

Anthropometric assessment of muscularity during growth: estimating fat-free mass with 2 skinfold-thickness measurements is superior to measuring midupper arm muscle area in healthy prepubertal children¹⁻³

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ABSTRACT

Background: Anthropometric measurements are widely used to determine body composition, especially in children.

Objective: Our aim was to compare 2 of the simplest anthropometry-based equations available for determining nutritional status and muscularity in children and adolescents, examined in relation to other methodologically independent muscle variables.

Design: Midupper arm muscle area (UAMA) and fat-free mass (FFM) according to the equations of Slaughter et al (*Hum Biol* 1988;60:709–23), as well as separate biochemical, physical, and radiologic muscle variables, were determined cross-sectionally in 91 males and 91 females aged 6–18 y. The ability of UAMA and FFM to estimate muscularity, as measured by 24-h creatinine excretion, grip force, and peripheral quantitative computer tomography analysis of forearm muscle, was compared after dividing the study population into prepubertal and pubertal groups.

Results: Before puberty, correlations of all 3 muscularity variables were higher with FFM than with UAMA in both males and females. Multiple regression analyses confirmed FFM to be the predominant predictor, with partial $R^2 \geq 0.68$ ($P < 0.001$). However, in puberty, FFM did not consistently show this major influence. Only before puberty did FFM provide a significantly better fit ($P < 0.05$) than did UAMA for 2 of the 3 muscularity variables in each sex.

Conclusions: The FFM estimate proved to be the better predictor for muscularity in healthy prepubertal children and is on a par with UAMA during puberty. FFM can be recommended as a simple anthropometric method to assess nutritional status before puberty, at least in healthy children. *Am J Clin Nutr* 2002;76:628–32.

KEY WORDS Anthropometry, arm muscle area, fat-free mass, creatinine, grip force, peripheral quantitative computer tomography, nutritional status, muscularity, children

INTRODUCTION

Over the years, many skinfold-thickness equations have been developed for predicting percentage fat mass and fat-free mass (FFM) in children as well as in adults. However, most of these estimates were developed by using multiple skinfold-thickness measurements (1–5). Few equations in the literature are based on only 2 skinfold thicknesses and were developed specifically for

children or adolescents (6–8). One such set of equations—the quadratic equations of Slaughter et al (7)—is frequently used in the United States and European countries (9–14). Recently, the Slaughter equations have been recommended for population studies in female adolescents because of their accuracy and simplicity (13).

Another simple approach to assessing nutritional status and muscle mass, which is widely used in children and adults (15–20), is the determination of upper arm muscle area (UAMA; 21). UAMA is calculated by using midupper arm circumference and triceps skinfold thickness, which also means that only 2 anthropometric measurements are required. The aim of the present study was to determine which of these simpler anthropometric bedside estimates of nutritional status is superior in predicting muscularity in healthy children. Three methodologically independent indicators of muscle mass, 24-h creatinine excretion, grip force, and peripheral quantitative computer tomography (pQCT)—all analyzed in the same children—were used for the comparison.

SUBJECTS AND METHODS

Subjects

The subjects were a subgroup of healthy children and adolescents (91 males and 91 females, aged 6–18 y) participating in the DONALD (Dortmund Nutritional and Anthropometric Longitudinally Designed) study, an ongoing observational study investigating the interrelations between nutrition, growth, and metabolic and

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endocrine changes during childhood and adolescence (11, 14). All subjects who had, within a 1-y period (July 1998–June 1999), been subjected to a single pQCT analysis of the forearm, performed a grip-force test, and collected a 24-h urine sample were included in the present study. Weight, height, body mass index, skinfold thicknesses, and upper arm circumference did not differ from the overall DONALD study. To clearly differentiate between prepubertal children on the one hand and adolescents and young adults on the other, subjects at either Tanner stage 1 or Tanner stages ≥ 3 were included. Tanner stages were determined by a physician according to pubic hair development (22). Ethical permission was obtained from the institutional review board of the Research Institute for Child Nutrition in Dortmund, the ethics committee of the medical faculty of the University of Cologne, and the “Bundesamt für Strahlenschutz” (Salzgitter, Germany). Informed parental consent and the child’s assent were obtained before entry into the study.

