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Body Composition in Children with Chronic Illness: Accuracy of Bedside Assessment Techniques

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Abstract

Objective—To evaluate the accuracy of estimated fat mass (FM) and fat free mass (FFM) from bedside methods compared with reference methods in children with chronic illnesses.

Study design—FM and FFM values were obtained by skinfold (SF), bioelectrical-impedance analysis (BIA), Dual-energy X-ray Absorptiometry (DXA), and deuterium dilution method in children with spinal muscular atrophy, intestinal failure and post hematopoietic stem cell transplantation. Spearman's correlation and agreement analyses were performed between a) FM values estimated by SF equations and by DXA; and b) FFM values estimated by BIA equations and by DXA and deuterium dilution methods. Limits of agreement (LOA) between estimating and reference methods within +/− 20% were deemed clinically acceptable.

Results—FM and FFM values from 90 measurements in 56 patients, 55% male and median age 11.6 years. Correlation coefficients between the SF-estimated FM values and DXA were 0.93–0.94 and between BIA-estimated FFM values and DXA were 0.92–0.97. Limits of agreement between estimated and DXA values of FM and FFM were greater than ±20% for all equations. Correlation coefficients between estimated FFM values and deuterium dilution method in 35 encounters were 0.87–0.91, and LOA were greater than ±20%.

Conclusion—Estimated body composition derived from skin fold and BIA may not be reliable for children with chronic illnesses. An accurate noninvasive method to estimate body composition in this cohort is desirable.

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Keywords

Body composition; isotope dilution; deuterium; dual X-ray absorptiometry; bioelectric impedance analysis; fat mass; fat free mass; muscle; children; bone marrow transplant; hematopoietic stem cell transplant; spinal muscular atrophy; intestinal failure

Malnutrition and alterations in body composition, fat mass (FM) and fat free mass (FFM), are prevalent in children with chronic illness.[1–3] Low FFM has been identified in children with chronic respiratory failure, stem cell transplantation, cystic fibrosis, and spinal muscular atrophy; and has been associated with poor clinical outcomes.[4–7] Fat mass and FFM may be influenced by the disease state, comorbidities and nutritional support. However, pediatric nutritional assessments are predominantly based on weight trends, and may not be able to detect underlying alterations in body composition.[2] Accurate serial body composition assessment is an important component of a comprehensive nutritional evaluation and might help determine the impact of chronic illness and nutritional interventions in children recovering from illness.

A variety of methods have been used to assess FFM and FM in children. Methods such as dual energy x-ray absorptiometry (DXA) and deuterium isotope dilution technique are resource-intensive and not routinely available in the clinical setting.[8, 9] Skinfold measurements and bioelectrical impedance analysis (BIA) are portable and inexpensive techniques that are extensively used in the clinical setting.[9–11] These techniques use equations to estimate FM from skinfold measurements; or estimate FM and FFM using equations applied to impedance and resistance values obtained by BIA.[12–20] These equations have been developed in heterogeneous cohorts of children, a majority of whom have no comorbidities.

In this study, we examined the correlation and agreement between estimated values of FM and FFM (using published equations for the skinfold and BIA techniques), and values obtained by reference techniques (DXA and deuterium isotope dilution).

Methods

We conducted a retrospective analysis of body composition measurements (FM and FFM) obtained during multiple encounters in 56 patients enrolled in three studies.[2, 21] The entire cohort represented children with chronic illnesses, specified below. Study procedures included DXA (n=91), BIA measurements (n=133), skinfold (SF) measurements (n=134), and deuterium dilution (n=36; in 2 of 3 studies). In some subjects, body composition assessments including simultaneous measurements by DXA, BIA, SF and deuterium dilution method were repeated over time. Data from 90 encounters, that included DXA, SF and BIA results, were included in the analyses of FM and FFM values; of these, 35 encounters that included deuterium dilution values were included in the analyses of FFM values. Tables I and II depict the characteristics, sample size and measurement distribution among the 3 studies. Study 1 (n=16 patients) was a prospective pilot study of children 5 to 14 years of age with intestinal failure (IF) from Boston Children's Hospital with multiple encounters.[2] Study 2 (n=10 patients) was a prospective cohort study of children ages 2 and

older with spinal muscular atrophy (SMA) type II and III at Boston Children's Hospital with single encounters (unpublished data). Study 3 (n=30 patients) was a randomized, double-blind, controlled clinical trial of parenteral nutrition (PN) provision in children over 6 years of age who received hematopoietic stem cell transplantation with multiple encounters.[21] All measurements were completed by experienced advanced dietitians from the Center for Nutrition at Boston Children's Hospital, using standard institutional protocols, including experienced dietitian staff from the institutional Clinical and Translational Study Unit. All measurements were completed on the same study visit. Institutional review boards (IRB) approved each study and parents or guardians gave written informed consent for participation, including subject assent, as appropriate for age and developmental level. Demographics, anthropometric measurements, and body composition data from skinfold measurements, BIA, DXA and deuterium isotope dilution technique were obtained and analyzed as a single cohort. The Boston Children's Hospital IRB approved the current study examining the aggregate data for post-hoc analysis.

