Original Article

Waist girth normalized to body build in obesity assessment

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Waist girth (WG) is regarded as the most significant anthropometric parameter associated with cardiovascular risk. The objective of the present study was to strengthen WG as an obesity marker by basing WG assessment not on gender but on individually measured body build characteristics that need not coincide with gender. We formulated a new marker, the Waist Reference Girth (WRG) and two corollaries, the Waist Deviation (WD) and the Percent Waist Deviation (%WD). The present research centered on deriving an equation for WRG from relevant trunk skeletal measurements that closely predicted WG in lean individuals. This equation would determine *any* individual's WRG and current WD. Trunk skeletal widths and chest depth as well as WG were measured on 507 physically active subjects (247 men and 260 women), predominantly lean young adults. Multiple regression analysis with the skeletal measurements as independent variables was performed on this data to predict WG. The unisex WRG equation WRG = Chest Sum $\times$ 1.635 predicted WG of 282 lean subjects (maximum WD of 4 cm) with R^2 of 0.87 (SEE of 3.0 cm). Male and female WG cutoff values for central obesity are usually taken at 94 cm and 80 cm respectively. For the average male and female WRG in this study (79 cm and 67.4 cm), these cutoff values are equivalent to WD of 15cm and 12.6cm respectively and to 19%WD for both genders (15/79 and 12.6/67.4). With %WD normalized for WRG, hence unaffected by intra-group or inter-group variations in the Chest Sum, %WD thresholds may better identify health risks linked to abdominal obesity than existing WG thresholds.

Key Words: waist girth, body build, waist reference girth, waist deviation, abdominal obesity, waist circumference

Introduction

Recent studies have focused on waist girth (WG) as the most significant and practical indicator of obesity associated with increased risk of cardiovascular and metabolic disease. In the methodology that uses WG to assess health risks, different absolute values are given as cutoff thresholds for excessive abdominal girths in men and women. In many studies among Caucasians, a WG threshold of 94 cm for men and 80cm for women has been proposed.[1] Anthropometric collections substantiate gender-based differences of 11 to 14 cm in WG for normal-weight, largely Caucasian civilian and military populations and indicate that in the leanest groups WG averages about 77 cm for men and 66 cm for women.[2-6] However, WG has a substantial range even within lean military groups, and average WG differs between the military personnel of different countries, from 67.5cm for the Vietnamese to 88.9cm for the Canadian military.[2,3] The large range in WG and differences in average WG must thus be mainly attributable to factors other than differences in leanness. Research has shown, furthermore, that for some ethnic groups health risks increase at a lower WG threshold than the one cited above.[7] Data also indicate that in some ethnic groups male-female differences in WG are less than the above-cited 11-14 cm difference.[8] In short, gender proves to be an insufficient marker for WG in normal-weight populations. The research for this paper suggests that WG as an obesity marker would be strengthened by replacing WG standards based on gender with WG standards based on individually measured body build characteristics that need not coincide with gender.

Our approach in this study is an extension of Behnke's work leading to the quantification of frame size from firm-pressure skeletal measurements and the prediction of lean body mass (or weight with normal percent fat) from frame size and height.[9] For a "Reference Group" of physically active subjects who were predominantly young adults, we derived "Reference Girths" for 12 sites along the trunk and limbs from related skeletal measurements along the trunk and limbs. The complete database for this Reference Group as well as a complete description of measurements, methods of statistical analysis, and the derivation of a "frame size" weight has been previously reported.[10]

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The present paper focuses on the determination of the Waist Reference Girth (WRG) and the Waist Deviation (WD), the difference between measured WG and a standard based on body build characteristics. Gender-specific WG thresholds presume the existence for each gender of a single WRG with acceptable leanness, so that, for each gender, a given WG threshold represents a uniform level of abdominal obesity. Our study seeks to replace gender by relevant skeletal dimensions that can be measured in each individual to determine his/her personal WRG. Once individuals' WRG and %WD (WD divided by WRG) are ascertained, we believe that %WD thresholds, with their individualized assessment of abdominal obesity, will be more consistently linked with health risks than currently accepted WG thresholds.

Subjects and measurements

Subjects

In the first stage of our study, authors GH and LJP measured 255 volunteers (106 men and 149 women) at San Jose State University and the United States Naval Postgraduate School, Monterey, California, most of whom were young adults and vigorously active at least two hours a week. Twelve girths, eight skeletal widths and chest depth between the sternum and the spine, height, weight, and four skinfold measurements (subscapular, triceps, suprailiac, and thigh) were taken on all 255 volunteers. Densitometric assessments were performed randomly on one-quarter of the subjects. Most of the persons measured had subscapular skinfolds of less than 15mm and densitometric percent fat below 18% for the men and below 25% for the women. However, no volunteers were excluded on the basis of excessive fatness, in order to have the largest possible range of body builds represented. Tentative regression equations were derived for each of the girths from the best combination of skeletal measurements in this core database.

