Development of equations and software for estimating weight in children with cerebral palsy

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ABBREVIATIONS

BMI/A	Body mass index for age
MUAC	Mid-upper arm circumference

AIM To develop equations and software to estimate weight using segmental measures for children with cerebral palsy (CP).
METHOD This was a cross-sectional study. Children and adolescents with CP of both sexes from 2 to 19 years old from five cities in Argentina were included. Weight, mid-upper arm circumference (MUAC), and clinical covariables were collected. Linear regression models with weight as the dependent variable and body segment lengths as predictors were developed and compared for R^2, adjusted R^2, and the root mean square of the error.
RESULTS In total, 381 children and adolescents (mean age 10y 5mo [SD 4y 9mo], range 2–19y; 231 males, 150 females) with a confirmed diagnosis of CP were included. Gross motor function based on the Gross Motor Function Classification System (GMFCS) was as follows: level I, 59; II, 55; III, 59; IV, 69; V, 139. The interaction between weight and other variables such as MUAC, sex, GMFCS, and age was analysed. The concordance correlation coefficient between estimated and observed weight was 0.94 (95% CI 0.93–0.95). From the results of the equations, a free software tool, named Weight Calculator CP, was developed.
INTERPRETATION Weight in children with CP can be predicted using MUAC, GMFCS, and age. Weight Calculator CP can be used in clinical practice when direct weight cannot be obtained.

Children with cerebral palsy (CP) tend to present lower weight and shorter status than typically developing children. In low- and middle-income countries, undernutrition tends to affect more than half of the children with CP.[1–6] On the other hand, children with CP in high-income countries tend to achieve a normal nutritional status but an increase in overweight and obesity can be observed.[7–9] Proper nutrition is critical for these children to maintain adequate function of their immune, nervous, respiratory, myocardial, musculoskeletal, and cognitive systems, as well as healing.[10–12] Malnutrition generates an increase in health care needs and reduces the child's participation in educational and social activities.[13,14]

Anthropometric information in children reflects their general health and is used to assess nutritional status, and weight is an essential measurement to assess growth. In children older than 2 years with CP, obtaining weight by direct measurement becomes more difficult owing to their lack of balance and their motor compromise, as they find it hard to stay still on a regular scale. This difficulty increases in low- and middle-income countries where wheelchair adapted scales, or even regular scales, are not available, whereby weight cannot be recorded.[15,16]

Mid-upper arm circumference (MUAC) is a segmental measure that has been proven to indirectly assess growth and changes in caloric and protein intake.[17,18] MUAC measurement uses the fat, bone, and muscle area of the arm as an indirect measure to evaluate body weight.[19,20] The World Health Organization recommends the use of MUAC as a measurement that, alongside weight for age, can be a diagnostic criterion for severe acute malnutrition in typically developing children,[21] but the study of this segmental measure has not been studied to estimate weight in children with CP.

In a previous paper, we developed equations to estimate weight in Argentinian typically developing children.[22] In this study it was observed that MUAC was the best segmental measure to estimate weight combined with variables such as age and sex.[22] To our knowledge, there are no equations available to estimate weight in children with CP. The aim of this study, therefore, is to develop an equation to estimate weight using segmental measures in children with CP from 2 to 19 years of age, and then to create a software tool to help use the equation in clinical practice.

METHOD

A cross-sectional study design was used to collect data about weight and height, as well as MUAC. The protocol for the study was registered in ClinicalTrials.gov (NCT03303755). Informed written consent was obtained from all participants and their parents or legal guardians. Consejo de Evaluación Ética de la Investigación en Salud, (COEIS) of the province of Córdoba approved the project (REPIS number 3262/3236).

The participants were children with a confirmed diagnosis of CP, from 2 to 19 years old. Those with genetic or metabolic syndromes that could have or had affected growth (e.g. Down syndrome, Angelman syndrome, chromosomal aberration, etc.) were excluded. Children from 17 rehabilitation and therapeutic educational centres that specialized in motor rehabilitation from five cities in Argentina (Córdoba, Buenos Aires, Jujuy, Santiago del Estero, and Catamarca) participated in the study. Of the 433 potential children, 381 agreed to participate and were available for the data collection dates.

Anthropometric measurements

Weight was obtained in kilograms to the nearest 100g using a wheelchair scale (BIOTECNICA Argentina, with capacity up to 300kg and precision of 50g) or a digital scale (TANITA model 585 FITSCAN, with capacity up to 150kg and precision of 100g), depending on the child's abilities. MUAC was measured at the midpoint between the acromion and the olecranon using a flexible and inelastic measuring tape SECA (in centimetres and millimetres) on the less affected side of the body.[23] During the measurement, the child was standing up with their arm bent 90° at the elbow, the right palm facing up, and the arm bare. On the basis of the results of our previous study with typically developing children,[22] MUAC is reliable and easy to measure in clinical practice as the required measuring equipment is accessible in most countries and has been proven to be related to undernutrition.[21] Therefore, in this study, MUAC was the only segmental measure studied related to weight.

