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BMI does not capture the high fat mass index and low fat-free mass index in children with cerebral palsy and proposed statistical models that improve this accuracy

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Abstract

Background/Objectives: Children with cerebral palsy (CP) are at risk for having a misclassified overweight/obesity status based on BMI thresholds due to their lower fat-free mass and similar fat mass compared to typically developing children. The primary objective was to determine if BMI could predict fat mass index (FMI) and fat-free mass index (FFMI) in children with CP.

Subjects/Methods: Forty-two children with CP and 42 typically developing children matched to children with CP for age and sex participated in the study. Dual-energy x-ray absorptiometry was used to assess body composition. Childrenwith CP who could ambulate without assistance were considered ambulatory (ACP) and the rest were considered nonambulatory (NACP).

Results: Children with CP had higher percent body fat (%Fat) and FMI and lower fat-free mass and FFMI than controls ($p < 0.05$) but no difference in fat mass ($p = 0.10$). When BMI wasstatistically controlled, NACP had higher %Fat, fat mass and FMI and lower FFMI than ACP and controls ($p < 0.05$). NACP also had lower fat-free mass than controls ($p < 0.05$). ACP had higher %Fat and FMI and lower fat-free mass and FFMI than controls ($p < 0.05$). BMIwas a strong predictor of FMI ($r^2 = 0.83$) and a moderately-strongpredictor of FFMI ($r^2 = 0.49$) in children with CP (both $p < 0.01$). Prediction of FMI ($R^2 = 0.86$) and FFMI ($R^2 = 0.66$) from BMI increased ($p < 0.05$) whenage, sex and ambulatory status were included.

Conclusion: Compared to typically developing children, children with CP have a higher FMI and lower FFMI for a given BMI which is more pronounced in NACP than ACP. The finding

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Conflict of Interest

All authors declare no conflict of interest.

suggests that the prevalence of overweight/obesity status may be underestimated in children with CP.

Keywords

cerebral palsy; BMI; fat mass index; fat-free mass index; body composition

INTRODUCTION

Body composition is very important in the assessment of nutritional status because of the alarming rise in childhood obesity[1] and the strong relationship between the level of body fat and chronic disease risk[2] and cardiovascular mortality.[3] Body mass index (BMI) is commonly used to assess obesity status and is a strong predictor of fat mass in typically developing children.[4] Unfortunately, BMI only serves as a proxy of total body fat because it does not distinguish between fat and fat-free components of the body. Percent body fat (%Fat), which is determined by dividing fat mass by total body mass, is a better marker of relative adiposity and disease risk than BMI because the fat and fat-free components of the body are measured. However, %Fat is limited because it may be driven by variationsin fat mass, fat-free mass or both. Therefore, the use of BMI and %Fat in classifying overweight/obesity status is questionable in populations with altered body composition.

Children with cerebral palsy (CP) are at an increased risk for having a misclassified overweight/obesity status based on BMI and %Fat because of their lower fat-free mass,[5–7] but similar fat mass[5, 8, 9] compared to typically developing children. BMI-based thresholds suggest the prevalence of obesity in children with mild-to-moderate CP[10] is similar to[1] or slightly lower than[11] the general population ofchildren and that ambulatory children with CP have a greater likelihood of being overweight/obese than children with CP with greater levels of motor impairment.[10, 12] It is possible that these findings are driven by the greater musculoskeletal deficits seen in nonambulatory than ambulatory children with CP[13–15] rather than lower accretion of fat. Therefore, BMI may not be capturing the true level of adiposity and leanness in children with CP, which may be further complicated by ambulatory status.

In an attempt to remedy the limitations of BMI and %Fat in the assessment of body composition in children,[16] fat mass index (FMI) and fat-free mass index (FFMI) have been proposed.[17–19] The advantage of FMI and FFMI over BMI and %Fat is that they distinguish between fat and fat-free mass, are relative to the individual’s height rather than body mass and they are not influenced by variation of fat-free mass or fat mass, respectively. However, to get an accurate assessment of FMI and FFMI, methods that are expensive, require extensive training and/or expose participants to ionizing radiation must be performed. The primary objective of the current study was to determine whether BMI can accurately estimate FMI and FFMI in children with CP. It was hypothesized that 1) BMI would correlate with FMI and FFMI but would underestimate FMI and overestimate FFMI in children with CP, and 2) these discrepancies would be more pronounced in nonambulatory thanambulatory children with CP. The secondary objective of this study was to create

statistical models to estimate FMI and FFMI based on BMI and other easily obtained characteristics.