In the second stage, technicians trained by LJP and GH performed identical girth and skeletal measurements on 4000 California health and fitness club members, all of whom engaged in several hours a week of vigorous physical activity. No skinfold or densitometric measurements were available for these health club volunteers, who were solely assessed by the regression equations derived in the first stage. The final database was expanded to 247 men and 260 women by the inclusion of 252 health and fitness club members, thus providing a sizable Reference Group of physically active individuals with a wide variety of body builds.[10]

Measurements

Skeletal width measurements followed the techniques described in Behnke and Wilmore.[9] A description of the pressed chest depth measurement can be found in Lohman *et al.*[11] A sliding anthropometer was used for firm-pressure measurements at the following sites: biacromial width, chest width at the nipple level (5^{th} rib level), biiliac width (between both sides of the iliac crest), bitrochanteric width (between the two greater trochanters), and chest depth (from the center of the sternum at nipple level to the spine at the same level). For the chest depth, the depth attachment on the anthropometer was activated. For chest width and depth measurements, maximum inspiration and expiration were averaged to obtain normal respiration. For a sub-sample of 21 women and 10 men, chest width at 10^{th} rib level with maximum inspiration and expiration averaged was included in the measurements. The sites for the relevant skeletal and girth measurements are illustrated in Figure 1. In our research, WG, which was measured with a plastic tape, was taken consistently just below the rib cage, as located by visual inspection or by palpation. With a single exception, this was the minimum measurement for all the women. A comparative girth measurement taken at the level of the iliac crest laterally and the omphalion anteriorly exceeded this minimum by 13.9 cm (SD of 5.5 cm) on average. For the men in our study, the girth at the iliac crest-omphalion level averaged 3.1 cm more than the girth just below the rib cage, with SD of 4.2 cm. For five men, all with large abdominal excesses, WG just below the rib cage was perceptibly larger than the lower-level measurement.

Statistical analysis

All the measurements of the stage 1 database were statistically analyzed on a Macintosh using NCSS statistical software. Analysis of the combined database of 507 subjects was done with NCSS 6.0 Statistical System for Windows on an IBM computer. Three complementary obesity measures, Waist-Hip ratio (WHR), Body Mass Index (BMI) and another index of abdominal obesity, the Conicity Index (CI) are added for comparative purposes.[12,13] Multiple regression analyses with various body build parameters as independent variables were performed to predict their association with WG. A *P* value <0.05 (2-tailed) was considered to be significant.

Results

Table 1 gives the measured characteristics of the 247 men and 260 women, including weight, height, age and WG. The chest sum combines skeletal chest width and depth at the nipple level. Skeletal sum, summing chest width, chest depth, bitrochanteric width, wrist girth and ankle girth, is included as a frame size indicator.

Deriving the waist reference girth equation

Chest width and chest depth were selected by stepwise regression analysis as the main skeletal determinants of WG for both men and women, with biiliac width and bitrochanteric width playing a subsidiary role. Height had a very small correlation (R^2 of 0.04 for men, 0.02 for women) with WG, and biacromial width had R^2 of only 0.03 for men, but 0.14 for women. In the database combining men and women, gender rather than height and biacromial width explained 66% of the variance in WG (R^2 of 0.44), but gender explained no additional variance in the presence of chest width and chest depth, which jointly had R^2 of 0.76 with WG. Only a slight improvement in the prediction for WG (R^2 of 0.78) was obtained with biiliac and bitrochanteric widths as additional skeletal variables. Hence, these data supported our simplifying the WRG concept by connecting it to only a single variable summing the chest width and the chest depth. These are also the two skeletal dimensions that on