Anthropometry

Body weight was measured with an electronic scale (Seca 753E; Seca Weighing and Measuring Systems, Hamburg, Germany) to the nearest 0.1 kg and standing height to the nearest 0.1 cm with a digital telescopic wall-mounted stadiometer (Harpenden, Coymych, United Kingdom). Anthropometric measurements were made on the right side of the body by the same highly experienced observers. Triceps and subscapular skinfolds were measured to the nearest 0.1 mm with a Holtain skinfold caliper (Holtain LTD, Crosswell, United Kingdom), and midupper arm circumference was measured with a metal tape (Chasmors LTD, London), with the right arm hanging relaxed at the subject’s side. For the estimation of FFM, the percentage of body fat was first calculated by using Slaughter et al’s skinfold-thickness equations (7).

For Tanner 1 males:

$$\% \text{Fat} = 1.21 (\text{triceps} + \text{subscapular}) - 0.008 (\text{triceps} + \text{subscapular})^2 - 1.7 \quad (1)$$

For Tanner 3 males:

$$\% \text{Fat} = 1.21 (\text{triceps} + \text{subscapular}) - 0.008 (\text{triceps} + \text{subscapular})^2 - 3.4 \quad (2)$$

For Tanner 4 and 5 males:

$$\% \text{Fat} = 1.21 (\text{triceps} + \text{subscapular}) - 0.008 (\text{triceps} + \text{subscapular})^2 - 5.5 \quad (3)$$

For all females:

$$\% \text{Fat} = 1.33 (\text{triceps} + \text{subscapular}) - 0.013 (\text{triceps} + \text{subscapular})^2 - 2.5 \quad (4)$$

The additional equations provided by Slaughter et al for overweight or obese boys and girls were not used because none of our subjects had a sum of triceps + subscapular skin fat folds > 35 mm. $\text{FFM}_{\text{Slaughter}}$ was then calculated as follows:

$$\text{FFM} = \text{body weight} - (\% \text{BF} \times \text{body weight})/100 \quad (5)$$

where BF is body fat.

UAMA was calculated by using the equation that was originally popularized by Jelliffe and coworkers (23, 24) and was then shown to be a useful index of muscle mass in healthy children by Trowbridge et al (21):

$$\text{UAMA} = [\text{arm circumference} - (\pi \times \text{triceps skinfold})]^2 / 4\pi \quad (6)$$

Grip force, forearm muscle area, and creatinine

Maximal isometric grip force of the nondominant hand was determined with a standard adjustable-handle Jamar dynamometer (Preston, Jackson, MI), as described recently (25). In short, the handle was adjusted so that the line of the subject’s proximal interphalangeal joints rested exactly on top of the adjustable handle. The subject was told to put maximum force on the dynamometer. The maximal value of 2 trials was noted. The scale of the dynamometer indicates the results in kilograms, which is incorrect, because this is the unit of mass, not force. Grip force (expressed in newtons) was calculated by multiplying the dynamometer reading by a factor of 9.81.

We used the XTC 2000 (Stratec, Pforzheim, Germany) to carry out pQCT analysis to determine forearm muscle area (FMA_{pQCT}). The following scan variables were used: slice thickness, 2 mm; voxel size, 0.4 mm; lower threshold, 20 mg/cm^3 ; upper threshold, 60 mg/cm^3 ; translational scan movement, 15 mm/s; software, 5.40. Single-slice measurements were made at a site corresponding to 65% of the ulnar length proximal to the radial endplate, because forearm circumference is greatest at this site (26). Muscle area was separated from bone and fat tissue by a built-in software algorithm (27).

Daily creatinine excretion was determined in 24-h urine samples. Subjects and parents received instruction and written guidance to ensure compliance in collection and a dietitian visited the families to discuss collection completeness in detail (14). Samples reported to be incomplete were excluded. Urinary creatinine concentration was measured by the Jaffé method with a Beckman-2 creatinine analyzer (Beckman Instruments, Inc, Fullerton, CA).

Statistical analysis

Data are represented as means \pm SDs. Pearson correlations and simple linear and multiple regression analyses were performed, as well as unpaired *t* tests to check for sex differences. The Pitman test (28) was used to determine the model with the better fit. For this, residuals of the regressions of each criterion variable with both $\text{FFM}_{\text{Slaughter}}$ (A) and UAMA (B) were calculated. The sum (A + B) and the difference (A – B) were calculated for each criterion variable and then A + B was correlated with A – B. Each correlation was checked to see if it was significantly different from zero. Where this was the case the residual with the smaller SD was the model with better fit. Statistical significance was set at $P < 0.05$, and all tests were two-tailed. Analyses were performed with SAS for WINDOWS (version 6.12; SAS Institute Inc, Cary, NC).

