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ORIGINAL PAPER

Evaluation of lean body mass in obese children

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Abstract Multiple skinfold anthropometry (MSA) and bioelectrical impedance analysis (BIA) are useful as clinically non-invasive, inexpensive and portable techniques, although it is not clear if they can be used interchangeably in the same patient to routinely assess her/his body composition. In order to compare BIA, MSA and DXA in the estimation of lean body mass (LBM) of a pediatric obese population, 103 obese [body mass index (BMI) > 97th percentile] children (median age: 11 years; range: 5.4–16.7 years) underwent nutritional evaluation. After an overnight fast, the subjects' anthropometric measurements were performed by the same investigator: body weight (BW), height, skinfold thickness (four sites); fat body mass (FBM) using Brook or Durnin equations and dual X-ray absorptiometry (DXA). BIA was performed using a bioelectrical impedance analyzer (Analicor-Eugedia, 50 kHz) and Houtkooper's equation to calculate LBM. Linear regression analysis was performed to evaluate the relationship between the prediction of LBM by MSA, DXA and BIA. The differences between the three techniques were analysed using Student's *t*-test for paired observations and the Bland and Altmann method. A considerable lack of agreement was observed between DXA- and BIA-LBM (δ=−4.37 kg LBM; $\delta-2\sigma$=−11.6 kg LBM; $\delta+2\sigma$=+2.8 kg LBM); between DXA- and MSA-LBM (δ=−1.72 kg LBM; $\delta-2\sigma$=−8.2 kg LBM; $\delta+2\sigma$=+4.8 kg LBM) and between BIA- and MSA-LBM (δ=−2.65 kg LBM; $\delta-2\sigma$=−10.5 kg LBM; $\delta+2\sigma$=+5.2 kg LBM). *Conclusion*: In obese children, DXA, BIA and MSA should not be used interchangeably in the assessment of LBM because of an unacceptable lack of agreement between them. The discrepancies between methods increase with the degree of obesity.

Keywords Bioelectrical impedance analysis · Body composition · Children · Dual X-ray absorptiometry · Multiple skinfold anthropometry · Nutrition · Obesity

Abbreviations

BIA	Bioelectrical impedance analysis
BW	Body weight
DXA	Dual X-ray absorptiometry
FBM	Fat body mass
LBM	Lean body mass
MSA	Multiple skinfold anthropometry

Introduction

In vivo estimations of various body compartments, rather than just body weight, are of importance in a variety of clinical and epidemiological situations [8, 24].

The body may be considered as two chemically distinct compartments: fat body mass (FBM) and lean body mass (LBM) [40]. There is increasing interest in LBM because of its relationship to calorie needs [1], physical performance and pharmacokinetics; moreover, such a model (FBM and LBM) is widely used in pediatrics because it provides

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information on the quality of growth, identifying children and adolescents whose health is at risk because of obesity or abnormal body composition secondary to chronic disease or medication use [15, 39].

Several methods are available for assessing body composition [29]; of these, hydro-densitometry, dual X-ray absorptiometry (DXA) and ^{40}K spectrometry are accurate and reproducible but have the disadvantages of being uncomfortable for sick children and expensive and time consuming to carry out as well as requiring extensive training of technicians. Only multiple skinfold anthropometry (MSA) and, more recently, bioelectrical impedance analysis (BIA) are useful as clinically non-invasive, inexpensive and portable techniques [27], although these are less sensitive and less precise than the first-mentioned methods. While MSA is routinely used by nutritionists, several technical sources of error must always be taken into consideration, such as inter- and intra-examiner reproducibility or the compressibility of subcutaneous fat and calibration of skinfold calipers [28]. Conversely, BIA does not require an experienced examiner, is highly reproducible, is completely free of discomfort and requires little subject cooperation. This technique, which estimates total body water, following which the appropriate equations are used to derive LBM and FBM, has been shown to have potential for measuring body composition and may be associated with less inter-observer variation than traditional skinfold thickness measurements.

Validation studies have shown that BIA has a sensitivity and precision that is at the very least highly correlated with conventional MSA in both adults and children [22, 23, 30, 36], suggesting that these two techniques might be used interchangeably to routinely assess body composition. However, very little data are available in the literature on the usefulness of these techniques for the assessment of body compartments in pediatric obese subjects [10, 18, 25].

This study was conducted to compare BIA and MSA as methodologies for estimating LBM of a pediatric obese population, using DXA as the reference method, and to evaluate the agreement between the three techniques with the aim of using them interchangeably.