Body composition assessment

All anthropometric measurements were performed in triplicate, and the average value of these three measurements was recorded. At each study visit, subjects' weights were obtained on an electronic digital scale accurate to the nearest 0.1kg per institutional standard protocol, without shoes and with light clothing on. Standing height was measured to the nearest 0.1cm for those patients able to stand. If patients had contractures or were unable to stand, a segmental length was measured by trained dietitians while the patient rested on a bed. Segmental length was measured from the top of the scalp to the acromion process, to the top of the iliac crest to mid-patella to the ball of the heel. Triceps, biceps, iliac, and subscapular skinfold thickness (SF) were measured to the nearest 0.2 mm using skin calipers and standard technique.[2, 21].

Estimating Methods of FM and FFM—Fat mass (kg) and FM% were estimated using the following published equations; Brook, Wendel 2-skinfold (Wendel 2SF) and Wendel 4-skinfold (Wendel 4SF).[12, 22]

Bioelectrical impedance analysis (BIA): A multifrequency bioelectrical impedance device (Bodystat Quadscan 4000®, Bodystat, Inc., Isle of Man, British Isles) was used with subjects in the supine position. Current-injector electrodes were placed just below the phalangeal-metacarpal joint in the middle of the dorsal side of the right hand and below the metatarsal arch on the superior side of the right foot. Detector electrodes were placed on the posterior side of the right wrist, midline to the pisiform bone of the medial side with the wrist semi flexed and between the medial and lateral malleoli on the superior side of the right ankle. Impedance was measured at 5, 50, 100, and 200 kHz. Estimated FFM% was calculated from published BIA based equations represented in Table 3.[13–18, 20]

Reference methods for FM and FFM measurements—Whole body DXA scans were obtained in subjects 5 years and older in the anterior posterior supine position using a Hologic Discovery A (Hologic, Inc) fan beam scanner generating X-rays at 2 energy levels (100 and 70 kV) for studies completed before September 2014 (n = 80) and the Hologic

Horizon A (Hologic, Inc) for studies completed on and after September 2014 (n = 10). The devices use the differential attenuation of the X-ray beam at these two energies to calculate the bone mineral content and soft tissue composition in the scanned region. Using the Hologic Pediatric Upgrade software, data were reported as grams of FM and grams of FFM mass. Percent FM and FFM were calculated using measured total body weight.

Enteral nutrition was held one hour prior to administration of deuterium enriched water (^2H_2O). A baseline pre-deuterium administration urine sample was obtained. A 0.2 grams/kg dose of ^2H_2O, prepared by the Pharmacy Department, was then administered either orally or via gastrostomy. A minimum of 3.5 hours after ^2H_2O administration a post-deuterium urine sample was collected. Isotope enrichment was measured by gas isotope mass spectrometry (Metabolic Solutions, Inc, Nashua, New Hampshire). Total body water was calculated and used to derive FFM as previously published.[2]

Statistical Analyses—Data were tested for normality by the D'Agostino and Pearson test and found to be non-normally distributed.[23] Continuous data are presented as median (interquartile range) and categorical data as frequency (percentage). Estimated FM (kg) by previously published equations and FM (kg) obtained by DXA were examined for correlation and agreement analysis. Estimated FFM (kg) by previously published equations and FFM (kg) measured by DXA and deuterium dilution isotope techniques were examined for correlation and agreement analysis. Spearman's rank correlation coefficient was used to examine for correlation (R and 95% confidence intervals). The Bland-Altman (BA) method was used to examine the agreement (mean bias and 95% limits of agreement) between the 2 methods.[24] Proportional bias in the BA plot was considered significant if the R^2 of the slope of the plotted percent difference versus mean values between the two methods of measuring body composition was >0.7. We decided a priori that R >0.7 would be considered a strong correlation and that clinically acceptable limits of agreement between estimated and measured values would be within ±20%. Some of the subjects had repeated body composition measurements at different time points. To examine the impact of these repeat measurements on the analyses, we examined the correlation and agreement analyses using only the initial measurements, and including all measurements. Statistical significance was set at $P< 0.05$. Statistical analyses were completed using Prism (v 5.04, Graph-Pad Software Inc, La Jolla, California).

Results

The combined cohort included 56 individual patients of whom 55% were male and the median age was 11.6 years (7.4, 16.3). Median weight for age z-score (WAZ), height for age z-score (HAZ), and body mass index z-score (BMIZ) were −0.35 (−1.15, 0.5), −0.82 (−1.7, −0.18), and 0.31 (−0.33, 1.1), respectively. Table 1 summarizes the baseline characteristics of the individual and combined cohorts. The HSCT and IF cohorts were significantly different in median age, (HSCT 13.9 years vs. IF 7.6 years, $p<0.001$). Estimated and measured values of FM% and FFM% for patients in the individual cohorts and for the combined cohort are presented in Table 2.