RESULTS

Mean values for age, physical characteristics, anthropometric measurements, body composition, and 24-h creatinine excretion of the subjects according to developmental stage and sex are presented in **Table 1**. Skinfold measurements were significantly higher for females than for males in both age groups, whereas $\text{FFM}_{\text{Slaughter}}$ and the methodologically independent muscle variables, grip force, creatinine, and FMA_{pQCT} were higher for males. Values for height and UAMA were also significantly lower in females in the pubertal group.

The associations of grip force with $\text{FFM}_{\text{Slaughter}}$ and UAMA are shown in **Figure 1**. It is discernible that $\text{FFM}_{\text{Slaughter}}$ alone explained between 46% and 74% of the overall variability of grip force in males and females, whereas UAMA only explained

TABLE 1

Age, physical characteristics, anthropometric measurements, body composition, and 24-h creatinine excretion of the subjects according to developmental stage and sex¹

	Prepubertal		Pubertal	
	Males (n = 59)	Females (n = 50)	Males (n = 32)	Females (n = 41)
Age (y)	8.7 ± 2.0 ²	8.4 ± 1.8	14.9 ± 2.1	14.4 ± 2.4
Height (cm)	135.8 ± 13.1	132.9 ± 11.7	170.2 ± 11.1	163.7 ± 9.3 ³
Weight (kg)	31.9 ± 10.7	29.6 ± 8.5	59.6 ± 11.1	56.2 ± 12.2
BMI (kg/m ²)	16.9 ± 2.8	16.5 ± 2.3	20.4 ± 2.2	20.8 ± 3.0
FMA _{pQCT} (mm ²)	1984 ± 379	1784 ± 329 ³	3455 ± 666	2700 ± 391 ⁴
Grip force (N)	131.4 ± 50	108.9 ± 44.0 ⁵	318.2 ± 98.8	238.8 ± 46.5 ⁴
UAMA (cm ²)	22.6 ± 5.3	20.7 ± 4.6	39.4 ± 8.7	32.5 ± 5.9 ³
FFM _{Slaughter} (kg)	25.8 ± 5.8	23.5 ± 4.9 ⁵	48.8 ± 10.3	40.8 ± 6.4 ³
24-h Creatinine excretion (mmol/d)	5.0 ± 1.7	4.2 ± 1.4 ⁵	10.7 ± 3.2	8.3 ± 2.1 ³
Arm circumference (cm)	19.9 (19.2, 20.7) ⁶	19.8 (19.1, 20.6)	25.7 ± 2.3	25.4 ± 2.7
Biceps fat fold thickness (mm)	5.2 (4.7, 5.8)	6.8 (6.1, 7.6) ⁴	6.7 ± 3.3	9.0 ± 3.4 ³
Triceps fat fold thickness (mm)	10.0 (9.0, 11.1)	11.9 (10.7, 13.2) ⁵	12.1 ± 5.5	17.2 ± 5.6 ⁴
Subscapular fat fold thickness (mm)	6.3 (5.6, 7.1)	7.6 (6.7, 8.7) ⁵	10.8 ± 5.1	14.4 ± 7.3 ³

¹FMA_{pQCT}, forearm muscle area as measured with peripheral quantitative computer tomography; UAMA, midupper arm muscle area; FFM_{Slaughter}, fat-free mass according to Slaughter et al (7).

² $\bar{x} \pm SD$.

³⁻⁵Significantly different from males: ³ $P < 0.01$, ⁴ $P < 0.001$, ⁵ $P < 0.05$.

⁶Geometric \bar{x} ; 95% CI in parentheses.

32–50%. The data in **Table 2** also show that before puberty, FFM_{Slaughter} was more closely correlated with FMA_{pQCT} and creatinine than was UAMA.

In the older age group, FFM_{Slaughter} and UAMA were almost on a par in relation to FMA_{pQCT} for males, whereas FFM_{Slaughter} correlated better with creatinine (Table 2). In pubertal females, UAMA showed a slightly better relation with both variables. In multiple regression analyses (with FFM_{Slaughter}, UAMA, age, and sex as potential predictors), FFM_{Slaughter} proved to be the predom-

inant predictor for all criterion variables (grip force, FMA_{pQCT}, and creatinine) in the prepubertal group, with values for partial R^2 ranging from 0.68 to 0.74 and sex and UAMA showing no influence (**Table 3**). In the pubertal group, results were less consistent. A primary effect of FFM_{Slaughter} was seen for grip force and creatinine. However, UAMA showed a major influence on FMA_{pQCT}. Here FFM_{Slaughter} as well as sex only explained a small portion of variability.

