Measuring body composition and energy expenditure in children with severe neurologic impairment and intellectual disability[1–3]

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ABSTRACT

Background: Accurate prediction equations for estimating body composition and total energy expenditure (TEE) in children with severe neurologic impairment and intellectual disability are currently lacking.

Objective: The objective was to develop group-specific equations to predict body composition by using skinfold-thickness measurements and bioelectrical impedance analysis (BIA) and to predict TEE by using data on mobility, epilepsy, and muscle tone.

Design: Measures of body composition with the use of skinfold-thickness measurements (percentage of body fat) and BIA (total body water) were compared with those from isotope dilution (reference method) by using intraclass correlation coefficients (ICCs) and Bland and Altman limits of agreement analyses. With the use of the same methods, the outcomes of cerebral palsy–specific TEE equations were compared with those of the doubly labeled water method (reference method). Group-specific regression equations were developed by using forward-stepwise-multiple-correlation-regression analyses.

Results: Sixty-one children with a mean ($\pm$SD) age of 10.1 $\pm$ 4.3 y (32 boys) were studied. A new equation based on the sum of 4 skinfold-thickness measurements did not improve agreement ($n = 49$; ICC = 0.61), whereas the newly developed BIA equation—which includes tibia length as an alternative for standing height—did improve agreement ($n = 61$; ICC = 0.96, SEE = 1.7 kg, $R^2 = 0.92$). The newly developed TEE equation, which uses body composition, performed better ($n = 52$; ICC = 0.87, SEE = 180 kcal, $R^2 = 0.77$) than did the equation of Schofield ($n = 52$; ICC = 0.82, SEE = 207 kcal, $R^2 = 0.69$).

Conclusions: Current cerebral palsy–specific equations for measuring body composition and energy expenditure are inaccurate. BIA is more accurate at assessing nutritional status in this population than is the measurement of skinfold thickness. The newly developed TEE equation, which uses body composition, provides a reasonable estimate of energy expenditure in these children despite its variability. *Am J Clin Nutr* doi: 10.3945/ajcn.110.003798.

INTRODUCTION

Both undernutrition and overnutrition are major health concerns in children with severe neurologic impairment and ID[4] (1). However, measuring the nutritional state in these children is challenging. The weight-for-height score is less suitable, because height often cannot be reliably measured because of contractures and scoliosis, so that segmental measures such as knee height and tibia length must be applied (2, 3). Alternatively, body composition may serve to measure the nutritional state of children with neurologic impairments (4). Field methods such as skinfold-thickness measurements and BIA are considered valid when applied in healthy children (5–7) but may be less accurate in children with neurologic impairments (8), because these children have altered growth patterns (9) and fat distribution (10).

A comparable challenge in the care of children with severe neurologic impairment and ID is calculating optimal caloric intake. This should be based on a reliable estimate of energy expenditure. Prediction equations to estimate energy expenditure in children without disabilities were developed by the WHO Committee (11) and by Schofield et al (12). However, these equations, generally based on sex, age, and weight, tend to overestimate energy expenditure in children with severe CP (13–15). The main cause for the lower energy expenditure is thought to be the limited motor activity of these children (4, 16). In earlier research, other factors such as the effect of spasticity (13), muscle tone (16), and epileptic activity (17) have also been considered.

CP-specific equations for calculating body composition with the use of skinfold-thickness measurements developed by Gurka et al (18) and CP-specific equations for calculating energy expenditure developed by Krick et al (16) have not been cross-

validated in a separate sample. Validating is possible by using reference methods such as isotope dilution for measures of body composition and the DLW method for measures of energy expenditure. The aim of this study was to establish the accuracy of these CP-specific prediction equations by comparing their outcomes with their respective reference method in 61 children with neurologic impairment and ID. If validity proved inaccurate, we intended to develop new equations.

SUBJECTS AND METHODS

Subjects and design

The study sample consisted of 61 children with severe neurologic impairment and ID (32 boys and 29 girls) recruited from several children's day care centers in the Netherlands. The parents or legal guardians of the children provided written informed consent. The Dutch Central Committee on Research Involving Human Subjects approved the study protocol (P05.0102C). Recruitment started in March of 2007.

