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Original article

Comparison of paediatric weight estimation methods at a tertiary hospital in Ghana

Rafiuk Cosmos Yakubu [a,b,*], Samuel Blay Nguah [a,c], Nedda Ayi-bisah [a,b]

[a] Department of Child Health, Komfo Anokye Teaching Hospital, Kumasi, Ghana
[b] Tamale Teaching Hospital, Tamale, Ghana
[c] Kwame Nkrumah University of Science and Technology, School of Medicine and Dentistry, Kumasi, Ghana

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ABSTRACT

Introduction: Weight estimation in children is critical in paediatric emergencies. The Broselow Tape (BT) and most age-based formulae for weight estimation were derived in high-income countries and are thought to overestimate the weight of children in low-income countries. This study sought to validate the 2017 BT, and eight age-based weight estimation formulae among Ghanaian children and to derive a weight estimation formula using this data.

Methods: A cross-sectional study was conducted in the Tamale Teaching Hospital (TTH) in Ghana. Children aged between 2 months and 13 years had their weights estimated by the 2017 BT and eight age-based formulae. These estimated weights were compared to the weight of the children measured by a calibrated Seca scale using mean percentage error (MPE) and the percentage of weight estimates within 10% and 20% of actual weight. Bland-Altman method was used to assess agreement between estimated and actual weight of the children. A new formula was derived by linear regression.

Results: Seven hundred and seventy-five children took part in the study. The 2017 BT, Original APLS (APLS1) and Nelson's formulae performed best with proportion of weight estimates within 10% of actual weight being 47.5%, 51.1% and 47.5% respectively. The formula developed in this study was: $W_E = 3Am / 10 + 5$ (for infants <12 months), $W_E = 2A + 7$ (1 to 4 years) and $W_E = 2A + 9$ (5 to 13 years), where W_E is estimated weight, A_m is age in completed months and A is age in completed years. The new formula had similar accuracy as the three best performing methods in this study.

Conclusion: The Broselow Tape, APLS1 and the Nelson's formula were the most accurate in this study. APLS1 and the Broselow Tape can be used for weight estimation in Ghanaian children when no other better method is available.

African relevance

- This is the first study of weight estimation among children in Ghana.
- A new age-based weight estimation formula was derived using data from Ghanaian children.
- The Original APLS and Nelson's formulae were the most accurate age-based methods of weight estimation.
- The 2017 Broselow Tape was most precise method of weight estimation.

Introduction

The weight of a child is required for calculating dosages of drugs, volumes of resuscitation fluids, determining ventilator settings and the size of equipment to be used on critically ill children. Accurate dosages of drugs and volumes of fluids are required to ensure appropriate response to treatment and avoid drug toxicity. Children are weighed on calibrated scales to obtain the weight on which drug dosage calculation and other medical interventions are based. In emergencies [1] and in low-income countries where calibrated scales are not always available [2] it may not be possible to weigh children, so clinicians often rely on weight estimates based on the age or height/length of the child. The

* Corresponding author at: Tamale, West Africa, Ghana.
E-mail address: rafiukcosmos@gmail.com (R.C. Yakubu).

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most commonly used weight estimation systems are the Broselow Tape (BT), developed in the United States of America [3] and age-based formulae derived using data of children predominantly from high-income countries [4–6].

There are newer methods of weight estimation that combine height/length of a child or a surrogate such as humeral length and a measure of body habitus which is either subjectively determined [7] or derived from a measure of mid-arm circumference (MUAC) [8,9]. These two-dimensional methods have been shown in many studies to be more accurate than methods using age, length or MUAC alone, but are still not widely available in developing countries like Ghana [10–12]. There is variability in the performance of various weight estimation systems in various parts of the world and among different ethnic groups and races [5]. In high income countries for instance, the BT and the older age-based weight estimation methods like the Original Advanced Paediatric Life Support (APLS1) formula, have been shown to underestimate the weight of children [13,14]. In low and middle income countries however, the BT and the newer age-based methods of weight estimation have been shown to overestimate the weight of children, sometimes to potentially dangerous degrees [15–17]. It is therefore important to ensure that weight-estimation methods are validated in one's own setting [10]. Also, weight estimation formulae are likely to perform better in the population in which they were derived. To the best of the author's knowledge, no method of weight estimation has been validated in a population of Ghanaian children and no formula has been derived using data from Ghanaian children.