In the prepubertal group, the Pitman test yielded significantly smaller SDs of the residuals for the regression of FFM_{Slaughter} on grip force and creatinine in males and on grip force and FMA_{pQCT} in females when compared with UAMA. All other residual SDs for FFM_{Slaughter} and UAMA (both before and during puberty) were not significantly different, except for the regression on creatinine in pubertal males, where FFM_{Slaughter} was smaller.

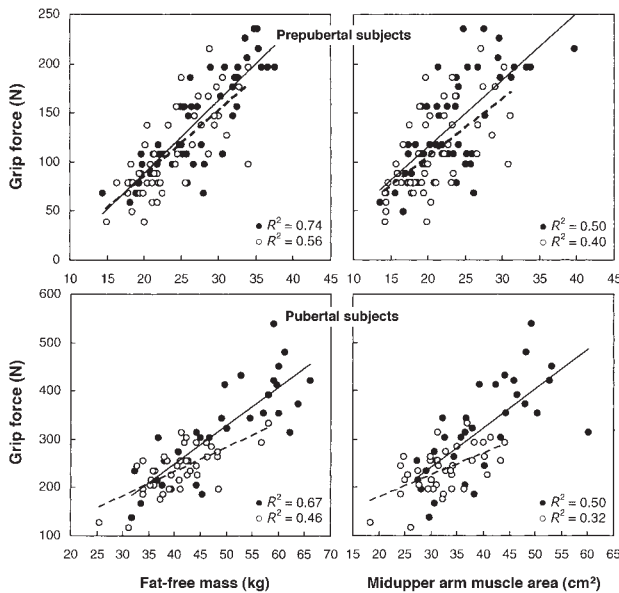


FIGURE 1. Grip force plotted against fat-free mass and midupper arm muscle area in prepubertal (n = 59) and pubertal (n = 32) males (●, solid line) and prepubertal (n = 50) and pubertal (n = 41) females (○, dotted line). $P < 0.001$ for all simple linear regressions.

TABLE 2

Pearson's correlation coefficients of muscle area and 24-h creatinine excretion with fat-free mass and midupper arm muscle area (UAMA) in prepubertal and pubertal subjects¹

	Prepubertal (n = 59 M, 50 F)		Pubertal (n = 30 M, 41 F)	
	FFM _{Slaughter} kg	UAMA cm ²	FFM _{Slaughter} kg	UAMA cm ²
FMA _{pQCT} (mm ²)				
Males	0.86	0.81	0.89	0.91
Females	0.86	0.77	0.65	0.72
24-h Creatinine excretion (mmol/d)				
Males	0.82	0.73	0.75	0.57
Females	0.84	0.82	0.60	0.63

¹FFM_{Slaughter}, fat-free mass according to Slaughter et al (7); FMA_{pQCT}, forearm muscle area as measured with peripheral quantitative computer tomography. $P < 0.001$.

TABLE 3

Stepwise multiple regression analysis of all subjects with grip force, FMA_{pOCT}, and 24-h creatinine excretion as the dependent variables according to pubertal development¹

	Grip force			FMA _{pOCT}			24-h Creatinine		
	Partial R ²	Coefficient	P	Partial R ²	Coefficient	P	Partial R ²	Coefficient	P
Before puberty (n = 109)									
FFM _{Slaughter}	0.681	4.24	<0.001	0.744	64.76	<0.001	0.694	0.25	<0.001
UAMA	—	—	NS	—	—	NS	—	—	NS
Age	0.049	10.28	<0.001	—	—	NS	—	—	NS
Sex	—	—	NS	—	—	NS	—	—	NS
Puberty (n = 73)									
FFM _{Slaughter}	0.683	5.63	0.001	0.053	25.08	<0.001	0.557	0.18	<0.001
UAMA	—	—	NS	0.761	39.74	<0.001	—	—	NS
Age	0.028	8.67	<0.05	—	—	NS	—	—	NS
Sex	0.025	-29.71	<0.05	0.036	-277.88	<0.001	—	—	NS

¹FMA_{pOCT}, forearm muscle area measured with peripheral quantitative computer tomography; FFM_{Slaughter}, fat-free mass according to Slaughter et al (7); UAMA, midupper arm muscle area.

