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Estimates of Body Fat in Children by Hologic QDR-2000 and QDR-4500A Dual-Energy X-ray Absorptiometers Compared With Deuterium Dilution

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Abstract

We evaluated the accuracy with which the Hologic QDR-4500A and QDR-2000 densitometers measure fat mass (FM) in 95 children. FM was derived from total body water measured by deuterium dilution (DD) in all children, by QDR-4500A in 50, and by QDR-2000 in 45 children. Compared with DD, both instruments underestimated FM (QDR-4500A: 3.35 ± 2.5 kg, $P < 0.0001$; QDR-2000: 1.05 ± 1.5 kg, $P < 0.0001$). Both absorptiometers showed magnitude biases relative to DD (QDR-4500: $r = +0.70$, $P < 0.001$; QDR-2000: $r = -0.51$, $P < 0.001$). We conclude that neither densitometer is equivalent to DD for estimation of children's FM. The QDR-4500A's current calibration seems to provide an even greater underestimate of FM than the QDR-2000.

Keywords

children; body composition; fat mass; dual-energy x-ray absorptiometry; calibration

INTRODUCTION

In the United States, the percentage of children and adolescents who are overweight, defined as a body mass index (BMI) greater than or equal to the 95th percentile, has tripled over the last 30 years (1). Metrics based on BMI do not directly reflect body fat mass (FM) in children (2,3). The ability to assess body FM accurately in children is necessary to develop effective prevention and treatment strategies for childhood obesity.

Dual-energy x-ray absorptiometry (DXA), with the pencil beam mode that was used in earlier instruments like the Hologic QDR-2000, has been generally accepted as an excellent method for estimating body FM in children (4). However, 3 recent adult studies have found that, relative to other criterion methods, the Hologic QDR-4500 array beam DXA underestimates FM by 2–5% (5–7). We therefore compared the accuracy of the QDR-4500 array beam and QDR-2000 pencil beam DXA in estimating the body FM of children using deuterium dilution (DD) as the criterion method.

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METHODS

Ninety-five healthy children (40 boys and 45 girls), with BMI range 14–55 kg/m² and age 6–12 years (Table 1), were recruited for participation in studies for healthy child volunteers and for overweight children seeking obesity treatment. The studies were approved by the National Institutes of Health Intramural Clinical Research Review Board. Both parent and child signed consent and assent forms for protocol participation.

The subjects underwent determination of percentage of fat mass (%FM) by 2 methods: from total body water measured by DD in all children, and DXA by either the QDR-4500 array beam instrument or the QDR-2000 pencil beam instrument (Table 1). Both body composition studies were completed within 95 days of one another (mean $\pm$ SD: 32.8 $\pm$ 45.7 days) and occurred in random order. Only subjects whose BMI changed less than 4% between the 2 tests were considered eligible for inclusion. On average, BMI did not significantly change between the 2 measurements for either the QDR-2000 ($P = 0.65$) or the QDR-4500 ($P = 0.92$), and the average change in body weight between studies for the entire group was 0.57 $\pm$ 1.2 kg (maximal weight difference 2.2 kg). A subgroup analysis of 72 subjects who were matched for age, sex, race, pubertal status, BMI-SD score and FM by DD was also studied (Table 2), as was a third subgroup restricted to 56 subjects who underwent DD and DXA less than 30 days apart and had no significant changes in body weight. Estimated FM based on DD was considered the criterion method against which the DXA results were compared. After a 12-hour fast, subjects were given 2.5 g deuterium oxide (²H₂O) per kg estimated total body water. Urine samples were immediately collected before ²H₂O administration, and again 3 and 4 hours after the ²H₂O dose. One hour after the dose of labeled water, a standard liquid breakfast shake was given. All subsequent oral intake was recorded. If subjects were unable to void at either the 3- or 4-hour points, an additional 200 mL of plain water was offered at each time point. Urine samples were analyzed for DD as previously described, (5) and body composition was estimated assuming that 0% of body FM is water (8) and applying a correction to account for nonaqueous hydrogen exchange (TBW = DD space/1.042). Children are believed to have a higher aqueous fraction of the FFM than young adults (9); therefore, FFM was calculated using age- and sex-adjusted values for the hydration factor of FFM as suggested by Fomom et al. (10), and continuing the linear fits derived from the data of Fomom et al for children 10–12 years. DD-derived FM was then calculated by subtracting FFM from total body mass. Body composition was determined by DXA using a pencil beam densitometer (model QDR-2000, pediatric software version 11.2; Hologic Inc., Bedford, MA) in 45 children between March 1997 and December 2000 and using a fan beam densitometer (pediatric software version 5.64; Hologic model QDR-4500A) in 50 other children between January 2001 and March 2003. FM and %FM were obtained following the manufacturer's recommendations.

