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How well do waist circumference and body mass index reflect body composition in pre-pubertal children?

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Running head: Waist circumference and BMI in children

Abstract

Objective: To investigate the quantitative relationship between WC and height and subsequently the association between Waist Circumference Index (WCI), BMI, and body composition in pre-pubertal children.

Design: Cross-sectional sample (n = 227; boys = 127) of pre-pubertal Black children (age range 8.8 to 11.0 years) from the Bone Health sub-study of the Bt20 birth cohort study set in Soweto-Johannesburg, South Africa. Measures of height, weight, and waist circumference by anthropometry, total and truncal fat and lean mass by Dual-energy X-ray Absorptiometry (DXA) were used in the analysis. Pearson's correlation coefficients were used to examine the associations between BMI, WC, and body composition outcomes.

Results: WC was independent of height when height was raised to a power of approximately 0.8. BMI and WCI (WC/Ht) were significantly associated with total and truncal fat and lean mass in both sexes (all $P < 0.001$). BMI demonstrated consistently and significantly higher correlations with body composition than WCI and this association was significantly greater for fat mass than lean mass.

Conclusion: BMI, rather than WCI, would be a better screening tool for total and truncal fat mass in both sexes prior to puberty.

Keywords: BMI; waist circumference; fat mass; lean mass; pre-pubertal children

Introduction

There has recently been an increasing interest in the use of waist circumference (WC) as an indicator of overweight, abdominal fat, and risk of obesity in both adults and youth (McCarthy *et al,* 2001, 2003; Fredriks *et al,* 2005). This is largely because of accumulating evidence that centralisation of fat during adolescence and early adulthood is associated with increased metabolic disease risk, such as diabetes and cardiovascular disease in later adulthood (Flodmark *et al,* 1994; Caprio *et al,* 1996, Kissebah, 1996; Freedman *et al,* 1999). At the same time criticism has been levelled at the generalised use of Body Mass Index (BMI) and/or Waist-Hip Ratio to indicate overweight and fat centralisation respectively (Taylor *et al,* 2000). The former provides no indication of body fat distribution or percentage and the latter has been found to be a poorer indicator of centralisation in both adults (Rankinen *et al,* 1999; Taylor *et al,* 1998) and children (de Ridder *et al,* 1992; Fox *et al,* 1993; Goran *et al,* 1998) than WC alone. Indeed waist circumference is increasingly recognised as a more sensitive indicator of visceral adipose tissue and obesity related health risk than any other anthropometric dimension in adults (Shen *et al,* 2006).

Previous reports on samples of children that cover both the pre-pubertal and pubertal period find significantly stronger associations for WC than for BMI. It is important that these analyses distinguish between pre-pubertal and pubertal children because longitudinal analyses of fat patterning in children and adolescents have demonstrated that centralisation is an adolescent phenomenon and is not particularly marked prior to adolescence (Cameron *et al,* 1994). The possibility that WC is not necessarily better than BMI during childhood in reflecting fat centralisation makes sense if significant centralisation does not occur prior to puberty. During puberty increased centralisation would result in WC becoming a more sensitive indictor of abdominal fat than BMI. However, most authors do not adjust for pubertal status, rather they group their sample of children and adolescents into one homogeneous group. In a comparison of BMI, waist circumference, and triceps-subscapular skinfold ratio as screening measurements for the metabolic syndrome, Moreno *et al* (2002) found waist circumference to be the best predictor in a sample of 140 children, aged between 7 and 15 years, of whom 68 were obese. However, these authors do not mention the assessment of pubertal status even though they apparently did test “metabolic syndrome variables” for a “pubertal effect” but no details were provided. Certainly no control for pubertal status was used in the anthropometric analysis. Lee *et al’s* (2007) recent study of the metabolic syndrome in 2284 Taiwanese children (1227 boys) aged 6 to 12 years did not report pubertal status assessment, nor did Singh et al (2007) investigating the prevalence of the metabolic syndrome in 1083 Indian adolescents (571 boys) aged 12-17 years. McCarthy (2006) advocates that waist circumference should be routinely taken in clinical and epidemiological settings because of its importance in identifying abdominal fatness and because of the availability of waist circumference reference charts. No mention, however, is made of controlling for pubertal status. Lee *et al* (2006) found that waist circumference was an independent predictor of insulin resistance in a sample of black (*n* = 56) and white (*n* = 89) American youths aged 8 to 17 years. Only 14 (Black) and 17 (White) of the participants were pre-pubertal so the results relate more to those already into puberty than for those who have yet to reach puberty.

