International Journal of Obesity (2007) 31, 53–58
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PEDIATRIC HIGHLIGHT

Comparison of ultrasonographic and anthropometric methods to assess body fat in childhood obesity

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Background: Pattern of fat distribution rather than obesity is of importance for cardiovascular morbidity and mortality. The accurate measurement of total and regional fat mass requires sophisticated and often expensive methods that have limited applicability in the clinical setting.
Objective: The aim of this study is to evaluate body fat distributions by ultrasound (US) as a gold standard method for measuring visceral, preperitoneal and subcutaneous fat layers and comparing with anthropometric results, and then to find the most reliable anthropometric measurement in childhood obesity.
Materials and methods: Study group of 51 obese children (21 F, 30 M) (mean age $\pm$ s.d.: 11.5 $\pm$ 2.6 years) and control group of 33 non-obese children (17 F, 16 M) (mean age $\pm$ s.d.: 12.2 $\pm$ 2.7 years) were recruited for this study. Anthropometric measurements as body mass index (BMI), waist circumference (WC), waist/hip ratio (WHR), triceps and subscapular skinfold thicknesses were taken from all the participants. Abdominal preperitoneal (P), subcutaneous (S) fat at their maximum (max) and minimum (min) thickness sites, visceral (V), triceps (TrUS) and subscapular (SsUS) fat thicknesses were also measured ultrasonographically.
Results: In the obese group, BMI was significantly correlated with US measurements of fat thicknesses, except Pmin and SsUS, whereas in the control group, BMI was significantly correlated with all US fat measurements. The relation of US measurements with skinfold thickness and WC was more significant in the control than in the obese group. No relation between WHR and US fat thickness measurements was found in both groups. Multiple regression analysis, using V as the dependent variable and anthropometric parameters, gender and the group as the independent variables, revealed BMI was the best single predictor of V (R^2: 0.53).
Conclusion: This study suggests that the validity of the anthropometric skinfold thickness in the obese children is low. Despite the limitations reported in the literature, in our study, BMI provides the best estimate of body fat. WHR in children and adolescents is not a good index to show intra-abdominal fat deposition.
International Journal of Obesity (2007) **31**, 53–58. doi:10.1038/sj.ijo.0803414; published online 20 June 2006

Keywords: childhood obesity; body fat distribution; anthropometry; ultrasound

Introduction

Obesity in children and adolescents has become an increasing clinical and public health concern.[1–3] Obesity is defined as excess adipose tissue. Unfortunately, the accurate measurement of total fat mass requires sophisticated and often expensive methods that have limited applicability in the clinical setting.[4] Anthropometry is the single most portable, universally applicable, inexpensive and non-invasive method available to assess the proportions, size and composition of the human body.[5] Body mass index (BMI, weight (kg)/height^2 (m^2)) is a simple and convenient proxy measure of obesity, which is now widely recommended for pediatric use.[6,7] There are well-known limitations regarding the use of BMI. In children, relationships between BMI and the fat and fat-free components of the body are further complicated by varying growth rates and maturity levels.[4,8,9] Skinfold thickness measurements are another traditional techniques that can be applied easily and are stated to provide a reliable estimate of obesity and regional fat distribution.[10–13] However, there are limitations associated with the caliper method, which may result in inaccurate estimates of subcutaneous fat thickness and, consequently, of total body fat. These limitations include the inability to control

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Received 9 July 2005; revised 19 April 2006; accepted 9 May 2006; published online 20 June 2006

inter- and intra-subject variation in skinfold compressibility, the inability to palpate the fat–muscle interface and the impossibility of obtaining interpretable measurements on very obese subjects.[14,15] Consequently, traditional measurements such as BMI and skinfold thickness do not measure fat in accurate quantitative terms.[16]