Even though similar studies have been conducted elsewhere, some of these were retrospective studies [10], involved healthy children outside clinical settings [18] or used virtual BT weight estimates. In this study, however, we recruited children presenting to the hospital prospectively and used the BT to estimate their weights rather than predicting their BT weight estimates using height/length measurements.

This study sought to validate the 2017 BT and eight age-based weight estimation formulae (Table 1) namely the original (2005) Advanced Paediatric Life Support formula (APLS1) and the revised (2011) Advanced Paediatric Life Support (APLS2) formula, Argall [4], Best Guess (BG) [6], Chinese Age Weight Rule (CAWR) [19], Luscombe [13], Michigan [20] and Nelson's [21] formulae among a Ghanaian paediatric population. We also sought to derive a simple to use weight estimation formula using data from these children.

Table 1
Age-based weight estimation formulae.

Name	Formula	Age-range (years)	Country of origin
APLS1	(2 × Age in years) + 8	1–12	UK
APLS2	(0.5 × age (months) + 4)	1–11 months	UK
	(2 × age) + 8	1–5 years	
	(3 × age) + 7	6–12 years	
Argall	(3 × age) + 6	1–10 years	UK
Best Guess	(age in mo + 9) / 2	<12 months	Australia
	(2 × age) + 10	1–5 years?	
	4 × age	6–14 years?	
Chinese Age Weight Rule	(3 × age) + 5	1–10 years	Hong Kong (ethnic Chinese)
Luscombe	(3 × age) + 7	1–10 years	UK
Michigan	(3 × age) + 10	2–12 years	USA
Nelson	(age (months) + 9) / 2	3–11 months	USA
	(2 × age) + 8	1–6 years	
	((age × 7) − 5) / 2	7–12 years	

APLS1 – Original Advanced Paediatric Life Support formula, APLS2 – New Advanced Paediatric Life Support formula, UK – United Kingdom, USA – United States of America.

Methods

This was a prospective cross-sectional study conducted at the Tamale Teaching Hospital (TTH), an academic tertiary hospital in Ghana, from March through May 2019.

Study population

Children between the ages of 2 months and 13 years were included in the study. Children who needed immediate resuscitation, had conditions that could affect their weight like oedema or were on medications that could affect their weight including long term steroids were excluded from the study. Also excluded from the study were children with limb deformities like contractures that precluded an accurate measurement of their length/height and those children who were taller than the BT (143 cm) or who were severely malnourished.

Sample size

To determine a minimum of 10% difference between any two weight estimation methods in the proportion of children estimated within 10% (P10) of their body weight the following were employed in calculating the sample size. Using a significance level of 0.01 and a power of 0.9, 754 patients were required for the study.

Also, using an alpha of 0.05 and power of 80%, we determined that a minimum of 47 patient measurement pairs was required to determine a minimum correlation coefficient of 0.4 between two measurements by two independent estimators.

Study procedure

Children attending the children's emergency unit, admitted to the paediatric in-patient wards or attending the out-patient's department of the TTH were assessed for inclusion into the study. For those who fulfilled the inclusion criteria, informed consent was obtained from the parent or caretaker of the child and assent from children 7 years and above. Data was then taken and entered into a structured case report form. Data taken included age and gender. The BT estimated weight was then determined by allowing the child to lie supine on a flat surface and the BT placed alongside the child from the crown of the head to the heel. The weight at the same horizontal location as the heel of the child was recorded as the BT estimated weight. The height of children aged >2 years old was taken using a calibrated Seca stadiometer to the nearest 0.1 cm. Data was collected by either of two investigators (RCY and NA), however, forty-seven randomly selected children had their BT estimated weights done by both data collectors concurrently to determine inter-rater reliability.