We identified 90-paired DXA and SF and BIA measurements. Thirty-five encounters had deuterium isotope dilution method in addition to DXA, BIA and SF measurements. Table 3 summarizes the agreement and correlation analyses between the measured and estimated values of FM (kg) and FFM (kg) using these methods. The analyses using only the measurements from the initial time point for each subject and the analyses using all measurements reflected the same trend, and therefore the results of the analyses using all measurements are presented here. Correlation between all estimated FM and FFM values by equations and measured FM and FFM values by DXA, and deuterium isotope dilution method where applicable, revealed a Spearman correlation of >0.7. The limits of agreement for estimated FM by all skinfold equations and measured FM values by DXA; and between estimated FFM by all BIA equations and measured FFM by DXA or deuterium isotope dilution method were greater than the a priori determined range of ±20%. The narrowest limits of agreement in the agreement analysis between estimated and measured FM were for the Wendel 4SF equation and DXA, −46.88% to 28.2%. (Figure C) The narrowest limits of agreement in the agreement analysis between estimated and measured FFM by were for the Deurenberg equation and DXA, −25.49 to 19.96%. (Figure D)

Discussion

In a heterogeneous cohort of children with chronic illness, we report that currently used estimating equations for FM and FFM by noninvasive bedside methods are inaccurate and not reliable. We detected a strong correlation between FM and FFM values derived by estimating equations with values measured by DXA and deuterium dilution method. However, the limits of agreement between the estimated and measured values were at or above +/− 20%, and therefore not clinically acceptable. Based on our findings, currently published equations for FM and FFM by skinfolds and BIA techniques do not provide accurate estimations of these body composition values. New estimating equations for bedside techniques, specifically developed for children with chronic illness are needed to allow reliable trending of body composition in this population.

A variety of pediatric chronic illnesses, including chronic respiratory failure, cerebral palsy, cystic fibrosis and IF impact body composition, particularly alterations in lean body mass.[12, 25, 26] Routine weight, height and BMI trends over time may be unable to detect underlying deterioration of lean mass in these populations. Accurate assessment of body composition is important in children with chronic illness, as it has been associated with poor clinical outcomes.[4, 5, 2728, 29] Characterization of weight as FFM and FM allows assessment of response to nutritional interventions aimed at decreasing FFM loss and improving clinical outcomes.[5, 6]

Reference methods of body composition measurement such as dual X-ray absorptiometry (DXA), isotope dilution, and CT scan, require special instruments, resources and expertise. Hence, these methods have limited applicability in the clinical setting. Portable and relatively noninvasive methods such as BIA and skinfolds are popular and have been employed in a variety of populations and settings. These methods rely on equations to derive FM or FFM from SF thickness or body tissue impedance to electric current using BIA. Many BIA and SF equations have been developed, primarily in healthy children, to estimate

body composition. In our current study, these equations were not in agreement with reference methods, and the accuracy of these equations cannot be assumed in clinical practice.

The Brook FM estimating equation was developed in a small cohort of healthy children and compared with deuterium dilution method with a reported correlation coefficient of 0.98.[30] The Wendel 2SF and 4SF equations were developed with a mixed dataset composed primarily of healthy children, and a small cohort of children with trisomy 21, nephrotic syndrome and celiac disease. The Wendel 2SF and 4SF equations for males and females had a correlation coefficient between 0.85 to 0.92.[12] In our study all SF-based estimating equations had strong correlation coefficients but wide limits of agreement, reducing their clinical applicability. The inaccuracy of SF-based FM estimating equations may be due to inaccurate measurement of SF or invalid equations that were derived from healthy pediatric populations. Accuracy of SF measurements may be influenced by the operator experience/skill, location of the measurement, patient cooperation, and underlying disease.[31–34353610] Lastly, SF measurements may not represent fat distribution accurately, often underestimating visceral fat, which has been associated with clinical outcomes.[37, 38]

BIA is portable, relatively simple to perform, and has a lower risk of error from inter-observer variability. The device is relatively inexpensive and maintenance is not cumbersome. Hence, several equations have been developed using impedance and resistance values from BIA to estimate FFM. In relation to reference methods such as DXA and deuterium isotope dilution method, these equations have correlation coefficients greater than 0.9.[12–20] These equations were derived using body composition data from mostly healthy children from diverse ethnic backgrounds and a wide age range. In our current study, BIA based FFM estimating equations had strong linear correlation with reference methods, but limits of agreement were wider than +/− 20%. Inaccuracies of the BIA-derived body composition values might be due to erroneous measurement of impedance to electric current. Bioelectrical impedance analysis assumes a constant hydration state, therefore altered fluid states can significantly influence the accuracy of impedance measurements.[39] This technique also assumes a symmetric geometry, which can be altered in severely obese patients or possibly patients with contractures or other truncal or extremity deformities.[39, 40]