Population and methods

A total of 103 obese children (59 girls and 44 boys), whose median age was 11 years (range: 5.4–16.7 years), were included in our study. Obesity was defined as body mass index (BMI) > 97th percentile of the reference values for age and gender [33, 34]. Clinical history and physical examination excluded health problems other than obesity.

After an overnight fast, the subjects' anthropometric measurements were performed by the same investigator at the Necker-Enfants Malades outpatient clinic. Height was measured to the nearest 0.5 cm on a standardized wall-mounted height board. Body weight (BW) was determined to the nearest 0.1 kg by a standard physician scale with the child dressed only in light underwear and without shoes. BMI was calculated as weight (in kg) divided by height squared (in m^2). The BMI z-score, calculated using the method and the values in French children reported by Rolland-Cachera et al. [33], have been used to make results comparable across age-groups.

Multiple skinfold anthropometry

Skinfold thickness was determined to the nearest millimeter at the left biceps, triceps, subscapular and suprailiac sites using a Holtain skinfold caliper calibrated to exert a constant pressure of 10 g/mm^2 (Holtain Ltd, Crymych, UK). Triplicate readings were made at each site to improve the accuracy and the reproducibility of the measurements.

The generalized equations of Brook and Durnin and Rahaman (in accordance with different ages) for predicting body density were used in this study [5, 9]. FBM was derived according to Siri equation [40]. LBM was calculated as the difference between BW and FBM.

Bioelectrical Impedance analysis

Impedance was measured, after 10 min of resting, using a bioelectrical impedance analyser (Analycor-2 Eugedia) which applies a 50-kHz oscillating current of 800 μA. The child was first invited to empty his/her bladder and then, in dry underwear, was positioned to lie quietly supine with arms slightly apart from the body; the legs were separated so that the thighs were not touching. A tetrapolar electrode placement was used, with electrodes placed on the dorsal surface of the right hand and foot, at the distal

Table 1 Median values (range) of weight, height, BMI and LBM in the evaluated population

Variables	Boys (n=44)	Girls (n=59)
Age (years)	11.1 (5.8–16.7)	10.6 (5.4–16.2)
Weight (kg)	52.1 (28.9–115.9)	52.7 (25.5–103.2)
Height (m)	1.47 (1.17–1.74)	1.43 (1.06–1.49)
BMI (kg/m^2)	26.9 (20.9–39)	26.6 (21.7–36.5)
BMI z-score	3.52 (2–5.5)	3.88 (2.3–6.1)
LBM MSA (kg)	37.05 (22.3–78.6)	35.3 (17.7–64.6)
LBM DXA (kg)	35.9 (22–71.1)°	33.5 (16.7–68)*
LBM BIA (kg)	38.8 (23–80.8)°	36.8 (18.4–74.8)*

°* $p<0.05$

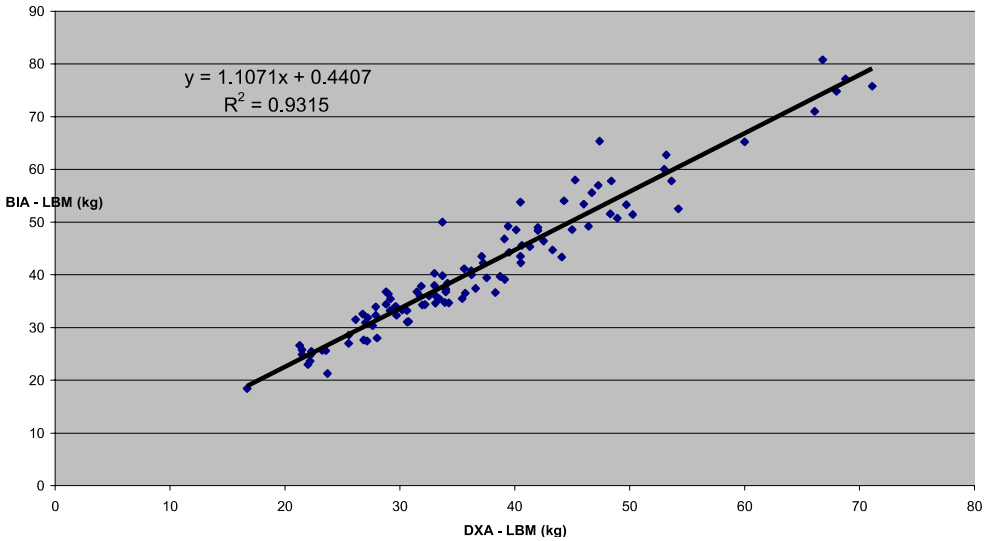

Fig. 1 Linear regression between DXA-LBM and BIA-LBM

metacarpals and metatarsal, respectively, and between the distal prominences of the radius and the ulna at the wrist and the medial and lateral malleoli at the ankle. New electrodes were placed before each reading, and care was taken that the distance between them was at least 3 cm to avoid any possible interaction between electrodes which can cause elevated resistance readings [14, 16].

