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Validation of Pediatric Weight Estimation Formulae in a Suburban Cameroonian Population: A Cross-sectional Study

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ABSTRACT

We assessed the accuracy of the Nelson, Best Guess and Advanced Pediatric Life Support (APLS) formulae in estimating weight in a suburban Cameroonian pediatric population, by conducting a cross-sectional study using 544 children aged 1 month to 12 years. Agreement between measured and estimated weight was poor for Nelson [concordance correlation coefficient (CCC) 0.89 (95% confidence interval (CI) 0.87–0.90)] and Best Guess [CCC 0.88 (95% CI 0.86–0.90)] formulae, and moderate for the APLS formula [CCC 0.92 (95% CI 0.90–0.93)]. On Bland–Altman analysis, all three methods had limits of agreement (APLS −42.2 to –45.6%, Best Guess −42.7 to –55.1%, Nelson −36.4 to –42.4%) above the −10 to –10% set as criteria for clinical agreement. Conclusively, the accuracy of all three formulae was clinically unacceptable in our study population, suggesting the need for studies aimed at deriving more accurate formulae adapted for use in our context.

KEYWORDS: Nelson formula, Best Guess formula, APLS formula, Cameroon

INTRODUCTION

Weight is an essential anthropometric parameter, as it is critical for drug dosage calculations and other life-saving interventions [1, 2]. Accurate weight measurements are obtained using standardized weighing scales. Weighing could be time-consuming and not feasible in a severely injured or critically ill child [3, 4]. In certain settings, weighing scales are missing [5], making a strong case for a simple and accurate method of weight estimation.

Over the past years, various weight estimation methods have been proposed, including the Advanced Pediatric Life Support (APLS), Best Guess and Nelson formulae [6–8]. These calculations have the advantage of being fast and make it possible to prepare some drug doses for a critically ill child before the arrival [9]. These methods were conceived using pediatric populations of the western world and have accuracies, which have been shown to vary among different populations [10–13]. Consequently, studies have been carried out in countries across the world [14–17], and in Africa [18–20], with the aim of validating the applicability of these formulae in different settings. This is important, as an underestimation of weight can be associated to a suboptimal therapeutic response, while an overestimation can cause drug toxicity, especially of drugs with a low therapeutic index.

In Cameroon, various weight estimation formulae are used. However, no data exist to our knowledge on the accuracy of these formulae in a Cameroonian pediatric population. To bridge this gap, we set out to assess the accuracy of the Nelson, Best Guess and APLS weight estimation formulae in a suburban Cameroonian pediatric population.

MATERIALS AND METHODS

Study design and protocol

We carried out a cross-sectional study over 7 months (1 February to 31 August 2017), using the immunization centers and outpatient consultation units of two government health facilities (Mankon Sub-Divisional Hospital and the Bamenda Regional Hospital) in Bamenda. Bamenda is the capital of the Northwest Region of Cameroon, located 366 km northwest of the nation's capital, Yaoundé. We included children aged 1 month to 12 years using a consecutive, convenience sampling method. Excluded from the study were children who presented with conditions that could falsify their actual weights [such as malnutrition (mid-upper arm circumference <12.5 cm and or weight for height Z score < –2], acute diarrhea and vomiting and edema of any cause) and critically ill children in need of urgent treatment.

Approval for the study was obtained from the ethical committee of the Northwest Regional Delegation for Health, Cameroon, as well as from the administrative authorities of the various hospitals used as recruitment sites. A signed informed consent was obtained from the parent or legal guardian of children recruited into the study.

Data collection

Data collected included age, sex and weight. Weights were measured using a battery powered portable Seca 216 digital floor scale and readings recorded to the nearest 0.1 kg. Special care was taken that shoes and heavy cloths were removed before weighing. At the beginning of each day, scales were calibrated with a standard 5 kg weight and validated as accurate before use. Collected data were then entered into Microsoft Office Excel 2013 spreadsheets for windows and exported into the STATA software version 13.0 for windows, for statistical analysis.

