A Comparison of the Performance of the Midarm Circumference and the Nelson Weight Estimation Formulas in Nigerian Children

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Abstract

Background: In emergencies, two commonly used weight estimation methods are Nelson and mid-arm circumference (MAC)-based formulae. Nelson's method requires the child's age while the MAC formula offers weight estimation without any prior details of the child, which is useful in our environment due to the lack of proper vital statistics documentation. **Methodology:** We measured the weight, height, and MAC of 1390 children aged 1–12 years. Values got from the measurements were substituted in MAC and Nelson formulae for weight estimation. The estimated weights were compared to the actual weights of the children. **Results:** A total of 1390 children were enrolled. The mean of enrolled children's actual weight was significantly higher than the mean weight estimated using MAC and Nelson formula. MAC method overestimated weight in children 1–7 years and underestimated weight in those 8–12 years old. On the other hand, the Nelson formula underestimated weights in children 2–11 years and overestimated weight in 1 and 12-year olds. **Conclusions:** Both the MAC and Nelson method have their deficiencies in weight estimation. Though the Nelson formula appears slightly more accurate than the MAC, weight estimates from both methods were mostly within the actual weight agreement limits.

Keywords: Actual weight, children, comparison, formulae, mid-arm circumference, nelson

Introduction

Medications, intravenous fluids, and equipment sizes (endotracheal tube etc.) used in pediatric patients are computed based on weight.[1] Ideally, all pediatric patients should be weighed; however, this may not be possible at all times, as in emergencies, trauma, etc. Therefore, different methods have been used to estimate weight, each with its advantages and disadvantages.[2-5] The weaknesses of these tools and formulae remain that they under/overestimate weight among children with increasing variability in patients who are at extremes of nutritional status (undernourished or obese) and also among children of different race and ethnicity.[2-5]

Age-based weight estimation in the pediatric population is based on the child's correct age and remembering the right formula for that age. The caregiver who took the child to the hospital in an emergency may not know the child's age. The memorization of age-based formulas like the Nelson formula is encouraged on advanced life support courses; still, memory is capricious in emergencies.[6] Increased stress causes errors in calculations and may lead to mistakes.[6] With the limitations associated with the currently available weight estimation tools and formulae, researchers worldwide are still searching for better ways to estimate weight.[5] A simple, reliable anthropometric tool for rapid estimation of weight in emergencies will be invaluable in resource-poor settings where appropriate weight estimation tools may not be uniformly reliable. A weighing scale may not be immediately available in health centers or to the first-response providers.

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The mid-arm circumference (MAC) is one of such proposed methods of weight estimation.[5,7-10] The MAC has been widely used as an indicator of childhood nutrition status in resource-poor countries.[11] The performance of MAC in weight estimation in children compared with other weight estimation tools has been researched in the context of malnutrition categories based on the MAC.[7] It has long been known to correlate with weight.[1,12] However, the first MAC-based weight estimation tool was only published 10 years ago among Chinese children. The formula states thus: Weight in kg= (MAC in cm − 10) ×3.[1] It performed well in older children, but poorly in pre-school children.[1,12] Furthermore, among Filipino children aged 1–12 years old, MAC demonstrated the most robust relationship and correlation to weight compared to other methods.[5] It was the most accurate and precise in predicting the weights, regardless of body mass index (BMI).[5]

We hypothesized that MAC could provide the basis of a more reliable and readily available weight estimation tool than the Nelson formula when compared with actual weights among children in Enugu Nigeria. Therefore, this study compared the Nelson formula and the MAC-based formula with children's actual weight in Enugu Nigeria.

Methodology

Study area

A multicenter cross-sectional study was conducted concurrently over two and a half years between January 2017 and May 2019 in two tertiary hospitals: The Enugu State University Teaching Hospital and the University of Nigeria Teaching Hospital, both in Enugu state. These hospitals offer specialized medical services and serve as a referral center to primary, secondary, and private health facilities from within and outside Enugu state.

Study participants

Children aged 1 to 12 years who presented to the emergency room and outpatient clinic were included in the study and consecutively enrolled. Children whose parents/caregivers refused to consent, and those who informed consent could not be reasonably given because of the child's medical condition were excluded from the study. We also excluded children with severe medical conditions such that an actual weight cannot be measured, and those with any medical condition which could substantially affect the weight or height of the child. These include but are not limited to amputation, growth hormone deficiency, severe joint contractures, neurological defects, severe edema, or severe dehydration. None of the children enrolled were on any growth-limiting medications. There was no form of coercion. The researchers made known to the parents/caregivers that they were free to withdraw their children from the study at any time and this will have no effect on their treatment or hospital visit. All those who met the criteria for inclusion were enrolled consecutively till the sample size was met.

