



Short paper

Development and validation of a novel paediatric weight estimation equation in multinational cohorts of sick children



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ABSTRACT

Aim: In sick children who are unable to be weighed estimation of weight is often required, but the routinely used equations lack accuracy and precision. This study aimed to develop a novel equation (Children's European Estimator of Weight-CEEW) using measurements of mid-upper arm circumference (MUAC) and other predictors in multinational groups of sick children in Europe.

Methods: Weight estimation equations were developed in 2086 children from the UK, Greece and the Netherlands, using a combination of demographics, MUAC and height measurements. The final CEEW equations were compared against the performance of the European Resuscitation Council (ERC), Advanced Paediatric Life Support (APLS) and the Cattermole equations.

Results: Two final CEEW equations were developed, incorporating measurements of age, gender and MUAC, with (CEEW1) or without (CEEW2) the inclusion of height. Both equations presented very high coefficients of determination ($R^2 > 96.5\%$), minimal mean prediction error and narrower limits of agreement than the comparator equations. 88% (CEEW1) and 77% (CEEW2) of weight estimates fell within 15% of measured body weight. These figures compared with less than 57%, 57% and 37% for the ERC, APLS and Cattermole equations respectively.

Conclusion: The CEEW equations performed substantially better than other routinely used equations for weight estimation. An electronic application for mobile use is presented.

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Introduction

Measurement of body weight in sick children is essential for calculation of resuscitation fluid volumes, defibrillation energy settings and emergency drug dosages; particularly in those drugs with a narrow therapeutic window. Measuring weight with scales is

undoubtedly the 'gold standard' and should be applied where possible. However, there are clinical situations where measuring the weight of a sick child might not be possible, such as in critical care or during their initial resuscitation and stabilisation in emergency medicine.

A European survey in paediatric critical care departments showed that while 97% of units used body weight, a weighing protocol was present in only 12% of these, and weight was often predicted rather than measured [1]. Prediction models have gained wide acceptance with several equations available to quickly estimate weight. Those most commonly used are endorsed by the European Resuscitation Council (ERC) and the Advanced Paediatric Life Support (APLS) course and are based solely on the age of the child [2–4]. While these are easy to compute, substantial evidence

Abbreviations: APLS, Advanced Paediatric Life Support; ERC, European Resuscitation Council; CEEW, Children's European Estimator of Weight; MUAC, mid-upper arm circumference.

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suggests these are frequently inaccurate, particularly when used for individual patient estimates [2–4]. The advent of mobile applications enables use of accurate, complex mathematical algorithms to predict weight, while minimising computation errors.

This study aimed to develop a set of equations (Children's European Estimator of Weight-CEEW) to predict weight using a combination of demographics, height and mid-upper arm circumference (MUAC), a dynamic proxy for body size which is convenient to measure in the emergency setting. The performance of the CEEW equations was compared against other popular methods in multinational cohorts of sick children. We also developed and present an electronic application for free mobile use of the CEEW equation.

Methods

Subjects

To develop the CEEW equations, sick children (0.1–18 years) were recruited from the Emergency Department of the Royal Hospital for Sick Children, Glasgow. Data were merged with datasets from independent studies in sick children in the United Kingdom (Royal Hospital for Sick Children, Glasgow), Greece (Hippokraton Hospital, Thessaloniki) and the Netherlands (Erasmus MC-Sophia Children's Hospital, Rotterdam) [5,6].

For all patients, demographics and disease information were collected from medical notes and via face-to-face interview. Presence of chronic conditions likely to affect nutritional status (e.g. Crohn's disease) was recorded as binary response. Body weight and length/height were measured according to the World Health Organisation standards and as described previously [7]. MUAC was measured, to the nearest 0.1 cm, at the mid-point between the acromion process and the olecranon [8].

Development of the CEEW equation

Stepwise linear regression analysis was used to construct predictive models for weight using age, gender, presence of chronic illness likely to affect nutritional status and MUAC. Height was also considered as a predictor of weight, but as this might be difficult to measure in acutely unwell children, separate models were produced with (CEEW1) and without (CEEW2) inclusion of height. Data were transformed on the logarithmic scale and polynomials were used to improve model fit, as measured by the coefficient of determination and distribution of residuals.