So, whilst WC is generally accepted as a better indicator of risk in pre-adult samples, those samples contain few pre-pubertal children and thus do not test whether WC is better than BMI prior to puberty as the centralisation of fat primarily takes place only after the onset of puberty.

McCarthy (2006) highlights concern over the influence of height on WC in both children and adults. He reports that whilst a high correlation between WC and height is recognised "…the precise influence of height on WC remains quantitatively unclear" and that a variable combining height and WC "may partly correct for the effect of height on WC". We have used the current analysis to investigate the quantitative relationship between height and WC to determine what power of height (Ht^Y) results in a zero correlation between WC/Ht^Y and Ht and thus renders WC independent of height. This paper thus explores the quantitative relationship between WC and height and the association between BMI, WC, and body composition in pre-pubertal children.

Methods

Subjects and measures

Anthropometric and body composition data were measured in 227 African children (boys=127; girls =100) aged between 8.8 and 11.0 years from the Bone Health (BH) sub-cohort of the Birth to Twenty (Bt20) birth cohort study set in Soweto-Johannesburg, South Africa (Yach *et al,* 1991). The BH study was established in 1999 and included 523 of the Bt20 participants plus a further 160 new participants who were born in the study area and in the same birth date range as the original cohort. The BH study had the specific goals of investigating bone health and development during adolescence and included extra measurement protocols that added annual dual-energy X-ray absorptiometry (DXA) to the basic morphological measurement protocol. The sample of 227 participants for the current analysis was chosen on the basis of normal birth weight and gestational age, Tanner stage 1 (pre-pubertal) for breasts/genitalia and pubic hair, and complete morphological and body composition data. Height (Ht), sitting height (SH) and weight (Wt) were assessed using standard techniques (Cameron, 1984). WC was measured around the narrowest part of the torso between the iliac crest and lowest rib. DXA was used to determine body composition in terms of fat (FM) and lean mass (LM) using an Hologic 4500A (software version 11.2).

Statistical Analyses

All data analyses were undertaken using the Statistical Package for the Social Sciences (SPSS) statistical software package version 15.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were used to determine the mean and standard deviation (*s.d.*) of key anthropometric and DXA outcomes. Independent t tests were used to determine statistically significant differences between genders. Pearson's correlation coefficients were used to examine the associations between BMI, WC, and body composition.

Height is strongly and positively associated with all anthropometric and body composition variables. In order to control for height when using fat and lean masses, Wells *et al* (2002) recommended the use of the fat mass index (FMI) and fat-free mass index (FFMI) in which the body composition variable is divided by Ht^2. Wells used body composition components based on a physiological model in which fat and fat-free mass were derived from total body water following isotopic dilution techniques on 72 children aged 8 years. The current analysis uses fat and lean mass derived from an anatomical model consistent with the DXA method and thus does not use precisely the same components as lean mass but includes the essential fat that is not found in fat-free mass.

The power with which to raise height was determined through log-log regression. Following the recommendations of Wells *et al* (2002), log-log regression was used in the current analysis on Fat Mass (FM), Lean Mass (LM) and WC for the whole sample and for the sexes separately resulting in indices that were independent of height. Because of concern over the centralisation of fat the current analysis also investigates DXA derived truncal fat (TFM) and lean masses (TLM). The same analysis strategy as for total (excluding the head) fat and lean masses was used except that the log-log regressions are against sitting height as well as height to test whether truncal body composition would be more related to a measure of size excluding the legs rather than to total height. The percentage of the variation in a particular index (i.e. fat mass index) that was attributable to height was calculated using the following equation:

$$\% \text{ Variation} = (1-\sqrt{(1-r^2)}) \times 100$$

Bt20 obtained ethical permission for the current study through a human subject’s clearance issued by the University of the Witwatersrand, South Africa. Written informed consent was gained from all participants and their primary caregivers.