Sample size calculation

The number of study participants in this study was calculated using the Cochran formula, $N = f(\alpha,\beta).2s^2/(\delta)^2$ for calculating sample size based on a confidence interval of 95% is equivalent to a confidence coefficient of 1.96.[13]

N = minimum sample size;[13]

α=0.05 was taken for level of significance;[13]

1-β= power of the test (β was assumed to be 0.9, so 1-β was calculated to be 0.1);[13]

δ= the smallest difference in means was 10%;[13]

s = standard deviation of 20 from a previous study done on age-based weight estimation by Eke *et al*.[14]

The minimum sample size was 1008 children for all age categories.

Measures and data collection

The actual weights of the children were measured using the Omron digital scale (HN-289-EB) for children ≥2 years old. An infant weighing scale was used for those <2 years old. They were weighed wearing light clothing and no footwear. Weights were rounded off to the nearest 0.1 kg. Height was measured using a stadiometer [SECA213, Hamburg August 2014] for children two years and above, while the length of children <2 years was measured using SECA headboard.) The formula, weight in kilogram and height/length in meters was used to calculate the BMI. The BMI was categorized as underweight (<5th percentile), normal (5–85th percentile), overweight (85th–95th percentile), and obese (>95th percentile) based on their BMI for age and sex (BMIFA).[15]

The weights of the enrollees were estimated using the following formulae:

i. Nelson's Formulae:[16]
   - 3–12 months: (age in months + 9)/2;
   - 1–6 years: (age in years × 2)+ 8;
   - 7–12 years: (age in years × 7-5)/2.

ii. MAC was measured in the right arm at the midpoint between the olecranon's tip and the acromion, the arm hanging loosely using nonstretchable tape.[7] The actual MAC was then substituted into the formula.[1]
   - (MAC-10) x 3 to obtain the estimated weight.

Questionnaires administered by the researcher and/or trained research assistants were used for data collection. The children's basic socio-demographic characteristics which included age, gender, and socio-economic status of the child's family using Oyedeji's formula were collected. Oyedeji's formula[17] uses a two-factor index of parental occupation and educational attainment for scoring. Each classification factor was graded one to five with class one being the highest social class and class five, the lowest. Each parent was scored separately by finding the average score of the two factors. The mean score for both parents to the nearest whole number was the social class assigned to the child. The child's social class was determined by that of the living parent or guardian. For purposes of this study, classes one and two of the Oyedeji classification represented the upper social class, class three, the middle social class. In contrast, classes four and five represented the lower social class.

Statistical analysis

Information obtained was entered into a Microsoft Excel Sheet and analyzed using SPSS version 19 (SPSS Inc., Chicago, IL USA) software. We calculated the difference between the actual weight and the estimated weights by the MAC weight-estimation formula and the Nelson formula. We also calculated the mean percentage error; (×100 [estimated weight minus measured weight]/measured weight) to compare the estimated weights and actual weight.[18] A Bland-Altman plot was displayed to present the bias and 95% limits of agreement graphically. We plotted the percentage differences (errors) between estimated and measured weights on the y-axis while the two averages were on the x-axis. The limits of agreement showing the degree of reliability were represented by the dotted lines while the scattered points' spread depicts the extent of agreement.

Results

Characteristics of study participants

The summary of the clinical characteristics of the surveyed children is shown in Table 1. A total of 1390 children between the ages of 1–12 years were enrolled for this study. The male-to-female ratio was 0.74. A majority (52.2%) were from families in the low socio-economic class while 427 (30.7%) and 237 (17.1%) were from families in the middle and high socio-economic class, respectively. Approximately eight out of ten (76.5%) of the surveyed children had a normal BMIFA. Thirty-one (2.2%) of surveyed children were severely thin, 58 (4.2%) thin, 141 (10.1%) were overweight, and 98 (7.1%) obese.

