ORIGINAL ARTICLE

A Comparison of Actual versus Estimated Weights among Filipino Children Using the Original and Updated Advanced Paediatric Life Support (APLS) Formulae, Mercy Method and Broselow Tape: A Prospective Study

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ABSTRACT

Introduction. In resuscitating children, actual weight should be obtained before intervention. However, this is not always possible in the emergency setting. Identifying a simple, accurate, and precise method of weight estimation is essential in the delivery of optimal care for Filipino children seen at the emergency department.

Objectives. To evaluate and compare the accuracy and precision of different weight estimation methods in Filipino children.

Methods. A cross-sectional, single-center study was conducted among patients aged >28 days-12 years seen at the Philippine General Hospital Emergency Room. The traditional and updated Advanced Pediatric Life Support (APLS), Broselow tape, and Mercy Method were used for weight estimation. Bland Altman analysis was performed to see the mean difference and limits of agreement between actual and estimated weights of the children.

Results. Broselow tape gave the closest average weight estimate, overestimating it by 0.7 kg, followed by Mercy method at 0.955 kg higher than actual. Traditional APLS yielded 1.565 kg and the Updated APLS 3.299 kg. Mercy Method had the narrowest limit of agreement.

Conclusion. Among the four weight estimation methods, Broselow tape is the most accurate while the Mercy method is the most precise. Traditional APLS performed better than the updated APLS. Length-based methods and anthropometric surrogates proved to be more reliable than age-based formulae.

Keywords: pediatrics, weight estimation, Broselow, Mercy method, APLS

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INTRODUCTION

During pediatric resuscitation, most interventions are based on the weight of the child. These include the following: the dose of medication, fluid volume requirement for resuscitation, size of equipment to be used, and defibrillation energy levels. This is because there is often insufficient time to weigh critically ill children. Thus, rapid and reliable weight estimation is an essential step in pediatric emergency resuscitation.[1] Several weight estimation methods have been described in the literature including age-based formulae,[2,3] length-based methods with and without body habitus modification,[4,5] and visual estimation by the caregiver or by the healthcare provider,[6] each of which has its advantages and limitations. Nevertheless, very little is known about the accuracy and precision of these methods in Filipino children.

Over the years, several weight estimation methods have been discussed in the literature. Studies that investigated patient and provider abilities to accurately guess children's weight showed that parents and legal guardians were highly accurate, generally with 70% to 80% within 10% of actual weight, whereas estimations by physicians, nurses, and paramedics were less accurate.[6] Parents, however, are not always around to provide this information. Apart from parental recall or provider estimation, the most commonly used strategies for estimating body weight rely on a child's age or length.[7] A recent study[8] done on Filipino children evaluated four age-based formulae: the widely used traditional Advanced Paediatric Life support (APLS) formula, the updated APLS formula, the United Kingdom-derived Luscombe formula, and Australia-derived Best Guess formula. Results of this study showed that the traditional APLS was more accurate than newer age-based formulae (updated APLS formula, Luscombe formula, and the Best Guess formula). Among the length-based methods, Broselow tape is the most widely used.[9] Several studies of the Broselow method performed in a wide variety of countries showed an average accuracy (proportion of estimated weights within 10% of actual weight) for the Broselow method at 54. The method tended to underestimate actual weight in children from developed countries and overestimate it in children from countries in which underweight or malnutrition are common.

Malnourished children warrant special attention due to their predisposition to complications. Based on the 8th National Nutrition Survey (NNS), the prevalence of underweight among 0 to 59 months is 20% and the overweight/obese prevalence among adolescents 10-19 years old is 8.3%.[10] Age-based and length-based strategies tend to underestimate weight in those who are overweight and overestimate in those who are underweight and there is a need for more study in low-income and malnourished populations to identify or develop tools to assist with emergency weight estimation.[5] The Mercy method incorporates anthropometric surrogates for both stature (humeral length [HL]) and body habitus (mid-upper arm circumference [MUAC]), which provides a more accurate estimate of weight than methods that rely on a single variable.[8] Published literature[11,12] has shown variable potential for the use of MUAC as a weight estimation tool but this has yet to be evaluated. No prospective studies have been done to evaluate this method that incorporates body habitus in the local population.

Identifying a simple, accurate, and precise method of weight estimation will greatly aid in the delivery of optimal care for Filipino children seen at the emergency department. For pediatric resuscitation, precise and accurate weight estimation is critical to minimize medical errors such as over or under dosage of emergency drugs and electrical therapy, fluid overload, and wrong size of equipment.