The average of three resistance readings was recorded for each subject. Houtkooper's equation was used to calculate LBM [21].

Dual X-ray absorptiometry

All of the subjects underwent total body DXA [31, 32] to assess FBM. A Hologic QDR 1000/w model 5.35 was utilized; this apparatus uses a dual-energy source of X-rays that provides alternating pulses of 40 and 100 kV. The radiation dose to each child was 1.5 mrem, which is approximately one-tenth of the exposure from a standard chest X-ray [2]. For each child, the DXA measurement and the BIA and MSA evaluations were carried out the same day and under the same conditions.

LBM was then calculated as the difference between BW and FBM.

All parents gave their informed consent for their child to participate in the study. The study was performed according to the Declaration of Helsinki.

Statistics

Linear regression analysis was performed to evaluate the relationship between the prediction of LBM by DXA, BIA and MSA. The differences between the three techniques were analysed using Student's *t*-test for paired observations.

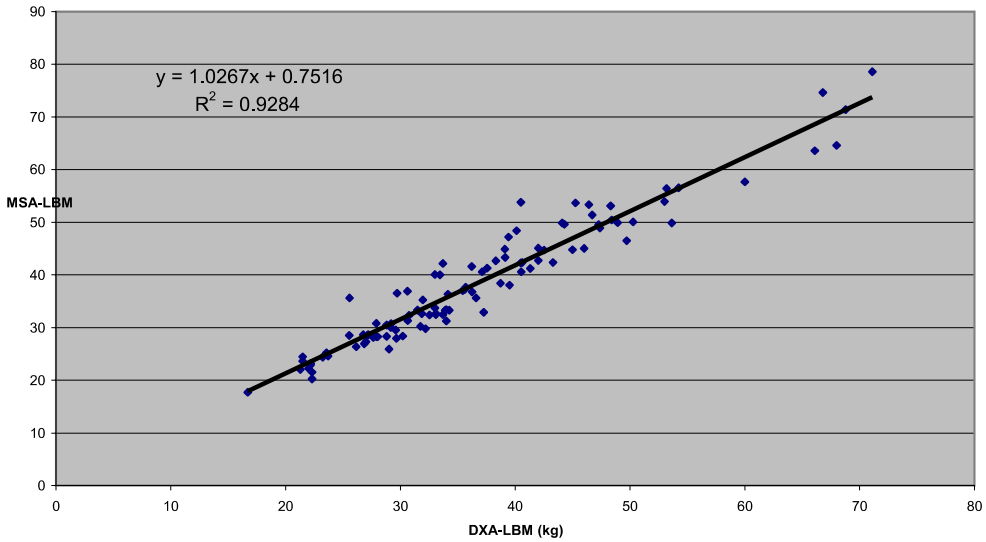

Fig. 2 Linear regression between DXA-LBM and MSA-LBM

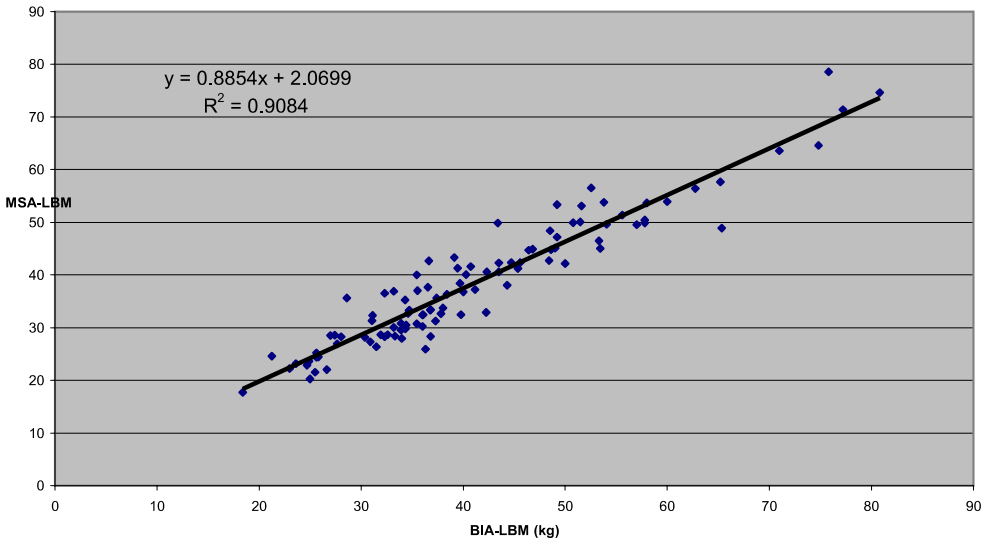

Fig. 3 Linear regression between BIA-LBM and MSA-LBM

Statistical significance was predetermined as p less than 0.05. The Bland and Altman method was used to assess the agreement between DXA, BIA and MSA [3] as it analyses the distribution of differences, for each child, between LBM-assessing methods.