For those children who were able to stand, height or length was measured in centimetres to the nearest millimetre with a portable stadiometer (SECA model 213). When direct height could not be obtained, it was estimated using published equations for children with CP using knee height.[24] All research assistants were trained in the measurement method according to international standards.[25] Measurements were taken twice by two health professionals, and the average measure was used for analysis. If a difference greater than 0.5cm was observed for height or 2mm for MUAC, the measurement was repeated.

Nutritional status was defined on the basis of weight for age, height for age, and body mass index for age (BMI/A) according to sex. Measurements were converted to z-scores on the basis of growth charts from the World Health Organization[26] using WHO Anthro Plus version 1.0.4 software (WHO, Geneva, Switzerland). The cut-off points to assess the nutritional anthropometric status were defined as follows. Weight for age and BMI/A z-scores between −1.99 and 1.99, and a height for age z-score greater than −2.0 were considered normal. Moderate undernutrition was established when z-scores of weight for age, height for age, or BMI/A were between −2 and −2.99, while severe undernutrition was considered when z-scores of weight for age, height for age, or BMI/A were less than −3. Overweight was defined if BMI/A z-scores were between 2 and 3, and obesity when the BMI/A z-scores were greater than 3.

What this paper adds

- Equations can be used to estimate weight in children with cerebral palsy via body segments.
- Weight can be estimated according to age and gross motor function.
- The average difference between estimated and observed weights was 119g.

Clinical and demographic characteristics

The Gross Motor Function Classification System (GMFCS) reports five levels of motor function in children with CP according to international guidelines.[27] GMFCS levels were classified by physicians and physiotherapists according to the expanded and revised definition during physical assessments and rehabilitation processes.

Age, sex, and other characteristics were collected from clinical reports. These included information about type of CP, tube feeding, and nutritional outcomes for undernourishment.

Statistical analysis

Discrete data were reported in absolute and relative (percentage) frequencies with 95% confidence interval (CI) and continuous data as mean (SD) or median and interquartile range. To identify the relation between weight and the segmental measure MUAC, Pearson's correlation was used in normal distributed variables and Spearman's correlation in the case of non-normality, and R^2 determination was calculated. Linear regression models were performed to develop the equations, calculating R^2, adjusted R^2, and the root mean square of the error. A p-value less than 0.05 was pre-defined as statistically significant for a two-sided test.

To analyse the degree of agreement between the observed and the estimated weights, Bland–Altman plots were made with a 95% agreement limit,[28] and coefficients of correlation agreement with their 95% CI were calculated. The average difference (d) between estimated and observed weights was calculated with 95% CIs.[29] STATA 13.0 (Stata Corp LP, College Station, TX, USA) was used for analysis. The software was developed using JAVA by the research team of the Instituto de Investigaciones Clínicas y Epidemiológicas (INICyE), Universidad Nacional de Córdoba (Cordoba, Argentina).

RESULTS

Of the sample of 381 children and adolescents, 231 (60.6%) were male and 150 (39.4%) were female. The mean age was 10 years 5 months (SD 4y 9mo). The characteristics of the children with CP can be seen in Table S1 (online supporting information).

Neither the weight nor the MUAC presented a normal distribution, so they were analysed using Spearman's correlation. MUAC showed a correlation of Spearman with the weight of ρ=0.87 (0.83–0.90) (R^2=0.81) in males, and of ρ=0.88 (0.83–0.91) (R^2=0.79) in females, both with a significance of p<0.001. The scatter plots by sex are shown in Figure S1 (online supporting information).

Differences in weight for each age group of the children with CP were compared as male versus female, and GMFCS levels I to III versus levels IV and V. No statistically significant differences were observed according to sex in weight and MUAC between males and females: 28.6kg (15.7) versus 28.2kg (14.1), p=0.775, and 19.7cm (4.7) versus 19.9cm (4.6), p=0.524 respectively. On the other hand, there were statistically significant differences in weight and MUAC according to the GMFCS level I to III versus IV and V: 31.9kg (15.7) versus 25.6kg (13.9), p<0.001, and 20.8cm (4.2) versus 19.0cm (4.8), p<0.001.