The inclusion criteria were the following: age 2–19 y, proven or estimated IQ <55 y, and a motor impairment, defined as hypertonic or hypotonic generalized CP, or a motor developmental delay to such an extent that the child could at best crawl. The motor impairment had to correspond with GMFCS levels 4 or 5 (19). The GMFCS is a 5-level classification system that describes gross motor function on the basis of self-initiated movement with particular emphasis on sitting, walking, and wheeled mobility. Level 4 means that the child is able to walk with a walking aid for 100 m, and level 5 means that the child is completely nonambulatory. An active infection or an altered water balance (edema or dehydration) at the time of the study were exclusion criteria.

The DLW technique, anthropometric measurements, and BIA were performed at the children's day care centers on the same day. All additional measurements were performed there within 2 wk.

Doubly labeled water technique

Subjects were studied ≥ 3 h after their morning feeding. They received a weighted dose of $^2H_2^{18}O$ (^2H_2O:10%, $H_2^{18}O$:5%; Cambridge Isotope Laboratories, distributed by Buchem BV) of 3 g/kg body wt (20) orally or via a gastrostomy tube. The DLW container was washed out with 50 mL plain tap water, and this volume was also administered. Children with severe oral-motor impairment drank it from a sipping cup with a lid or through a plastic syringe in the corner of the mouth to avoid spillage. Any spilled fluid was caught in the child's preweighed bib, which was then weighed to determine the amount of spillage.

Baseline saliva and urine samples were taken just before administration of the DLW. Five additional samples were collected 1, 5, 8, 11, and 15 d later. Urine samples were collected in diapers with cotton batting pads. Saliva was sampled with a cotton mouth swab for 1 to 2 min and stored in a plastic container (Salivette; Sarstedt). Intake of liquids was not allowed for 30 min before the saliva sampling to avoid dilution of the sample. Enrichment of the isotopes in the samples was measured in quintuplet in a high-temperature conversion elemental analyzer coupled with a Delta XP isotope-ratio mass spectrometer via a Conflo-III Interface (Thermo Fisher). TEE was calculated by using the modified Weir's equation (21) from the measured mean daily carbon dioxide production rate (in mol/d). This equation requires measuring the respiratory quotient. The food quotient most closely approximates the respiratory quotient (22). Individual food quotients were calculated on the basis of a 3-d food questionnaire if available. If not available, the child was assigned the mean food quotient of the study population, which was 0.84. TBW was estimated from the dilution spaces of both isotopes. FFM was derived by using age-related proportions of water in FFM as suggested by Fomon et al (23) and Boileau et al (24). After FFM was subtracted from body weight, the resulting fat mass was expressed as %BF. We published a more detailed technical description of the application of the DLW technique elsewhere (25).

Anthropometric measures

Tibia length was defined as the distance from the medial side of the tibial plateau to the inferior edge of the medial malleolus and was measured to the nearest 0.1 cm with a flexible tape. Weight was measured to the nearest 0.1 kg by using an electronic wheelchair scale (Universal PM 7050; Lopital) or a digital sling scale. Height was measured from crown to heel in triplicate by using a flexible tape measure while the child was in the recumbent position.

Skinfold thickness was measured at 4 sites (triceps, biceps, subscapular, and suprailiacal) with Harpenden skinfold calipers (John Bull). All measurements were made in triplicate to the nearest 0.1 mm by 2 investigators (RR and an experienced anthropometrist). The mean value of the measurements was entered in the analysis. Interobserver error for skinfold-thickness measurements was tested in a separate sample of 12 children (technical error of the measurement <1 mm). Measurements were obtained from the left side of the body. %BF was calculated from 2 skinfolds (triceps and subscapular) by using the equation from Gurka et al (18). Because pubertal state is a component of this equation, secondary sex characteristics (breasts in females and pubic hair in males) were assessed by using the methods of Tanner (26).