Our study combined 3 distinct cohorts with prospectively collected body composition data. These cohorts represent children with chronic illnesses in whom body composition was assessed using near identical study procedures. The baseline anthropometric status of our study cohort was comparable with that of previously published studies that included patients with similar diagnoses.[414243] We included 90-paired values to examine the correlation and agreement between estimating and reference methods. We included multiple available and clinically used estimating equations and reference methods. Our study design allowed us to examine the agreement between estimating and measured values in a wide range of ages and clinical diagnoses. A strong correlation between measured body composition from 2 methods reflects at best an association between the two values, but does not provide information as to the accuracy of the estimating method. Mean bias and limits of agreement obtained by the BA method may provide more information regarding the accuracy of the estimating method, however there might be a risk for proportional bias across a wide range

of measured values. Proportional bias was not significant in our cohort, as seen in the BA plot of % difference versus mean value of the two methods of measuring body composition. Limits of agreement may also be affected by sample size and the performance of the reference method. Our results add to the existing literature on comparison between clinically applicable and practical estimating and reference methods that are available to clinicians. [4445] The deuterium dilution method was only completed in 35 patients in 2 of the 3 cohorts. This smaller sample size may have contributed to differences between how estimating equations and DXA versus estimating equations and deuterium dilution method compared in our analyses. The analyses in our current study were also limited by its retrospective nature. Variables that might influence estimating methods, such as fluid status and inflammation were not recorded in the original studies. The agreement between estimated and measured values may be variable between the distinct cohorts that were combined for our study. The numbers in each cohort were too small to make meaningful determination of the impact of disease type on accuracy of estimating methods. The diverse underlying disease processes also did not allow for comparison of disease severity. There were few patients with paired estimated and measured values by isotope dilution.

Most currently available equations to estimate FM and FFM by SF and BIA methods cannot be reliably used at the bedside or in the outpatient clinics during convalescence. New equations, validated in children with chronic illness, are desirable.

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References

1. Martinez EE, Smallwood CD, Bechard LJ, Graham RJ, Mehta NM. Metabolic assessment and individualized nutrition in children dependent on mechanical ventilation at home. The Journal of pediatrics. 2015; 166:350–7. [PubMed: 25444009]
2. Mehta NM, Raphael B, Guteirrez IM, Quinn N, Mitchell PD, Litman HJ, et al. Comparison of body composition assessment methods in pediatric intestinal failure. Journal of pediatric gastroenterology and nutrition. 2014; 59:99–105. [PubMed: 24614122]
3. Mehta NM, Newman H, Tarrant S, Graham RJ. Nutritional Status and Nutrient Intake Challenges in Children With Spinal Muscular Atrophy. Pediatric neurology. 2016; 57:80–3. [PubMed: 26803333]
4. Thomson MA, Quirk P, Swanson CE, Thomas BJ, Holt TL, Francis PJ, et al. Nutritional growth retardation is associated with defective lung growth in cystic fibrosis: a preventable determinant of progressive pulmonary dysfunction. Nutrition. 1995; 11:350–4. [PubMed: 8580575]
5. Martinez EE, Bechard LJ, Smallwood CD, Duggan CP, Graham RJ, Mehta NM. Impact of Individualized Diet Intervention on Body Composition and Respiratory Variables in Children With Respiratory Insufficiency: A Pilot Intervention Study. Pediatric critical care medicine : a journal of the Society of Critical Care Medicine and the World Federation of Pediatric Intensive and Critical Care Societies. 2015; 16:e157–64.
6. Aniwidyaningsih W, Varraso R, Cano N, Pison C. Impact of nutritional status on body functioning in chronic obstructive pulmonary disease and how to intervene. Current opinion in clinical nutrition and metabolic care. 2008; 11:435–42. [PubMed: 18542004]
7. Cano NJ, Roth H, Court-Ortune I, Cynober L, Gerard-Boncompain M, Cuvelier A, et al. Nutritional depletion in patients on long-term oxygen therapy and/or home mechanical ventilation. The European respiratory journal. 2002; 20:30–7. [PubMed: 12166577]