Results

Median values and ranges of weight, height, BMI, BMI z-score and LBM are reported in Table 1.

LBM predicted by DXA was significantly different from that predicted by BIA (BIA-LBM; $p<0.05$). There was no significant difference in the assessment of LBM by DXA and MSA, or by MSA and BIA.

As shown in Figs. 1 and 2, the assessment of LBM by DXA (DXA-LBM) was highly correlated to BIA-LBM ($y=1.1071x + 0.4407$; $r^2=0.9315$; $p<0.05$) and the assessment of LBM by MSA (MSA-LBM) ($y=1.0267x + 0.7516$; $r^2=0.9284$; $p<0.05$). Figure 3 also shows a good correlation between BIA-LBM and MSA-LBM ($y=0.8854x + 2.0699$; $r^2=0.9084$; $p<0.05$).

Discrepancies between the three methods are more clearly expressed in Figs. 4, 5 and 6: according to the Bland and Altman analysis, there is a a considerable lack of agreement between DXA- and BIA-LBM ($\delta=-4.37$ kg LBM; $\delta-2\sigma=-11.6$ kg LBM; $\delta+2\sigma=+28$ kg LBM); between DXA- and MSA-LBM ($\delta=-1.72$ kg LBM; $\delta-2\sigma=-8.2$ kg LBM; $\delta+2\sigma=+4.8$ kg LBM) and between BIA- and MSA-LBM ($\delta=-2.65$ kg LBM; $\delta-2\sigma=-10.5$ kg LBM; $\delta+2\sigma=+5.2$ kg LBM). As shown in Figs. 7 and 8, the discrepancies between methods increase with the degree of obesity.