Results

Descriptive data for boys and girls are displayed in Table 1. Of the standard anthropometric data only WC was significantly different between the sexes ($P < 0.05$)

with boys having larger WC. For both total and truncal DXA body composition values boys had significantly lower total ($P < 0.01$) and truncal ($P < 0.05$) fat mass values and significantly higher total and truncal lean mass (both at $P < 0.001$).

Table 1 near here

The regression procedure requires a log-log regression of the variable of interest (FM, LM, TFM, TLM, and WC) against height or sitting height. The resulting gradient is used as the power $^{(Y)}$ with which to raise height or sitting height. Table 2a shows the results of this regression for the sexes combined and separately for FM and LM, Table 2b for WC, and Table 2c and 2d for TFM and TLM against both sitting height (2c) and height (2d). In addition, we have included the relationship of the variable of interest with Ht^2 because Wells *et al's* (2002) indices use that denominator and thus created a natural comparison with the effect of gradient calculated from the current data.

Tables 2a, 2b, 2c, and 2d near here

The power with which to raise height to achieve a fat mass index independent of height was approximately 3.0 in the whole sample and in the sexes separately. Significant correlations between FM/Ht^2 v Ht were found only for boys at 0.193 ($P < 0.05$). In this case height accounted for only 1.9% of the variation in fat mass and thus was not considered biologically significant. Height needed to be raised by a power of approximately 2.6 to produce independence of lean mass. Ht^2 as the denominator resulted in significant correlations for both sexes combined and separately, but the variation in lean mass due to height was a maximum of 3.6% and again not biologically meaningful. Log waist circumference and log height (Table 2b) were related with gradients of approximately 0.8 suggesting that WC/Ht would be an effective index (hereafter called Waist Circumference Index or WCI) and that index was independent of height in the whole sample and for both sexes independently. Correlations of WC/Ht^2 against Ht were highly significant (*P* < 0.001) with height accounting for 12 to 14% of the variation in WC.

Using SH^Y or SH^2 as a denominator for TFM or TLM proved to be no better than using Ht or Ht^2 (Tables 2c and 2d). Indeed X/SH^2 was significantly (*P* < 0.05) related to sitting height for both fat and lean mass when both sexes were combined. For the sake of consistency with FMI and LMI it was therefore decided to use Ht^2 as the denominator for TFMI and TLMI.

Table 3 near here

Table 3 illustrates the relationship between BMI and WCI and indices of total and truncal fat and lean components of body composition from DXA scans. For the whole sample and the sexes separately all correlations were positive and highly significant *(P* < 0.001) demonstrating that both BMI and WCI reflect both fat and lean components. There were no significant differences between sexes. However, across both sexes BMI was consistently and significantly more related to FM than WCI suggesting that BMI rather than WCI would be more effective as a screening tool.

Discussion

The quantitative relationship between WC and height and the association between BMI, WC, and body composition have been explored in 227 pre-pubertal South African black children. Log-log regressions of FM and LM against height were undertaken to confirm Wells *et al's* use of Ht^2 as an appropriate denominator to produce indices that were independent of height (Wells *et al,* 2002). The same strategy was used for waist circumference and demonstrated that Ht^2 was not appropriate to create an index of waist circumference that was independent of height.

Height raised to the power of about 0.8 (0.74 - 0.81) produced an independent index. This was close enough to 1.0 to justify the use of WC/Ht as an appropriate index that was independent of height. Truncal fat and lean masses were tested against sitting height and height with the result that these variables were best suited to an index using Ht^2.

BMI and WCI have highly significant associations with DXA determined measures of total and truncal fat and lean tissues in these African pre-pubertal children. The fact that BMI demonstrates consistently and significantly higher correlations with body composition than WCI and that this association is significantly greater for fat mass than lean mass suggests that BMI, rather than WC, would be a better screening tool for fatness.