8. Teigen LM, Kuchnia AJ, Mourtzakis M, Earthman CP. The Use of Technology for Estimating Body Composition: Strengths and Weaknesses of Common Modalities in a Clinical Setting. Nutrition in clinical practice : official publication of the American Society for Parenteral and Enteral Nutrition. 2016
9. Zemel BS, Riley EM, Stallings VA. Evaluation of methodology for nutritional assessment in children: anthropometry, body composition, and energy expenditure. Annual review of nutrition. 1997; 17:211–35.
10. Mok E, Letellier G, Cuisset JM, Denjean A, Gottrand F, Hankard R. Assessing change in body composition in children with Duchenne muscular dystrophy: anthropometry and bioelectrical impedance analysis versus dual-energy X-ray absorptiometry. Clinical nutrition. 2010; 29:633–8. [PubMed: 20427103]
11. Ellis KJ. Human body composition: in vivo methods. Physiological reviews. 2000; 80:649–80. [PubMed: 10747204]
12. Wendel D, Weber D, Leonard MB, Magge SN, Kelly A, Stallings VA, et al. Body composition estimation using skinfolds in children with and without health conditions affecting growth and body composition. Annals of human biology. 2016:1–13.
13. Chumlea WC, Guo SS, Kuczmarski RJ, Flegal KM, Johnson CL, Heymsfield SB, et al. Body composition estimates from NHANES III bioelectrical impedance data. International journal of obesity and related metabolic disorders : journal of the International Association for the Study of Obesity. 2002; 26:1596–609.
14. Deurenberg P, van der Kooy K, Leenen R, Weststrate JA, Seidell JC. Sex and age specific prediction formulas for estimating body composition from bioelectrical impedance: a cross-validation study. International journal of obesity. 1991; 15:17–25. [PubMed: 2010255]
15. Houtkooper LB, Going SB, Lohman TG, Roche AF, Van Loan M. Bioelectrical impedance estimation of fat-free body mass in children and youth: a cross-validation study. Journal of applied physiology. 1992; 72:366–73. [PubMed: 1537738]
16. Houtkooper LB, Lohman TG, Going SB, Hall MC. Validity of bioelectric impedance for body composition assessment in children. Journal of applied physiology. 1989; 66:814–21. [PubMed: 2708210]
17. Kushner RF, Schoeller DA, Fjeld CR, Danford L. Is the impedance index (ht2/R) significant in predicting total body water? The American journal of clinical nutrition. 1992; 56:835–9. [PubMed: 1415001]
18. Lewy VD, Danadian K, Arslanian S. Determination of body composition in African-American children: validation of bioelectrical impedence with dual energy X-ray absorptiometry. Journal of pediatric endocrinology & metabolism : JPEM. 1999; 12:443–8. [PubMed: 10821224]
19. Nguyen QD, Fusch G, Armbrust S, Jochum F, Fusch C. Impedance index or standard anthropometric measurements, which is the better variable for predicting fat-free mass in sick children? Acta paediatrica. 2007; 96:869–73. [PubMed: 17537015]
20. Williams J, Wake M, Campbell M. Comparing estimates of body fat in children using published bioelectrical impedance analysis equations. International journal of pediatric obesity : IJPO : an official journal of the International Association for the Study of Obesity. 2007; 2:174–9.
21. Sharma TS, Bechard LJ, Feldman HA, Venick R, Gura K, Gordon CM, et al. Effect of titrated parenteral nutrition on body composition after allogeneic hematopoietic stem cell transplantation in children: a double-blind, randomized, multicenter trial. The American journal of clinical nutrition. 2012; 95:342–51. [PubMed: 22205317]
22. Zemel BS, Riley EM, Stallings VA. Evaluation of methodology for nutritional assessment in children: anthropometry, body composition, and energy expenditure. Annual Reviews in Nutrition. 1997; 17:211–35.
23. D'Agostino RBBA, D'Agostino RB Jr. A suggestion for using powerful and informative tests of normality. Am Stat. 1990; 44:316–21.
24. Altman DGBJ. Measurement in medicine: the analysis of method comparison studies. The Statistician. 1983; 32:307–17.
25. Campanozzi A, Staiano A. Impact of malnutrition on gastrointestinal disorders and gross motor abilities in children with cerebral palsy. Brain & development. 2010; 32:168. [PubMed: 19427751]