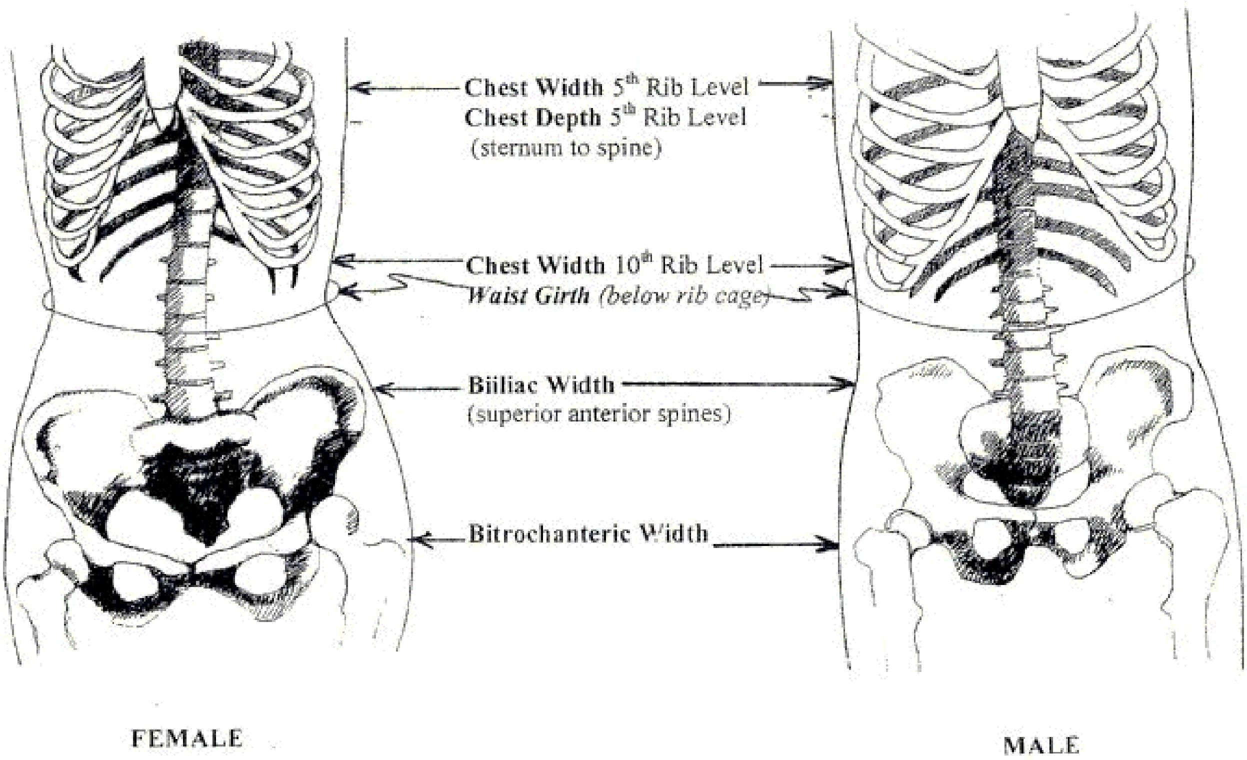

Table 1. Clinical characteristcis of the 247 men and 260 women

	Men (*N* = 247)			Women (*N* = 260)		
	Mean	SD	Range	Mean	SD	Range
Age	31.6	10.2	18-65	28.7	8.9	18-67
Height (cm)	177.8	7.2	157-198	164.9	6.5	147-183
Weight (kg)	78.1	10.5	54-116	60.6	9.6	42-105
Biacromial width (cm)	41.2	2.1	34.1-47.4	36.5	1.8	32.2-42.6
Chest Width (cm)	29.9	2.1	24.7-35.6	26.1	1.8	22.2-33.2
Chest Depth (cm)	20.8	2.1	14.4-27.5	17.7	1.8	14.3-26.8
Biiliac Width (cm)	28.1	2.1	19.4-34.7	27.6	2.3	18.7-33.3
Bitrochanteric width (cm)	32.5	1.9	27.5-38	31.5	2	24.7-37.8
Chest Sum (cm)*	48.3	3.5	39.1 – 58.3	41.2	3	35.6-53.7
Skeletal Sum (cm) **	123.6	6.7	106.7-141.5	111.5	6.0	96.6-134.3
Conicity Index***	1.17	0.07	1.03-1.43	1.06	0.06	0.92-1.26
Waist-Hip ratio	0.86	0.06	0.74-1.07	0.73	0.05	0.64-0.95
BMI (kg/m^2)	24.7	2.8	18.3-36.8	22.3	3.2	16.9-38.2
Waist Girth (cm)	84.5	8.8	67-113	69.8	7.6	58-101.5

*chest sum =(chest depth + chest width at the nipple level) × 0.92 for men, 0.90 for women; **skeletal sum =chest width + chest depth + bitrochanteric width + wrist girth + ankle girth; ***WG (m) / (0.109 × square root of Weight (kg) / Height (m))

Table 2. Statistical distribution of waist girth, waist reference girth, waist deviation, and % waist deviation