In adults, waist circumference (WC) and the waist–hip ratio (WHR) have been the most extensively used indirect measures of visceral fat.[17,18] In children, there is no correlation between WHR and visceral fat.[19–21] Computed tomography (CT) and magnetic resonance imaging (MRI) are accurate imaging techniques for assessing body fat distributions, but disadvantages are cost, radiation exposure (for CT) and use limited to a research setting.[22] The use of dual energy X-ray absorptiometry (DXA) to measure total abdominal fat may provide a stronger measure of visceral fat, but this technique cannot resolve subcutaneous fat from visceral fat.[22] Ultrasound (US) has been proposed as an alternative non-invasive technique to measure subcutaneous and visceral fat thickness because it may overcome some limitations of the anthropometric measurements.[23–28] To minimize the intra- and inter-observer variabilities, the degree of operator training is important, that is, the operator should be able to maintain constant pressure on the probe.[23] The purpose of this investigation is to assess preperitoneal, visceral and subcutaneous fat thicknesses using US, to determine body fat distribution and to compare US fat thicknesses with anthropometric measurements.

Subjects and methods

The study group comprised of 51 obese children (21 F, 30 M) (mean age$\pm$s.d.: 11.5$\pm$2.6 years) and the control group consisted of 33 non-obese children (17 F, 16 M) (mean age$\pm$s.d.: 12.2$\pm$2.7 years). The control group was selected from subjects of same age with normal growth and development and no endocrinological problems, who were admitted to general pediatric polyclinics. The same investigator performed anthropometric measurements and complete physical examination, including pubertal staging, neurological, mental and dysmorphic findings. Tanner classification was used for pubertal staging.[29,30]

Anthropometric measurements as BMI, WC, WHR, Tr and Ss skinfold thicknesses were taken from all the participants. Abdominal preperitoneal (P), subcutaneous (S) fat at their maximum (max) and minimum (min) thickness sites, visceral (V), triceps (TrUS) and Ss (SsUS) fat thicknesses were also measured ultrasonographically.

Anthropometry

Body weight was measured to the nearest 0.1 kg with a balance scale (Baurer, PS 07), and height was measured to the nearest 0.1 cm with stadiometer (Hyssna Limfog, AB, Canada) with subjects lightly dressed and without shoes. BMI (Quetelet index) was calculated as weight (kg) divided by height square (m^2). The degree of obesity was quantified using Cole's reference data.[31] Skinfold thickness was measured using an electronic skinfold caliper (skin foldmeter, Growth and Metabolic Service, Kabi Pharmacia, United Kingdom) by the same investigator at the following sites: Tr – half-way between the acromion and the olecranon; and Ss – 1 cm below the inferior angle of the scapula. Using a plastic measuring tape, WC was measured midway between the lower rib margin and the iliac crest, and hip circumference was measured at the widest point over the great trochanters and WHR was calculated. Both circumferences were measured in the standing position and at the end of gentle expiration. All measurements were taken three times at each site, and mean of the three values was used.

Ultrasonography

US measurements of subcutaneous, preperitoneal and visceral abdominal fat layers were performed. A LOGIQ α 200 US machine (GE Medical Systems, Milwaukee, WI, USA) was used for the US measurements. A 7.5 MHz linear-array probe was used to measure the subcutaneous and preperitoneal fat layers. TrUS and SsUS measurements were performed at the same marked sites where the anthropometric measurements were carried out. It was placed perpendicular to the skin on the mid-upper abdominal wall. Midline longitudinal scans were obtained from the xiphoid process to the navel along the linea alba. Smin and Pmax were measured just below the xiphoid process (Figure 1a). Smax and Pmin were measured 5 cm above the umbilicus (Figure 1b). The measurements of Smin and Smax were taken directly from the screen using electronic calipers placed at the skin–fat and fat–linea alba interfaces (Figure 1). Pmax was measured in the region just below the xiphoid process between the posterior aspect of linea alba and the anterior surface of the left lobe of the liver (Figure 1a). Pmin was obtained 5 cm above the umbilicus between the posterior aspect of the linea alba and the