Table 2 shows the mean weight of enrolled children in the various age categories. Overall, the mean of the actual weight of enrolled children (24.86 ± 10.94 kg) was significantly higher compared to the mean weight estimated using the MAC (24.24 ± 9.55 kg; t = 4.862, P = 0.001) and the Nelson formula (23.37 9.45 kg; t = 10.08, P = 0.001). Overall, weight estimates using the Nelson formula better correlated to the actual weight compared to the weight estimates using the MAC, (r = 0.905 [P = 0.001] vs. r = 0.863 [P = 0.001]).

Table 1: Summary statistics of children enrolled in this study

Study parameter	Variables	Frequency, *n* (%)
Age of respondents (years)† (*n*=1390)	1	117 (8.4)
	2	143 (10.3)
	3	127 (9.1)
	4	106 (7.6)
	5	72 (5.2)
	6	76 (5.5)
	7	59 (4.2)
	8	102 (7.3)
	9	183 (13.2)
	10	198 (14.2)
	11	130 (9.4)
	12	77 (5.6)
Gender (*n*=1390)	Male	591 (42.5)
	Female	799 (57.5)
Socioeconomic class (*n*=1389)	High	237 (17.1)
	Middle	427 (30.7)
	Low	725 (52.2)
BMI *Z*-score category (*n*=1390)	Severe thinness	31 (2.2)
	Thinness	58 (4.2)
	Normal	1060 (76.4)
	Overweight	98 (7.1)
	Obesity	141 (10.1)

†Age at last birthday. BMI: Body mass index

Error estimation between actual weight and estimated weight

Summarised in Table 3 is the mean percent error (MPE), which indicates the degree of deviation of estimated weight using the MAC and Nelson formula from the actual weight. The analysis showed that the MAC overestimated weight by double digits in children 1–4 years old by approximately 36.85% (95% confidence interval [CI] 30.79–42.90) in one-year-olds, 21.36% (95% CI 17.37–25.35) in the two-year-olds, 11.36% (95% CI 7.97–14.76) in the three-year-olds and 7.15% (95% CI 3.51–10.80) in four-year-old children. The formula overestimated weight to a lesser degree in the five, six, and seven-year-old categories by 1.72%, 0.49%, and 1.02% respectively. In all other age categories, weight was underestimated by 3.47% among the eight-year-olds, 7.75% among the nine-year-olds, 10.18% in those 10 years of age, 13. 20% in the 11-year-olds and 12.69% in the 12-years age category. Overall, the MAC weight estimation had an error of weight overestimation by 2.39% (95% CI 1.16–3.61).

Unlike the MAC formula, the Nelson formula mostly underestimated mean weights in almost all age categories (by a factor of 2.52% to 14.72%) except in the one year and 12 year age groups where it overestimated the weights by 0.85% (95% CI-2.91–4.62) and 5. 03% (95% CI 0.57–9.48) respectively. The Nelson formula had an overall error of weight underestimation by 3.02% (95% CI- 4.03, - 2.01).

The bland altman plots

Figure 1 shows the Bland Altman plots of the MAC estimated and actual weights of respondents. A birds-eye view shows that the estimated weights were well clustered around the line of agreement. On closer look, it was noted that the weight estimates in the younger age groups were mostly over the line of agreement (solid line) but well within the limits of agreement (dotted lines). The reverse is the case in older age groups where weight estimates congregated mostly below the line of agreement with many estimates falling outside the limits of agreement compared to the younger age categories.

Table 2: Difference in mean weight between the actual measurement and midarm circumference and nelson estimation

Variables	Actual weight		MAC estimation		Nelson formula	
	n	Mean±STD (W1)	Mean±STD (W2)	Mean difference±STD (W2-W1)	Mean±STD (W3)	Mean difference±STD (W3-W1)
Age category (year)						
1	117	10.28±1.86	14.17±4.49	3.89±3.52	10.00±0.00	−0.28±1.87
2	143	13.16±2.59	16.07±4.54	2.91±3.13	32.50±0.00	−1.16±2.60
3	127	14.90±2.47	16.70±4.40	1.80±2.91	36.00±0.00	−0.90±2.48
4	106	17.75±3.14	19.14±5.17	1.38±3.43	39.50±0.00	−1.75±3.14
5	72	19.16±3.77	19.72±5.86	0.56±3.31	12.00±0.00	−1.16±3.77
6	76	21.96±4.25	22.03±5.01	0.07±2.90	14.00±0.00	−1.97±4.26
7	59	25.41±4.00	25.72±5.53	0.30±3.45	16.00±0.00	−3.41±3.99
8	102	27.65±5.34	26.71±6.49	0.94±3.65	18.00±0.00	−2.15±5.34
9	183	31.20±7.05	28.96±8.76	−2.24±3.99	20.00±0.00	−2.51±7.54
10	198	34.42±7.39	31.07±8.61	−3.38±4.64	22.00±0.00	−1.92±7.39
11	130	37.01±7.22	32.23±8.64	−4.97±4.40	25.50±0.00	−1.01±7.22
12	77	38.93±7.44	33.95±7.86	−4.98±4.94	28.68±0.00	0.56±7.43
Overall	1390	24.86±10.94	24.24±9.55	−0.63±4.79	23.37±0.00	−1.45±5.53