Whilst WCI has a lesser relationship than BMI with fat mass, it has a remarkably lower relationship with lean mass. Given this situation changes in WCI appear to reflect changes in fat rather than lean components and thus WCI might be useful to distinguish body composition differences between individuals who have similar BMIs.

Why should BMI rather than WC be a better indicator of body composition? The development of fat and lean components prior to puberty is similar in boys and girls although of different magnitudes in that girls are gradually acquiring a greater fat mass and boys a greater lean mass. Consequently our data confirmed that by the end of childhood girls and boys differ significantly in their fat and lean masses (Ackerman *et al,* 2006) (Table 1).

The centralisation of fat does not occur until puberty (Cameron *et al,* 1994) so it would not be expected that WC would reflect that centralisation until puberty commenced. Prior to puberty both BMI and WC should reflect general fat and lean masses and not necessarily the pattern to be expected during pubertal development. However, gonadarche occurs earlier in girls than boys, reflecting the earlier maturation of the hypothalamic-pituitary-gonadal (HPG) axis, and girls in late childhood begin to demonstrate significantly greater total and truncal fat mass. Waist circumference appears to reflect in girls the increasing fat content, whilst in boys it reflects the predominant lean tissue mass.

Why then do almost all previous reports on the relationship between these simple anthropometric measures and body composition during "childhood" result in WC being considered the most important indicator? It is apparent that almost all previous reports do not make an appropriate allowance for pubertal status and do not distinguish between the pre-pubertal and pubertal child. Even though common age ranges cover the pre-pubertal and pubertal years e.g. 7-14, 8 -19, etc the authors do not record an appropriate allowance for pubertal status. In addition, the majority of previous reports have discussed the use of WC as an alternative to BMI to classify overweight and/or obesity. Their aim was not to see if WC was a better indicator of body composition but to see if WC classified overweight and obesity with the same rigour as BMI. The combination of not allowing for pubertal status and not testing the quantitative association between WC and height in order to create an independent index of WC has, we would suggest, resulted in the erroneous belief that WC is the best indicator of risk throughout childhood and adolescence. The patterns of growth of fat and lean tissue during childhood and adolescence suggest that WC should become more important as an indicator of fat deposition during puberty when most of the centralisation of fat occurs. The fact that we find that WC is not better (and in fact worse) than BMI in reflecting either fat or lean tissue prior to puberty concurs with the relationship expected from known growth patterns. We would expect that WC would increase in importance during the course of pubertal development and reflect the degree of association seen in other analyses of pubertal or adolescent youths.

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Table 1 Descriptive statistics of anthropometric and DXA determined values of fat and lean mass

	Mean (*s.d.*)	
	Boys (*n* 127)	Girls (*n* 100)
Age (yrs)	10.12 (0.50)	10.02 (0.50)
Weight (kg)	30.98 (5.88)	29.98 (5.38)
Height (m)	1.35 (0.06)	1.35 (0.06)
Sitting height (m)	0.68 (0.03)	0.67 (0.03)
Body mass index (kg/m^2)	16.80 (2.42)	16.47 (2.35)
Waist circumference (cm)	57.83 (5.69)	56.25 (5.89)*
Total[‡] fat mass (kg)	6.45 (3.67)	7.73 (3.50)**
Total[‡] lean mass (kg)	20.15 (3.24)	18.28 (2.88)***
Truncal fat mass (kg)	2.29 (1.67)	2.72 (1.57)*
Truncal lean mass (kg)	9.83 (1.72)	8.92 (1.37)***

***** $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

[‡] Total mass excluding the head

Table 2a Results of the log-log regression of fat mass (FM), and lean mass (LM), against height (Ht). The gradient $^{(Y)}$ is used as the power to raise Ht (Ht^Y) to test the correlation of FM or LM (both denoted as X) against Ht. Variation % is the percentage variation of X attributable to height in a significant correlation between X/Ht^2 v Ht.