26. Sood M, Adams JE, Mughal MZ. Lean body mass in children with cystic fibrosis. Archives of disease in childhood. 2003; 88:836.
27. Pichard C, Kyle UG, Morabia A, Perrier A, Vermeulen B, Unger P. Nutritional assessment: lean body mass depletion at hospital admission is associated with an increased length of stay. The American journal of clinical nutrition. 2004; 79:613–8. [PubMed: 15051605]
28. Kenchaiah S, Evans JC, Levy D, Wilson PW, Benjamin EJ, Larson MG, et al. Obesity and the risk of heart failure. The New England journal of medicine. 2002; 347:305–13. [PubMed: 12151467]
29. Willig TN, Carlier L, Legrand M, Riviere H, Navarro J. Nutritional assessment in Duchenne muscular dystrophy. Developmental medicine and child neurology. 1993; 35:1074–82. [PubMed: 8253288]
30. CGD B. Determination of Body Composition of Children from Skinfold Measurements. Archives of disease in childhood. 1971; 48:182–4.
31. Group WHOMGRS. Reliability of anthropometric measurements in the WHO Multicentre Growth Reference Study. Acta Paediatr Suppl. 2006; 450:38–46. [PubMed: 16817677]
32. Stomfai S, Ahrens W, Bammann K, Kovacs E, Marild S, Michels N, et al. Intra- and inter-observer reliability in anthropometric measurements in children. Int J Obes (Lond). 2011; 35(Suppl 1):S45–51.
33. Vicente-Rodriguez G, Rey-Lopez JP, Mesana MI, Poortvliet E, Ortega FB, Polito A, et al. Reliability and intermethod agreement for body fat assessment among two field and two laboratory methods in adolescents. Obesity. 2012; 20:221–8. [PubMed: 21869760]
34. Leppik A, Jurimae T, Jurimae J. Reproducibility of anthropometric measurements in children: a longitudinal study. Anthropologischer Anzeiger; Bericht uber die biologisch-anthropologische Literatur. 2004; 62:79–91. [PubMed: 15109037]
35. Hume P, Marfell-Jones M. The importance of accurate site location for skinfold measurement. Journal of sports sciences. 2008; 26:1333–40. [PubMed: 18821122]
36. Vegelin AL, Brukx LJ, Waelkens JJ, Van den Broeck J. Influence of knowledge, training and experience of observers on the reliability of anthropometric measurements in children. Annals of human biology. 2003; 30:65–79. [PubMed: 12519655]
37. Pineau JC, Frey A. Comparison of skinfold thickness models with DEXA: impact of visceral adipose tissue. The Journal of sports medicine and physical fitness. 2016; 56:541–5. [PubMed: 25678207]
38. Ishizaki M, Kedoin C, Ueyama H, Maeda Y, Yamashita S, Ando Y. Utility of skinfold thickness measurement in non-ambulatory patients with Duchenne muscular dystrophy. Neuromuscular disorders : NMD. 2017; 27:24–8. [PubMed: 27793470]
39. Chumlea, CSS. Human Body Composition. Heymsfield, SBLT.Wang, Z., Going, SB., editors. United States: Human Kinetics; 2005. p. 79-88.
40. Deurenberg P. Limitations of the bioelectrical impedance method for the assessment of body fat in severe obesity. The American journal of clinical nutrition. 1996; 64:449S–52S. [PubMed: 8780361]
41. Moore GE, Lindenmayer AW, McConchie GA, Ryan MM, Davidson ZE. Describing nutrition in spinal muscular atrophy: A systematic review. Neuromuscular disorders : NMD. 2016; 26:395–404. [PubMed: 27241822]
42. Olieman JF, Penning C, Spoel M, Ijsselstijn H, van den Hoonaard TL, Escher JC, et al. Long-term impact of infantile short bowel syndrome on nutritional status and growth. The British journal of nutrition. 2012; 107:1489–97. [PubMed: 21917192]
43. Bouma S, Peterson M, Gatza E, Choi SW. Nutritional status and weakness following pediatric hematopoietic cell transplantation. Pediatric transplantation. 2016; 20:1125–31. [PubMed: 27770486]
44. Nichols J, Going S, Loftin M, Stewart D, Nowicki E, Pickrel J. Comparison of two bioelectrical impedance analysis instruments for determining body composition in adolescent girls. International journal of body composition research. 2006; 4:153–60. [PubMed: 17607326]
45. Wattanapenpaiboon N, Lukito W, Strauss BJ, Hsu-Hage BH, Wahlqvist ML, Stroud DB. Agreement of skinfold measurement and bioelectrical impedance analysis (BIA) methods with dual energy X-ray absorptiometry (DEXA) in estimating total body fat in Anglo-Celtic

Australians. International journal of obesity and related metabolic disorders : journal of the International Association for the Study of Obesity. 1998; 22:854–60.