Bioelectrical impedance analysis

Bioimpedance was measured at least 4 hours after the last meal using a single-frequency Bio-impedance Analyzer (Akern SRL, Florence, Italy), using the tetrapolar technique. Two electrodes (BIAmed electrodes; Zwaag) were placed on the dorsal side of the hand and 2 on the foot. The child was positioned using the methods described by Veugelers et al (27). Resistance and reactance values were recorded in triplicate, and mean values were calculated. TBW was calculated by using the equation of Pencharz et al (28), which is based on height and resistance.

Energy expenditure

The CP-specific equation by Krick et al (16) estimates TEE by calculating BMR according to Fleisch (29) and accounting for muscle tone, activity, and normal growth. The factor for catch-up growth was omitted to enhance comparability with our data.

To develop an accurate prediction equation to estimate energy expenditure, various variables thought to influence energy expenditure in these children were quantified. Degree of movement

was measured with accelerometers (Actigraph model GT1M; Actigraph) worn for 2 d on the left wrist and ankle and 2 d on the right wrist and ankle to account for any asymmetry. Accelerometer data were imported into Actilife Software (version 2.1.8; Actigraph) as rough counts. In the absence of normative values for this population, degree of movement was roughly categorized into 2: little and high—with a cutoff at the mean if distribution was normal and at the median if distribution was skewed. Mobility was assessed by using the GFMCS developed by Palisano et al (19). Parents stated whether their child had epilepsy by answering a yes or no question. The treating physiotherapist or rehabilitation physician quantified muscle tone of the trunk and the extremities in a standardized, but unvalidated, questionnaire (*see* Table S1 under "Supplemental data" in the online issue). Muscle tone was scored as normotonia, hypotonia, hypertonia, or hypotonic trunk and hypertonic extremities.

Statistical analysis

The results are presented as means ± SDs. Differences in the children's characteristics were tested by using an independent *t* test. The outcomes of the previously established CP-specific equations for body composition and energy expenditure were compared with their corresponding outcomes from the reference method by using ICCs, SEEs, and RMSEs. Agreement was evaluated by using Bland and Altman limits of agreement analysis and was expressed as means ± 2 SDs.

Forward-stepwise-multiple-correlation-regression analysis was used to determine the best predictors of %BF for a skinfold equation, of TBW for a BIA equation, and of TEE for an equation to estimate energy expenditure. Each time, variables were selected with an *F* test; an α of 0.05 served as a cutoff for selection. To create a skinfold equation, the sum of 4 skinfold thicknesses, weight, age, sex, and tibia length were entered into the analysis. To create an equation based on the bioimpedance measurements from BIA, tibia length squared divided by the resistance, reactance, weight, age, and sex were entered. Most BIA equations include a variable of height squared divided by resistance, because the BIA method rests on the principle that bioimpedance of the geometrical system (ie, the body) is dependent on the length of the conductor (ie, body height) and its configuration (30). Tibia length served as a proxy measure for height. To create a new prediction equation for estimating energy expenditure based on this sample, the outcome of Scho-Wt, mobility (GMFCS level), low or high degree of movement, muscle tone, and presence of epilepsy were entered into the analysis. Because the sample was relatively small, we entered the outcome of Scho-Wt as a fixed variable into the analysis because that equation is based on a proven model using a much larger sample size. The Schofield equation with weight and height was purposely not chosen because of the inaccuracies in the measurement of height explained above. A separate, similar model to estimate TEE was added in which TBW, measured by the isotope dilution method, was entered instead of the outcome of the Schofield equation. The other variables were not replaced. To establish whether the latter model was accurate, TBW extracted from the best performing, newly developed model using either skinfold thicknesses or bioimpedance was used to calculate TEE in every child. An ICC of the predicted TEE compared with

measured TEE using the DLW method was calculated. Furthermore, for every model, RSE and RMSE were calculated.

To account for the contribution of each variable to the newly developed equations, partial η^2 was calculated. Partial η^2 describes the proportion of total variation attributable to the factor, partialling out other factors from the total nonerror variation (31).

A bootstrap analysis was performed to provide cross-validation. After cross-validation, the ICC of the predicted value compared with the value of the reference method was calculated. All analyses were performed by using SPSS software (version 18.0, SPSS for Windows; SPSS Inc) and R (version 2.10.1; R Foundation). Finally, scatter plots of all developed models were made comparing the measured outcomes of the reference method with the predicted values of the field methods.