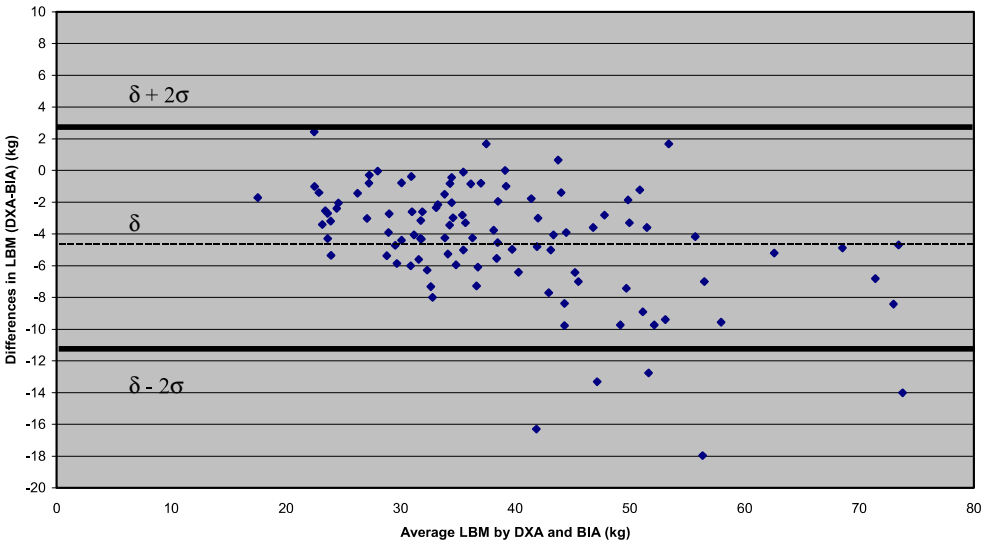

Fig. 4 LBM assessment: limits of agreement between DXA and BIA

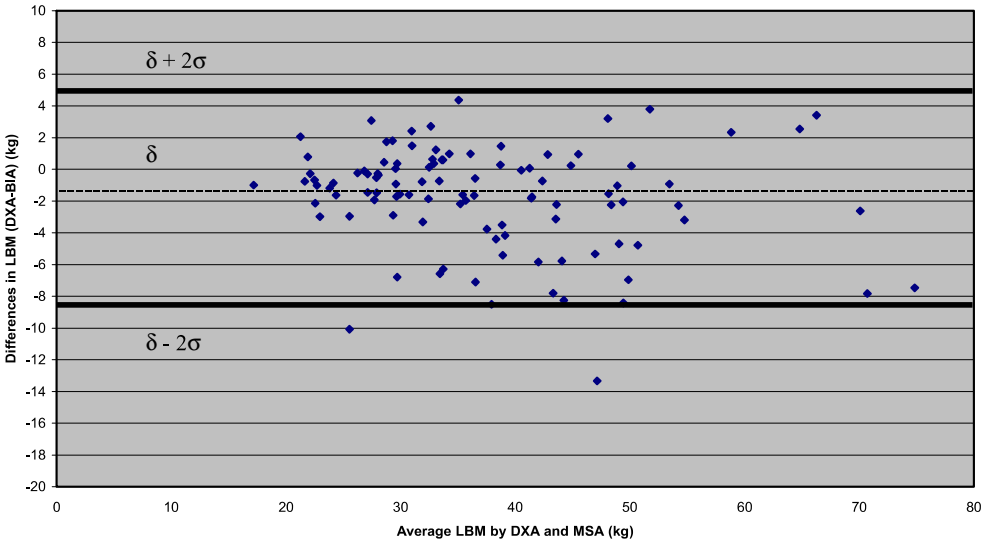

Fig. 5 LBM assessment: limits of agreement between DXA and MSA

Discussion

As expected, this study shows that among the subjects evaluated there is a significant correlation between the assessment of LBM by DXA, BIA and MSA. However, this does not mean that the three methods provide the same values of LBM for each child. Indeed, r^2 measures the strength of a relation between two variables and not the agreement between them [3]. The discrepancies in the different methods of LBM assessment are clearly expressed by the Bland-Altman method, which demonstrates a considerable lack of agreement between DXA and BIA (with discrepancies of up to 11.6 kg), between DXA and MSA (with discrepancies of up to 8.2 kg) and between BIA and MSA (with discrepancies of up to 10.5 kg). Differences between LBM values measured by BIA or MSA, and those measured by DXA are likely to be more striking in subjects with a higher grade of obesity, as measured by the BMI z-score (Figs. 7, 8). All of these differences are not obvious from a linear regression analysis, resulting in an unacceptable lack of agreement between the three methods.

This study was performed on obese children, and the results suggest that in order to better appreciate the longitudinal variations of the body composition of a child, the same assessing technique should always be performed. The replacement of one method by another one during the nutritional follow-up of a subject may lead to an over- or under-estimation of FBM and changes in LBM. As the aim of hypocaloric diets for obese children is to reduce weight without affecting growth velocity, the preservation of LBM should be assessed longitudinally by the appropriate methods. Such methods should give reproducible results and should also be applicable for use by inexperienced examiners to avoid inter-observer differences.

A previous study from our group [6] showed that the discrepancies between BIA- and MSA-LBM may be as