Data analysis

From the recorded ages, estimated weights using APLS, Best guess and Nelson formulae were computed. Computed weights were then expressed as a percentage of the measured weight (100 × estimated weight/measured weight). We standardized all measured weights to a value of 100%. Standardizing allowed for more accurate clinical relevance as a difference of 1 kg in a child who weighs 5 kg (20% error) is not of equal importance as a difference of 1 kg in a child who weighs 25 kg (4% error).

Estimated weights within 10% (90–110%) of measured weights were considered clinically identical. Estimated weights <90% or >110% of the measured weights were classified as underestimation and overestimation, respectively. Differences between the proportions of clinically identical estimates from the different methods were compared using Cochrane Q test.

Agreement between measured and estimated weights was assessed using Lin's concordance correlation coefficient (CCC), a measure of both precision and bias. CCC was interpreted using the scale proposed by McBride [21] on which CCC values; <0.90, 0.90–0.95, 0.95–0.99 and >0.99 represent poor, moderate, substantial and almost perfect agreement, respectively. Agreement between standardized estimated weights and measured weights was further tested using Wilcoxon sign test. Bland–Altman analysis was conducted using standardized weights from the various estimation formulae and standardized measured weights with limits of agreement (LOA) of −10 to –10% set as criteria for clinical agreement. We concluded with sensitivity analysis by age group (<1 year, 1–6 years and >6 years) and gender.

Table 1. Weight estimation performance per formula and by age groups

Weight estimation formula	<1 year[a]			1–6 years[b]			>6 years[c]		
	<90%[d] (%)	90–110%[e] (%)	>110%[f] (%)	<90%[d] (%)	90–110%[e] (%)	>110%[f] (%)	<90%[d] (%)	90–110%[e] (%)	>110%[f] (%)
APLS[g]	53.9	36.1	10.0	32.8	36.8	30.5	15.0	37.9	47.1
Best Guess	17.0	47.0	36.1	4.6	16.1	79.3	50.0	27.9	22.1
Nelson	12.9	48.9	38.1	29.3	39.5	31.2	11.3	46.2	42.5

[a]Age: 3–11 months.
[b]Age: 12–72 months.
[c]Age: > 72 months.
[d]<90%: Underestimated weight.
[e]90–110%: Correctly estimated weight.
[f]>110%: Overestimated weight.
[g]APLS: Advance Pediatric Life Support.

Table 2. Concordance analysis between measured weight and estimated weight per formula

Weight estimation formula	CCC[a]	Pearson	Bias
APLS[b]	0.92 (0.90–0.93)	0.92	1.00
Best Guess	0.89 (0.87–0.90)	0.90	0.99
Nelson	0.88 (0.86–0.90)	0.90	0.98

[a]CCC = concordance correlation coefficient.
[b]APLS = Advanced Pediatric Life Support.

RESULTS

Of the 544 children enrolled, 54.2% were male and 45.8% were female. The median age was 19.2 months [interquartile range (IQR) 6.0–60.0]. Measured weights ranged from 3.3 to 55.0 kg with a median weight of 19.2 kg (IQR 8.2–20.0). The <1 year age group made up 42.3% (230 of 544) of the study sample, while the 1–6 years and >6 years age group made up 40.3% (219 of 544) and 17.5% (95 of 544) of the study sample, respectively.

Nelson's formula correctly estimated weight in a greater proportion of our sample [43.9% (95% confidence interval, CI = 39.4–48.7)], compared with the Best Guess [32.2% (95% CI 28.2–36.1)] and APLS [36.8% (95% CI 32.7–40.8)] formulae. The difference in proportions of correctly estimated weights was statistically significant both for Nelson and APLS formulae compared with Best Guess formula ($p < 0.001$). There was no statistically significant difference between the proportions of correctly estimated weight by Nelson formula and APLS formula ($p = 0.053$).