Linear regression was used to compare FM estimates by DD and the 2 densitometers, followed by Bland–Altman comparisons (11), to assess systematic and magnitude biases, with the difference in FM estimation (ie, FM by each DXA method vs DD) compared by ANCOVA, with race, sex, age, weight change and time between measurements as covariates.

RESULTS

FM by DD was significantly correlated with FM estimated by both densitometers (Figs. 1A and B, for each $r \geq 0.99$, $P < 0.0001$). However, both densitometers significantly underestimated FM in 6- to 12-year-old children in comparison to DD: The QDR-4500 underestimated FM by 3.35 $\pm$ 2.5 kg ($P < 0.0001$ vs DD) and an absolute difference in %FM of 4.9% ($P < 0.0001$ vs DD). The QDR-2000 underestimated FM by an absolute difference of 1.05 $\pm$ 1.5 kg ($P < 0.0001$ vs DD) and an absolute difference in %FM of 2.34% ($P < 0.0001$ vs DD). Thus, the QDR-4500A seemed to underestimate FM by an additional 2.29 kg ($P <$

0.0001) relative to the QDR-2000. Bland–Altman comparisons (11) revealed there were magnitude biases for both the QDR-2000 and the QDR-4500A; however, the biases had slopes with differing signs (Fig. 1). The QDR-4500A underestimated FM to a greater extent for higher average percent body fat ($r = +0.7$, $P < 0.0001$), whereas the QDR-2000 underestimated FM to a greater extent for lower FM ($r = -0.5$, $P < 0.0001$).

Because of the differences in body adiposity of the 2 study groups, we also examined results in a subgroup of 72 subjects who were matched for age, sex, race, pubertal status, BMI-SD score and FM by DD (Table 2). In this subgroup, the QDR-4500A significantly underestimated FM by 2.81 ± 2.2 kg ($P < 0.0001$ vs DD) and an absolute difference in %FM of 4.4% ($P < 0.0001$ vs DD). The QDR-2000 significantly underestimated FM by an absolute difference of 0.87 ± 1.5 kg ($P = 0.0013$ vs DD) and had an absolute difference in %FM of 0.47% ($P = 0.23$ vs DD). An additional analysis restricted to 56 subjects who underwent DD and DXA less than 30 days apart similarly found greater underestimation of DD body FM by the QDR-4500A than the QDR-2000 instrument (3.49 ± 2.7 vs 0.58 ± 2.0 kg, $P < 0.001$; 4.9 ± 2.8 vs $1.4 \pm 5.0\%$, $P = 0.001$). In both subgroup analyses, the direction of the magnitude biases for the 2 DXA instruments were similar to those of the entire cohort.

DISCUSSION

We compared the ability of the fan beam DXA Hologic QDR-4500 and the pencil beam DXA Hologic QDR-2000 to estimate FM in 6- to 12-year-old normal weight and overweight African American, White, American Indian and White-Hispanic children against DD as the criterion method. We found that neither machine estimated FM, as determined from total body water measurements from DD, without bias, but the DXA QDR-4500A seemed to underestimate FM in children to an even greater extent than the QDR-2000 instrument. These results were found for the entire cohort and for a subgroup matched for age, sex, race, pubertal status, BMI-SD score and FM by DD.