DISCUSSION

Because they are easy to use, skinfold-thickness prediction equations are the most widely used method of assessing fatness and nutritional status for clinical purposes. A simple alternative for the evaluation of nutritional status, which is also frequently applied, is the determination of UAMA (15–20). The advantage of UAMA is that only 2 anthropometric measures (triceps skinfold thickness and upper arm circumference) are required to quickly yield an index of muscularity. Of the few published skinfold formulas, for which only 2 anthropometric measurements (triceps and subscapular or triceps and suprailiac) are required, Slaughter et al's equations (7) in particular have recently been recommended for population studies because of their accuracy and simplicity (13). The quadratic equations of Slaughter et al agreed more closely with the 4-compartment model's measurement of body composition than did most of the other skinfold-thickness equations tested (13). In accordance with these findings, FFM_{Slaughter} has, in the present study, proved to be more successful in predicting muscularity than the other quick and simple alternative, UAMA.

There is no gold standard for body composition measurements in vivo. All methods incorporate assumptions that do not hold true in all cases, and the best model is derived by using a combination of measurements, thereby minimizing the importance of such assumptions (12). The 4-compartment model of body composition, obtained by combining several measurement techniques (dividing body weight into fat, water, mineral, and protein), is more robust to interindividual variability in the composition of FFM. However, this important reference method is very costly and requires more time and technical facilities, which are not widely available (29). The lack of these technical facilities led us to use alternative methods available in our institute as criterion variables for the comparison of FFM and UAMA.


Grip strength was chosen because it represents a well-established measure of muscle function reflecting fairly well the body's nutritional status (30, 31). Another widely used indicator of muscle mass is 24-h urinary creatinine (which is noninvasive and biochemical; 14, 32–34). In addition, the radiographic technique of computerized tomography is the method of choice to most accurately determine muscle area (16, 35).

The anthropometric assessment of UAMA has been repeatedly shown to provide useful information on the nutritional status of children, adolescents, and adults (15–20). This widely accepted and

clinically practical method is frequently used because of its simplicity, low cost, and noninvasiveness. However, to our knowledge, UAMA has never been directly compared with other comparably simple estimates of muscularity to identify the better predictor of nutritional status as determined by separate methodologically independent approaches.

The present findings indeed confirm that reasonably close associations exist between UAMA and different indexes of muscularity in children and adolescents. However, although we correlated the regional UAMA with 2 other regional muscularity variables (FMA_{pOCT} and grip force), another easily obtainable muscularity variable, the whole-body indicator FFM_{Slaughter}, correlates even better with the same 2 variables, especially in prepubertal children. Calculation of the corresponding R² yielded explained variabilities for all criterion variables (FMA_{pOCT}, creatinine, and grip force) that were 4–24% higher for FFM than for UAMA before puberty. Also, in multiple regression analyses, especially in prepubertal children, FFM proved to be the major predictor for all criterion variables. In 4 out of 6 possible comparisons in prepubertal children, the Pitman Test showed that FFM_{Slaughter} was the estimate with significantly better fit when compared with UAMA. The reason why the model fit of FFM_{Slaughter} was not significantly better than that of UAMA regarding creatinine in females and FMA_{pOCT} in males is not known. However, the fact that most comparisons in prepubertal children are significantly in favor of FFM_{Slaughter} speaks for its superiority. This superiority of FFM_{Slaughter} over UAMA agrees with recent observations that even metabolic markers of insulin regulation can be predicted with greater precision after including several skinfold-thickness measurements (36). On the other hand, body composition is subject to more-rapid changes during puberty, and this may explain why there is no longer a clear difference between the methods in that period. Also, the fact that the Slaughter et al equations are applied according to Tanner stage means that in puberty FFM_{Slaughter} is not assessed as an entity. This could be a disadvantage.

Wells et al (12) observed an overall poor agreement of the Slaughter et al equations with 4-compartment-model data in 8–12-year-old children. However, the Slaughter et al equations showed a lower mean bias than did several published formulas based on bioelectrical impedance analyses (12). In addition, 95% limits of agreement for percentage body fat were only modestly higher with Slaughter et al's skinfold prediction ($\pm 8.0\%$) than with dual-energy X-ray absorptiometry measurements ($\pm 6.5\%$). These data, consid-

ered along with the fact that body mass index has no significant correlation with body fat in leaner children but that Slaughter et al's model strongly does (37), again emphasize that Slaughter et al's equations are a reasonable predictor of nutritional status. An additional advantage of FFM_{Slaughter} is that a real component of body composition, given in kilograms, is obtained. The advantage of UAMA is, however, that in bedridden children it is relatively easier to perform the required measurements and involves minimal or no removal of clothing. In conclusion, the FFM estimate proved to be the better predictor for muscularity before puberty in healthy children and is on a par with the also easy-to-obtain UAMA during puberty. 

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