The proportion of correctly estimated weights was identical for both male and female participants using the APLS ($p = 0.09$) and Best Guess ($p = 0.45$) formulae. However, Nelson formula was more accurate in estimating weight for males (48.4%) compared with females (38.5%); $p = 0.02$. The proportion of correctly estimated weights for each formula varied considerably among the different predefined age groups as demonstrated in Table 1.

Results of concordance analysis between the measured weights and estimated weights using each formula are shown in Table 2, and are graphically displayed on reduced major axis regression graphs (Figs 1–3). The level of agreement between measured weight and estimated weight was poor for Best Guess and Nelson formula; CCC of 0.89 (0.87–0.90) and 0.88 (0.86–0.90), respectively, and moderate for the APLS formula; CCC of 0.92 (0.90–0.93).

On Wilcoxon signed rank test, the difference between measured weights and estimated weights computed using the APLS, Nelson and Best Guess formulae was statistically significant ($p = 0.015$ for the APLS formula; $p = 0.000$ for both Nelson and Best Guess formulae).

On Bland–Altman analysis, 95% LOA were −42.2 to 45.6% for the APLS formula, −42.7 to 55.1% for Best Guess formula and −36.4 to 42.4% for Nelson's formula, all above the −10 to 10% threshold set

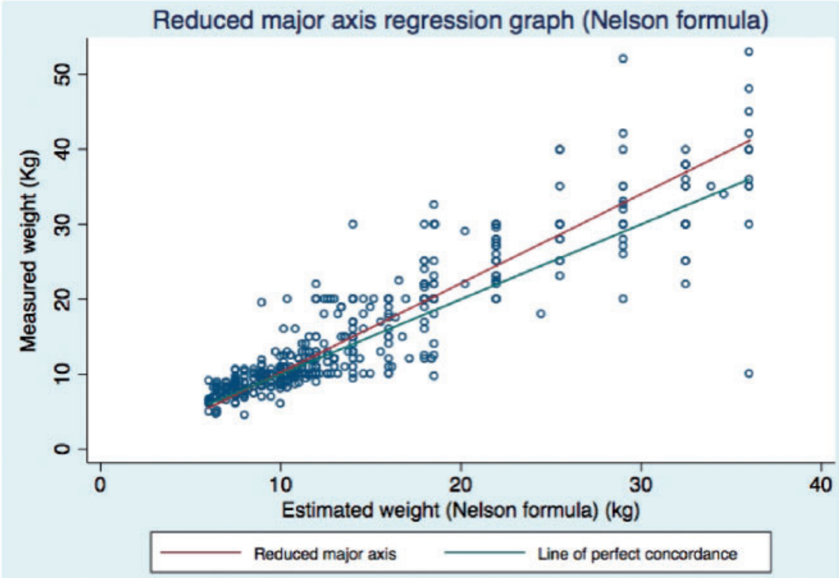

Fig. 1. Reduced major axis regression graph for Nelson's formula.