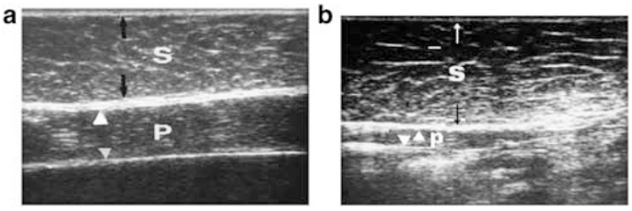

Figure 1 Longitudinal sonograms of the upper abdomen on the xiphoid–umblical line showing the subcutaneous (S) and preperitoneal (P) fat layers. (**a**) Sonogram obtained below the xiphoid process to measure the minimum subcutaneous fat thickness (arrows) between the skin–fat and fat–linea alba interfaces and the maximum preperitoneal fat thickness (arrowheads) between the linea alba–fat interface and the surface of the liver. (**b**) Sonogram obtained just above the umbilicus to measure the maximum subcutaneous fat thickness (arrows) between the skin–fat and linea alba–fat interfaces and the minimum preperitoneal fat thickness (arrowheads) between the internal face of the linea alba and peritoneum, which is displayed as an echogenic line. Muscle was excluded from all measurements.

peritoneum, which is displayed as an echogenic layer (Figure 1b).[32] A 3.5 MHz convex-array probe was used to evaluate visceral fat thickness, which was measured just above the umbilicus between the posterior aspect of the abdominal wall and the anterior wall of the abdominal aorta (Figure 2).[32]

Statistical analysis

Mean values, standard deviations and ranges were calculated for age, weight, height, BMI and measurements of fat layers. Independent *t*-tests were used to analyze the significance of difference in both groups. Pearson's correlation coefficients and backward multiple regression analysis were used to assess the associations between anthropometric and sonographic measurements. A *P*-value of less than 0.05 was regarded as significant.

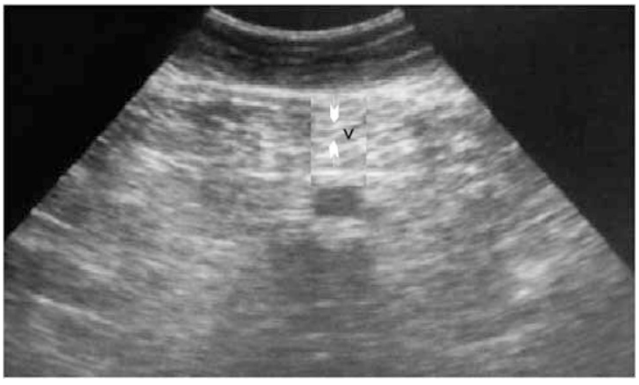

Figure 2 Transverse sonogram just above the umblicus displays the visceral (V) fat measured between the posterior aspects of the abdominal wall of the aorta.

Results

Mean age, anthropometric and US measurements of the both groups are shown in Table 1. When compared according to sex, WHR, Pmax, Smax and Smin measurements differed significantly in the obese group ($P<0.05$). WHR measurement was significantly greater in males than that in females. On the contrary, Pmax, Smax and Smin measurements were greater in females than those in males. In the control group, WHR, Tr and and TrUS measurements showed a significant difference between both sexes ($P<0.05$), whereas WHR measurement was significantly greater in males, and Tr, TrUS measurements were significantly greater in females (Table 1).