SUBJECTS AND METHODS

Subjects and study design

Forty-two children with CP and 73 typically developing children (controls), some of whom had participated in previous studies,[20, 21] were included in this cross-sectional study. Normative graphs published by the Centers for Disease Control and Prevention[22] were used to determine age- and sex-basedpercentiles of height, body mass and BMI. Of the 73 controls, 42 that were between the 5th and 95th percentile for height, body mass and BMI and matched to a child with CP for age (± 1.5 y), sex and race were included in this study. All matched participants were between 4 and 12 years of age. The study wasapproved by the Institutional Review Board. Consent and assent were obtained from parents/guardians and participants, respectively.

Anthropometrics

Height and body mass were measured while children wore minimal clothing and were without shoes or braces. For ambulatory children with CP and controls, height was measured in an erect standing position using a stadiometer to the nearest 0.1 cm. For nonambulatory children with CP, total body height was estimated from knee height using a caliper (Ross Knee Height Caliper, MedHelp, San Francisco, CA) and the equation by Stevenson et al.[23] Total body height of nonambulatory children with CP was also estimated using forearm length, as described by Miller et al.[24] Body mass of all children was determined using a digital scale (Detecto 6550, Cardinal Scale, Webb City, MO)to the nearest 0.1 kg.

Gross motor function

A physician assistant assessed the gross motor function of children with CP using the Gross Motor Function Classification System (GMFCS).[25] This scale ranges fromI to V with I and II reflecting gross motor independence, such as walking and running, but with limited ability of speed, balance and coordination, III reflecting the use of assistive walking devices and IV and V reflecting wheelchair empowered mobility. In the current study, children with CP who could ambulate without an assistive device (i.e., GMFCS of I and II) were considered ambulatory and children with CP who could only ambulate with an assistive device (i.e., GMFCS III) or could not ambulate (i.e., GMFCS IV and V) were considered nonambulatory.

Body composition

Fat mass and fat-free mass were determined using a total body scan and dual-energy X-ray absorptiometry (DXA; Discovery W, Pediatric Whole Body Analysis; Hologic Inc., Bedford, MA). To limit motion during the scan, children with CP were secured from the waist down using the BodyFIX (Medical Intelligence Inc, Schwabmunchen,Germany) and a modified procedure, as previously described.[21] The modified BodyFIX procedure has no effect on body composition estimates from DXA in children.[20]

After completion of the scan, total body (excluding the head) FMI and FFMI were determined by dividing tissue mass (kg) by height (m) squared as follows:

$$\text{FMI} = \text{fat mass (kg)} / \text{height (m)}^2$$

$$\text{FFMI} = \text{fat-free mass (kg)} / \text{height (m)}^2$$

Repeat testing of body composition estimates using DXA conducted previously in 20 children (5–14 y) yielded intraclass correlation coefficients > 0.99 and coefficients of variation < 1 %.[20]

Statistical analysis

Data were analyzed using SPSS version 24.0 (IBM Corp, Armonk, NY). Height, height percentile, BMI, FMI and FFMI were determined using standing height for ambulatory children with CP and controls and height estimated from knee height (and forearm length) in nonambulatory children with CP. All variables were checked for normality by examining skewness, kurtosis and the Shapiro-Wilk test. Group differences between children with CP and controls were determined using an independent *t* test if the data were normally distributed and a Mann-Whitney *U* test if the data were non-normally distributed. Subgroup differences among nonambulatory children with CP, ambulatory children with CP and controls were determined by ANOVA if the data were normally distributed and by the Kruskal-Wallis test if the data were non-normally distributed, and ANCOVA using BMI as a covariate. Bonferroni post hoc tests were conducted if the variances were equal or Games-Howell post hoc tests if the variances were unequal. One sample t-tests were used to determine whether the BMI percentile was different from the 50th age- and sex-based percentile in the controls and in the children with CP. Values are presented as mean ± SD unless stated otherwise. Alpha level was set at 0.05. All tests were two-tailed. The magnitude of the effects were determined using Cohen's d (*d*), with 0.2, 0.5 and 0.8 representing small, moderate and large effect sizes, respectively.[26]

Bivariate linear regression was used to determine the relationship between BMI and FMI and between BMI and FFMI. The interactions between BMI and FMI and between BMI and FFMI were assessed between groups. Multiple linear regression was used to determine the amount of variance of FMI and FFMI explained by BMI, age, sex and a dichotomous variable for ambulatory status for children with CP (i.e., ambulatory or nonambulatory). All independent predictors (i.e., BMI, age, sex and ambulatory status) were examined for interactions and if they there were not significant contributors, they were removed from the final model. The same set of analyses were performed using forearm length to estimate height for BMI, FMI and FFMI in nonambulatory children with CP. The reason separate statistical models were created using knee height and forearm length to estimate total body height in nonambulatory children with CP is because both approaches are commonly used to estimate height in this group of children.[23, 24] We wanted our statistical models estimating FMI and FFMI to be applicable to as many scientists as possible. The resulting models using

total body height estimated from knee height for nonambulatory children with CP were cross-validated in children with CP using the leave-one-out method.[27]