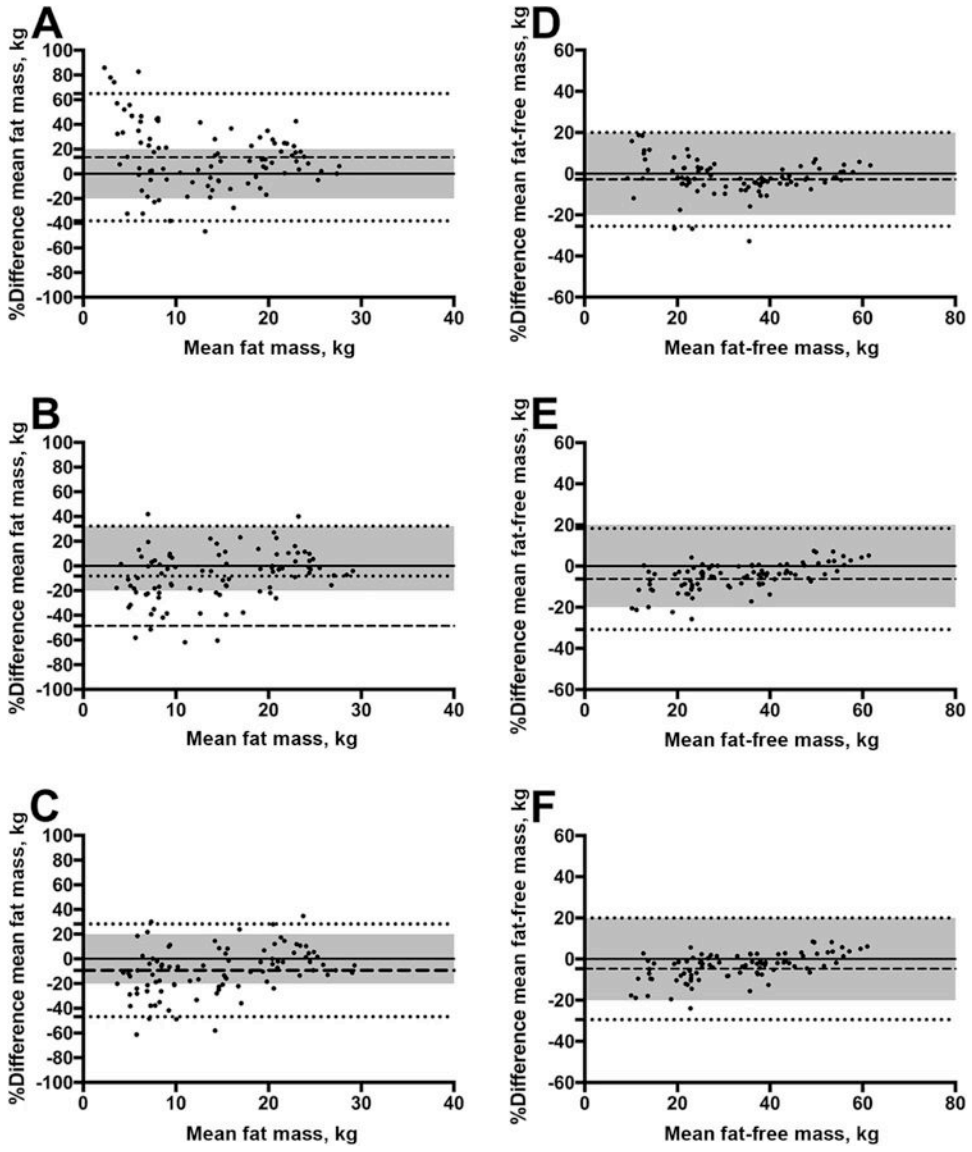

Figure. Bland-Altman Plots- Agreement between Fat Mass (FM) FM and Fat Free Mass (FFM) estimating equations and Dual-Energy X-Ray Absorptiometry (DXA)

Dashed line represents the bias; Dotted lines represent the limits of agreement; Gray band represents the a priori determined clinically applicable +/− 20% limits of agreement

A. FM estimated by the Brook equation versus FM determined by DXA (bias 13.38%, 95% LOA −38.13% to 64.9%); B. FM estimated by the Wendel 2 Skinfold equation versus FM determined by DXA bias −8.25%, 95% LOA −48.61% to 32.12%); C. FM estimated by the Wendel 4 skinfold equation versus FM determined by DXA (bias −9.34%, 95% LOA −46.88% to 28.2%); D. FFM estimated by the Deurenberg equation versus FFM determined by DXA (bias −2.77%, 95% LOA −25.49% to 19.96%); E. FFM estimated by the Houtkooper equation versus FM determined by DXA (bias −6.29%, 95% LOA −30.85% to 18.27%); F. FFM estimated by the Rush equation versus FM determined by DXA (bias −4.77%, 95% LOA −29.46% to 19.93%)

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Table 1

Characteristics of individual and combined cohorts at study enrollment

Characteristics Median (IQR)	SMA (n=10)	IF (n=16)	HSCT (n=30)	Combined cohort (n=56)	P-Value
Age	9.3 (6, 17.7)	7.2 (4.6, 9.8)	13.6 (11.6, 18.4)	11.61 (7.4, 16.3)	<0.0001
Sex (n, % male)	5 (50)	11 (69)	15 (50)	31 (55)	NA
Weight (kg)	34.0 (17.7, 40.7)	19.8 (15.7, 25.6)	59.6 (34.4, 66.9)	35.6 (20.6, 60.8)	<0.0001
WAZ	−1.09 (−2.8, 0.3)	−0.91 (−1.1, −0.34)	0.25 (−0.72, 0.9)	−0.35 (−1.15, 0.5)	0.04
Height (cm)	124.7 (112.2, 153.8)	108.6 (99.3, 122.9)	159.4 (138.3, 165.3)	135.9 (114.9, 160.7)	<0.0001
HAZ	−0.82 (−1.6, −0.34)	−1.49 (−2.4, −0.95)	−0.33 (−1.14, 0.49)	−0.82 (−1.7, −0.18)	0.09
BMI (kg/m^2)	16.2 (15.7, 21.9)	16.55 (15.3, −0.95)	21.5 (17.4, 24.1)	17.76 (16, 23.4)	<0.0001
BMIZ	0.01 (−2, 1)	0.37 (−0.44, 1.1)	0.39 (−0.21, 1.1)	0.31 (−0.33, 1.1)	0.63
MAC (cm)	20 (15.5, 23) *	16 (15, 19)	27 (−0.21, 1.1)	21.5 (16, 28)	<0.0001

* n=9

WAZ- weight for age Z-score; HAZ- height for age z-score; BMIZ- BMI z-score; MAC- Mid-upper Arm Circumference;

SMA- Spinal Muscular Atrophy; IF- intestinal failure; Hematopoietic Stem Cell Transplant.