The correlation between anthropometric and US measurements in both groups is revealed in Table 2. In the obese group, BMI is correlated with all US fat thickness measurements ($P<0.05$), except Pmin and SsUS. Tr was correlated with Pmax, Smin and TrUS ($P<0.05$). Ss was correlated with Pmax, Smax, Smin and TrUS ($P<0.05$). The relation between WC and Pmax, Smax and Smin was significant ($P<0.05$). In the control group, the relation between BMI and US fat measurements was significant ($P<0.05$). Tr was correlated with all ultrasonographically measured fat layers ($P<0.05$), except V fat. Ss was correlated with all US measurements ($P<0.05$). The relation between WC and all US fat measurements, except Pmin and SsUS was significant ($P<0.05$). No relation between WHR and ultrasonographically measured fat layers was found in both groups ($P>0.05$). As shown in Table 3, multiple regression analysis, using V as the

Table 1 Mean age, anthropometric and US measurements of both groups in accordance with sex

	Obese			*Control*		
	Female (n:*21*) *Mean*±*s.d.*	*Male* (n:*30*) *Mean*±*s.d.*	*Total* (n: *51*) *Mean*±*s.d.*	*Female* (n:*17*) *Mean*±*s.d.*	*Male* (n:*16*) *Mean*±*s.d.*	*Total* (n:*33*) *Mean*±*s.d.*
Age (year)	11.9±3.0	11.2±2.3	11.5±2.6	12.4±2.8	12.0±2.8	12.2±2.7
BMI (kg/m^2)	29±3.7	29±3.2	28.8±3.4*	18.4±1.9	18.5±5.7	18.5±2.3
WHR	0.86±0.1*	0.93±0.1*	0.9±0.2 *	0.77±0.1§	0.81±0.1§	0.8±0.1
WC (cm)	88.2±8.9	90.6±13.6	89.5±9.8*	63.9±9.4	65.3±8.5	64.6±8.9
Tr (mm)	27.0±8.9	26.0±7.9	26.5±8.2*	11.5±5.0§	7.4±4.3§	9.5±5.0
Ss (mm)	33.0±11.3	32.0±10.7	32.3±10.8*	9.2±4.0	6.3±4.0	7.6±4.2
Pmax (mm)	12.5±3.0*	10.6±3.8*	11.4±3.6*	7.1±5.3	5.5±4.9	6.3±5.0
Pmin (mm)	3.95±1.4	3.6±1.6	3.8±1.5*	2.7±0.4	2.1±0.9	2.4±1.2
Smax (mm)	32.2±7.9*	27.6±7.0*	29.5±7.6*	10.2±4.3	8.4±6.4	9.3±5.4
Smin (mm)	20.0±5.8*	16.8±4.6*	18.1±5.3*	6.6±3.5	5.2±4.9	5.3±4.2
V (mm)	42.0±9.2	46.0±14.9	44.3±12.9*	20.4±9.2	26±9.0	23.0±9.4
TrUS (mm)	10.9±3.4	10.4±5.5	10.6±4.7*	5.9±2.0§	4.5±3.6§	5.2±2.9
SsUS (mm)	11.5±5.5	11.9±5.5	11.7±5.4*	5.0±4.3	4.0±4.0	3.0±4.1

Abbreviations: BMI, body mass index; Pmax, preperitoneal maximum; Pmin, preperitoneal minimum; SS, subscapular; SsUS, subscapular ultrasound; Smax, subcutaneous maximum; Smin, subcutaneous minimum; Tr, triceps; TrUS, triceps ultrasound; V, visceral; WC, waist circumference; WHR, waist/hip ratio. $^{*,\S}P<0.05$.

Table 2 The correlation between anthropometric and US measurements in both groups[§]

	Obese					*Control*				
	BMI (kg/m²)	*Tr (mm)*	*Ss (mm)*	*WHR*	*WC (cm)*	*BMI (kg/m²)*	*Tr (mm)*	*Ss (mm)*	*WHR*	*WC (cm)*
Pmax (mm)	0.376*	0.305*	0.343*	0.132	0.409*	0.580*	0.382*	0.655*	0.242	0.402*
Pmin (mm)	0.193	0.127	0.236	0.227	0.076	0.527*	0.355*	0.603*	0.252	0.296
Smax (mm)	0.514*	0.200	0.367*	0.098	0.346*	0.669*	0.637*	0.859*	0.113	0.494*
Smin (mm)	0.500*	0.337*	0.369*	0.227	0.420*	0.628*	0.540*	0.831*	0.274	0.391*
V (mm)	0.282*	0.157	0.021	0.081	0.188	0.534*	0.227	0.410*	0.058	0.381*
TrUS (mm)	0.320*	0.372*	0.296*	0.290	0.124	0.379*	0.685*	0.661*	0.290	0.389*
SsUS (mm)	0.154	0.113	0.195	0.213	0.219	0.727*	0.724*	0.795*	0.294	0.251