OBJECTIVES

General Objective

The study aims to evaluate and compare the accuracy and precision of different weight estimation methods in Filipino children.

Specific Objectives

1. To compare the mean difference between measured weight and estimated weights using the four methods.
2. To determine limits and ranges of agreement of the four methods compared to actual weight via Bland-Altman analysis.

MATERIALS AND METHODS

Study Design

A cross-sectional, single-center study was conducted among pediatric patients (aged >28 days to 12 years) seen at the Philippine General Hospital Emergency Room. The study protocol was approved by the University of the Philippines Manila Research Ethics Board (UPMREB) before the conduct of the study.

Study Population

We enrolled patients aged > 28 days to 12 years, male or female seen at the Pediatric Emergency Room Triage from July to August 2017. The exclusion criteria were: refused to give consent, required acute resuscitation, have limb deformities or contractures, or have underlying pathological or pharmacological management that could produce abnormal body composition for age (severe edema, chronic steroid use, chronic illness affecting growth).

The sample size for each method was computed and the largest sample size of 115 was used. The normogram used for the sample size estimation was developed by Altman[13]. Considering different formulae for various age groups, convenience sampling blocked by age was used, requiring at least 115 patients for each age group. A total of 350 patients were enrolled.

Study Procedure and Data Collection

The Pediatric Emergency Room Triage officer screened all patients upon their arrival at the emergency department according to standard protocol. After an initial assessment, the investigator discussed the study with the patients and their parents. Questions and clarifications were addressed for patients and parents who were willing to discuss the study further. Patients were then fully assessed against the inclusion and exclusion criteria and written informed consent and verbal assent, whenever applicable, were obtained from those who were willing and able to participate. Patients who declined to take part were not obliged to join and were managed according to the standards of care by the physician-in-charge.

The following data were collected for all the participants:

1. **Demographic profile:** Age (in completed months for those < 12 months, in completed years thereafter), sex (male or female)

2. **Anthropometrics**
   a. Actual weight, rounded to the nearest 0.1 kilograms, was obtained using calibrated digital weighing scales. Patients were weighed in their underwear or other light-weight clothing without shoes. A digital infant weighing scale (Fuji FB-20) was used for patients less than 2 years and a medical platform scale (SH-8106) for children 2–12 years old. Unit calibration for both scales was done at the Metrology Laboratory at the start and the end of the study. For those who were unable to stand unassisted, indirect weighing was done where the parent's weight was subtracted from the combined parent and child weight to determine the child's weight. Scales were placed at 0 reading before every weight measurement. The primary investigator took the weight and the length/height of all the subjects included in the study.
   b. For patients 2 to 12 years old, height was measured using a stadiometer with the heels, buttocks, and head in contact with the height rule, and the head was aligned in the horizontal plane (for those who can stand unassisted). The recumbent length in patients less than two years was measured using a calibrated infantometer or using a standard vinyl tape measure properly calibrated before data collection. Measurements were recorded to the nearest 0.1 cm.

3. **Weight estimation**

   Using the Broselow tape, a patient was classified under a color zone with a specified estimated weight. The Broselow Pediatric Emergency Tape was placed on a hospital bed (flat surface) with the color-coded/weight side visible. The red end of the tape was positioned at the top of the patient's head, with the edge of the examiner's hand resting at the red end of the tape. Proper placement was maintained at the head of the patient. The free hand was run down from the patient's head and the edge of the free hand that lands on the tape adjacent to the patient's heels indicate the patient's approximate weight in kilograms and the patient's color zone.

   For the Mercy Method, the humeral length (HL) was measured from the upper edge of the posterior border of the acromion process to the tip of the olecranon process using a standard vinyl tape measure properly calibrated before data collection. Measurements were recorded to the nearest 0.1 cm. All measurements were done by a single investigator. The mid-upper arm circumference (MUAC) was measured at the midpoint of the humerus with the left arm hanging down at the child's side using a standard vinyl tape measure properly calibrated before data collection. Measurements were recorded to the nearest 0.1 cm. All measurements were done by a single investigator.