STD: Standard deviation

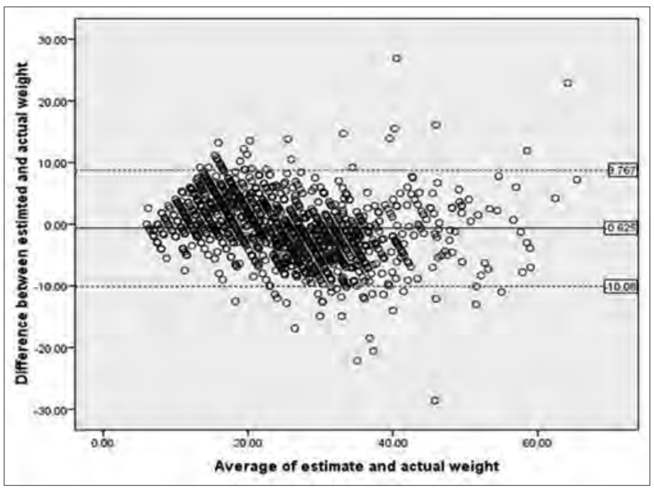

Figure 1: Bland Altman plot of showing agreement between the weight estimation using the midarm circumference and actual weight

Stratification by gender in Figure 2 showed no significant difference in weight estimates. Figure 3 shows the Bland Alman plot of the Nelson formula based. It demonstrated that weight estimates were equally under and overestimated across all age categories. Like the MAC formula, some weight estimates using the Nelson formula were predominantly outside the limits of agreement in older age categories. Gender stratification showed no significant change in distribution in the scatter plot [Figure 4].

Agreements between measured and estimated weights

The agreement analysis is summarised in Table 4. Overall, the Nelson formula had a slightly better agreement within ± 10% (44% vs. 40%) and ± 20% (75% vs. 72%) compared to the MAC formula. Within each category, the level of superior agreement showed no clear pattern. The Nelson formula better agreed with the ± 10% of the actual weight in 1–3 years category and 1-–4 years old category in the ± 20%. Beyond the ages, the MAC showed better agreement with actual weight compared to the Nelson formula.

Discussion

We reported that the Nelson formula had a marginally better agreement with actual weight than the midarm circumference estimates. Previous studies had also demonstrated variable potential for MAC as a weight estimation tool in children.[19-21] At the same time, the Nelson method has also been shown to perform better than most age-based weight estimation formulas.[10,22] In resource-constrained settings like ours, where a weight scale may not be readily available to healthcare providers, a simple but reliable tool for rapid weight estimation in children will be useful.[23]

In this study, the weight estimation in children using MAC-based and Nelson formulae were not consistently accurate in all age categories compared to their actual weights. The subjects' overall mean weight was considerably higher than the mean estimated weight using the MAC. For the children in the younger age categories (one to four years), MAC overestimated their weights by double digits while overestimating the weight to a much lesser degree in children aged five to seven years. However, for the older age categories (8-12 years) their weight was underestimated by MAC-based formula. Badeli and his colleagues in Iran also reported this weak correlation.[24] In contrast with the findings, scholars in the Philippines reported that the MAC-based formula had the best correlation with weight among children aged 1–12 years when compared with the APLS and Broselow Tape.[5] Furthermore, Cattermole *et al*. also noted that MAC-based weight formula had the strongest relationship with weight in healthy Chinese children especially school-aged children (6–12 years).[1] The formula was at least as accurate and precise as the Broselow method

Table 3: Mean percentage error for the mid-arm circumference and Nelson formula weight estimation