To estimate the weight, MUAC was analysed with different covariates to see which gave the best fit to the predicted value (Table 1). It was observed that age and GMFCS level are variables that best adjust the results of the equation to predict weight. The equation to estimate weight in children with CP is presented in Table 2, and the constants and coefficients of the final linear multiple regression model are presented in Table S2 (online supporting information). The distribution of residuals was checked in both models (GMFCS levels I–III and IV–V) with the Kolmogorov–Smirnov test, resulting in d=0.08, p=0.225, and d=0.09, p=0.085 respectively. The models were validated using bootstrapping. If the values estimated by bootstrapping are compared with those returned by the functions of the models, a very small difference is observed (Table S2). The confident concordance correlation between estimated and observed weight was 0.94 (95% CI 0.93–0.95). The average difference (d) between estimated and observed weights in all children with CP was 119g (95% CI −196 to 220), p=0.911. An analysis according to GMFCS showed that the average difference between estimated and observed weights for GMFCS levels I to III (n=173) was 250g (95% CI 70–430), p=0.879, and the average difference between estimated and observed weights for GMFCS levels IV and V (n=208) was −20g (95% CI −37 to 3), p=0.994.

Table 1: Linear regression between weight and MUAC (n=381)

Parameters included in model	N	R^2	Adjusted R^2	RMSE	p
MUAC	381	0.80	0.80	6.76	<0.001
MUAC and age	381	0.87	0.87	5.38	<0.001
MUAC by sex					
Females	150	0.79	0.79	6.44	<0.001
Males	231	0.81	0.81	6.88	<0.001
MUAC by GMFCS level					
I–III	173	0.82	0.82	6.66	<0.001
IV and V	208	0.79	0.78	6.41	<0.001
MUAC by GMFCS level and age					
I–III	173	0.90	0.90	4.97	<0.001
IV and V	208	0.86	0.86	5.18	<0.001

RMSE, root mean square of the error; MUAC, mid-upper arm circumference; GMFCS, Gross Motor Function Classification System.

Table 2: Equations to estimate weight in children and adolescents with cerebral palsy

Parameter	Equation
GMFCS levels I–III	EW=2.52×MUAC (cm)+1.19×age (y)−32
GMFCS levels IV–IV	EW=2.02×MUAC (cm)+0.97×age (y)−22.5

Each equation must be completed with the value of the years of age, without considering the months. GMFCS, Gross Motor Function Classification System; EW, estimated weight; MUAC, mid-upper arm circumference.

The Bland–Altman plot shows that estimated weight values predict observed weight values with reasonable accuracy (Fig. 1). At individual clinical level, 81.9% of the children included in the study had an estimate weight with a 0 to 5kg difference with their real weight, 10.5% an estimate weight with a 6 to 9.9kg difference with their real weight, and 7.6% presented a difference more than 10kg compared with their real weight. No difference was found between GMFCS levels (Table S3, online supporting information).

When analysed by age group, the means and 95% CIs of estimated weight and observed weight values did not show statistical differences through ages 2 to 19 years, as shown in Figure 2.

Weight Calculator CP

A software tool was developed to calculate the estimated weight in children and adolescents with CP. The Weight Calculator CP is free to access (http://inicye.webs.fcm.unc.edu.ar/weight-calculator-cp).

DISCUSSION

To our knowledge, this is the first study to: (1) present the development of an equation to estimate weight in children with CP and (2) develop a free online software tool that can be used in clinical practice for this purpose.

In a clinical context, this equation will allow health professionals to easily estimate the weight of children with CP using only a flexible tape measure, especially in low- and middle-income country settings where access to accurate scales is extremely limited, particularly wheelchair accessible scales, with a very reasonable estimation error that ranges between −130g and +150g on average.

MUAC has previously been used as an indirect measure to assess growth and body mass, and to detect malnutrition owing to its association with weight,[17,21] in

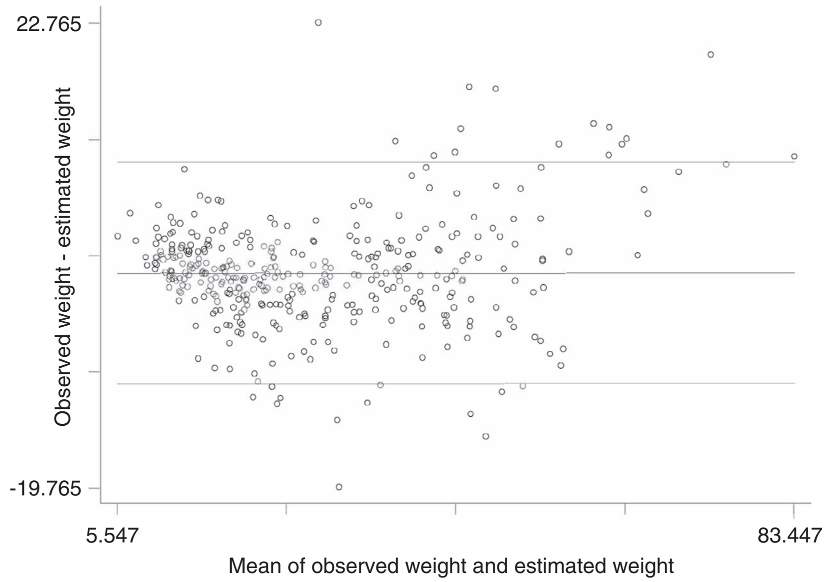

Figure 1: Bland–Altman plot for observed and estimated weight in children and adolescents with cerebral palsy (n=381). Data points represent the individual children. The mean is represented by the centred line (−0.119), and the upper and lower lines represent 1.96 standard deviation and the 95% confidence intervals for the agreement (−10.0 to 9.8).