	Mean	SD	Min.	10th	25th	50th	75th	90th	95th	99th	Max
247 Men											
WG (cm)	84.5	8.8	67.1	73.9	77.9	83.4	90	97.8	100.8	110.8	113.2
WRG (cm)	79.0	5.6	63.9	71.9	75.5	79.0	82.7	86.5	88.6	91.4	95.3
WD (cm)	5.5	5.7	-6.6	-1.6	1.3	5.1	9.0	13.3	16.8	22.5	24.0
%WD	6.9	7.0	-8.5	-2.0	1.7	6.4	11.2	16.1	20.5	26.7	27.7
260 Women											
WG (cm)	69.8	7.6	57.9	61.7	64.6	68.3	72.8	80.3	85	96.2	101.5
WRG (cm)	67.4	4.7	58.2	62.4	64.6	66.6	69.8	73.9	76.2	83.7	87.8
WD (cm)	2.4	5.2	-12.4	-3.5	-.9	2.2	5.2	9.6	12.0	19.0	21.9
%WD	3.5	7.4	-15.8	-5.3	-1.3	3.2	7.7	14.0	17.0	25.0	29.4

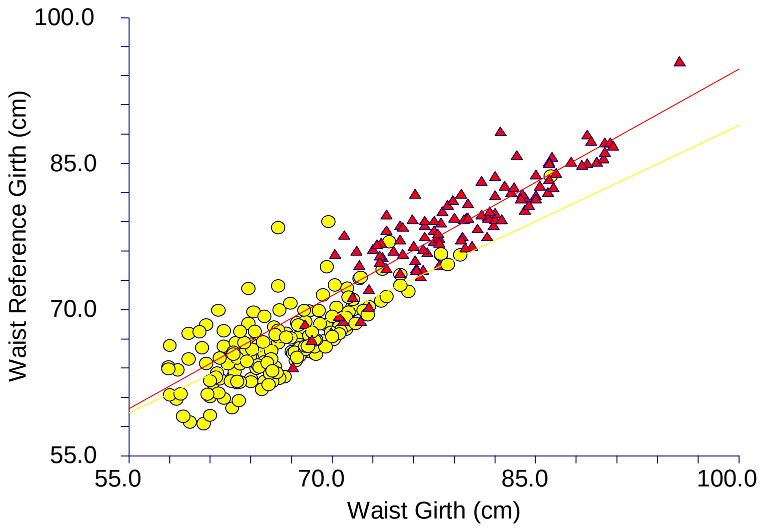

Figure 2. Waist girth vrsus waist reference girth

average show the greatest difference between men and women (see Table 1). The following equation predicting WG was calculated from the 507-subject database:

WG = Chest Sum x 1.726 Equation (1)

with R^2 of 0.76 (SEE of 5.5 cm).

In Chest Sum, chest width was calculated by multiplying the 5th rib (nipple) level measurement by 0.92 for the men and by 0.90 for the women. The 5th rib level measurement was thus converted to the 10th rib level chest width on the basis of the average ratio between the 10th rib and 5th rib level chest width in the male and female sub-samples on whom both chest widths were measured.

To arrive at a WRG equation (an equation that predicts WG in *lean* individuals), the 225 subjects whose WG exceeded WG predicted by Equation 1 were eliminated. The WG equation for the remaining 282 subjects, all of them lean subjects as defined by the group regression equation, had R^2 of 0.87 (SEE of 3 cm) with WG and a smaller multiplier for Chest Sum than Equation 1. The resulting equation for these lean individuals serves as the WRG equation for any individual:

WRG = Chest Sum x 1.635 Equation (2)

Figure 2 shows the relationship between WG and WRG for the 282 subjects from whose data the WRG equation was derived. For the 111 men, WRG averaged 79.1 cm and ranged from 64 - 95 cm (66.7 cm and 58-84 cm for the 171 women). Table 2 gives the statistical distribution by gender of WG, WRG based on Equation 2, and the corresponding WD and %WD (WD divided by WRG). The 247 men's average WRG from this equation is 79 cm (48.3 x 1.635) and that of the 260 women is 67.4 cm (41.2 x 1.635). WRG for the 507 subjects ranges from 58.2 cm (chest sum of 35.6 cm) to 95.3 cm (chest sum of 58.3 cm), with women at the lowest end of the distribution and men at the highest end, the same range as for the 282 subjects in Figure 2.

Waist reference girths, % waist deviation, and waist girth thresholds

As Table 3 demonstrates, gender does not create a clear demarcation line between female and male WRG, as there are 80 men and 113 women in the chest sum categories separating the italicized median female and male categories in Column 3. There are 5 men with a chest sum of

39-41 cm and 11 women in the median male category (47-49 cm) and larger.