Table 2

Fat mass percentage by estimating and measuring methods per individual and combined cohort, median (IQR)

Study Variables	SMA	IF	HSCT	Combined cohort
Fat Mass %				
Estimated FM% by skinfold based equations	(N = 9)	(N = 30)	(N = 94)	(N =134)
Brook	31.38 (25.1, 37.1)	21.25 (16.0, 24.6)	26.91 (20, 33.0)	24.57 (18.9, 31.6)
Wendel 2 SF	36.41 (31.8, 42.1)	29.99 (25.5, 32.8)	30.98 (26.6, 36.8)	30.93 (26.5, 35.6)
Wendel 4 SF	36.08 (34.5, 43.6)	29.71 (27.9, 34.8)	31.90 (26.5, 37.1)	32.15 (27.4, 36.8)
Measured FM%	(N = 7)	(N = 10)	(N = 74)	(N = 91)
DXA	48.46 (48.0, 55.3)	22.18 (8.08)	29.07 (22.8, 36.6)	28.82 (22.5, 38.4)
Fat Free Mass %				
Estimated FFM% by BIA based equations	(N = 10)	(N = 29)	(N = 94)	(N = 133)
Deurenberg	62.35 (54.4, 68.6)	68.44 (63.8, 78.2)	70.49 (65.6, 76.9)	69.89 (64.5, 77.0)
Kushner 1	47.61 (43.6, 56.6)	76.18 (72, 86.4)	70.22 (59.5, 78.8)	71.36 (59.1, 79.5)
Kushner 2	50.75 (46.5, 58.8)	76.22 (72.1, 84.2)	69.04 (60, 76.6)	70.41 (60, 77.6)
Houtkooper	62.96 (56, 67.6)	82.01 (78.7, 87.2)	73.84 (66.2, 80.3)	75.92 (66.7, 81.7)
Horlick	69.66 (59.9, 74)	88.49 (84.8, 96.6)	78.53 (66.1, 88.8)	80.85 (69.4, 88.54)
Schaefer	58.74 (51.4, 70.8)	78.31 (74.8, 83.9)	70.7 (59.2, 44.9)	72.84 (60.9, 79.7)
Rush	61.28 (54.7, 66.2)	80.66 (77.4, 86.2)	72.61 (65.1, 79.2)	74.63 (65.6, 80.3)
Measured FFM%				
Deuterium dilution isotope	(N = 7)	(N = 28)	(not done)	(N = 35)
	65.34 (54.6, 66.6)	78.69 (71.3, 85.1)	–	75.21 (66.5, 83.3)
DXA	(N = 7)	(N = 10)	(N = 74)	(N = 91)
	51.54 (44.7, 52)	77.88 (72.5, 80.6)	70.93 (63.4, 77.2)	71.18 (61.6, 77.5)

SMA- spinal muscular atrophy; IF- intestinal failure; HSCT- hematopoietic stem cell transplant; FM- fat mass; SF- skinfold; DXA- dual energy X-ray absorptiometry

Table 3

Correlation and agreement analysis between estimated and measured fat mass and fat free mass in the combined cohort

Comparison Variables	Correlation		Agreement Analysis	
	R	95% Confidence Intervals	Bias	95% Limits of Agreement
Fat Mass (kg) measured by DXA vs estimated by Skinfold based equation-				
Brook	0.93	0.89–0.95	13.38	−38.13 to 64.9
Wendel 2SF	0.93	0.89–0.95	−8.25	−48.61 to 32.12
Wendel 4SF	0.94	0.91–0.96	−9.34	−46.88 to 28.2
Fat Free Mass (kg) measured by DXA vs estimated by BIA based equation-				
Deurenberg	0.97	0.96–0.98	−2.77	−25.49 to 19.96
Houtkooper	0.95	0.93–0.97	−6.29	−30.85 to 18.27
Horlick	0.93	0.90–0.96	−11.3	−38.89 to 16.3
Schaefer	0.92	0.88–0.95	−0.41	−31.01 to 30.19
Rush	0.95	0.93–0.97	−4.77	−29.46 to 19.93
Kushner1	0.93	0.89–0.95	1.14	−29.94 to 32.22
Kushner2	0.94	0.90–0.96	1.5	−26.29 to 29.25
Fat Free Mass (kg) measured by Deuterium dilution isotope technique vs estimated by BIA based equation-				
Deurenberg	0.91	0.82–0.95	6.06	−30.35 to 42.46
Houtkooper	0.90	0.81–0.95	−8.36	−45.67 to 28.95
Horlick	0.90	0.81–0.95	−16.47	−55.11 to 22.17
Schaefer	0.89	0.79–0.95	−3.27	−47.74 to 41.2
Rush	0.90	0.81–0.95	−6.67	−44.75 to 31.4
Kushner 1	0.87	0.75–0.94	0.77	−52.13 to 53.67
Kushner 2	0.89	0.78–0.94	0.74	−46.2 to 23.92

DXA- dual x-ray energy absorptiometry; SF- skinfold; DXA- dual-energy x-ray absorptiometry; BIA- bioelectrical impedance analysis