   The HL and the MUAC measured for each patient were rounded to the nearest 1.0 cm and the corresponding fractional weight for each measurement was obtained from a published table[14] (Supplementary Table 1) and summed to generate an estimated weight. Age-based calculations of weight were computed at the data analysis stage. The traditional APLS used the formula: Weight (kg) = (2 x age in years) + 8. The updated APLS weight was computed as follows:

   1–11 months: weight (kg) = (0.5 × age in months) + 4
   1–5 years: weight (kg) = (2 × age in years) + 8
   6–12 years: weight (kg) = (3 × age in years) + 7

Outcomes Measured

The primary outcomes for the study were:

1. Mean difference of actual weight to estimated weight using the different methods
2. Levels of agreement determined by applying the Bland-Altman approach

Statistical Analysis

Data encoding was performed by a single investigator using Microsoft Excel. Descriptive statistics were used to summarize the clinical characteristics of the patients. Frequency and proportion were used for nominal variables, median, and range for ordinal variables, and mean and SD for interval/ratio variables. Bland Altman analysis was performed to see the mean difference (measuring accuracy) and the limits of agreement (measuring precision) between the actual weight of the children and different estimated weights. All valid data was included. Missing variables were neither replaced nor estimated. The null hypothesis was rejected at 0.05 α-level of significance. STATA 12.0 was used for data analysis.

RESULTS

A total of 350 children were enrolled: aged > 28 days to 11 months (n = 115), aged 1 to 5 years (n = 116), and aged 6 to 12 years (n = 119). The mean (± SD) age of the children was 3.89 years (± 3.5). Of the 350 children, 202 (57.7%) were male. The mean weight and mean height were 14.25 ± 8.32 kg and 92.24 ± 26.63 cm, respectively. In our study population, 72% had normal weight for height/Body mass Index (BMI). Table 1 shows a summary of the demographic and anthropometric parameters of the population while Table 1.1 shows the parameters for each age group.

Table 2 presents the mean difference, limits of agreement and the difference in variance of the four methods used. Tables 2.1 to 2.3 present the results for each age group. Six participants had heights longer than length of the Broselow

Table 1. Demographic and clinical profiles of Filipino children with actual and estimated weights (n=350)

	Mean ± SD
***Age** (years)*	3.89 ± 3.55
< 1 year old (n=115)	115 (32.86)
1-5 years old (n=116)	116 (33.14)
6-12 years old (n=119)	119 (34)
***Males**, n (%)*	202 (57.7)
***Actual weight** (kg)*	14.25 ± 8.32
***Actual height** (cm)*	92.24 ± 26.63
***BMI** (kg/m²)*	15.63 ± 2.64
***Mid-upper arm Circumference** (cm)*	15.56 ± 2.93
***Humeral length** (cm)*	19.31 ± 5.67
Estimated weight	
Traditional APLS	15.81 ± 7.1
Updated APLS	17.55 ± 11.2
Broselow Tape	14.93 ± 8.6
Mercy method	15.20 ± 8.34

APLS, Advanced Pediatric Life Support

Table 1.1. Demographic and clinical profiles of Filipino children with actual and estimated weights stratified according to age group (n=350)

	<1 year old (n=115)	1–5 years old (n=116)	6–12 years old (n=119)
	Mean ± SD		
***Males**, n (%)*	68 (59.1)	66 (56.9)	68 (57.1)
***Actual weight** (kg)*	6.54 ± 1.87	12.81 ± 3.81	23.1 ± 6.95
***Actual height** (cm)*	62.82 ± 7.9	90.55 ± 11.6	122.33 ± 12.08
***Body mass index** (kg/m²)*	16.33 ± 2.72	15.36 ± 2.04	15.21 ± 2.95
***Mid-upper arm circumference** (cm)*	13.27 ± 1.67	15.4 ± 1.92	17.93 ± 2.88
***Humeral length** (cm)*	13.02 ± 1.9	19.29 ± 2.7	25.42 ± 2.83
***Weight for height**, n (%)*			
Obese	4 (3.48)	0	-
Overweight	5 (4.35)	10 (8.62)	-
Risk of Overweight	13 (11.30)	6 (5.17)	-
Normal	81 (70.43)	84 (72.41)	-
Wasted	7 (6.09)	10 (8.62)	-
Severely Wasted	5 (4.35)	6 (5.17)	-
***BMI for age**, n (%)*			
Obese	-	-	1 (0.84)
Overweight	-	-	3 (2.52)
Risk of Overweight	-	-	8 (6.72)
Normal	-	-	87 (73.1)
Wasted	-	-	11 (9.24)
Severely Wasted	-	-	9 (7.56)

tape and were removed from the total population for the analysis of the Broselow tape method (n = 344). Overall, the Broselow tape gave the closest average weight estimate to actual, overestimating the latter by 0.7 kg (95% CI 0.4,1.01). Using the Mercy method, estimates of weight were 0.955 (95% CI 0.77, 1.14) kg higher than actual. Despite this, estimates using the latter had a narrower limit of agreement (Mercy method -2.5 to 4.41 kg vs. Broselow tape - 4.97 to 6.39 kg). For all methods, concordance with the actual was better at lower weights (Figures 1 to 4).