RESULTS

Physical characteristics of study participants

The physical characteristics of children with CP and their 42 matched controls are shown in **Table 1**. Compared to controls, children with CP had lower height ($d = 0.649$, $p = 0.004$), height percentile ($d = 1.291$, $p < 0.001$) and body mass percentile ($d = 0.820$, $p < 0.001$). There were no group differences in age ($d = 0.054$, $p = 0.806$), body mass ($d = 0.350$, $p = 0.115$), BMI ($d = 0.127$, $p = 0.767$) or BMI percentile ($d = 0.083$, $p = 0.578$). When children with CP were separated based on ambulatory status, compared to controls, nonambulatory children with CP had lower height percentile ($d = 1.484$, $p < 0.001$) and body mass percentile ($d = 0.991$, $p = 0.011$). Compared to controls, ambulatory children with CP had lower height ($d = 0.690$, $p = 0.019$), height percentile ($d = 1.151$, $p < 0.001$) and body mass percentile ($d = 0.688$, $p = 0.045$). There were no differences in physical characteristics between nonambulatory and ambulatory children with CP (all $d < 0.58$, $p > 0.05$). Furthermore, BMI percentile was not different from the 50th age-and sex-based percentile in the total group of children with CP, the nonambulatory and ambulatory subgroups of children with CP or controls ($p > 0.40$).

Body composition

Estimates of body composition are shown in **Table 2**. Compared to controls, the total sample of children with CP had higher %Fat ($d = 0.838$, $p < 0.001$) and FMI ($d = 0.650$, $p = 0.033$), lower fat-free mass ($d = 0.729$, $p = 0.001$) and FFMI ($d = 0.639$, $p = 0.005$), but no difference in fat mass ($d = 0.387$, $p = 0.102$). When BMI was statistically controlled, the differences between children with CP and controls remained and fat mass was higher in children with CP ($p = 0.020$).

When children with CP were separated based on ambulatory status, compared to controls, nonambulatorychildren with CP had higher %Fat ($d = 1.144$, $p = 0.005$) and FMI ($d = 0.825$; $p = 0.044$), and lower fat-free mass ($d = 0.881$, $p = 0.011$) and FFMI ($d = 1.046$; $p = 0.003$). Ambulatory children with CP alsohad lower fat-free mass ($d = 0.620$, $p = 0.045$) than controls, though there were no group differences in FMI or FFMI (both $d < 0.51$, $p > 0.05$).There were no differences in any body composition measure between nonambulatory and ambulatory children with CP(all $d < 0.55$, $p > 0.05$). However, when BMI was statisticallycontrolled, nonambulatory children with CP compared to ambulatory children with CP and controls had higher %Fat ($p = 0.030$ and $p < 0.001$, respectively), fat mass ($p =0.037$ and $p = 0.002$, respectively) and FMI ($p = 0.032$ and p #x003C; 0.001, respectively), and lower FFMI ($p = 0.028$ and $p < 0.001$, respectively). Nonambulatory children also had lower fat-free mass than controls ($p = 0.001$). Furthermore, compared to controls, ambulatory children with CP had higher %Fat ($p = 0.041$) and FMI ($p = 0.019$) and lower fat-free mass ($p = 0.006$) and FFMI ($p = 0.036$).

Figure 1 highlights the lack of group difference in BMI, but the unique distribution of FMI (nonambulatory children with CP > ambulatory children with CP > controls) and FFMI (nonambulatory children with CP < ambulatory children with CP < controls) when BMI was statistically controlled.