RESULTS

Subject characteristics

Subject characteristics are summarized in **Table 1** for subgroups stratified by sex, presence of gastrostomy, and GMFCS level. TBW was significantly higher in boys than in girls. TBW was also higher in children without gastrostomy than in children with gastrostomy. %BF was significantly higher in children with GMFCS level 5 than in those with GMFCS level 4. TEE was significantly higher in boys than in girls, higher in children without gastrostomy than in children with gastrostomy, and higher in children with GMFCS level 4 than in children with GMFCS level 5. Thirty-four children were prepubescent (Tanner stages 1 or 2), and 27 children were either pubescent (Tanner 3) or postpubescent (Tanner 4 or 5).

Data on muscle tone were collected from 54 of the 61 children. Fifteen children had hypotonia, 20 had hypertonia, and 19 had a hypotonic trunk and hypertonic extremities. Epilepsy was present in 41 of 61 children. Actigraphy succeeded in 52 of 60 children. The movement data were skewed because lower scores predominated; therefore, the median was used to distinguish between a low degree and a high degree of movement. The histogram is shown elsewhere (*see* Figure S1 under "Supplemental data" in the online issue). The movement data reflected that 27 children had a high degree of movement and 25 had a low degree of movement. Data on mobility, muscle tone, epilepsy, and movement were available from 52 children. Effects of these variables on measured TBW and TEE are shown in **Table 2**.

Agreement of the available CP-specific equations with the outcome of the reference method

In 7 of 61 children, either the subscapular or the triceps skinfold-thickness measurement could not be obtained. In 5 other children, none of the 4 skinfold thicknesses could be measured. All 12 children in whom skinfold-thickness measurements failed were fed by gastrostomy tube. Their skinfolds could not be easily separated from the underlying muscle tissue. The DLW test and BIA succeeded in all children.

The Bland and Altman limit of agreement analyses between the outcomes of the Gurka, Pencharz, and Krick equations compared with the outcome of the reference method are presented in

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TABLE 1
General characteristics of the subjects[1]

	Male (n = 32)	Female (n = 29)	P	No gastrostomy (n = 33)	Gastrostomy (n = 28)	P	GMFCS 4 (n = 6)	GMFCS 5 (n = 55)	P
Age (y)	10.5 ± 4.4	9.6 ± 4.3	0.41	10.8 ± 4.4	9.2 ± 4.3	0.17	9.5 ± 4.9	10.1 ± 4.3	0.74
Weight (kg)	32.8 ± 17.2	27.8 ± 11.6	0.19	33.9 ± 16.8	25.2 ± 10.7	0.02	28.5 ± 11.0	30.6 ± 15.3	0.75
Length (cm)	135.4 ± 22.6	128.8 ± 19.1	0.22	137.9 ± 22.4	125.1 ± 18.9	0.02	135.6 ± 23.0	131.9 ± 21.1	0.68
Percentage body fat (%)	35.0 ± 9.7	39.1 ± 11.7	0.15	35.6 ± 10.8	38.4 ± 10.6	0.34	25.4 ± 5.7	38.3 ± 10.5	0.01
TBW (kg)	15.2 ± 6.8	11.9 ± 4.4	0.03	15.4 ± 6.6	10.9 ± 3.8	0.00	15.5 ± 6.4	13.4 ± 5.9	0.41
TEE (kcal)	1267 ± 445	1029 ± 372	0.03	1282 ± 404	946 ± 338	0.00	1619 ± 417	1103 ± 398	0.00

[1] All values are means ± SDs. Measures of body composition and energy expenditure were taken from the reference method. GMFCS, Gross Motor Function Classification System; TBW, total body water; TEE, total energy expenditure.

Table 3. The corresponding Bland and Altman plots are presented elsewhere (*see* Figure S2 under "Supplemental data" in the online issue). Individual variance explained and ICCs of the comparisons are described in Table 3.

On average, %BF was overestimated by using the equation by Gurka et al (18); TEE was overestimated by using the equation by Krick et al (16). TBW was underestimated by using the equation of Pencharz et al (28).