Abbreviations: BMI, body mass index; Pmax, preperitoneal maximum; Pmin, preperitoneal minimum; SsUS, subscapular ultrasound; Ss, subscapular; Smax, subcutaneous maximum; Smin, subcutaneous minimum; Tr, triceps; TrUS, triceps ultrasound; V, visceral; WC, waist circumference; WHR, waist/hip ratio. [§]*r* value, *$P<0.05$.

Table 3 Regression coefficients and *P*-value from multiple regression analysis for the prediction of visceral fat thickness from all anthropometric measurements, gender and the group

Independent variables	*Visceral fat thickness*	
	Regression coefficient	P-*value*
Constant	−3.403	0.602
Gender	−4.421	0.068
BMI	1.848	0.000
	R^2 (adj.) 0.528	

Abbreviations: BMI, body mass index.

dependent variable, and anthropometric parameters, gender and the group (obesity status) as the independent variables, revealed BMI was the best single predictor of V ($y=-3.403+1.848x$ ($P<0.0001$)).

Discussion

Many clinical and epidemiological studies have confirmed the existence of a close relationship between the distribution of body fat, metabolic disorders, and increased risk of morbidity and mortality.[33–39] Thus, the main prognostic problem in obesity is to estimate accurately the quantity and distribution of fat in the body.

Both CT and MRI have been used in children and adolescents for this purpose.[19–21] CT has been recognized as a reliable and reproducible means for determining the amount of subcutaneous fat and intra-abdominal adipose deposits.[40,41] Considering the high ionizing radiation exposure, great expense and somewhat low availability of CT, alternative non-invasive methods to quantify regional adiposity have been used in clinical and epidemiological studies. Evidence in the literature has suggested that V measured by US could be a reliable method to quantify visceral fat compared with that of CT.[24–27] Suzuki *et al*.[24] reported that the thickness of regional subcutaneous and preperitoneal fat layers in the upper median abdomen measured by US are closely correlated with the subcutaneous and visceral fat assessed by CT at the umblical level, respectively. In this study, Pmax/Smin ratio was positively correlated with visceral/subcutaneous ratio (V/*S*) obtained by CT (*r*: 0.746; $P<0.0001$). Pmax was correlated with V but not with subcutaneous fat. On the other hand, Smin was correlated with subcutaneous fat but not with Pmax. These results indicate that preperitoneal fat reflects the amount of visceral abdominal fat.

Adipose tissue accumulates mainly in intra-abdominal and subcutaneous sites. In males, fat typically accumulates in the upper segment of the body, both subcutaneously and intra-abdominally. This is apparent visually as a bulging abdomen in an apple-shaped distribution. In females, adipose tissue accumulates subcutaneously, over the thighs in a pear-shaped gluteal distribution.[42] Gender-related patterns of body fat deposition become established during puberty and, as with total body fat, show significant familial associations.[21,22,42,43] Dixon *et al*.[12] compared abdominal fat distribution in men and women using CT. They reported that men have significantly more fat within the abdominal cavity and women have similar total fat, but store a greater proportion of it in their subcutaneous tissues. In our study, WHR was found to be greater in males than that in females while there is no difference regarding WC in both groups. Pmax, Smax and Smin were significantly higher in females than those in males in obese group. Our study revealed that subcutaneous fatness is greater in females compared to males. In the control group, Tr and TrUS were detected higher in females, which might be related to the physiological difference in body fat and muscle distribution in both sexes during puberty.