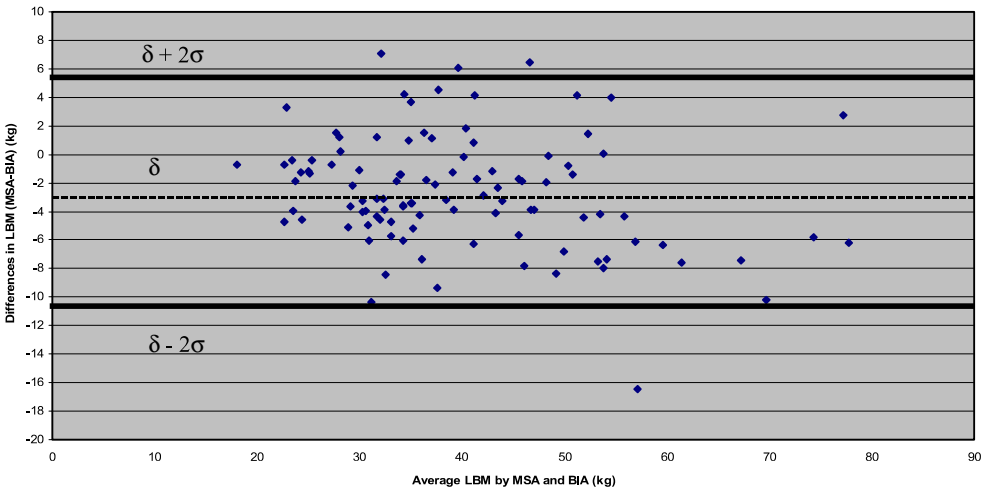

Fig. 6 LBM assessment: limits of agreement between MSA and BIA

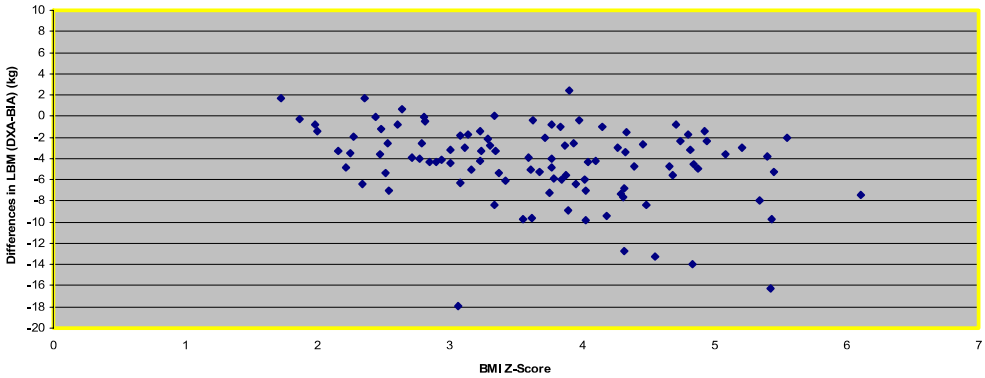

Fig. 7 Agreement between DXA and BIA plotted against BMI z-score

great as 3.9 kg if the two techniques are performed in a population of pediatric subjects without any limitations of race, age, gender, disease or BMI.

MSA is the most utilized technique for the routine estimation of body compartments [27], but its accuracy is limited by practical errors – examiner- and/or patient-related. Indeed, there is a large inter- and intra-observer variance. Moreover, this method is based on the incorrect assumptions that every person presents with the same proportions between subcutaneous and total fat and that there is no inter-individual difference in adipose tissue composition and compressibility [29]. Multiple anthropometric equations have been calculated to estimate body density from multiple skinfold measurements; the prediction equations of Brook [5] and Durnin and Rahaman [9] were used in this study because they have been validated for a pediatric population.

DXA was initially designed for assessing bone mineral mass and may still be considered as a reference method for measuring FBM. LBM can be easily calculated from the difference between total body weight and FBM. For clinical purposes, this technique is a good compromise between cost, reproducibility and precision. In addition, it has been used extensively in pediatric practice and validated for nutritional uses in both adults and children [11–13, 20, 41, 43].

BIA is a new and relatively non-invasive technique [4, 26] which only requires the measurement of the subject's height, weight, electrical resistance and reactance between two pairs of topically placed electrodes using an alternating current, which reduces the influence of skin resistance in the measurement [7]. This method relies on the principle that LBM conducts electrical current, whereas FBM acts as an isolator and conducts little of the current. Its usefulness in estimating body composition is increasing because it presents an excellent intra- and inter-observer reproducibility of estimates [18, 19, 35, 42]. BIA aims to measure both intra-and extra-cellular water, while multiple regression equations predicting LBM have been developed by comparison with reference methods [21, 26, 30, 37]. The Houtkooper's formula was used in the present study because it has been validated for children and adolescents.

Although most of the research on conductivity techniques has focused on their use to assess body composition, it has to be stressed that BIA is not a direct measure of FBM or LBM. LBM is accurately predicted by best-fitting formulas only when there is a fixed relation between the water compartment and LBM; this is not the case in a growing healthy subject, especially if obese. The hydration of LBM, in fact, may increase with increasing fatness from 72.6% to 73.5% [38]. This is the major limitation of BIA, at least in pediatric patients.