In assessing abdominal obesity from WRG, it is preferable to use %WD rather than WD in Table 3, in that the absolute WRG magnitudes differ widely here. The abdominal obesity thresholds of 94cm for men and 80cm for women proposed by Lean *et al.*,[1] correspond closely to the 20 %WD threshold for the median male and female chest sum categories (Column 6). Specifically, for men whose WRG is 79 cm (the group mean in Table 2), WD is 15 cm at Lean's male WG threshold (WD = 94 – 79 = 15 cm) and results in 19 %WD (15/79 = 19%), the same %WD as for women with the group's average WRG of 67.4cm and WD of 12.6cm. Of the 62 men and 84 women (Column 3) in the italicized chest sum categories, 47 men and 74 women (Column 5) have WG below the 10 %WD threshold (Column 4) and 11 men and 8 women (Column 7) have WG below the 20 %WD threshold (Column 6). Only four men and two women (Column 9) exceed both Lean's thresholds and the 20 %WD threshold in Column 8 (maximum %WD is 29.4 among the 507 subjects).

For men and women whose chest sum is typical for their gender, Lean's WG thresholds closely match abdominal fatness above 20 %WD. This is not true for many of the men and women in Column 5 and Column 7 in Table 3 whose chest sum exceeds that typical for their gender. While their %WD is below 20 % or even 10 %, their WG often exceeds 94 cm and 80 cm respectively. Conversely, WG below the obesity threshold would not have detected 20 %WD among small-chest individuals (or even 30 %WD in the lowest chest sum category). Had a stringent WG threshold corresponding to 10 %WD been selected for the typical chest sum categories, that is, 86.4 cm for men and 72.7 cm for women (Column 4, Table 3), WG for one-quarter to one-third of the subjects would have exceeded this threshold, but would have yielded false positives for obesity for many of the subjects identified by the lower thresholds. Even then, abdominal obesity in most of the small-chest men and women would have gone undetected.

Comparison of %WD with other obesity indicators

The correlation between WG on the one hand and BMI, WHR, and Conicity Index (CI) has been examined in a number of studies. Table 4 gives the correlation matrix of these four obesity indicators and %WD. The body-build variable Chest Sum also appears in the correlation matrix. Correlations for the 260 women are given above the diagonal and those for the 247 men below the diagonal.

The 507-subject database reported previously allows many additional statistical analyses relating the different obesity indicators with body build factors,[10] as it includes additional girth and skeletal data suggestive of frame size and body composition estimates. Table 5, which includes all twenty women in the database with greater than 15 %WD, illustrates more specifically how these traditional obesity indicators relate to %WD and how they are affected by skeletal characteristics. As discussed earlier, a chest sum of less than 40.7 cm results in WG below 80cm for all the women with 15 to 20 %WD, whereas, with a chest sum above 46cm, the same %WD will induce a WG in excess of 88cm.

A large BMI results when frame size (skeletal sum) - quantified as the sum of chest width, chest depth, bitrochanteric width, wrist and ankle girths - is large in relation to height. Yet for the twenty women height has r of only 0.25 with frame size (and no correlation with chest sum). A large chest sum to bitrochanteric width ratio increases WHR, just as a large chest sum to frame size ratio increases CI. Furthermore, all excess weight, whether due to abdominal or gluteal fatness or even to muscle excesses, raises BMI, while weight excess unrelated to WG lowers WHR and CI. Thus WG and BMI often tend to yield comparable results, as do WHR and CI, but the two pairs may move in sharply different directions (e.g subject no. 19). Given the multitude of individual body build constellations, it is not surprising that in Table 5 the different obesity indicators rarely agree with each other or with %WD. Nevertheless, average values for %WD, WG, BMI, WHR, and CI for the twenty women are all aligned near the respective obesity thresholds for these indicators.

Because of unusual body build combinations, none of the four obesity indicators detect any obesity in three cases (nos. 1, 10, and 13), while in a fourth case (no. 8), all four strongly overestimate obesity. Concordance and divergence of obesity assessments arising from individual body build constellations are equally prevalent for the 240 women with less than 15 %WD. Among the latter, BMI exceeds 25 for 31 women (four above 30), WG exceeds 80cm for 13 (one above 88), and nine women exceed the respective WHR and CI thresholds. For 12 of the 31 women there is concordance between BMI and WG, but only three of the 31 women exceed all four thresholds. One of the three women, in particular, illustrates the converse of cases 1, 10, and 13 in Table 5. Her 6 %WD corresponds to WG of 93.4 cm, BMI of 32, WHR of 0.85, and CI of 1.19 not only because of her extremely large chest sum (53.7 cm) and large frame size (132.1 cm) for height, but also because the ratio of chest sum to bitrochanteric width and to frame size is typical of male rather than female proportions. However, average values of %WD (2.2%) WG (68.6 cm), WHR (0.72) and CI (1.05) for the 240 women are well-matched.