Development of prediction equations based on current body-composition data

To predict %BF from skinfold thicknesses, the sum of 4 skinfolds was the only variable selected in the stepwise-multiple-correlation-regression analysis. Weight, age, sex, and tibia length did not add to the amount of variation explained in %BF determined by using the reference method. This generated the following equation:

$$\%BF \text{ (skinfold thickness)} = 18.9 + 0.63 \times \text{(sum of 4 skinfold thicknesses)} \quad (1)$$

where the sum of 4 skinfold thicknesses is expressed in mm.

To predict TBW with the use of bioimpedance, tibia length squared divided by the resistance and weight were selected by the stepwise-multiple-correlation-regression analysis and entered into the linear regression analysis. These variables were both significant predictors of TBW. Reactance, age, sex, and pubertal status were not statistically significant. The resulting equation was as follows:

$$\text{TBW (BIA)} = 2.09 + 5.44 \times \text{(tibia length)}^2/\text{Rz} + (0.19 \times \text{weight}) \quad (2)$$

where TBW is in kg, tibia length is in cm, resistance (Rz) is in Ω, and weight is in kg.

The individual variance explained and ICC between measured and predicted outcomes of both models are shown in Table 3. The BIA model also contains an ICC between measured and predicted outcomes after cross-validation, the RSE and the RMSE.

Development of a prediction equation based on energy expenditure data

In the model using the Schofield equation to predict TEE, the outcomes of Scho-Wt, movement category (high or low), and

GMFCS level were selected in the stepwise-multiple-correlation-regression analysis. Presence of epilepsy and muscle tone did not add to the amount of variation explained in energy expenditure measured by the DLW method.

In **Table 4**, Scho-Wt is presented. To calculate TEE for a child that has a GMFCS score of 5 plus a low degree of movement, 280 kcal should be subtracted from the outcome of the basic TEE equation. In case of a high degree of movement, 222 kcal should be added. If the GMFCS score is 4 instead of 5, 431 kcal should be added.

In the model using TBW from the reference method to predict TEE, TBW, movement category, and GMFCS were also selected. Table 4 contains the same basic equation now containing TBW. The general correction has to be applied in every child. The additional corrections are only applied if a child has GMFCS level 4 or moves around a lot.

Explained variance (R^2), ICC between predicted and measured outcomes, RSE, and RMSE are provided in Table 3. The model containing TBW seems to predict energy expenditure better (ICC after cross-validation = 0.85; RMSE = 188 kcal) than does the model using the Schofield equation (ICC after cross-validation = 0.79; RSE = 214 kcal). When TBW from the newly developed BIA equation is applied in the energy expenditure model containing the TBW variable, ICC between measured TEE using the DLW method and outcome of the EE equation using TBW is 0.83.

To account for the contribution of each variable to the newly developed equations, partial η^2 was calculated. The outcomes of these analyses are presented in **Table 5**. Of note is that the

TABLE 2
Data on variables influencing energy expenditure[1]

	TBW	TEE
	kg	*kcal*
Muscle tone (n = 54)		
Hypertonic (n = 20)	12.7 ± 4.8	1082 ± 336
Hypotonic (n = 15)	12.2 ± 4.6	1061 ± 354
Mixed tone (n = 19)	14.5 ± 6.3	1178 ± 430
Movement (n = 52)		
Low movement (n = 25)	14.9 ± 5.8	1091 ± 376
High movement (n = 27)	11.7 ± 5.0	1145 ± 450
Epilepsy (n = 61)		
Present (n = 41)	12.8 ± 4.8	1087 ± 393
Not present (n = 20)	15.4 ± 7.8	1301 ± 467

[1] All values are means ± SDs. TBW, total body water; TEE, total energy expenditure.