Estimating FMI and FFMI from BMI, age, sex and ambulatory status

Scatter plots in **Figure 2** demonstrate the relationship between BMI and FMI (A) and FFMI (B). BMI was a strong predictor of FMI and a moderately-strong predictor of FFMI in children with CP (r^2 = 0.83 and 0.49, respectively, both $p < 0.001$) and a moderately-strong predictor of FMI and FFMI in controls (r^2 = 0.59 and 0.47, respectively, both $p < 0.001$). The prediction of FMI (R^2 = 0.86) and FFMI (R^2 = 0.66) from BMI significantly increased (both R^2 change, $p < 0.05$) when age, sex and ambulatory status were included in the regression model, as shown in **Table 3** where height was estimated from knee height in nonambulatory children with CP for the calculation of BMI, FMI and FFMI (models 1 and 2, respectively). The prediction of FMI (R^2 = 0.84) and FFMI (R^2 = 0.67) from BMI increased (R^2 change, p = 0.051 and 0.003, respectively) when age, sex and ambulatory status were included in the regression model, as shown in **Table 3** where height was estimated from forearm length in nonambulatory children with CP for the calculation of BMI, FMI and FFMI (models 3 and 4, respectively). All interaction terms between independent variables did not significantly contribute and were therefore not included in the model. Using the leave-one-out cross validation analysis procedure for children with CP, FMI from DXA and FMI predicted from BMI, age, sex and ambulatory status using model 1 (**Table 3)** were strongly correlated (r^2 = 0.81, $p < 0.001$; **Figure 3A**) and FFMI from DXA and FFMI predicted from BMI, age, sex and ambulatory status using model 2 **(Table 3)** were moderately correlated (r^2 = 0.54, $p < 0.001$; **Figure 3B**).

DISCUSSION

To our knowledge, this is the first study to examine the relationship between BMI and its fat and fat-free equivalents (i.e., FMI and FFMI) in children with CP. Consistent with previous studies, BMI was not different in children with CP compared to typically developing children.[7,13,15] In addition, the BMI percentiles of children with CP in the present study were not different from the 50th age- and sex-based percentiles. However, FMI was higher and FFMI was lower in children with CP compared to typically developingchildren. Although the differences were more profound in nonambulatory than ambulatory children with CP, they were present in both groups. The result suggests that there may be a greater risk of misclassifying overweight/obesity status based on BMI in children with CP than in typically developing children. The finding is problematic because chronic diseases often find their roots in childhood and obesity-related complications, such as metabolicsyndrome[28] and cardiovascular-related mortality,[29] are higher in adults with CP compared to the general population. Moreover, there is a high multi-morbidity prevalence in adults with CP that is related to obesity and higher levels of motor impairment.[30] Therefore, there is a need to more accurately assess overweight/obesity status in children with CP to better evaluate body composition types that may accelerate chronic disease progression. Fortunately, in the

present study, we also developed and validated statistical models that more accurately estimate FMI and FFMI by BMI in children with CP.

Although %Fat is viewed as a better marker of body composition and overweight/obesity status than BMI, it is flawed because it results from variation in fat tissue, fat-free tissue or both. This is demonstrated by the finding in the present study that children with CP had higher %Fat but no difference in fat mass compared to typically developing children. Instead, children with CP had lower fat-free mass, which is consistent with a previous study.[7] When body tissues were expressed relative to height using FMI and FFMI, children with CP had a higher proportion of fat and a lower proportion of fat-free tissue than typically developing children. Understanding this unusual body composition profile in children with CP is clinically important because, based on previous findings, %Fat has been recommended for routine use to assess their body composition.[31]

BMI was strongly related to FMI and moderately-to-strongly related to FFMI in children with CP. These relationships were strengthened when age, sex and ambulatory status were included in the models with 86 % of the variance in FMI and 66 % of the variance in FFMI explained. The model predicting FMI cross-validated very well, as indicted by the strong relationship between the measured and predicted values ($r^2 = 0.81$). Although the model predicting FFMI was not as accurate, it still cross-validated reasonably well, as indicated by the moderately-strong relationship between the measured and predicted values ($r^2 = 0.54$).

The present study has several strengths. First, we compared body composition of children with CP and typically developing children using FMI and FFMI. Previous studies that reported on the absolute mass of fat and fat-free tissue in children with CP did not capture the proportion of these tissues because they did not account for their shorter stature compared to their typically developing peers. Moreover, fat-free mass may be accruing at a slower rate than fat mass in children with CP, which would go unnoticed when using %Fat to determine body composition. Therefore, FMI and FFMI may be better indicators of body composition than BMI and %Fat because they are expressed relative to the individual's height and are independent of the other tissue. Second, because the differences in body composition were more pronounced in nonambulatory than ambulatory children with CP compared to typically developing children, statistical models need to consider ambulatory status. Moreover, the independent predictors in the model are measures that are easily attainable during routine clinical visits or visits pertaining to research study participation. Determining height and weight for BMI, age, sex and ambulatory status do not require expensive equipment, accessibility to specialized facilities, rigorous training or exposure to radiation. Third, we matched each child with CP with a typically developing child based on age, sex and race (n = 42 per group). Moreover, the controls were not different from the 50th percentile for BMI. The pattern of study results was the same when all typically developing children (n = 73) were compared to the children with CP. Lastly, body composition was assessed using the same DXA scanner and software. It can be difficultto acquire an adequate sample of children with a clinical condition to create statistical models. This can lead to merging of data from different sites or comparing data to reference studies. Both scenarios pose the risk of differences in machinery, software or techniques used to acquire the data which can influence comparisons.[32]