Compared to the traditional APLS formula (Figure 1), estimation using updated APLS formula resulted in a greater bias, through weight overestimation (Figure 2). The plots of differences between the Broselow method and actual weight (Figure 3) and the Mercy method and actual weight (Figure 4) were roughly distributed about the mean.

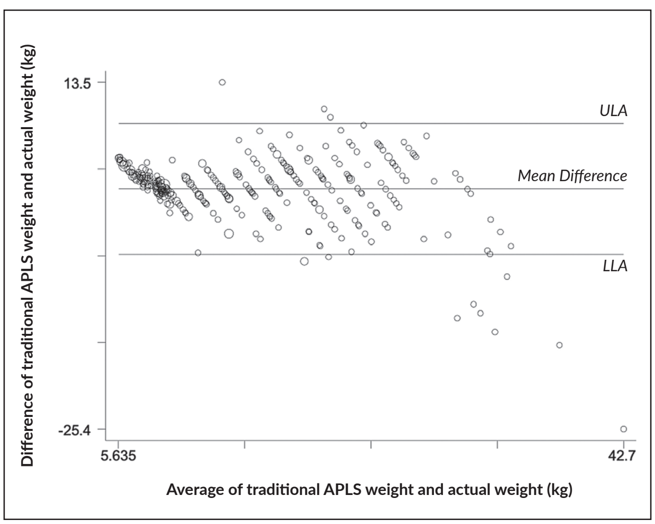

Figure 1. Bland-Altman plot for traditional APLS and actual weight. *(ULA: upper limit of agreement; LLA: lower limit of agreement).*

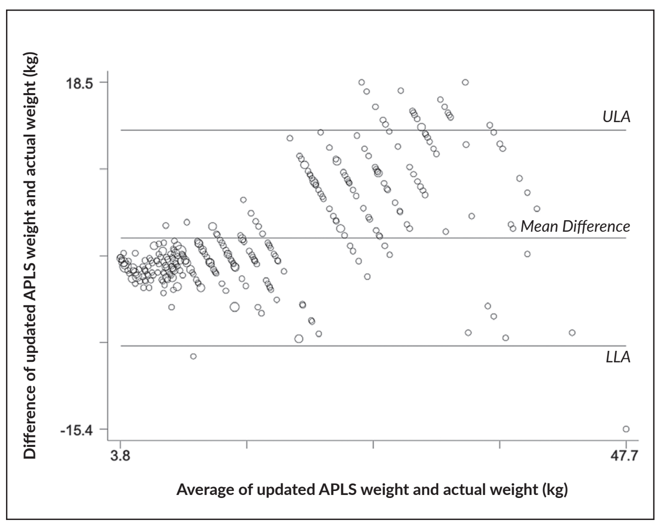

Figure 2. Bland-Altman plot for the updated APLS and actual weight. *(ULA: upper limit of agreement; LLA: lower limit of agreement).*

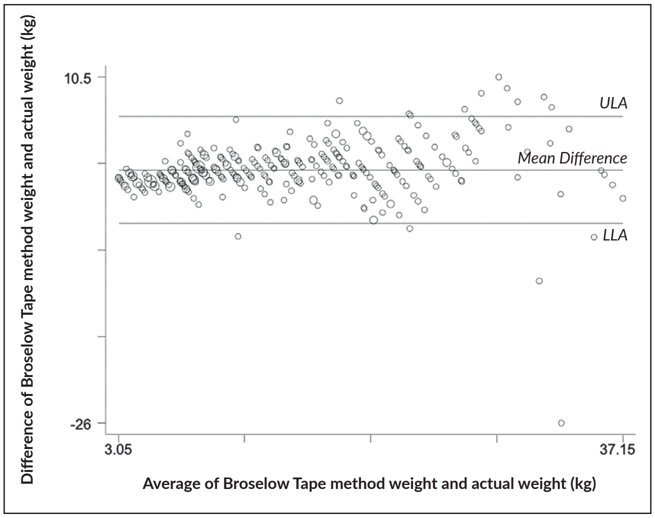

Figure 3. Bland-Altman plot for the Broselow Tape method and actual weight. *(ULA: upper limit of agreement; LLA: lower limit of agreement).*