TABLE 3
Comparison between the cerebral palsy–specific equations and the newly developed equations from the current study[1]

Equation	Mean difference[2] ± 2 SD	R^2	ICC[3]	ICC[4]	SEE/RSE	RMSE
Skinfold-thickness measurement (%BF)						
Gurka et al (18) ($n = 54$)	−9.2 ± 16.7	0.27	0.51	—	5.1	5.1
Newly developed equation ($n = 49$)	—	0.44	0.59	—	7.6	7.6
BIA (TBW in kg)						
Pencharz et al (28) ($n = 61$)	2.6 ± 4.4	0.88	0.94	—	2.2	2.2
Newly developed equation ($n = 61$)	—	0.92	0.96	0.95	1.7	1.8
Total energy expenditure (kcal)						
Krick et al (16) ($n = 54$)	179 ± 596	0.45	0.66	—	252	252
Newly developed equation based on Schofield's equation (12) ($n = 52$)	—	0.69	0.82	0.79	207	214
Newly developed equation using TBW from reference ($n = 52$)	—	0.77	0.87	0.85	180	188

[1] %BF, percentage of body fat; BIA, bioelectrical impedance analysis; ICC, intraclass correlation coefficient; RMSE, root mean squared error; RSE, residual SE; TBW, total body water.
[2] Mean difference calculated as the value determined with the outcome field method minus that determined with the reference method.
[3] Before cross-validation.
[4] After cross-validation.

contribution of both variables to the BIA equation is comparable. In addition, the contribution of TBW to the newly developed TEE equation using body composition is somewhat larger than the Schofield variable in the TEE equation using the Schofield equation. Scatter plots of the measured outcome compared with the predicted outcome using the new models are presented in **Figure 1**.

DISCUSSION

This study showed that current prediction equations for assessing body composition and energy expenditure are inaccurate in children with severe neurologic impairment and ID. Whereas a new equation based on skinfold-thickness measurements did not improve the predictability, the newly developed BIA equation did and had very acceptable limits of agreement. In addition, it incorporates a segmental measure (tibia length) rather than standing height, which was not readily measurable in this population because of contractures and scoliosis. In estimating energy expenditure, the newly developed equation that builds on TBW measurements is a better predictor of energy expenditure

than is a model containing the Schofield equation. Our results even show that TBW, calculated by the BIA equation, can be applied to estimate energy expenditure with the use of the TEE equation without greatly diminishing the accuracy of the latter equation.

Isotope dilution

Several other studies on children and adults with CP have compared outcomes of measurements of body composition with those of isotope-dilution methods (4, 10, 15, 32, 33). One possible limitation of the isotope-dilution method is that it relies on accurate estimates of the water content of FFM of the subject, ie, the hydration factor. Whereas the hydration factor of adults is constant at 0.732, it may be higher in young children and decrease with age (23, 24). The applicability of these reported hydration factors in children with CP has been debated (10, 32), but these observations remain to be fully verified. Because children with overt dehydration and edema were excluded from our study, we are confident that the outcomes of the isotope-dilution method accurately reflect true body composition.

TABLE 4
Newly developed equations based on Schofield's equation and based on total body water (TBW) measurements ($n = 52$)[1]

	Model with Schofield equation	Model using TBW from DLW method
Age 3–9 y		
M	BMR = (0.095 × weight, in kg) + 2.110	
F	BMR = (0.085 × weight, in kg) + 2.033	
Age 10–18 y		
M	BMR = (0.074 × weight, in kg) + 2.754	
F	BMR = (0.056 × weight, in kg) + 2.898	
Equation for TEE (kcal)	1.1 × BMR × 238.8	60.7 × TBW (kg)
Additional corrections		
General correction	−280 kcal	+175 kcal
High degree of movement	+ 222 kcal	+344 kcal
GMFCS level 4	+ 431 kcal	+194 kcal

[1] BMR, basal metabolic rate (in mJ); DLW, doubly labeled water; GMFCS, Gross Motor Function Classification System; TEE, total energy expenditure.

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TABLE 5
Partial η^2 per variable[1]

Model	Partial η^2
BIA equation ($n = 61$)	
Tibia length^2/Rz	0.46
Weight	0.42
TEE equation using Schofield ($n = 52$)	
BMR from Schofield equation	0.66
GMFCS level 4	0.26
High level of movement	0.20
TEE equation using TBW ($n = 52$)	
TBW	0.74
GMFCS level 4	0.23
High level of movement	0.21

[1] BIA, bioelectrical impedance analysis; BMR, basal metabolic rate; GMFCS, Gross Motor Function Classification System; Rz, resistance from BIA measurement; TBW, total body water; TEE, total energy expenditure.