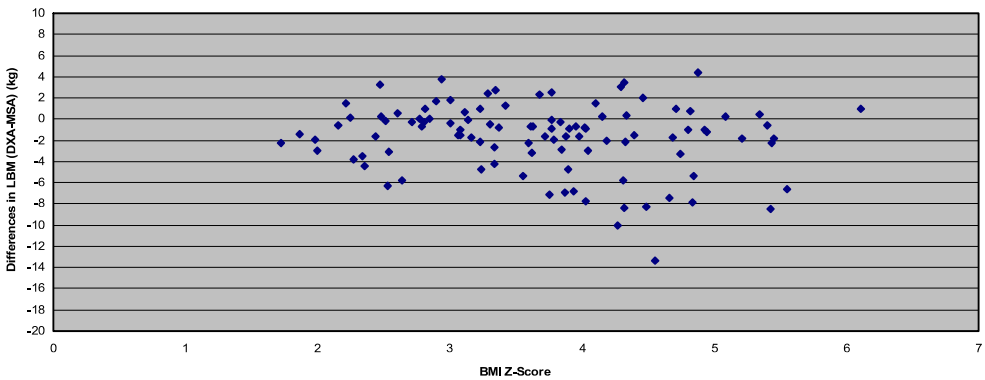

Fig. 8 Agreement between DXA and MSA plotted against BMI z-score

Based on our results, we conclude that DXA, MSA and BIA, although highly correlated, are not interchangeable techniques for assessing body composition in obese children, thereby confirming previous data regarding healthy children [17]. Discrepancies between methods increase with the degree of obesity. In clinical practice one should always use the same technique for studying a given population.

References

1. Bekx MT, Carrel AL, Shriver TC, Li Z, Allen DB (2003) Decreased Energy expenditure is caused by abnormal body composition in infants with Prader-Willi Syndrome. J Pediatr 143:372–376
2. Ben Hariz M, Goulet O, De Potter S, Ruiz, JC, Mandel C, Ricour C (1994) Composition corporelle chez l'enfant en nutrition parentérale prolongée: comparaison entre anthropométrie et absorptiométrie biphotonique. Nutr Clin Metabol 8:71–75
3. Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurements. Lancet 1:307–310
4. Boulier A, Fricker J, Thomasset AL, Apfelbaum M (1990) Fat free mass estimation by the two electrode impedance method. Am J Clin Nutr 52:581–585
5. Brook CGD (1971) Determination of body composition of children from skinfold measurements. Arch Dis Child 46:182–184
6. Campanozzi A, Goulet O, Salomon R, De Potter S, Martin D, Colomb V, Ricour C (1994) Mesure de la composition corporelle chez l' enfant: comparaison de l' impédancemétrie et de l' anthropométrie. Nutr Clin Metabol 8:37
7. Davies PSW, Preece MA (1988) The prediction of total body water using bioelectrical impedance in children and adolescents. Ann Hum Biol 15:237–240
8. Davison KK, Marshall SJ, Birch LL (2006) Cross-sectional and longitudinal associations between TV viewing and girls' body mass index, overweight status, and percentage of body fat. J Pediatr 149:32–37
9. Durnin JVGA, Rahaman MM (1967) The assessment of the amount of fat in the human body from measurements of skinfold thickness. Br J Nutr 21:681–689
10. Elberg J, McDuffie JR, Sebring NG, Salaita C, Keil M, Robotham D, Reynolds JC, Yanovski JA (2004) Comparison of methods to assess change in children's body composition. Am J Clin Nutr 80:64–69
11. Ellis KJ (1997) Body composition of a young multiethnic male population. Am J Clin Nutr 66:1323–1331
12. Ellis KJ, Abrams SA, Wong WW (1997) Body composition of a young multiethnic female population. Am J Clin Nutr 65:724–731
13. Ellis KJ, Shypailors RJ, Pratt JA, Pond WG (1993) Accuracy of DXA based body composition measurements for pedatric studies. Basic Life Sci 60:153–156
14. Field CR, Freundt-Thurne J, Schoeller DA (1990) Total body water measurement by ^{18}O dilution and bioelectrical impedance in well and malnourished children. Pediatr Res 27:98–102
15. Foster BJ, Leonard MB (2004) Measuring nutritional status in children with chronic kidney disease. Am J Clin Nutr 80:801–814
16. Gartner A, Maire B, Delpeuch F (1992) Importance of electrode position in bioelectrical impedance analysis. Am J Clin Nutr 56:1067–1068
17. Gutin B, Litaker M, Islam S, Manos T, Smith C, Treiber F (1996) Body-composition measurement in 9-11-y-old children by dual-energy X- ray absorptiometry, skinfold-thickness measurements, and bioimpedance analysis. Am J Clin Nutr 63:287–292
18. Hetmann BL (1994) Impedance: a valid method in assessment of body composition? Eur J Clin Nutr 48:228–240
19. Heitmann BL (1990) Evaluation of body fat estimated from body mass index, skinfolds and impedance. A comparative study. Eur J Clin Nutr 44:831–837
20. Heysmsfield SB, Wang J, Heshka S, Kehayias JJ, Pierson RN (1989) Dual-photon absorptiometry: comparison of bone mineral and soft tissue mass measurementsin vivo with established methods. Am J Clin Nutr 49:1283–1290
21. Houtkooper LB, Going SB, Lohman TG, Roche AF, Van Loan M (1992) Bioelectrical impedance estimation of fat-free body mass in children and youth: a cross-validation study. J Appl Physiol 72:366–373
22. Houtkooper LB, Lohman TG, Going SB, Hall MC (1989) Validity of bioelectrical impedance for body composition assessment in children. J Appl Physiol 66:814–821
23. Jackson AS, Pollock ML, Graves JE, Mahar MT (1988) Reliability and validity of bioelectrical impedance in determining body composition. J Appl Physiol 64:529–534
24. Kotler DP, Tierney AR, Wang J, Pierson RN Jr (1989) Magnitude of body cell mass depletion and the time of death from wasting in AIDS. Am J Clin Nutr 50:444–447
25. Kushner RF, Kunigk A, Alspaugh M, Andronis PT, Leitch CA, Schoeller DA (1990) Validation of bioelectrical impedance analysis as a measurement of change in body composition in obesity. Am J Clin Nutr 52:219–223
26. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gomez JM, Heitmann BL, Kent-Smith L, Melchior JC, Pirlich M, Scharfetter H, Schols AM, Pichard C; Composition of the ESPEN Working Group (2004) Bioelectrical impedance analysis: review of principles and methods. Clin Nutr 23:1226–1243
27. Lofthouse CM, Azad F, Baildam EM, Acobeng AK (2002) Measuring the nutritional status of children with juvenile idiopathic arthritis using the bioelectrical impedence method. Rheumathology 41:1172–1177
28. Lohman TG (1981) Skinfolds and body density and their relation to body fatness: a review. Hum Biol 53:181–225
29. Lukaski HC (1987) Methods for the assessment of human body composition: traditional and new. Am J Clin Nutr 46:537–556
30. Lukaski H, Bolonchuk W, Hall C, Siders W (1986) Validation of tetrapolar bioelectrical impedance method to assess human body composition. J Appl Physiol 60:1327–1332
31. Mazness RB, Barden HS, Bisek JP, Hanson J (1990) Dual energy X-ray absorptiometry for total-body and regional bone- mineral and soft-tissue composition. Am J Clin Nutr 51:1106–1112
32. Mazness RB, Peppler WW, Gibbons M (1984) Total body composition by dual photon absorptiometry. Am J Clin Nutr 40:834–839
33. Rolland-Cachera MF, Cole TJ, Sempé M, Tichet J, Rossignol C, Charraud A (1991) Body mass index variations: centiles from birth to 87 years. Eur J Clin Nutr 45:13–21
34. Rolland-Cachera MF, Sempé M, Guilloud-Battaille M, Patois E, Pequignot- Guggenbuhl F, Fautrad V (1982) Adiposity indices in children. Am J Clin Nutr 36:178–184
35. Schaffer F, Georgi M, Zieger A, Scharer K (1994) Usefulness of bioelectric impedance and skinfold measurements in predicting fat free mass derived from total body potassium in children. Pediatr Res 35:617–624
36. Segal K, Gutin B, Presta E, Wang J, van Itallie T (1985) Estimation of human body composition by electrical impedance methods: a comparative study. J Appl Physiol 58:1565–1571