The predictive ability of the models and β -coefficients of each predictor were tested using bootstrapping in the R statistical package. Five hundred bootstrap datasets were constructed using a random sample of half of the data to fit the regression model and the other half of the sample to test the predictive ability. Results were averaged over the 500 bootstraps. Agreement between predicted and measured weights was calculated using 95% limits of agreement.

Performance of other existing weight prediction equations

The predictive ability of the ERC and the APLS weight prediction equations, commonly used in clinical practice [9], and an equation based on measurements of MUAC (developed by Cattermole, in healthy Hong Kong Chinese children) [10] were tested in the same cohort of patients. The mean prediction error (accuracy) and 95% limits of agreement between measured and predicted weight (precision), were calculated for the ERC, APLS and the Cattermole equations and displayed graphically on Bland-Altman plots. Prediction error was expressed in mass of weight (kg) and as a percentage (%) of measured weight. The percentages of patients with predicted

values falling within 10%, 15% and 20% of the measured weight (error bands) were calculated.

Ethical considerations

Approval to carry out the study was obtained by the local research ethics committee (12/WS/0154). In all cases, carers and children (when age appropriate) provided signed informed consent according to Good Clinical Practice for research.

Results

Subject characteristics

Data from 2086 UK, Dutch and Greek participants (males: 1200, 58%) were used in the development of the CEEW equation. Four hundred and twenty four participants (20.3%) were infants (<1 y). Eight percent were obese and six percent had short stature or were underweight (Table 1).

Development and performance of the CEEW equations

Age, gender, height and MUAC were all significant predictors of weight and were included in the multivariate model. Presence of a chronic illness likely to affect nutritional status was not a significant predictor of weight. Multiple multivariate models were tested with stepwise inclusion of predictors. Height explained the gender effect on prediction of weight; hence this became non-significant in multivariate analysis. Two final CEEW equations were produced: CEEW1, which includes height/length measurements; and CEEW2, where height was replaced by gender.

CEEW1: $\ln(\text{weight}) = 0.0151222388 \times \text{Age} - 0.0011458885 \times \text{Age}^2 + 0.2967431897 \times \text{MUAC} - 0.0104572693 \times \text{MUAC}^2 + 0.0001381567 \times \text{MUAC}^3 + 0.0149652312 \times \text{Height} - 1.4955305740$

CEEW2: $\ln(\text{weight}) = 0.1443608977 \times \text{Age} - 0.0040395021 \times \text{Age}^2 + 0.4223311859 \times \text{MUAC} - 0.0148641297 \times \text{MUAC}^2 + 0.0001923541 \times \text{MUAC}^3 + 0.0258703205 \times \text{Gender} - 1.6251030158$

Both of the CEEW equations presented very high (>96.5%) coefficients of determination (Table 2). The CEEW equations performed better than the comparator equations, presenting the lowest mean bias and the narrowest limits of agreement; hence the greatest precision on per subject estimations (Table 2 and Supplementary Fig. S1 in the online version at DOI: <http://dx.doi.org/10.1016/j.resuscitation.2017.04.025>). The proportions of estimated body weights falling within 10%, 15% and 20% of actual measurements were superior for the CEEW equations than the comparator equations, particularly for CEEW1 (Table 2). The proportion of subjects with weight estimation within 15% of the true value was 77% for CEEW2, 88% for CEEW1, 57% for ERC, 57% for APLS, and 37% for Cattermole (Table 2). The performance of the ERC, APLS and the Cattermole equations was similar in each of the international cohorts (Supplementary Table S1 in the online version at DOI: <http://dx.doi.org/10.1016/j.resuscitation.2017.04.025>).

Discussion

In this study, we have proven that the CEEW equations, which incorporate a dynamic, indirect measurement of body size, perform better than the current equations used in clinical practice and an alternative equation using MUAC.

This was demonstrated by the tighter limits of agreement and a higher percentage of estimated weights falling within each of the error bands. Collectively, these findings suggest the accuracy of the CEEW method is superior, particularly in terms of individual estimates, which are clinically more important than group means.

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