For the men, similar patterns of convergence and divergence between the different obesity indicators were observed. Among the 30 men with greater than 15%WD, in six cases WG, BMI, WHR, and CI were all below their respective thresholds because of the subjects' small chest sum, and in ten cases all five obesity indicators were above their thresholds. The 19%WD average for the 30 men corresponded to WG of 96.6, BMI of 27, WHR of 0.94, and CI of 1.28. For the 217 men with less than 15 %WD. there were 83 with BMI >25 (4 subjects >30), 17 with WG >94.2 cm (3 subjects >102 cm), 11 with WHR >0.94, and only two with CI >1.28. Their average 5 %WD corresponded to WG of 82.9 cm, BMI of 24.4 kg/m^2, WHR of 0.85, and CI of 1.15.

Table 3. Distribution of subjects in chest sum categories by gender and %Waist Deviation (median female and male chest sum categories in italics)

Column 1	Column 2	Column 3		Column 4	Column 5		Column 6	Column 7		Column 8	Column 9	
Chest sum	Average WRG	Subjects, *N*		10 %WD = WRG × 1.1	Subjects, *N*		20 %WD = WRG × 1.2	Subjects, *N*		30 %WD = WRG × 1.3	Subjects, *N*	
in cm	in cm	M	F	in cm	M	F	in cm	M	F	in cm	M	F
35 – 37	59.1	0	8	65	0	7	70.9	0	1	76.8	0	0
37 - 39	62.3	0	44	68.5	0	39	74.7	0	5	81	0	0
39 - 41	*65.5*	*5*	*84*	*72.7*	*3*	*74*	*78.6*	*2*	*8*	*85.2*	*0*	*2*
41 - 43	68.5	13	68	75.4	10	60	82.2	3	7	89	0	1
43 - 45	71.8	16	27	79	11	21	86.2	5	6	93.3	0	0
45 - 47	75.2	51	18	82.7	41	10	90.2	9	6	97.8	1	2
47 - 49	*78.5*	*62*	*7*	*86.4*	*47*	*6*	*94.2*	*11*	*1*	*102*	*4*	*0*
49 - 51	81.8	44	2	90	32	1	98.2	10	1	106.3	2	0
51 - 53	84.9	32	1	93.4	21	0	101.9	9	0	110.4	2	1
53 - 55	88	17	1	96.8	8	1	105.6	7	0	114.4	2	0
55 - 58.5	90.7	7	0	99.8	3	0	108.8	3	0	117.9	1	0
		247	260		176	219		59	35		12	6

Columns: (1) See Table 1; (2) Average Waist Reference Girth for chest sum category; (3) Total subjects in chest sum category; (4) 10%WD (5) subjects in chest sum category, WG less than WRG x 1.1; (6) 20%WD (7) subjects in chest sum category, WG between WRG x 1.1 and 1.2; (8) 30%WD; (9) subjects in chest sum category, WG between WRG x 1.2 and 1.3, maximun for group is 29.4%WD.

Table 4. Correlation Matrix of obesity indicators and chest sum (women above, men below diagonal).

	Chest sum	WG	BMI	WHR	CI	%WD
Chest sum	1	0.74	0.72	0.45	0.44	0.13
WG	0.77	1	0.87	0.74	0.80	0.76
BMI	0.73	0.80	1	0.50	0.46	0.58
WHR	0.52	0.81	0.50	1	0.87	0.66
CI	0.50	0.86	0.45	0.89	1	0.76
%WD	0.12	0.72	0.47	0.69	0.81	1

WG, waist girth; CI, conicity index; WHR, waist-hip ratio; %WD, % waist deviation

Table 5. Obesity indicators and skeletal data for 20 women with greater than 15% Waist Deviation