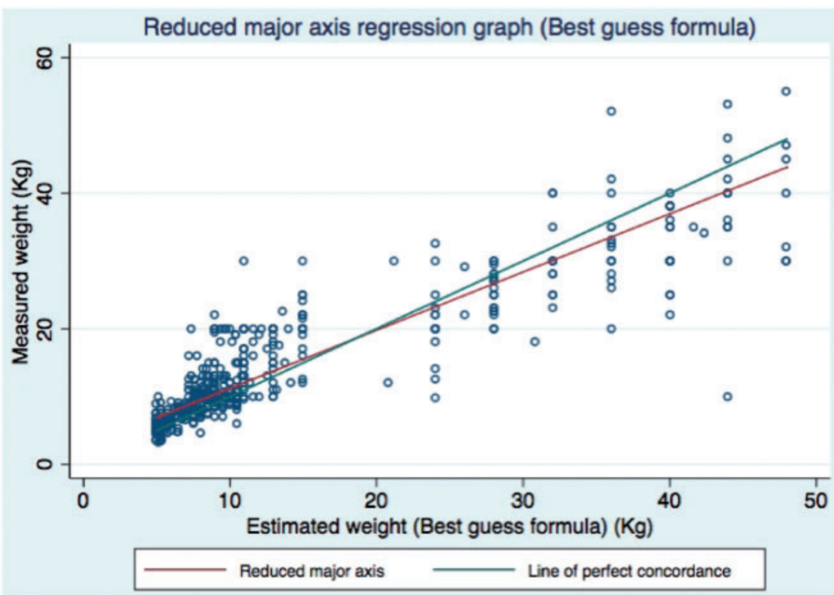

Fig. 2. Reduced major axis regression graph for Best Guess formula.

as criteria for clinical agreement (Figs 4–6 and Table 3).

DISCUSSION

Overall, Nelson's formula correctly estimated weight in a greater proportion of the sample than the Best Guess and APLS formulae. However, none of the studies accurately estimated weight in up to 50% of the sample.

The performance of each method varied considerably within different age groups. The APLS formula mostly underestimated weight, a finding similar to

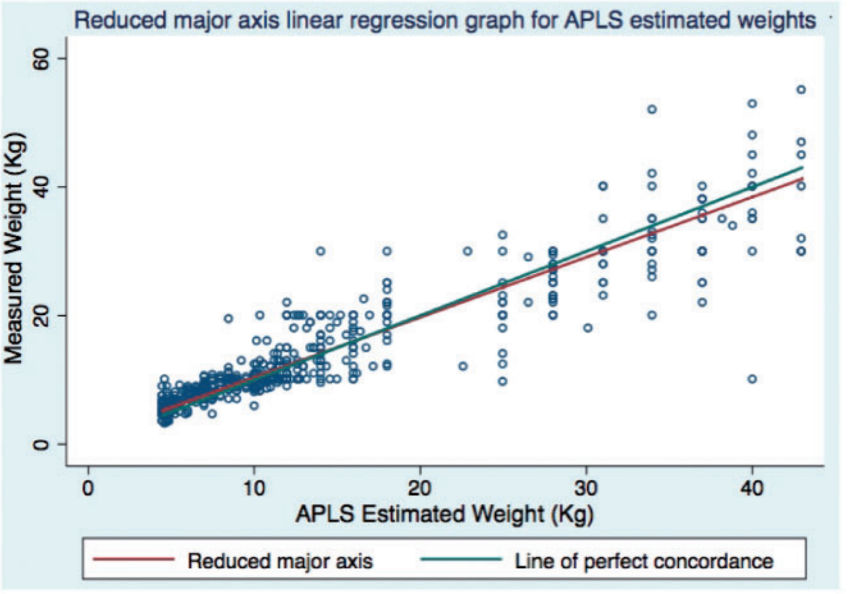

Fig. 3. Reduced major axis regression graph for APLS formula.