The limitations of this study must be discussed. First, markers of cardiometabolic health were not assessed. Although FMI and FFMI thresholds that discriminate metabolic syndrome have been introduced for older children and young adults (12 to 20 years),[33] studies are neededto determine appropriate thresholds for younger children. Second, it is unknown if the statistical models developed in the current study can be used to monitor changes in body composition of children with CP due to growth, as well as surgery, treatment or nutritional changes. Children with severe cases of CP may be enterally-fed whichcan significantly affect growth.[34] Unfortunately, the effectofenteral feeding on the BMI to FMI and BMI to FFMI relationships could not be assessed in the present study duetothe small number of children who were enterally-fed. Third, measurement of total height is difficult in childrenwith CP, especially in nonambulatory children. In the present study, total height was estimated from knee heightand forearm length in nonambulatory children with CP. Although there was very good agreement between heightestimated from these two approaches (r = 0.91 and no difference in values, $p = 0.30$), models that estimate FMI and FFMI from BMI using the different height estimates for nonambulatory children with CP are presented in **Table 3**. Lastly, there is controversy surroundingthe use of FMI to classify overweight/obesity status in children[35, 36] because it is unclear if fat mass scales to height squared, which is used in the BMI, FMI and FFMI calculations, or if it scales to height at another power (*e.g.*, cubed). Ideally, the index chosen would not correlate with height. The differences in the strength of the correlation with height between fat mass expressed relative to height squared or height cubed vary depending on age.[35] Because the primary objective of the current study was todetermine if BMI is capturing the proportion of the fat and fat-free components in children with CP, fat and fat-free mass were expressed relative to height squared for ease of comparison with BMI.

In conclusion, despite no group difference in BMI, children with CP had higher FMI and lower FFMI compared to typically developing children. Although the discrepancies were more profound in nonambulatory than ambulatory children with CP, they existed in both groups of children. Because many studies that document overweight/obesity status are done so using BMI,[10–12, 37] the prevalence of overweight/obesity in children with CP may be even higher than reported previously. Importantly, this study provides validated statistical models to estimate FMI and FFMI from inexpensive, routine and easily attainable measures of BMI, age, sex and ambulatory status to provide a more accurate assessment of body composition in children with CP.

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Abbreviations:

CP	cerebral palsy
BMI	body mass index

%Fat	percent body fat
FMI	fat mass index
FFMI	fat-free mass index

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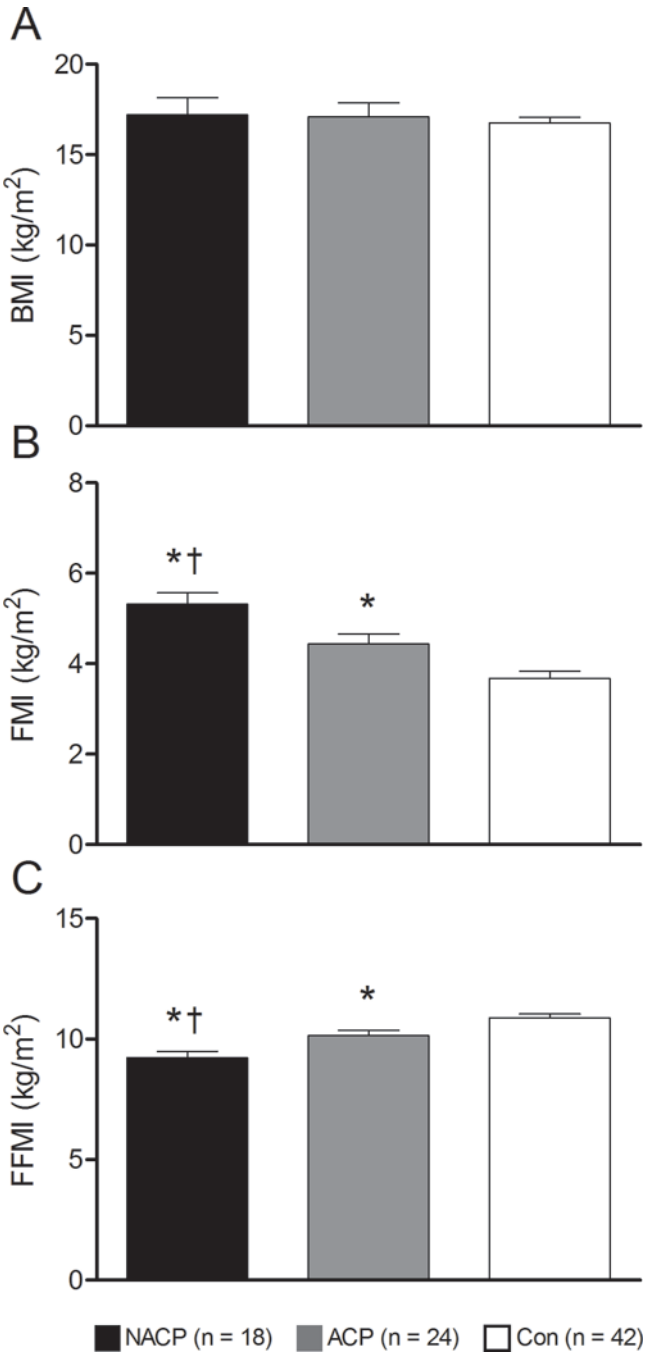