	%WD	WG, cm	BMI, kg/m^2	WHR	CI	Chest sum, cm	Skeletal sum, cm	Bitrochanteric width, cm	Height, cm	Hip, cm
1)	15.2	72.2	21.9	0.73	1.07	38.3	111.3	32.9	174	98.6
2)	15.5	85.4	23.6	0.78	1.21	45.2	120.3	34.7	176.5	109.5
3)	16.4	79.2	24.4	0.81	1.16	41.6	112.2	30.2	161.3	97.4
4)	16.4	85.6	27.2	0.76	1.16	45	116	32.9	167.6	112.1
5)	16.9	83.4	29.7	0.78	1.09	43.6	120.8	35.3	165.1	107.5
6)	16.9	83	25	0.77	1.15	43.4	118.9	35.5	174	108.1
7)	16.9	77.9	22.6	0.78	1.16	40.7	113	33.8	167.6	100.1
8)	17	94.2	30.9	0.91	1.22	49.2	118.6	31.7	162.6	103.5
9)	17.5	88.2	31.7	0.82	1.12	45.9	121	32.9	165.1	107.9
10)	17.6	74.7	23.2	0.75	1.12	38.8	109.2	32.9	160	100
11)	17.7	80	26.8	0.76	1.12	41.6	111.9	32.2	160.7	104.6
12)	18.1	90.1	27.4	0.95	1.26	46.7	116.9	30	156.5	95.2
13)	18.3	73.1	23.2	0.77	1.1	37.8	107.2	29.9	161.3	94.9
14)	19.9	90.5	29.3	0.84	1.21	46.2	121.2	33.2	160.2	108.1
15)	20	79.6	29.5	0.76	1.06	40.6	117.6	33.5	160	104.3
16)	21.2	80.5	26.7	0.75	1.1	40.6	115.1	33.5	170.2	107.2
17)	21.3	101.5	35.3	0.89	1.19	51.2	134.3	35.8	172.7	114
18)	23.5	83.6	25.3	0.8	1.17	41.4	116.8	34.5	170	104.1
19)	27.7	96.2	38.2	0.75	1.11	46.1	128.6	37.8	165.1	128.3
20)	29.4	96.3	30.9	0.94	1.25	45.5	121.7	34.2	161	102.6
Average	19.2	84.8	27.6	0.805	1.15	43.5	117.6	33.4	165.6	105.4
Range	14.2	29.3	16.3	0.22	0.2	13.4	27.1	7.9	20	33.4

%WD, % waist deviation; WG, waist girth; BMI, body mass index; WHR, waist-hip ratio; CI, conicity index

Discussion

Regression analysis on data of physically active, largely lean women and men established a strong correlation between the dimensions of the thorax and WG. The WRG equation: Chest Sum x 1.635 characterized the 282 subjects whose WG did not exceed Chest Sum x 1.726, the WG regression equation for the 507 subjects. This WRG equation projects WG with the same average leanness as that of these 282 subjects for all possible combinations of width and depth of the rib cage, our Waist Reference Girth (WRG). The correlation (R^2) of 0.76 (SEE of 5.5 cm) between WG for the 507 subjects and their WRG compared favorably with R^2 between WG and gender, which was 0.44 (SEE of 8.2 cm).

The WRG equation developed in our study is based on an approximation of the measured chest width at 10th rib level, because this is the chest width level which best correlates with WG, a fact that emerged only after the completion of 5th rib level measurements on most of the subjects in the database. We found that the average chest tapering between nipple level and the bottom of the rib cage (ratio of 10th rib width to 5th rib width) was 92% (male) and 90% (female) in the sub-sample on whom it was ascertained - a finding that was confirmed in subsequent research on other groups. However, the range was from 75% to 98%, which in some instances led to an over-estimation of WRG by 6-7 cm (as evidenced in Table 2 and Fig. 2). In other cases, WRG was under-estimated by as much as 3-4cm. Hence, for maximum individualization of WRG, Chest Sum should incorporate a 10th rib chest width measurement rather than the approximation used in our study. Moreover, variations in average tapering may occur among different ethnic groups, an additional reason for using the 10th rib level chest width measurement. When only 5th rib (not 10th rib) chest width is available, more complicated gender-specific and ethnicity-specific WRG equations than the chest sum equation presented here may offer somewhat more accurate results.

The WRG projected from the chest sum for each gender approximates WG average, range, and distribution in military groups with subscapular skinfolds around 10 mm.[2,5,6] It is thus not surprising that the average difference in male and female WRG also coincides with the typical 11-12cm WG difference between lean male and female Caucasian military personnel. Our database's statistical WG distribution resembles that of less lean military personnel or young adult civilians before obesity became as widespread as it is today, an indication that our subjects are representative of the same population group. (Our male subjects have a somewhat larger WD than the women in Table 2 because, in contrast to the women, the majority of the men were health club members rather than university students). Data obtained in 2003 by SizeUSA, a survey of body size using 3D-scanning technology, extracted WG values for a large American population sample.[14] Corrections suggested to the authors by the staff of TC2, the company responsible for the survey, allowed adjustment of SizeUSA's WG data to our measurement site and tape measurements. With these corrections, WG was 76 cm for 18-25 year-old Caucasian women and 88.9 cm - the uncorrected value - for their male counterparts. On the assumption that the chest sum obtained in our study applies to the current population sample, the young adults of 2003 have 14 %WD instead of the 5 %WD average for our database. At any rate, the same WG gender difference of 12-13 cm persists, because chest size differences have remained unchanged.