Figure 4. Bland-Altman plot for the Mercy method and actual weight. *(ULA: upper limit of agreement; LLA: lower limit of agreement).*

Table 2. Comparison of Bland-Altman statistic for each weight estimation method

	Mean difference (95% CI)	Limits of agreement	Range	Pitman's test of difference in variance (r)	P-value
Traditional APLS	1.565 (1.18 to 1.95)	-5.79 to 8.92	5.64 to 42.7	0.342	<0.001
Updated APLS	3.299 (2.75 to 3.85)	-7.24 to 13.84	3.8 to 47.7	0.568	<0.001
Broselow tape (n=344)	0.708 (0.41 to 1.01)	-4.97 to 6.39	3.05 to 37.2	0.170	0.002
Mercy method	0.955 (0.77 to 1.14)	-2.5 to 4.41	3.25 to 56.2	0.012	0.820

Table 2.1. Comparison of Bland-Altman statistic for each weight estimation method (age less than 1 year, n=115)

	Mean difference (95% CI)	Limits of agreement	Range	Pitman's test of difference in variance (r)	P-value
Traditional APLS	2.488 (2.15 to 2.83)	-1.18 to 6.16	5.64 to 13.3	-0.456	<0.001
Updated APLS	0.269 (0.02 to 0.52)	-2.43 to 2.97	3.8 to 10.15	-0.143	0.135
Broselow tape	-0.131 (-0.36 to 0.1)	-2.62 to 2.36	3.05 to 11.15	0.177	0.059
Mercy method	0.814 (0.6 to 1.03)	-1.52 to 3.15	3.25 to 11.7	-0.004	0.969

Table 2.2. Comparison of Bland-Altman statistic for each weight estimation method (age 1 to 5 years old, n=116)

	Mean difference (95% CI)	Limits of agreement	Range	Pitman's test of difference in variance (r)	P-value
Traditional APLS	0.835 (0.38 to 1.3)	-4.16 to 5.83	7.75 to 21.05	-0.437	<0.001
Updated APLS	0.835 (0.38 to 1.3)	-4.16 to 5.83	7.75 to 21.05	-0.437	<0.001
Broselow tape	0.568 (0.23 to 0.91)	-3.14 to 4.28	7.25 to 22.05	-0.373	<0.001
Mercy method	1.284 (1.02 to 1.55)	-1.58 to 4.15	6.9 to 24.55	0.099	0.292

Table 2.3. Comparison of Bland-Altman statistic for each weight estimation method (age 6 to 12 years old, n=119)

	Mean difference (95% CI)	Limits of agreement	Range	Pitman's test of difference in variance (r)	P-value
Traditional APLS	1.386 (0.4 to 2.37)	-9.4 to 12.2	16 to 42.7	-0.632	<0.001
Updated APLS	8.629 (7.62 to 9.64)	-2.46 to 19.72	18.5 to 47.7	-0.239	0.013
Broselow tape	1.704 (0.92 to 2.49)	-6.74 to 10.15	13 to 37.15	-0.104	0.279
Mercy method	0.771 (0.353 to 1.19)	-3.84 to 5.39	13.85 to 56.2	0.06	0.514

DISCUSSION

As of this writing, no single method has been identified to accurately estimate the weight of children across ages and lengths/heights. In our study, all the four methods used gave overestimations of the actual weight obtained. Between the two age-based methods, the Traditional APLS presented more accurate estimates which is consistent with the study[8] done in 2015 in a local population. The population from which the traditional APLS formula was based on may be more similar to the current population in developing countries such as the Philippines. The Broselow tape and the Mercy Method outperformed both age-based formulae for estimating weight. This finding is consistent with what has been previously reported in several studies[3,4,11,15] and in a systematic review[1] that length-based methods and anthropometric surrogates for stature and body habitus perform better than the age-based methods usually recommended in pediatric textbooks. In a meta-analysis[16] evaluating the accuracy of the Broselow tape as a weight estimation tool, it showed that the Broselow tape consistently was significantly more accurate than healthcare provider guesses and age-based formulas but performed less accurately than dual length- and habitus-based system – the Mercy method, the PAWPER tape and the Wozniak method. This was also observed in our study where the Mercy method yielded more precise results as compared to the Broselow tape. It also appeared to be accurate and precise over a broad range of ages. In a study done in South Africa[17], results showed that the accuracy of the Broselow tape as a drug-dosing and weight-estimation device can be substantially improved by including an appraisal of body habitus in the methodology.