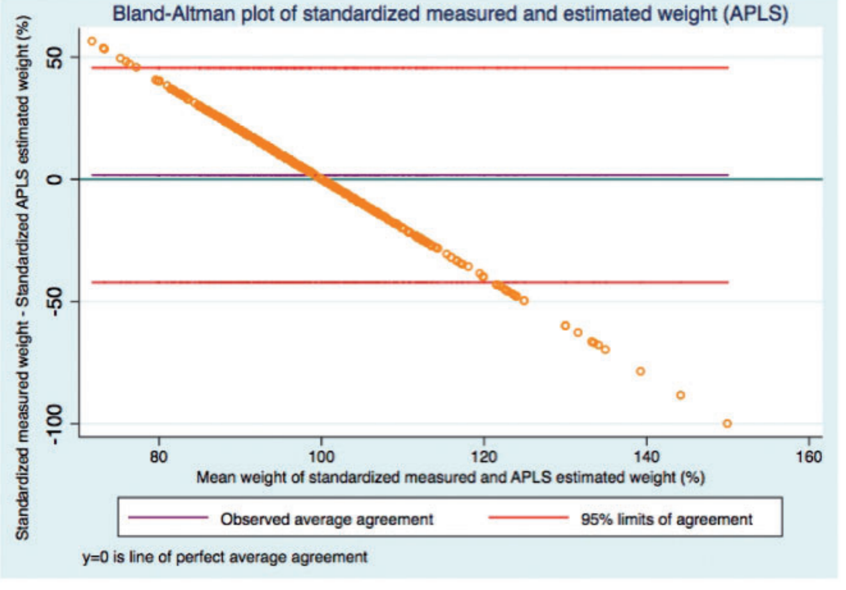

Fig. 4. Bland–Altman plot of difference between standardized weight and APLS estimated weight (expressed as a percentage of the measured weight) against the average of measured and APLS estimated weight expressed in percentages.

that obtained from studies done in Trinidad [17], and the UK [22]. In India, however, Varghese *et al.* [12] found the APLS formula to overestimate weight in their population. The Best Guess formula on the other hand mostly overestimated weights, consistent with findings of Omisanjo in Nigeria [20]. Similarly, Nelson's formula mostly overestimated weights, agreeing with reports from studies done in Nigeria

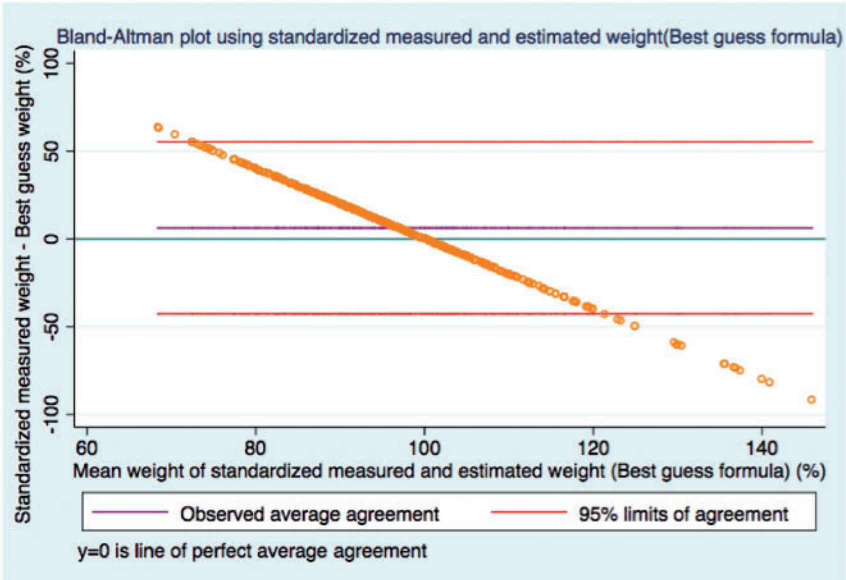

Fig. 5. Bland–Altman plot of difference between standardized weight and best guess estimated weight expressed as a percentage of the measured weight against the average of measured and APLS estimated weight expressed in percentages.