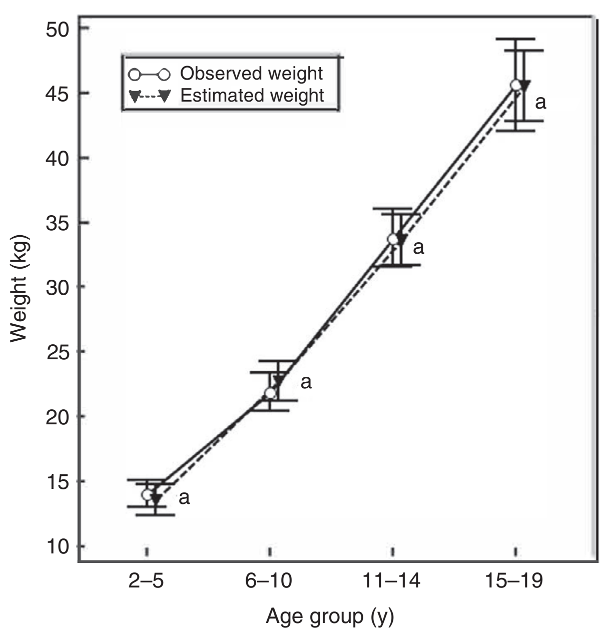

Figure 2: Mean and 95% confidence intervals of estimated weight and observed weight according to age group (n=381). $^{a}p>0.05$.

accordance with our results. Previous studies have also demonstrated that MUAC can be used as a variable to predict weight in children, although other segmental measures such as length were included.[30–33] Our study shows that MUAC combined with age and level of gross motor function can predict weight in children and adolescents with CP.

Equations to estimate height in children with CP have previously demonstrated that sex was not a variable that improves the equation.[24] In this study we analysed the influence of sex on weight and the equations, and, in concordance with previous studies, this variable was not significant. The level of gross motor function established with the GMFCS has been proven to affect growth in a much more significant way than sex in children because, with more severe motor compromise and as age and GMFCS increase, growth is more compromised.[13,34] In agreement with our study, this could possibly explain why GMFCS level and age were better variables than sex for our equation to estimate weight.

One potential limitation to the equation for estimating weight is that it is based on normative data from sample populations that vary widely. In this case, it is based on an Argentine population of children with CP. Because of this, caution should be exercised when applying these equations to children from another ethnic group and when it is used at an individual level. We found no published studies showing anthropometric differences between children with CP from different nations that compare high-income countries with low- and middle-income countries. Until proven otherwise, the generalizability of our findings should be limited to similar ethnically diverse populations.[35] At clinical level, differences greater than 10kg can be found in estimated weight with respect to observed weight in some children. For this reason, clinicians should be careful in interpreting individual weight estimates alone. Consequently, it is recommended to use direct MUAC measurements with estimated weight to evaluate the extent to which MUAC changes are associated with estimated weight changes according to the best clinical judgement.[23] More studies are needed to see which factors make children more prone to errors in their estimation.

Nevertheless, this study has several strengths. It is one of the largest cross-sectional studies published to propose equations for children with CP and, to our knowledge, the first to develop an equation and software to estimate weight in this population and the first to be developed in low- and middle-income countries where it is more difficult to access appropriate scales. Weight can be estimated in populations of children with CP when it cannot be obtained directly. Another advantage is that the equation developed to estimate weight uses MUAC, which is a simple and reliable measure and the software is very user-friendly. Furthermore, the equation includes children from 2 to 19 years of age, making it useful for the full paediatric age range.

CONCLUSION

The equations to estimate weight using MUAC and the Weight Calculator CP software developed in this study are accurate for estimating weight in children with CP from 2 to 19 years of age. The only information needed is: MUAC, age, and GMFCS level. This information is readily obtained from clinical reports or can be measured. The tools developed are simple to use, low-cost, and can be widely distributed in similar populations.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

SUPPORTING INFORMATION

The following additional material may be found online:

Table S1: Characteristics of study sample

Table S2: Coefficients of the final linear multiple regression model with 95% confidence intervals and validation of linear regression models using bootstrapping with 1000 iterations

Table S3: Difference between the observed and estimated weight in children with cerebral palsy

Figure S1: Scatter plots of weight and mid-upper arm circumference according to sex for cerebral palsy.

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