However, the Broselow tape has a limited range. Six (1.6%) of the 350 children had heights greater than the range of the Broselow tape while the Mercy method was able to give weight estimates for all the participants. Although surrogates are easy to obtain even for uncooperative children, this method necessitates knowledge in identifying anatomic landmarks to have an accurate measurement. It also requires a two-step process of getting anthropometrics and generating estimated weights from a published table. This method might be more error-ridden during a resuscitation scenario. The use of the Broselow tape, though less precise, may be more reliable as it is easier to use and does not require special knowledge or skills.

Among the four methods, only the Broselow tape and the Mercy method showed mean percent differences within 15% of the actual weight. The Mercy method (171/350) and the Broselow tape (167/344) predicted more children within 10% of their actual weight compared to the age-based formulae. The Traditional APLS and updated APLS yielded mean percent differences of 23.38% (± 18.78) and 22.21% (± 16.26%), respectively. Use of the age-based formulae may lead to incorrect dosing resulting to drug toxicity or to over-hydration which are serious adverse outcomes. In a systematic review and meta-analysis involving developing countries, no age-based method performed well; the Broselow tape performed better than any of the formulae and new generation weight estimation systems that make use of length and body habitus-based parameters such as the Mercy method, PAWPER tape and Wozniak method outperformed the other methods.[18]

One of the identified limitations of this study is selection bias, since we did not include those needing immediate resuscitation or the ones who were severely ill. We also excluded the ones with chronic illnesses which could have affected the body habitus of the patients. The majority of the study population (72%) was comprised of children in the normal BMI/weight-for-length and may pose issues regarding applicability in broader populations. Inter-observer variability cannot be assessed since only one investigator did all the measurements.

CONCLUSION

Among the four evaluated weight estimation methods, the Broselow tape is the most accurate with a 0.7 mean difference, followed by Mercy method with 0.955. Mercy method is the most precise with the narrowest limit of agreement (-2.5-4.41 kg). Between the two-age based methods, the traditional APLS performed better in this population than the updated APLS. Age-based formulae for weight estimation should no longer be used. Length-based methods such as Broselow tape and use of anthropometric surrogates such as Mercy method appear to be better options for our setting and it would be prudent to further investigate their use in our local population.

In future studies, inclusion of children with chronic diseases, those with malnutrition and those who are critically ill should be considered to broaden the applicability of the weight estimation methods. A larger number of investigators may also be considered to determine the degree of intra-observer and inter-observer variability and the ease of use of the weight estimation tools.

Statement of Authorship

Both authors contributed in the conceptualization of work, acquisition and analysis of data, drafting and revising and approved the final version submitted.

Author Disclosure

Both authors declared no conflicts of interest.

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SUPPLEMENT

Supplementary Table 1. Humeral length and mid-upper arm circumference bins with their corresponding fractional weight values[14]

Humeral Length (cm)	Partial Weight A (kg)	Mid-upper arm Circumference (cm)	Partial Weight B (kg)
9	0.5	10	2.8
10	0.7	11	3.8
11	0.9	12	4.6
12	1.5	13	4.9
13	2.0	14	5.3
14	2.8	15	5.9
15	3.4	16	6.5
16	4.2	17	7.4
17	5.0	18	8.0
18	6.1	19	9.4
19	7.2	20	10.9
20	8.1	21	12.4
21	9.1	22	14.3
22	10.4	23	16.5
23	11.4	24	18.0
24	12.6	25	20.5
25	13.7	26	23.4
26	14.7	27	25.5
27	16.6	28	27.8
28	18.3	29	30.5
29	19.6	30	33.3
30	21.4	31	36.3
31	23.7	32	39.6
32	25.5	33	44.8
33	27.3	34	46.5
34	29.2	35	50.2
35	31.0	36	53.2
36	33.5	37	55.7
37	34.5	38	60.3
38	36.5	39	61.1
39	38.2	40	67.0

Source: From "An improved pediatric weight estimation strategy," by S. Abdek-Rahman & A. Ridge. In The Open Medical Devices Journal (p 88), 2012. Copyright [2012] by Bentham Open