Variables	Mid-arm circumference estimation		Nelson formula estimation	
	MPE (%)±STD	95% CI	MPE (%)±STD	95% CI
Age category (years)				
1	36.85±33.07	30.79-42.90	0.85±20.56	−2.91-4.62
2	21.36±24.14	17.37-25.35	−5.72±16.86	−8.51-−2.93
3	11.36±19.33	7.97-14.76	−3.33±17.29	−6.36-−0.30
4	7.15±3.14	3.51-10.80	−6.72±19.22	−10.43-−3.02
5	1.72±16.37	−2.13-5.57	−2.47±19.44	−7.04-2.10
6	0.49±12.63	−2.40-3.37	−6.01±16.28	−9.73-−2.29
7	1.02±13.05	−2.38-4.42	−11.35±13.70	−14.92-−7.78
8	−3.47±13.32	−6.09-−0.85	−4.46±17.76	−7.95-−0.97
9	−7.75±13.06	−9.61-−5.80	−4.14±21.83	−7.32-−0.96
10	−10.18±12.41	−11.92-−8.42	−1.49±20.11	−4.31-1.33
11	−13.20±12.69	−15.4-−11.00	0.62±18.10	−2.52-3.76
12	−12.69±12.56	−15.54-−9.83	5.03±19.61	0.57-9.48
Overall	2.39±23.31	1.16-3.61	−3.020±19.16	−4.03-−2.01

STD: Standard deviation, CI: Confidence interval, MPE: Mean percentage error

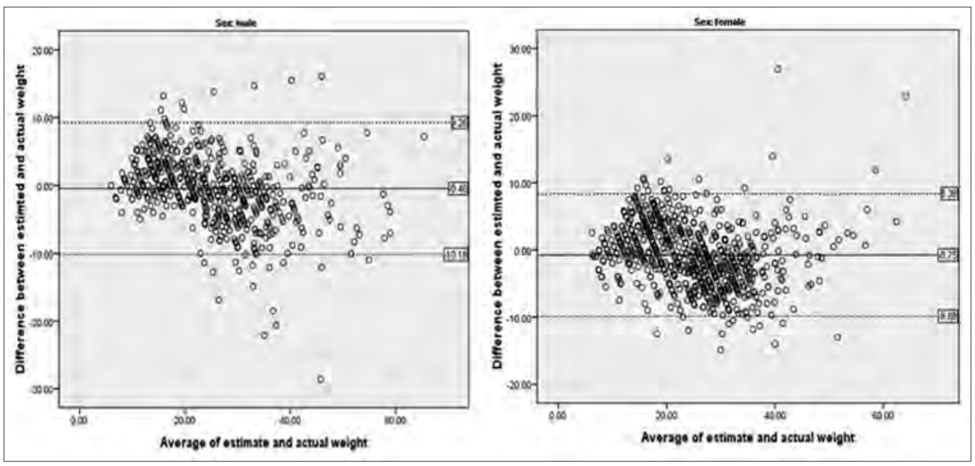

Figure 2: Bland altman plot of showing agreement between the weight estimation using the midarm circumference and actual weight stratified by gender

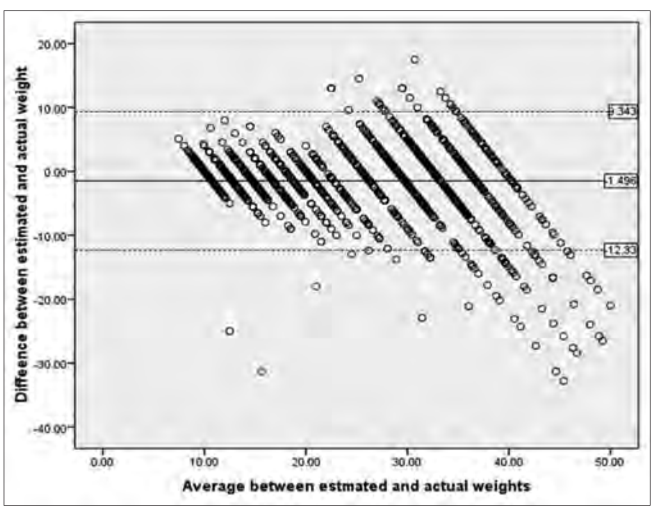

Figure 3: Bland altman plot of showing agreement between the weight estimation using the nelson formula and actual weight stratified by gender

and outperformed the age-based rule in school-age children, though it was found to be inadequate in pre-school children.[1]