Data management and statistical analysis

Data was double entered into two separate but identical databases created using Epidata version 4.4.2 by two different data entry clerks immediately after collection. The two sets of data were compared at the end of each day and discrepancies rectified using the hard copies of the case report forms. At the end of data collection, the completed dataset was exported to Stata SE version 14.1 for further cleaning and analysis. Continuous numerical variables were summarised and presented as their means and standard deviations when normally distributed and as their medians and interquartile ranges when not. Categorical variables were presented as counts with their corresponding percentages.

The estimated weights, using the eight different age-based formulae were calculated using the ages of the study participants (Table 1).

The primary outcome measure was the proportion of children whose weight were estimated within 10% (P10) and 20% (P20) of their actual weight by each method, a measure of the accuracy of each method. The precision of the weight estimation methods, denoted by Bland-Altman

Limits of Agreement (LOA = MPD ± 1.96SD) was the secondary outcome measure. The LOA define the range in which 95% of the differences between two methods of clinical measurement are expected to lie. Bland-Altman graphs with their LOA were plotted using Mean Percentage Difference (MPD = 100 * (W_E − W_A) / (W_E + W_A)), where W_A is the actual weight and W_E is the estimated weight, as the measure of bias for the plots [22,23]. The narrower the LOA the more precise the method.

Weight estimation bias/trueness was computed by finding the difference between estimated weights and the actual weight (Estimated weight, W_E − Actual weight, W_A) and their average determined as the Mean Error (ME). Since absolute weight differences hold different significance as a child grows older the weight differences were expressed as percentages of the scale-measured weights of the children and the mean determined as the Mean Percentage Error (MPE) as follows: 100 * (W_E − W_A) / W_A.

To determine if a significant difference exist between the accuracies of the various weight estimation methods, the P10 and P20 were pairwise compared using McNemar's test and reported as p-values after applying the Holm's correction for multiple comparison. In all analysis, a two-sided p-value <0.05 was considered as an indication of a statistically significant relationship.

In deriving the new formula using the data from this study, children were randomly divided into two equal groups: A derivation set and a validation set. The children who formed the derivation set were then divided into three age categories based on the points of inflexions of the curves into Infants (<1 year old), Pre-schoolers (1 to 4 year-olds), and School aged children (5 to 13 year-olds). Linear regression equations were derived to describe the mathematical relationship between age and weight for each age category. The resulting equations were then simplified to facilitate use in a clinical setting. The resulting equations were internally validated by applying these equations to the other half of children who did not form part of the derivation set using P10, P20, MPE and the Bland and Altman's method.

Determination of inter-observer reliability between BT measured weights was by intraclass correlation coefficient using data from 47 children who were measured concurrently but independently by two investigators.

Ethical approval for the study was granted by the Ethics Review Committee of the TTH (ID: TTHERC/17/01/18/01).

Results

Characteristics of study participants

Of the 840 children screened for the study, 65 were taller than the BT, leaving 775 children for final analysis of whom 432 (55.7%) were males. The children had a median age (IQR) of 52 months (27–87 months). The mean weight (±SD) of the participants was 17.2 kg (±7.8 kg) with a mean BMI of 15.1 kg/m^2. A greater proportion of the children had normal BMI (82.9%). The demographic and anthropometric characteristics of the children are shown in Table 2.

Derived formula for weight estimation

Using the data obtained, the linear relationships derived between the age and weight are as shown in Supplementary Table 1 and Supplementary Fig. 1. Simplification of the formula resulted in the estimated weight being: $W_E = 3A_M/10 + 5$ for children aged 2 months but less than a year, $W_E = 2A + 7$ for children 1 to 4 years old and $W_E = 2A + 9$ for children 5 to 13 years. For these formulae, A_M is the age in completed months, A is the age in completed years and W_E is the formula estimated weight.

Table 2
Distribution of ages, weights, heights and BMIs for the study participants.