These findings are in good accord with previous studies in adults, which found that the QDR-4500 array beam DXA may underestimate FM by 2–5%. Tylavsky et al. (5) found that the QDR-4500A systematically overestimated FFM by 3%, and therefore it underestimated FM by 2–3% in a cohort of 58 adults age 70–79 years. In a separate study, Deurenberg et al (6) found the QDR-4500A DXA to underestimate percentage of body fat (%BF) by 2–4% in a cohort of 291 subjects aged 18–75 years. More recently, Schoeller et al compiled 1195 adult subjects from 7 studies, finding a 5% underestimation of FM. Two separate studies comparing the Hologic QDR-1000 W pencil beam DXA to the 4500 array beam DXA found evidence of differing magnitude biases: The array beam DXA seemed to underestimate high %BF whereas the 1000 W pencil beam DXA underestimated low %BF (12,13). When evaluated against a 4-compartment model, the Hologic QDR-4500 array beam DXA has also been found to underestimate FM in adults (14,15). In children, 1 prior study of 33 subjects (ages 3–18) found the 4500 array beam DXA significantly underestimated fat as compared with the 2000 pencil beam DXA by $0.94 \pm 2.5\%$ (16). Several studies examining the relationship between the 4500 array beam DXA and 2000 pencil beam DXA have found that they are strongly predictive of each other, although their absolute values differ (6,16,17). Although the relationship between the 2000 pencil beam and 4500A array beam DXA has been studied in children (16), to our knowledge there are no prior pediatric studies analyzing the accuracy of the QDR-4500 DXA against a criterion method.

The strengths of this study include the use of DD, a well-accepted measure, as the criterion method, the wide range of BMI and FM among study subjects, the racial diversity of the cohort and the similar socioeconomic status of the 2 cohorts evaluated. The most significant limitation of this study is the lack of subjects studied with all 3 methods simultaneously. The difference

in the mean BMI-SD and FM of the subjects who were studied using the QDR-2000 and QDR-4500A is also potentially of concern. However, it seems unlikely that the much greater underestimation of FM by the QDR-4500A can be accounted for by the greater amount of overall FM measured because virtually the same magnitude of error in FM estimation was found in analyses restricted to children matched for body composition and demographic variables. Another limitation relates to the possibility that there may be differences in the hydration factor that is most appropriate to use for lean and obese children (18,19). Should it prove true that hydration factors need to be adjusted for obesity, the magnitude of the biases for the 2 DXA methods versus DD may not be accurately described. However, the relative differences between the 2 scanners at any level of FM would not be affected by this issue.

We conclude that relative to DD, both the QDR-2000 pencil beam DXA and the QDR-4500 array beam DXA underestimate percentage body fat in 6- to 12-year-old children. However, FM estimates obtained using the QDR-4500A seem to be underestimated to an even greater extent than by the QDR-2000. Based upon these data, we believe that studies making use of both these machines must take into account their differential underestimation of FM when reporting results. Additional studies are required to establish how best to reconcile results from these densitometers, particularly studies with simultaneously obtained data from both DXA instruments. One solution is to use the linear regression fits shown in Figures 1A and B to adjust results from each densitometer.