Figure 1.

Bar graphs represent (A) body mass index (BMI), (B) fat mass index (FMI) statistically controlled for BMI and (C) fat-free mass index (FFMI) statistically controlled for BMI for nonambulatory children with cerebral palsy (NACP), ambulatory children with CP (ACP) and typically developing children (Con). Values are means ± SE. *Different from controls, $p < 0.05$. †Different from ACP, $p < 0.05$.

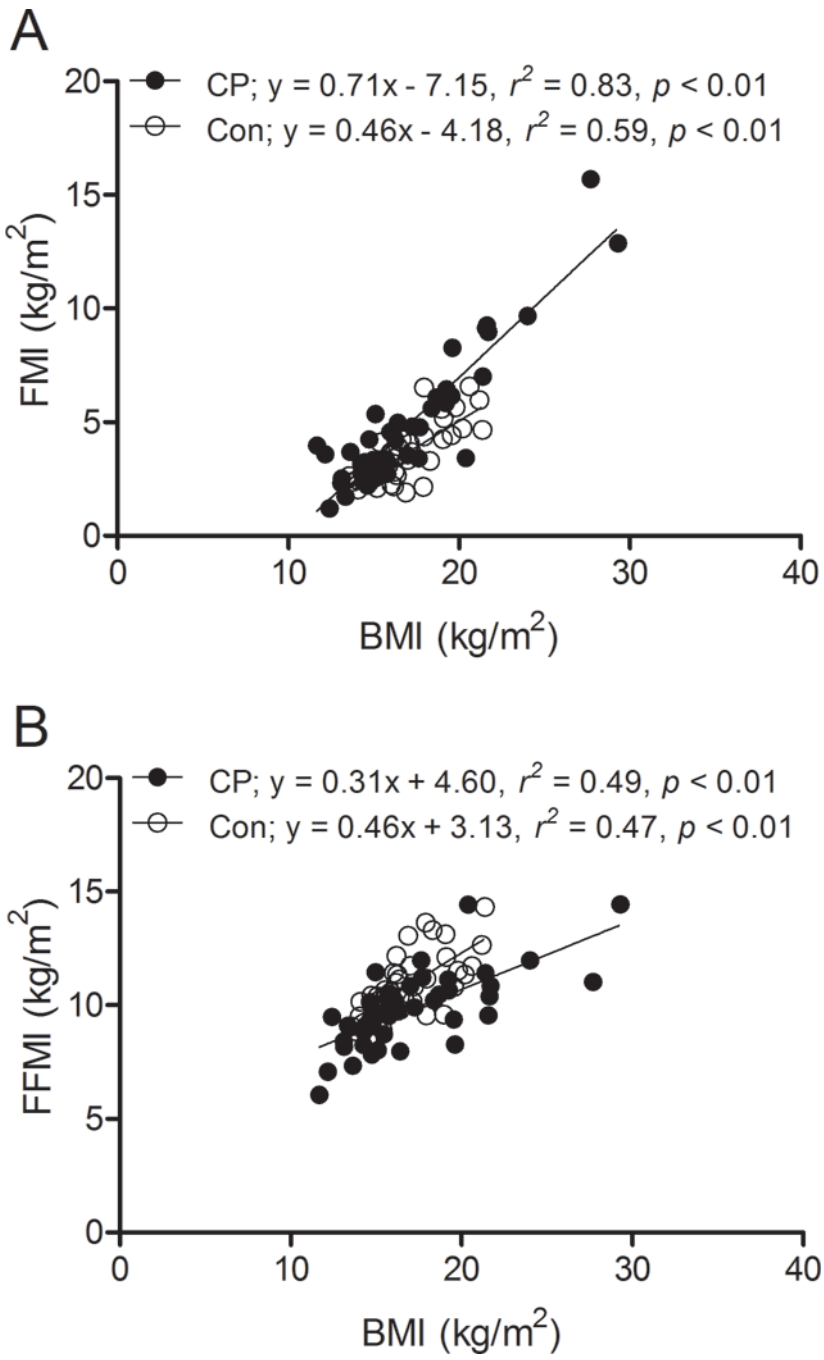

Figure 2.

