in obese persons. However, it is important to standardize the measurement location to immediately below the end of the lowest rib, which is usually at the anterior margin of the lateral regions of both sides of the trunk. In many subjects, the narrowest waist is at the lowest rib.

WC2

The narrowest waist is probably the most frequently recommended site. It is easy to identify the narrowest waist in most subjects. However, for some subjects, there is no single narrowest point between the lowest rib and the iliac crest because of either a large amount of abdominal fat or extreme thinness.

WC3

Identifying the absolute midpoint between the lowest rib and the iliac crest requires locating and marking the 2 anatomical landmarks. Thus, this method is more time-consuming than are the other 3 methods. In addition, misplacing either of the 2 marks has a significant effect on the measured WC.

WC4

We found the measurement immediately above the iliac crest to be the most difficult from a technical standpoint, especially in females, because the waist shape superior to the iliac crest decreases more than the waist shape in other regions of the trunk. It is very difficult when measuring this WC to stabilize the tape on a sharply curved skin surface. WC measurements at the iliac crest are often used for studies measuring VAT with a single computed tomography (8) or magnetic resonance imaging (26) slice at the L4–L5 level. Because the iliac crest is closer to L4–L5 than are the locations for the WC1, WC2, and WC3 measurements, WC measured above the iliac crest is appropriate for linking VAT with a single-slice computed tomography or magnetic resonance imaging measurement. The results of the present study indicate that percentage body fat is more highly correlated with WC4 values than with other WC values in both sexes.

These technical issues notwithstanding, all 4 sites had high reproducibility and CVs ≤ 1%. Because WC values vary between sites, values obtained by following the guidelines of one organi-

TABLE 5
Results of regression equations relating percentage body fat to waist circumference (WC, in mm) measured at each of the 4 sites for each sex[1]

Measurement site	WC coefficient	Constant	R^2	P
Males (n = 28)				
WC1	0.00853	16.5969	0.02	0.5335
WC2	0.00881	16.4546	0.02	0.5277
WC3	0.01079	14.4741	0.03	0.4199
WC4	0.01374	11.7664	0.04	0.3043
Females (n = 46)				
WC1	0.04801	−3.1299	0.67	0.0001
WC2	0.05046	−4.4795	0.68	0.0001
WC3	0.04739	−3.1441	0.66	0.0001
WC4	0.04797	−4.5817	0.66	0.0001

[1] WC1, immediately below the lowest rib; WC2, at the narrowest waist; WC3, midpoint between the lowest rib and the iliac crest; WC4, immediately above the iliac crest.

TABLE 6
Results of regression equations relating body fat mass (kg) to waist circumference (WC, in mm) measured at each of the 4 sites for each sex[1]

Measurement site	WC coefficient	Constant	R^2	P
Males (n = 28)				
WC1	0.03143	−10.6673	0.31	0.0023
WC2	0.03203	−10.8272	0.31	0.0023
WC3	0.03189	−11.3552	0.33	0.0014
WC4	0.03366	−13.0358	0.36	0.0007
Females (n = 46)				
WC1	0.07609	−37.5049	0.77	0.0001
WC2	0.07957	−39.3187	0.77	0.0001
WC3	0.07606	−38.3287	0.77	0.0001
WC4	0.07792	−41.4400	0.80	0.0001

[1] WC1, immediately below the lowest rib; WC2, at the narrowest waist; WC3, midpoint between the lowest rib and the iliac crest; WC4, immediately above the iliac crest.

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TABLE 7
Results of regression equations relating percentage fat in the trunk region to waist circumference (WC, in mm) measured at each of the 4 sites for each sex[1]

Measurement site	WC coefficient	Constant	R^2	P
Males (n = 28)				
WC1	0.05086	−14.4286	0.33	0.0122
WC2	0.05640	−18.3083	0.36	0.0084
WC3	0.05643	−19.4418	0.39	0.0053
WC4	0.05682	−20.09339	0.42	0.0038
Females (n = 46)				
WC1	0.04942	−5.8905	0.68	<0.0001
WC2	0.05177	−7.1356	0.68	<0.0001
WC3	0.04890	−6.0056	0.67	<0.0001
WC4	0.04950	−7.4900	0.67	<0.0001

[1] WC1, immediately below the lowest rib; WC2, at the narrowest waist; WC3, midpoint between the lowest rib and the iliac crest; WC4, immediately above the iliac crest.