	Fat Mass (FM)			Lean Mass (LM)		
	All	Boys	Girls	All	Boys	Girls
Gradient $^{(Y)}$	3.268	3.750	3.009	2.661	2.617	2.579
Corr. X/Ht^Y v Ht	0.015	0.048	-0.018	0.005	-0.001	0.018
Corr. X/Ht^2 v Ht	0.129	0.193*	0.083	0.260***	0.247***	0.267***
Variation (%)		1.9		3.4	3.1	3.6

* *P* < 0.05; ** *P* < 0.01; *** *P* < 0.001

Table 2b Results of the log-log regression of Waist Circumference (WC) against height (Ht). The gradient $^{(Y)}$ is used as the power to raise Ht (Ht^{Y}) to test the correlation of WC against Ht. Variation % is the percentage variation of WC attributable to height in a significant correlation between WC/Ht^{2} v Ht.

	Waist Circumference (WC)		
	All	Boys	Girls
Gradient $^{(Y)}$	0.799	0.813	0.740
Corr. WC/Ht^{Y} v Ht	0.016	0.019	0.014
Corr. WC/Ht v Ht	-0.079	-0.078	-0.098
Corr. WC/Ht^{2} v Ht	-0.487***	-0.513***	-0.472***
Variation (%)	12.7	14.2	11.8

***** $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 2c Results of the log-log regression of Truncal Fat Mass (TFM), and Truncal Lean Mass (TLM), against Sitting Height (SH). The gradient $^{(Y)}$ is used as the power to raise SH (SH^Y) to test the correlation of TFM or TLM (both denoted as X) against SH. Variation % is the percentage variation of X attributable to SH in a significant correlation between X/SH^2 v SH.

	Truncal Fat Mass (TFM)			*Truncal Lean Mass (TLM)*		
	All	Boys	Girls	All	Boys	Girls
Gradient $^{(Y)}$	3.649	3.610	3.849	2.330	2.401	2.192
Corr. X/SH^Y v SH	0.027	0.054	-0.006	0.009	0.008	0.008
Corr X/SH^2 v SH	0.156*	0.168	0.158	0.131*	0.143	0.109
Variation (%)	1.2			0.9		

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 2d Results of the log-log regression of Truncal Fat Mass (TFM), and Truncal Lean Mass (TLM), against height (Ht). The gradient $^{(Y)}$ is used as the power to raise Ht (Ht^Y) to test the correlation of TFM or TLM (both denoted as X) against Ht. Variation % is the percentage variation of X attributable to height in a significant correlation between X/Ht^2 v Ht.

	Truncal Fat Mass (TFM)			Truncal Lean Mass (TLM)		
	All	Boys	Girls	All	Boys	Girls
Gradient $^{(Y)}$	2.749	3.147	2.574	2.270	1.967	2.536
Corr. X/Ht^Y v Ht	0.000	0.018	-0.021	0.013	0.017	0.016
Corr X/Ht^2 v Ht	0.051	0.088	0.023	0.099	0.006	0.254*
Variation (%)						3.3

***** *P* < 0.05; ** *P* < 0.01; *** *P* < 0.001

Table 3 The relationship between BMI, Waist Circumference (WC) and indices of body composition; BMI = Body mass index (Wt/Ht^2); WCI = Waist circumference index (WC/Ht); FMI = fat mass index (FM/Ht^2); LMI = Lean Mass Index (LM/Ht^2); TFMI = Trunk fat mass index (TFM/ Ht^2); TLMI = Trunk lean mass index (TLM/ Ht^2)

	Pearson's correlation		
	All	Boys	Girls
BMI v. FMI[††]	0.841***	0.867***	0.887***
WCI v FMI	0.732***	0.752***	0.806***
BMI v LMI[††]	0.617***	0.668***	0.592***
WCI v LMI	0.451***	0.547***	0.306**
BMI v TFMI	0.668***	0.644***	0.746***
WCI v TFMI	0.631***	0.598***	0.735***
BMI v TLMI[†]	0.534***	0.531***	0.595***
WCI v TLMI	0.450***	0.523***	0.326**

**$P < 0.01$; ***$P < 0.001$; [††] $P < 0.01$ between BMI and WCI correlations for both sexes combined and separately; [†] between BMI and WCI correlations were significantly greater for the total sample ($P < 0.05$) and females ($P < 0.01$) but not for males