Body composition

Gurka's CP-specific equation (18) approximated the outcome of the reference method with a mean difference of 9.2%, but with fairly wide limits of agreement. The explanation is probably that this study included a very homogenous population without serious other comorbidity. Whereas their results are certainly generalizable to a sizable population of children with CP, they do not seem applicable to children with severe CP and intellectual disability.

Skinfold thickness predicts %BF poorly in this sample, probably because these children's fat distribution is altered, as proposed by van den Berg-Emons et al (10). Children with CP may have relatively more intraabdominal fat rather than sub-cutaneous fat compared with their nonhandicapped peers. In addition, Gurka et al (18) also reported that their equation performed less well in children with a higher %BF. Because our sample consisted mostly of children with very high %BF, this most likely explained the poor performance of predicting %BF with skinfold-thickness measurements. The reason for these high %BF values might be that FFM is relatively low because many of these children have wasted muscles (34) and reduced bone mass (35) as a result of their immobility. In addition to issues on its validity, measuring skinfold thickness is also less feasible because in 12 of 61 children, not all of required skinfold thicknesses could be obtained.

The fact that the equation based on bioimpedance performed better at predicting body composition than did skinfold-thickness measurements is surprising, because the reliability of bio-impedance measured by BIA is influenced by many factors: symmetrical body position, hydration status, consumption of food and beverages, ambient air and skin temperature, recent physical activity, and muscle tone (27, 30). As described above, we took these factors into account to the best of our ability. However, these prerequisites to a reliable recording might well affect its suitability in clinical practice.

Because measuring stature in children with contractures and scoliosis is often not possible, we entered tibia length instead of standing height into the multiple regression model. Accurate measurement of body height is important because a 2.5-cm over- or underestimation can result in a 1.0-L error in the estimation of TBW (30). This could explain why the equation by Pencharz et al
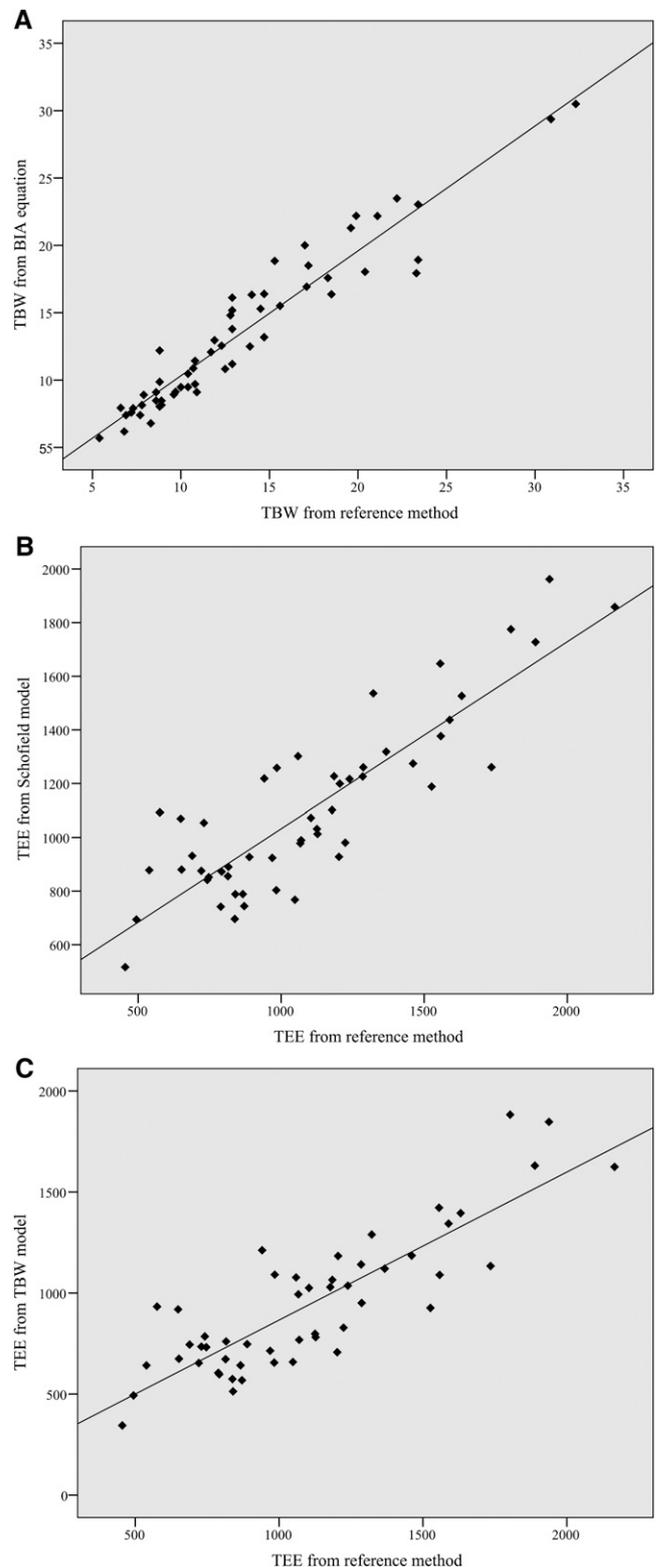