37. Segal KR, Van Loan M, Fitzgerald PI, Hodgdon JA, Van Itallie TB (1988) Lean body mass estimation by bioelectrical impedance analysis: a four site cross validation study. Am J Clin Nutr 47:7–14
38. Segal KR, Wang J, Gutin B (1987) Hydration and potassium content of lean body mass: effects of body fat, sex, and age. Am J Clin Nutr 45:865
39. Sentongo TA, Semeao EJ, Piccoli DA, Stallings VA, Zemel BS (2000) Growth body composition and nutritional status in children and adolescents with Crohn's disease. J Pediatr Gastroenterol Nutr 31:33–40
40. Siri WE (1961) Body composition from fluid spaces and density: analysis of methods. In: J. Brozek and A. Hanschels (eds) Techniques for measuring body composition. National Academy of Science, Washington D.C, pp. 223–244
41. Snead D, Kohrt W, Birge S, Holloszy J (1991) Comparison of body composition assessment by hydrodensitometry and dual energy radiography. J Bone Miner Res 6[Suppl]:S172
42. Vettorazzi C, Smits E, Solomons NW (1994) The interobserver reproducibility of bioelectrical impedance analysis measurements in infants and toddlers. J Pediatr Gastrenterol Nutr 19:277–282
43. Wells JCK, Fuller NJ, Dewit O, Fewtrell MS, Elia M, Cole TS (1999) Four compartment model of body composition in children: density and hydration of fat free mass and comparison with simpler methods. Am J Clin Nutr 69:904–912