	Males	Females	Total
Number (%)	432 (55.7)	343 (44.3)	775 (100.0)
Age in months *median (IQR)*	50(24–83)	55(30–95)	52(27–87)
Age category *n(%)*			
<1-Year	55 (12.7)	29 (8.5)	84 (10.8)
1 to 5 years	194 (44.9)	152 (44.3)	346 (44.7)
6 to 13 years	183 (42.4)	162 (47.2)	345 (44.5)
Weight (kg) *mean (SD)*	16.7 (7.6)	17.8 (8.0)	17.2 (7.8)
Weight category *n(%)*			
<10 kg	96 (22.2)	57 (16.6)	153 (19.7)
10 to 25 kg	271 (62.7)	220 (64.1)	491 (63.4)
>25 kg	65 (15.1)	66 (19.3)	131 (16.9)
Height (cm) *mean (SD)*	111.8 (17.0)	113 (16.8)	112.4 (16.9)
BMI (kgm^{-2}) *mean (SD)*	15 (1.6)	15.1 (1.9)	15.1 (1.7)
BMI categorization *n(%)*			
<5th percentile	38 (11.5)	29 (10.3)	67 (10.9)
5 to 85th percentiles	277 (83.4)	232 (82.3)	509 (82.9)
>85th percentile	17 (5.1)	21 (7.4)	38 (6.2)

Bias, accuracy and precision of the various methods of weight estimation

Table 3 shows the bias and proportion of weight estimates within 10% and 20% of actual weight for the various methods. All the methods except APLS1 overestimated the weight of Ghanaian children with the greatest degree of overestimation by the Michigan formula, with MPE of 38.3. The BT, APLS1 and the Nelson's methods were the most accurate methods with similar P10 values (Table 3 and Fig. 1). The P10 and P20 of these methods were also significantly better than the other methods studied (Supplementary Table 2). The BT had the narrowest LOA and so was the most precise method (Table 4 and Supplementary Figs. IIa and IIb). The new derived formula performed with similar accuracy as the BT, APLS1 and Nelson's methods (Supplementary Table 3).

Inter-rater reliability

The Intraclass Correlation Coefficient of weight measurements made by the BT by the two study raters was 0.996 (95%CI: 0.994 to 0.998, $p < 0.001$) which indicated good agreement between the two study raters.

Discussion

We set out in this study to determine the accuracies of the 2017 edition of the BT and eight age-based weight estimation formulae. In this study the 2017 BT, APLS1 and Nelson's formulae gave better weight estimates than the other age-based methods studied. The BT was more precise than all the age-based formulae, evidenced by its narrower LOA. Despite having a higher bias (9.42%) than APLS1 (1.11%) and the Nelson's formula (4.41%) a more precise method like the BT is more amenable to fine tuning to improve its performance compared to the inherently imprecise age-based formulae with wider LOA (Table 4).

Many studies and recent meta-analyses [15,24] of weight estimation methods have shown that the BT provides better weight estimates than

Table 3
Comparison of bias and accuracy of the various weight estimation methods.

	ME	MPE	RMSE	RMSPE	P10	P20
APLS	−0.45	1.11	3.55	15.91	51.09	80.61
APLS2	2.12	11.49	4.90	24.03	38.00	62.78
Argall	2.24	12.80	4.51	23.08	35.94	60.30
Best Guess	3.67	21.90	5.96	30.80	25.55	47.23
Broselow	1.45	9.42	2.77	14.80	47.48	82.32
CAWR	1.24	6.37	4.11	20.48	34.59	68.72
Luscombe	3.24	19.24	5.08	27.23	26.92	50.23
Michigan	6.87	38.30	8.08	43.60	5.60	17.30
Nelson	0.32	4.41	3.61	17.79	47.51	77.49
Derived formula	−0.46	−1.21	3.13	15.90	50.13	78.04