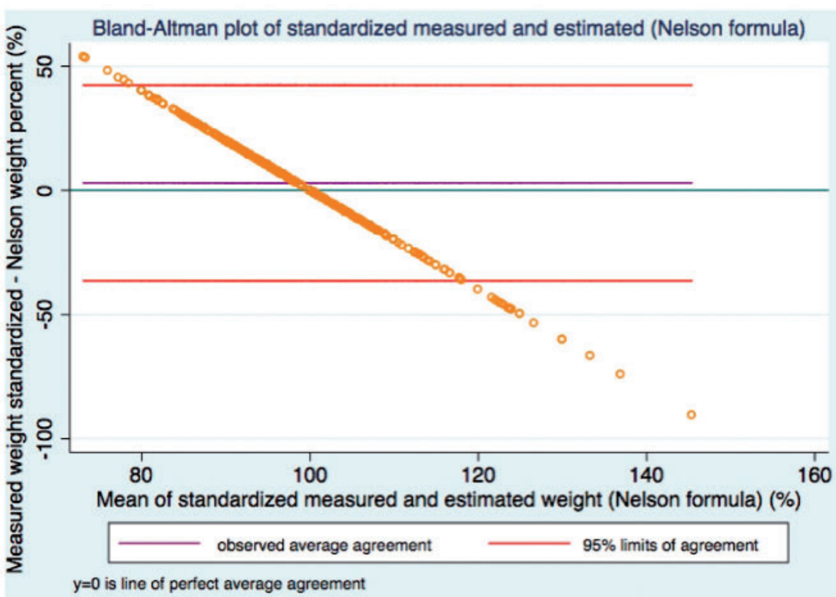

Fig. 6. Bland–Altman plots of difference between standardized weight and Nelson estimated weight expressed as a percentage of the measured weight against the average of measured and Nelson estimated weights expressed in percentages.

Table 3. Comparison of APLS, Best Guess and Nelson methods using Bland–Altman analysis

Weight estimation formula	Mean difference (%)	95% LOA[a]
APLS[b]	1.7	−42.2 to −45.6
Best guess	6.2	−42.7 to −55.1
Nelson	3.0	−36.4 to 42.4

[a]LOA = limits of agreement.
[b]APLS = Advanced Pediatric Life Support.

[20], Kenya [19] and India [12]. These findings could be explained by the fact the Nelson and Best Guess formulae were obtained in developed countries, where undernutrition is not as common as in developing settings like ours [23]. Compared with developing countries, children of a particular age group from developed countries have a greater body mass index. Indeed, Kelly *et al.* [24] noticed that the Best Guess formula overestimated weight in children with a low body mass index. The same trend has been reported from other developing countries [12, 19, 20, 25].

Concordance analysis between measured weight and estimated weight was poor for Nelson and Best Guess formulae, and moderate for the APLS formula. This highlights the low accuracy of these formulae in estimating weight in our study population. An explanation to this could be a difference in growth rates that may exist between the pediatric populations in which the formulae were derived and ours. In effect, a recent systematic review comparing data on certain anthropometric parameters (including weight) from about 55 different countries or ethnic groups to data obtained from the World Health Organization (WHO) Multicenter Growth Reference Study (MGRS) revealed variations in weight among different countries or ethnic groups [26]. This could account for the variability in the accuracy of various weight estimation methods when used in a country or ethnic group different from that in which they were derived.

On Bland–Altman analysis, all three methods estimated weight with LOA above those set as threshold for clinical significance, further supporting the lack of accuracy of these formulae at estimating weight in our study population. This poor accuracy of all three methods is concordant with results obtained by Wells *et al.* [27], who on evaluation of 20 different age-based pediatric weight estimation formulae (including the three evaluated in this study), using data from low- and middle-income South African children, found none to have reached an acceptable benchmark of accuracy. These findings were explained by the fact that no population could be homogeneous enough for age-based formulae to be effective. Also, age-based formulae have been shown to overestimate weights in settings with a high prevalence of underweight children [10, 28], and underestimate weights in settings with a high prevalence of overweight children [15].

As limitations, our study was done using one pediatric population only, which might not be representative of the entire Cameroonian pediatric population and therefore not generalizable; there was a skew of the study population toward the younger age groups, limiting the age group in which our results may be applicable to. However, a Wilcoxon sign test (which does not assume normality) done had results similar to those obtained from concordance analysis, making us confident of the applicability of the results obtained across the different age groups assessed.

In conclusion, the accuracy of all three formulae in estimating weight was clinically unacceptable in our study population. We suggest that similar studies be done using larger sample sizes nationwide, to validate our findings and possible derive more accurate formulae adapted for use in our context.

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