FIGURE 1. Scatter plots of the comparisons between the outcome of the newly developed equation to estimate total body water (TBW) by using bioimpedance analysis (BIA) measurements (A) and to estimate total energy expenditure (TEE) by using the outcome of the Schofield equation (B) and TBW measurements (C) by comparing them with the corresponding outcome of the reference method.

(28), which includes standing height, predicted TBW less well than did the equation using tibia length from the current data. Including tibia length in the equation rather than recumbent height increases feasibility and, on the basis of our results, also leads to a more accurate outcome. BIA probably performs better because it provides accurate estimates of body composition irrespective of where the fat is located, whereas skinfold-thickness measurements rely on assessing subcutaneous fat and ignore variations in intraabdominal fat.

Energy expenditure

The CP-specific equation by Krick et al (16) was not developed with the use of any objective measurement of energy expenditure, but was instead based on a comparison of its outcome with the diet prescription for these children on discharge. Besides this methodologic shortcoming, this equation overestimated energy expenditure with wide limits of agreement in the current study.

We developed 2 models to estimate energy expenditure, one containing TBW and another using the Schofield equation—a proven and valid model based on data from 2359 children aged 3–18 y. The first probably approaches the biology of these children best, because FFM accounts for 45% to 88% of REE (36). As mentioned earlier, FFM is reduced in children with neurologic impairments, which hampers the applicability of the model using the Schofield equation, which was developed in children with normal muscle and bone mass. Not surprisingly, the model containing TBW performed best (RSE = 180 kcal), even after cross-validation. In contrast, Schofield et al (12) found RSEs ranging from 67 kcal in young children to 111 kcal in adolescents. The higher SE of our data can be explained by the heterogeneity of our population, with its wide age range and relatively small sample size. Fortunately, the ICC was still high after TBW was applied, which was calculated by using the BIA equation, in the TEE model containing body composition. Therefore, the accuracy of estimating EE is not greatly reduced.

Conclusions

This study represents a new step in providing evidence of a valid and easily applied nutritional assessment technique, ie, BIA. On the basis of our results on validity and feasibility, we advise against the use of skinfold thickness to measure body composition in children with severe neurologic impairment and ID. To the best of our knowledge, this is also the first study to develop an equation specifically engineered for the target population based on an objective measurement of energy expenditure. Although the model containing body composition performed best, the model using the Schofield equation might be better applicable in practice, because not every professional has a BIA machine. Whereas agreement of the newly developed equations for body composition and energy expenditure is reasonable, it would be beneficial to cross-validate these equations in a comparable group of children with severe neurologic impairment. It would also be interesting to apply the currently developed equations in children who are considered malnourished based on TBW from bioimpedance data, then prescribe a diet based on calculated energy expenditure by using the new equation, and evaluate in a longitudinal design whether this diet improves weight and health status.

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