Our study has an obvious limitation with relatively small sample size. In the initial stage of our study, all physically active volunteers at San Jose State University were accepted and they were as ethnically diverse as the general California population on the basis of questionnaires filled out by them. No such information was obtainable for the health club members, who made up half of the database. The research was not designed to create a random population sample, as it included only physically active persons who volunteered to be measured. It is to be hoped that a study with a much larger sample will replicate our findings. Nevertheless, we believe that the subjects in our study were representative of body builds for persons in the normal weight range, as confirmed by U.S military data. Much larger chest sums may be typical of women in weight management groups such as the 300 women (measured by GH) whose chest sum averaged 49.3 cm, one centimeter larger than that of the 247 men. Conversely, Vietnamese men, on the basis of their 67.5 cm WG, probably have a chest sum similar to that of our study's female subjects.[2] Data on WG in normal-weight Chinese and Japanese groups suggest that gender differences in chest sum are smaller for these non-Caucasian groups.[2] Hence average WRG, its distribution, and typical gender differences found in our study cannot be extrapolated to other populations or to specific population sub-samples, for which targeted studies are needed. The results of our study will be validated, irrespective of differences in absolute WRG values, as long as WG of persons with subscapular skinfolds of 10 ± 5 mm in these groups approximates chest sum $\times$ 1.635.

As Table 5 indicates, WG, BMI, WHR, and CI can produce misleading obesity assessments for individuals whose bodily proportions do not match the typical Caucasian pattern. For population groups whose body build (overall frame size for height, thorax size, proportion of upper and lower trunk, thorax size compared to overall frame size) do not match the Caucasian model typical for our database, WG, BMI, WHR, CI will tend to create divergent abdominal obesity projections. The assessment of obesity by WD and %WD circumvents the confounding effect of individual and group differences in body build. With the WRG equation, a unisex table (such as Table 3) can be constructed expressing %WD as a function of chest sum and WG. Like height, chest sum is constant during adult years and needs only a single set of careful thorax width and depth measurements. Unlike height, which explains only a fraction of the variance in weight of normal-weight adults, the chest sum explains a very substantial part of the variance in WG in lean persons. Like weight, WG requires periodic remeasurement by individuals and medical examiners.

Since WRG is derived from the chest sum equation, it is geared to the WG measurement closest to the tenth rib level. The WG site just below the rib cage, which was the true "minimum" WG site for the 260 women and close to the "minimum" WG for all but a few of the 247 men in our study, lends itself to rapid, replicable, and reiterated measurements. Where the site is not perceptibly the minimum WG, palpation of the rib cage can substitute for visual inspection. Contraction of WG can help identify the proper level. Our WG site has the advantage of better reflecting upper body fat than any of the lower WG sites that have been studied and may thus respond more readily to changes in visceral fat than WG sites closer to the lower trunk.[15]

It seems plausible that WD and %WD, which quantify abdominal excesses, will correlate more highly with cardiovascular and metabolic risk factors than WG, which combines variations in abdominal excesses with variations in rib cage size. Even if a large rib cage should prove to be an independent risk factor, it is not susceptible to behavioral change. Once obesity assessment is normalized for body build and no longer automatically characterizes large-chest persons as obese, the current 20 %WD threshold (the accepted WG thresholds when applied to individuals with typical Caucasian thorax size) could be replaced by a 10-15 %WD threshold for earlier obesity detection and more effective intervention.

Our study did not ascertain the subjects' cholesterol, blood pressure, blood glucose levels or other health indicators. No evidence can therefore be adduced that WD and %WD in general or any specific %WD thresholds detect health risks more effectively than WG thresholds. The 507 healthy, physically active young adults in our study would not in any case have been the proper testing ground for this purpose. It is to be hoped that in future epidemiological studies %WD will be determined from WRG and WG as measured in our research. Such studies alone can verify whether abdominal obesity assessment normalized for body build predicts health risks more accurately than gender-specific WG thresholds, especially in populations whose body build differs sharply from that of typical Caucasian groups.[16-18]

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