Our study also showed that unlike the MAC, the Nelson formula mostly underestimated weights in surveyed children compared to their actual weights. Omisanjo *et al.*[25] in Ibadan Southwest Nigeria also documented a marginal underestimation of weight by the Nelson formula in children aged 1–5 years while overestimating the weights in other age groups. However, their study considered the MPE of the weight of the studied children in groups, unlike this study, which stratified the MPE in different age categories. Similarly, the Nelson formula also performed poorly in weight estimation in children in other studies in Kenya[26] and India.[27] Possible reasons for this poor performance in developing countries may be that the Nelson formula was derived using children's weight in a developed setting. Despite the seeming inaccuracies of the MAC and Nelson formula compared with the children's actual weight, Bland Altman's plot revealed that most of the

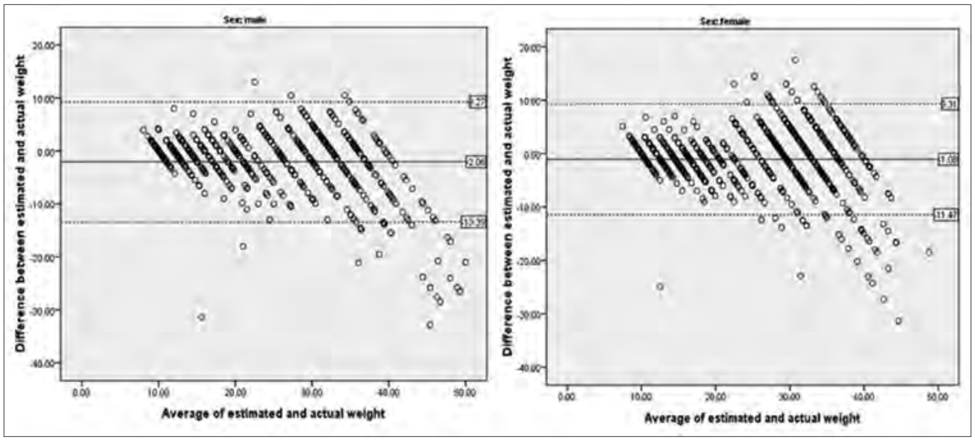

Figure 4: Bland altman plot of showing agreement between the weight estimation using the nelson formula and actual weight

Table 4: Proportion of agreement within 10% and 20% actual weight of estimated weight using the midarm circumference and Nelson formula

Age years	Level of agreement between estimated and actual weight				
	n	MAC (%)		Nelson formula (%)	
		±10%	±20%	±10%	±20%
1	117	21 (18)	44 (38)	52 (44)	84 (72)
2	143	32 (22)	72 (50)	69 (48)	118 (83)
3	127	36 (28)	80 (63)	58 (46)	103 (81)
4	106	41 (39)	73 (69)	39 (37)	77 (72)
5	72	39 (54)	58 (81)	32 (44)	54 (75)
6	76	42 (55)	68 (90)	37 (49)	60 (79)
7	59	32 (54)	55 (93)	21 (36)	41 (70)
8	102	63 (62)	87 (85)	37 (36)	68 (67)
9	183	93 (51)	159 (87)	87 (48)	141 (77)
10	198	93 (47)	155 (78)	52 (26)	142 (72)
11	130	42 (32)	92 (71)	82 (63)	97 (75)
12	77	21 (27)	59 (77)	62 (81)	56 (72)
Overall	1390	560 (40)	1002 (72)	610 (44)	1041 (75)

weight estimates of these methods were well within the zone of agreement of the actual weight of the children surveyed.

Conclusion

In summary, our study reports that both the midarm circumference and the Nelson formula had variable margins of errors to the actual weight depending on the age of surveyed children.

We conclude that the MAC estimation formula and the Nelson formula are not entirely accurate for weight estimation in children in our environment. Even though the Nelson formula appears slightly more accurate than the MAC, weight estimation from both methods was, however, within the limits of agreement of actual weight, and can therefore be used for weight estimation in emergencies. The MAC-based formula is beneficial, especially when the health worker cannot ascertain the age of the child.

Limitation

We calculated the respondents' estimated weight using ages based on their parents/caregivers' best recollection. We could not confirm all the stated ages of enrolled children with their birth certificates as the parents did not bring their children's birth certificates. Therefore, some undeterminable inaccuracy in weight estimation may have been introduced, leading to errors in analysis.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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