References

1. Ogden CL, Flegal KM, Carroll MD, et al. Prevalence and trends in overweight among US children and adolescents, 1999–2000. *JAMA* 2002;288:1728–32. [PubMed: 12365956]
2. Rolland-Cachera MF, Sempe M, Guilloud-Bataille M, et al. Adiposity indices in children. *Am J Clin Nutr* 1982;36:178–84. [PubMed: 7091028]
3. Field AE, Laird N, Steinberg E, et al. Which metric of relative weight best captures body fatness in children? *Obes Res* 2003;11:1345–52. [PubMed: 14627755]
4. Lockner DW, Heyward VH, Baumgartner RN, et al. Comparison of air-displacement plethysmography, hydrodensitometry, and dual X-ray absorptiometry for assessing body composition of children 10 to 18 years of age. *Ann N Y Acad Sci* 2000;904:72–8. [PubMed: 10865712]
5. Tylavsky F, Lohman T, Blunt BA, et al. QDR 4500A DXA overestimates fat-free mass compared with criterion methods. *J Appl Physiol* 2003;94:959–65. [PubMed: 12433854]
6. Deurenberg P, Deurenberg-Yap M, Foo LF, et al. Differences in body composition between Singapore Chinese, Beijing Chinese and Dutch children. *Eur J Clin Nutr* 2003;57:405–9. [PubMed: 12627175]
7. Schoeller DA, Tylavsky FA, Baer DJ, et al. QDR 4500A dual-energy X-ray absorptiometer underestimates fat mass in comparison with criterion methods in adults. *Am J Clin Nutr* 2005;81:1018–1025. [PubMed: 15883424]
8. Wang Z, Deurenberg P, Wang W, et al. Hydration of fat-free body mass: review and critique of a classic body-composition constant. *Am J Clin Nutr* 1999;69:833–41. [PubMed: 10232621]
9. Hewitt MJ, Going SB, Williams DP, et al. Hydration of the fat-free body mass in children and adults: implications for body composition assessment. *Am J Physiol* 1993;265:E88–95. [PubMed: 8338157]
10. Fomon SJ, Haschke F, Ziegler EE, et al. Body composition of reference children from birth to age 10 years. *Am J Clin Nutr* 1982;35:1169–75. [PubMed: 7081099]
11. Bland JMAD. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1:307–10. [PubMed: 2868172]
12. Litaker MS, Barbeau P, Humphries MC, et al. Comparison of Hologic QDR-1000/W and 4500W DXA Scanners in 13- to 18-Year Olds. *Obes Res* 2003;11:1545–52. [PubMed: 14694220]
13. Tothill P, Hannan WJ, Wilkinson S. Comparisons between a pencil beam and two fan beam dual energy X-ray absorptiometers used for measuring total body bone and soft tissue. *Br J Radiol* 2001;74:166–76. [PubMed: 11718390]

14. Visser M, Fuerst T, Lang T, et al. Validity of fan-beam dual-energy X-ray absorptiometry for measuring fat-free mass and leg muscle mass. Health, aging, and body composition study—Dual-Energy X-ray Absorptiometry and Body Composition Working Group. *J Appl Physiol* 1999;87:1513–20. [PubMed: 10517786]
15. Salamone LM, Fuerst T, Visser M, et al. Measurement of fat mass using DEXA: a validation study in elderly adults. *J Appl Physiol* 2000;89:345–52. [PubMed: 10904070]
16. Ellis KJ, Shypailo RJ. Bone mineral and body composition measurements: cross-calibration of pencil-beam and fan-beam dual-energy X-ray absorptiometers. *J Bone Miner Res* 1998;13:1613–8. [PubMed: 9783550]
17. Koo WW, Hammami M, Hockman EM. Interchangeability of pencil-beam and fan-beam dual-energy X-ray absorptiometry measurements in piglets and infants. *Am J Clin Nutr* 2003;78:236–40. [PubMed: 12885703]
18. Haroun D, Wells JC, Williams JE, et al. Composition of the fat-free mass in obese and nonobese children: matched case–control analyses. *Int J Obes (Lond)* 2005;29:29–36. [PubMed: 15520827]
19. Wells JC, Fuller NJ, Dewit O, et al. Four-component model of body composition in children: density and hydration of fat-free mass and comparison with simpler models. *Am J Clin Nutr* 1999;69:904–12. [PubMed: 10232629]
20. Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. *Arch Dis Child* 1969;44:291–303. [PubMed: 5785179]
21. Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in boys. *Arch Dis Child* 1970;45:13–23. [PubMed: 5440182]
22. Hollingshead, AB. Two Factor Index of Social Position. New Haven, CT: Yale University Press; 1958.