BMI reflects adiposity well in adult groups, and has long been an affordable and useful method of assessment in adult studies of obesity.[44,45] However, because of differences in the rates of maturation and its effect on body composition, assessment of adiposity by BMI has been more challenging in children.[4,8,9] The major limitation with BMI is that it cannot distinguish fat mass from fat-free mass. In addition, it does not give any information about fat distribution. Because in individuals with equivalent percent body fat, those with

more central obesity will have lower BMI compared with those with more peripheral obesity. BMI cannot differentiate between the intra-abdominal and subcutaneous fat deposits.[4,8,46] Despite these limitations, among anthropometric parameters, BMI in both groups showed a significant correlation with most US measurements. The most significant relation, using V as the dependent variable, was found to be with BMI among other proxy measures.

Traditionally, the skinfold caliper has been used to measure body fat non-invasively. However, there are limitations associated with the caliper method, which may result in inaccurate estimates of subcutaneous fat thickness and, consequently, of total body fat. These limitations include the inability to control inter- and intra-subject variation in skinfold compressibility, the inability to palpate the fat–muscle interface and the impossibility of obtaining interpretable measurements in very obese subjects.[14–15] US has been proposed as an alternative non-invasive technique to measure subcutaneous fat thickness because it may overcome some of the limitations of the caliper.[14] US scanners are capable of measuring subcutaneous fat at depths of 100 mm or more without tissue compression and can reliably detect density interfaces with an accuracy of 1 mm. Fanelli *et al*.[11] reported that the caliper and US techniques are equally effective in predicting body density and, hence, total body fat of lean man. In our study, while anthropometric measurements of skinfold thickness in control group were correlated with most of US measurements, this relation was seen more or less in obese subjects. This observation supports the view that anthropometric measurement of skinfold thickness is not reliable in obese subjects.

In adults, WHR has been the most extensively used indirect measure of visceral fat.[47,48] In actually, WC and abdominal sagittal diameter show a better correlation with visceral fat as determined by CT.[17,18] In children and adolescents, there is no correlation between WHR and visceral fat measured by various techniques.[19,20] In some studies, it was reported that WC provides a simple yet effective measure of truncal obesity.[19,49] In our study, WC in control group was found more related to US measurements of much more sites when compared with that in obese group. While WC in obese group was more related to abdominal subcutaneous fat thickness measurements and Pmax, no relation was found between WC and V. No relation between WHR and ultrasonographic fat thickness measurements was found in both groups. These results suggest that WC, but not WHR, might be a useful index to show truncal obesity.

It is hypothesized that the accumulation of visceral fat, or intra-abdominal adipose tissue, in children is influenced by 'modifiable' factors, such as those associated with diet, body fatness and physical activity, as well as 'non-modifiable' factors such as hormone levels, growth and maturation, gender and genetics.[22] Some studies suggest that intra-abdominal fat in children increases in proportion to overall fatness as seen in adults, whereas others have shown that obese children tend to accumulate subcutaneous and not visceral fat.[19,20] WHR is effected by age and sex. The sex difference in abdomen:hip ratios becomes significant at pubertal age, at about the time when sex difference in androgen and estrogen levels become manifest.[20,21] The ratio declines during childhood and adolescence in females, whereas that for males remains about the same.[50] The lack of relation between WHR and intra-abdominal and subcutaneous fat thickness measurements in our study can be explained by the effect of modifiable and non-modifiable factors on fat distribution in children and adolescents.

According to the findings of this study, we suggest that BMI is a useful parameter to predict body fat in children and adolescents. The validity of anthropometric measurement of skinfold thickness is low in obese children. On the contrary to that in adults, WHR is unsuccessful to show intra-abdominal adiposity in children and adolescents. WC is more reliable in this clinical setting.

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