Scatter plot demonstrating (A) the relationships between body mass index (BMI) and fat mass index (FMI) and (B) the relationships between BMI and fat-free mass index (FFMI) in children with cerebral palsy (CP) and typically developing children (Con).

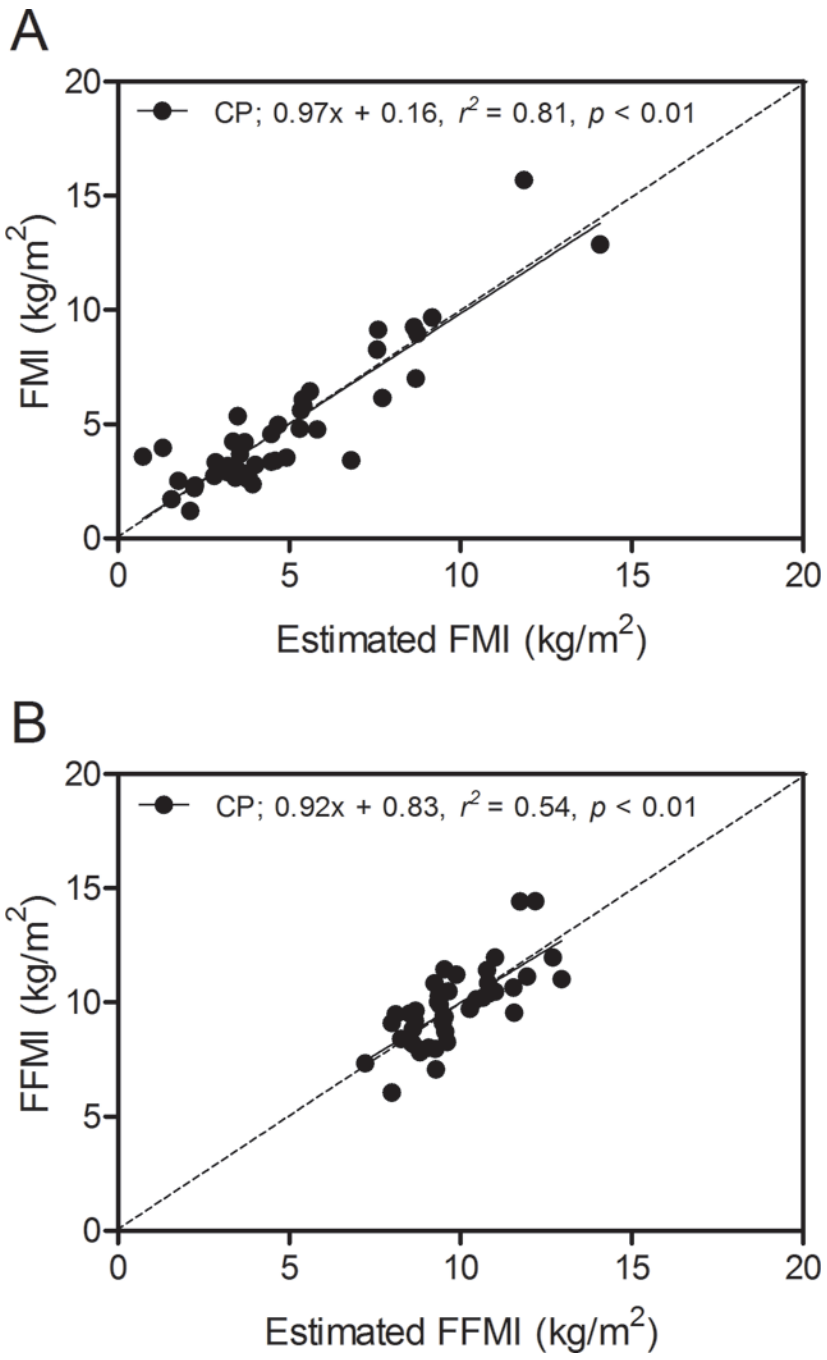

Figure 3.

Scatter plot comparing the measured values to the estimated values of (A) fat mass index (FMI) and (B) fat-free mass index (FFMI) in children with cerebral palsy (CP) using multiple linear regression and body mass index, age, sex and ambulatory status and the models shown in **Table 3**. The dotted diagonal line represents the line of identity.

Table 1.