TABLE 8
Results of regression equations relating trunk fat mass (kg) to waist circumference (WC, in mm) measured at each of the 4 sites for each sex[1]

Measurement site	WC coefficient	Constant	R^2	P
Males (n = 28)				
WC1	0.02857	−15.0303	0.81	<0.0001
WC2	0.03085	−16.5279	0.83	<0.0001
WC3	0.02961	−16.1022	0.84	<0.0001
WC4	0.02918	−15.9088	0.85	<0.0001
Females (n = 46)				
WC1	0.03602	−18.2169	0.92	<0.0001
WC2	0.03775	−19.1354	0.91	<0.0001
WC3	0.03604	−18.6374	0.92	<0.0001
WC4	0.03652	−19.7587	0.92	<0.0001

[1] WC1, immediately below the lowest rib; WC2, at the narrowest waist; WC3, midpoint between the lowest rib and the iliac crest; WC4, immediately above the iliac crest.

zation may not equal values obtained by following guidelines from other organizations. The need for an internationally accepted WC measurement site should therefore be addressed.

Technical considerations

The reproducibility of WC measurements at any site depends on the observer's skill. A potential source of measurement error for all WC sites is incorrectly positioning the tape measure on the subject's body. It is critical that the observer position the tape around the subject's body in a plane that is perpendicular to the long axis of the body. An inexperienced observer may overestimate the WC measurement by positioning the tape incorrectly. This may account for the larger measurement errors reported in earlier studies. Also, the heavy-duty tape measure used in our study is flexible, inelastic, and firm, making it easy to place around the trunk region of the body in the same plane, even with very obese subjects. However, more technical practice is required to standardize the tape tension for measurement. Another often-used tape measure, the Gulick II (Lafayette Instrument Co, Lafayette, IN), has a tension meter attached so that the tape's tension can be standardized during measurement. However, this tape is narrower and softer than the tape used in the present study, and it requires more practice to place it on the skin in the correct plane.

Prediction of adiposity

An important finding of the present study is that WC values measured at any of the 4 commonly used sites are almost equally associated with total body fat and trunk fat in each sex. The magnitudes of the associations are stronger in females than in males, and much stronger for trunk fat than for total body fat in both sexes. When the analyses were performed in adults only, the conclusions that we reached for the total group were not changed. Only a small number of children completed the full set of anthropometric measurements, because taking measurements 3 times at each of the 4 sites requires the subject to stand still for ≥20 min. Thus, we do not have enough data to perform separate analyses in children only.

The authors of previous studies reported conflicting views on the associations between WC and body fatness by sex. Some studies found that WC is associated with total body fat similarly in both sexes (27, 28), whereas others showed sex-specific associations (6, 13), as we found in this study. Our study indicates that the absolute WC value is more dependant on the specific measurement site in females than in males. This agrees well with biological differences in body shape between females and males. In general, for adults, variation in WC along the body axis is more defined in females than in males.

The current study also indicates that WC measured immediately above the iliac crest (WC4) has a higher correlation with total body fat than do WC values measured at the other 3 sites. However, studies by Clasey et al (4) and Lean et al (29) found that WC measured at the narrowest point of the torso (WC2) is a strong predictor of total adipose tissue and VAT measured with computed tomography.

Conclusions

The present study highlighted the similarities and differences between WC measurement sites and also identified important technical measurement issues that require further discussion and exploration. Because WC measurements are increasingly being promoted as part of clinical obesity evaluations, the present findings underscore important prevailing measurement issues and concerns that can form the basis of future research.

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