FIG. 1.

Linear regression plots of estimates of FM by DD against estimates of FM by (A) Hologic QDR-2000 pencil beam DXA ($y = 1.064x - 2.208$) and (B) Hologic QDR-4500 array beam DXA ($y = 0.890x + 0.729$). For A and B, the dashed line represents a perfect correlation (line of identity; $y = x$). Bland-Altman plots for magnitude and systematic biases in the estimation of body fat by DD (the criterion method) with (C) Hologic QDR-2000 pencil beam DXA and (D) Hologic QDR-4500 array beam DXA. For C and D, the dashed line $y = 0$ is shown along with a solid line fitted to the data to demonstrate magnitude biases.

TABLE 1

Clinical Characteristics of the Study Population

	Children studied using array beam DXA (Hologic QDR-4500), <i>n</i> = 50	Children studied using pencil beam DXA (Hologic QDR-2000), <i>n</i> = 45
Sex	Boys, <i>n</i> = 24 Girls, <i>n</i> = 26	Boys, <i>n</i> = 16 Girls, <i>n</i> = 29
Age, years (range)	10.4 ± 1.5 (7.0–12.9)	9.0 ± 1.5* (6.0–11.4)
Race (%)		
Non-Hispanic White	54	60
Non-Hispanic Black	40	40
Other	6	0
BMI, kg/m ² (range)	31.0 ± 8.5 (15.0–55.0)	22.8 ± 6.8* (14.3–48.5)
BMI-SD score (range)	2.10 ± 0.97 (−1.2–2.9)	1.7 ± 1.06* (−0.9–3.0)
FM by DD (kg, range)	32.9 ± 16.6 (4.1–74.0)	17.7 ± 10.7* (4.4–53.1)
Breast tanner stage, girls (%)		
Tanner 1	35	45
Tanner 2	23	41
Tanner 3 or greater	42	14
Boys' testes volume (mL)	3.3 ± 2.4	2.2 ± 0.7
Socioeconomic status score	2.9 ± 1.3	2.9 ± 1.1

Parametric values are given as mean ± SD, with range in parentheses. Pubertal development was established by physical examination following the stages of Marshall and Tanner (20,21). Socioeconomic status was determined as suggested by Hollingshead (22).

* *P* < 0.001 versus QDR-4500 DXA cohort.

TABLE 2
 Characteristics of the Study Subset Matched for Demographic and Body Composition Variables

	Hologic QDR-4500 subgroup, <i>n</i> = 37	Hologic QDR-2000 subgroup, <i>n</i> = 35
Sex	Boys, <i>n</i> = 17 Girls, <i>n</i> = 20	Boys, <i>n</i> = 14 Girls, <i>n</i> = 21
Age, years (range)	10.1 ± 1.6 (7.0–12.9)	9.4 ± 1.5 (6.3–11.7)
Race (%)		
Non-Hispanic White	57	63
Non-Hispanic Black	41	37
Other	2	0
BMI, kg/m ² (range)	27.5 ± 7.3 (15.1–38.2)	26.7 ± 6.3 (17.6–38.5)
BMI-SD score (range)	1.97 ± 1.06 (−1.2–2.9)	2.03 ± 0.59 (−0.9–3.0)
FM-DD, kg (range)	26.1 ± 13.5 (4.8–46.2)	24.4 ± 10.0 (4.9–53.1)
Breast tanner stage, girls (%)		
Tanner 1	38.9	33.3
Tanner 2	22.2	47.6
Tanner 3 or greater	38.9	19.1
Boys' testes volume (mL)	3.3 ± 1.8	2.3 ± 0.7
Socioeconomic status score	2.9 ± 1.3	3.0 ± 1.1
Difference in FM vs DD (kg)	−2.81 ± 2.2	−0.87 ± 1.5*
Difference in %FM vs DD (%)	−4.4 ± 2.6	−0.47 ± 2.3*

* *P* < 0.001 versus QDR-4500 DXA cohort.