Physical characteristics of children with cerebral palsy (CP) and controls (Con).

	All CP (n = 42)	NACP (n = 18)	ACP (n = 24)	Con (n = 42)
Age (y)	9.1 ± 2.5	9.9 ± 2.1	8.5 ± 2.6	9.2 ± 2.2
Sex male, n (%)	25 (60 %)	7 (39 %)	18 (75 %)	25 (60 %)
Height (m)	1.26 ± 0.16[1]	1.28 ± 0.16	1.25 ± 0.16[1]	1.35 ± 0.13
Height (%)	23 ± 27[1]	19 ± 27[1]	27 ± 28[1]	56 ± 24
Body mass (kg)	27.9 ± 10.9	28.3 ± 11.5	27.7 ± 10.7	31.3 ± 8.4
Body mass (%)	31 ± 33[1]	27 ± 33[1]	35 ± 33[1]	53 ± 21
BMI (kg/m^2)	17.1 ± 3.9	17.2 ± 4.1	17.1 ± 3.9	16.8 ± 2.1
BMI (%)	47 ± 36	44 ± 39	50 ± 34	50 ± 28

NACP, nonambulatory CP; ACP, ambulatory CP. Values are means ± SD. % reflects the percentile relative to age- and sex-based norms.

[1]Different compared to controls, $p < 0.05$.

Table 2.

Body composition of children with cerebral palsy (CP) and controls (Con).

	All CP (n = 42)	NACP (n = 18)	ACP (n = 24)	Con (n = 42)
%Fat	31.5 ± 10.7[1,2]	34.6 ± 11.6[1-3]	29.1 ± 9.5[2]	24.4 ± 6.3
Fat mass (kg)	8.3 ± 5.9[2]	9.3 ± 6.9[2,3]	7.5 ± 5.0	6.6 ± 2.7
FMI (kg/ht^2)	4.9 ± 3.0[1,2]	5.5 ± 3.4[1-3]	4.5 ± 2.2[2]	3.6 ± 1.3
Fat-free mass (kg)	16.0 ± 5.8[1,2]	15.3 ± 5.4[1,2]	16.5 ± 6.2[1,2]	20.3 ± 6.1
FFMI (kg/ht^2)	9.8 ± 1.7[1,2]	9.3 ± 1.5[1-3]	10.2 ± 1.8[2]	10.8 ± 1.4

FMI, fat mass index; FFMI, fat-free mass index; NACP, nonambulatory CP; ACP, ambulatory CP. Values are means ± SD.

[1]Different compared to controls, $p < 0.05$.

[2]Different compared to controls when BMI was statistically controlled, $p < 0.05$.

[1]Different compared to ACP when BMI was statistically controlled, $p < 0.05$.

Table 3.

Statistical models for predicting FMI and FFMI from DXA in children with cerebral palsy (CP) using BMI, age, sex and ambulatory status.

Model	Outcome Measure	Coefficients	β	t-value	SE	*p*	Model R^2	Model adjusted R^2
1	*FMI (kg/m^2)						0.862	0.847
		Intercept	-7.223	-7.274	0.993	0.000		
		BMI	0.736	14.572	0.051	0.000		
		Age	-0.111	-1.352	0.082	0.185		
		Female	0.546	1.327	0.412	0.193		
		NACP	0.818	1.993	0.411	0.054		
2	*FFMI (kg/m^2)						0.655	0.618
		Intercept	3.949	4.490	0.880	0.000		
		BMI	0.261	5.839	0.045	0.000		
		Age	0.221	3.026	0.073	0.004		
		Female	-0.383	-1.050	0.365	0.301		
		NACP	-1.066	-2.931	0.364	0.006		
3	†FMI (kg/m^2)						0.836	0.818
		Intercept	-6.837	-6.577	1.040	0.000		
		BMI	0.694	13.259	0.052	0.000		
		Age	-0.069	-0.824	0.084	0.415		
		Female	0.453	1.079	0.420	0.288		
		NACP	0.931	2.201	0.423	0.034		
4	†FFMI (kg/m^2)						0.668	0.632
		Intercept	3.791	4.243	0.894	0.000		
		BMI	0.284	6.312	0.045	0.000		
		Age	0.192	2.664	0.072	0.011		
		Female	-0.327	-0.905	0.361	0.372		
		NACP	-1.158	-3.186	0.364	0.003		

FMI, fat mass index; FFMI, fat-free mass index; NACP, nonambulatory children with CP. Height was used from standing height for ambulatory children with CP and controls and estimated from

*knee height or

†forearm length for nonambulatory children with CP. Age is in years; Female = 1; NACP = 1. All models are significant, $p < 0.001$, n = 42.