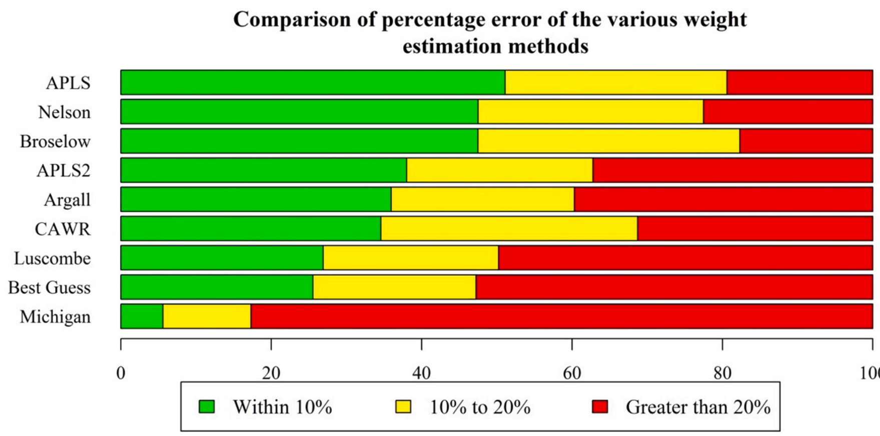

Fig. 1. Comparison of the percentage errors of the various weight estimation methods. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 4
Bland-Altman's Bias and limits for the percentage difference of the various weight estimation results.

	Bias (MPD)	Bias (95% CI)	LLA	LLA (95% CI)	ULA	ULA (95% CI)
APLS1	−0.2	−1.4 to 1.0	−31.6	−33.6 to −29.5	31.3	29.2 to 33.3
APLS2	9.0	7.7 to 10.3	−27.6	−29.9 to −25.4	45.7	43.4 to 47.9
Argall	10.5	9.2 to 11.8	−23.4	−25.6 to −21.1	44.3	42.1 to 46.6
Best Guess	18.0	16.8 to 19.3	−16.4	−18.5 to −14.3	52.5	50.4 to 54.6
Broselow	8.4	7.7 to 9.2	−12.5	−13.8 to −11.3	29.4	28.1 to 30.7
CAWR	4.4	3.0 to 5.9	−32.0	−34.4 to −29.5	40.8	38.4 to 43.2
Luscombe	16.1	14.9 to 17.4	−16.0	−18.2 to −13.9	48.3	46.1 to 50.4
Michigan	30.8	29.6 to 32.0	0.9	−1.2 to 3.0	60.7	58.7 to 62.8
Nelson	2.9	1.7 to 4.1	−29.6	−31.6 to −27.6	35.5	33.5 to 37.5
New formula	−2.5	−4.1 to −0.88	−34	−36.85 to 31.5	29.10	26.35 to 31.85

all age-based weight estimation formulae. A study in Rwanda by Manirafasha et al. [10]; however, found that, the accuracy of the BT depends on the version of tape used with the latest versions of the tape not performing significantly better than APLS1 in developing countries, as shown in this present study. The latest versions of the BT have been adjusted to better estimate the weights of an increasingly overweight and obese paediatric population in developed countries and so when applied to populations with higher degrees of undernutrition it tends to overestimate the weight of children to a greater extent [25]. For instance, a similar study in Nigeria using the 2017 edition of the BT among children in a setting with lower rates of underweight and stunting than Tamale showed a slightly lower degree of overestimation (MPE = 6.67%) and slightly better accuracy (P10 of 57.1% and P20 of 87.2%) than in the current study (MPE of 9.42% and P10 = 47.5%, P20 = 81%).

The new formula derived in this study is as accurate as the BT, APLS1 and Nelson's formulae which were the best performers in this study. Even though it can be used in a wider age-range than APLS1, it is more complex, with different formulae for three different age categories and so may be prone to a greater degree of error in clinical use than APLS1.

The variation in the performance of age-based formulae among different races and ethnic groups have led to calls for the derivation of new formulae specific for children in particular populations especially in developing countries [18]. Efforts to do this have failed to derive formulae with significantly better accuracies even with the inclusion of body habitus adjustment [10,26]. A recent formula derived using data from Rwandan children, the Rwanda Rule [10], did not perform significantly better than APLS1, just as the new formula in this study was not significantly more accurate than APLS1, albeit with slightly better accuracy than the study in Rwanda (P10 and P20 of 39.4% and 68.5% respectively for Rwanda rule and 50% and 78% for the new formula in the current study). It appears unlikely that age-based formulae will be able to reach a high level of accuracy because of the wide variation that exists in weight-for-age and the non-linear relationship between weight and age even when ethnicity and race are taken into account [27].

In the advent of the newer, more accurate dual length-based, habitus modified systems of weight estimation, some authorities have suggested that use of the BT and age-based formulae should be abandoned [16,26]. There is, however, no consensus in the literature what the benchmark accuracy for a weight estimation system should be. Also, the new methods are currently not widely available in low and middle income countries [28]. While Wells et al. [15] suggest a benchmark accuracy indicator of a P10 > 70% and P20 > 95%, Manirafasha and colleagues consider a P20 of ≥69% acceptable when no other more accurate methods are available [10]. It is, however, noteworthy that there is no objective evidence upon which these benchmarks are based or what degree of weight estimation error is tolerable even though it is reasonable to assume that this will depend on the therapeutic index and toxicity of specific medications. Clinicians would therefore have to choose the most accurate method available to them in circumstances that require weight estimation.

An ideal weight estimation method should be cheap, readily available, easy to use and provide accurate weight estimation across a broad range of age, length, stature and ethnicity. None of the methods studied here is ideal. Age-based rules are inherently inaccurate and imprecise and depend on knowledge of the age of the child (which may not always be available) and on correct recollection of the formula and performance of the required computations which may be difficult to do in emergency situations. All of these formulae have narrow age restrictions and cannot provide weight estimates for some age groups. The BT despite being more accurate and precise than the age-based methods with the additional advantage of having drug-dose and equipment size information to aid resuscitation has been unable to reach the high levels of accuracy demonstrated by the dual length-based, habitus-modified systems because the BT fails to adjust for body habitus. It is also expensive and not available in most facilities in Ghana. Some recent studies have however suggested that the drug dosing information on the BT was not sufficient for it to be used by itself as a resuscitation aid [16]. Another problem with the BT is that there is a significant number of adolescent children 10 years and above who are too tall for the tape and who cannot be considered to be of adult weight [29]. In this study 56% of children aged 10 years and above were taller than the BT. The newer methods of weight estimation have demonstrated in studies elsewhere to be more accurate and capable of being used in children up to 16 years of age [8] and also in adults 18 years and above [30]. It would be useful to study these methods and evaluate their use in our setting.

While all the methods of weight estimation in this study failed to reach the level of accuracy suggested by Wells et al. [15], the BT, APLS1, Nelsons formula and the new derived formula met the recommendation by Manirafasha et al. [10] in the absence of other more accurate methods. Until more accurate methods of weight estimation are available in Ghana, APLS1 should be chosen over other age-based formulae. The BT can be used in centres with access to this device in the absence of other more accurate methods. In view of the availability of newer, more accurate methods of weight estimation we will recommend research of the 2D weight estimation systems and possible adoption in our clinical practice if found in our setting to be more accurate, to ensure that the most accurate weight estimate is used for medical interventions in situations requiring weight estimation for children.

This is, to the best of the authors knowledge the first study comparing weight estimation methods in Ghana and to derive a formula using data from Ghanaian children. This was a single centre study and only children presenting at the times the study raters were available were included in the studies. A greater proportion of the children included in the study were younger than 10 years and had normal BMI. These may limit the generalisability of our results.

Dissemination of results

These results were presented as a dissertation to the West Africa College of Physicians for the award of a fellowship in the faculty of paediatrics.

CRediT authorship contribution statement

RCY and SBN conceptualised the study. RCY designed the study and got ethical approval for the study. RCY and NA collected the data. SBN did the statistical analysis. RCY wrote the manuscript which was critically reviewed by SBN and NA. All the authors approved the final version of the manuscript. The approximate proportions of the work done by each contributing author are RCY (60%), SBN (25%) and NA (15%).

Authors' contribution

Authors contributed as follow to the conception or design of the work; the acquisition, analysis, or interpretation of data for the work; and drafting the work or revising it critically for important intellectual content: RCY conributed 60%, SBN 25% and NA 15%. All authors approved the version to be published and agreed to be accountable for all aspects of the work.

Declaration of competing interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.afjem.2021.03.005.

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