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ORIGINAL RESEARCH

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Validation of two pediatric resuscitation tapes

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Abstract

Objective: This study aims to compare the actual weights of Filipino children with their estimated weights obtained from the Broselow tape and the Pediatric Advanced Weight Prediction in the Emergency Room eXtra Length-Mid-arm Circumference (PAWPER XL-MAC) tape.

Methods: A prospective, observational, cross-sectional study conducted among Filipino children admitted at the Pediatric Emergency Department (ED) of The Medical City in Pasig City, Philippines. Mean percentage error (MPE) determined bias. Modified Bland-Altman analysis was used to perform a visual comparison of the bias and extent of agreement. The proportion of weight estimates within 10% (p_{10}) and within 20% (p_{20}) of actual weight was calculated to determine the overall accuracy.

Results: A total of 220 Filipino children (63.2% male) were recruited. Both the Broselow and PAWPER XL-MAC tapes overestimate the actual weight by an average of 0.4% (95% limit of agreement [LOA] −29.4 to 30.2) and 1.3% (95% LOA −15.3 to 17.9) respectively. Across body mass index (BMI) groups, both tapes overestimate (MPE: +19.2 and +9.3) weight among underweight children and underestimate (MPE: −13.2 and −3.5; MPE: −18.6 and −5.5) weight among overweight and obese children. In measuring estimated weight within 10% and 20% of actual weight, the PAWPER XL-MAC performed best (79.6% and 96.8%).

Conclusion: The PAWPER XL-MAC tape performed better as a weight estimation tool compared to Broselow tape across different age groups and BMI-for-age groups of Filipino children. Both tapes tend to overestimate weight among younger and underweight children while underestimating weight among ages 7 to 10 years old, overweight, or obese children.

KEYWORDS
body mass index, body weight, emergency medicine, pediatrics, prospective studies, resuscitation, tertiary care centers

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1 | INTRODUCTION

1.1 | Background

In pediatric emergencies, determination of body weight is essential in the management of a critically unwell child.[1–3] During a high-stress and time-limited environment, it has been a challenge for emergency physicians to determine the child's actual body weight by obtaining it from calibrated scales.[1,3,4] Overestimation or underestimation of a child's weight may result in ineffective care by under- or overdosing medications leading to related morbidity or mortality.[1,5] Hence, a precise and accurate estimated weight is vital to ensure administration of the safe and effective medication doses as well as selection of proper equipment sizes.[2–4,6,7]

1.2 | Importance

The Broselow tape is the most commonly used pediatric weight estimation tape. However, recent international studies have shown its lack of sufficient accuracy by underestimating weights among obese children.[1,8] Thus, it is being compared to newer weight estimation methodologies of dual length- and habitus-based methods like the Pediatric Advanced Weight Prediction in the Emergency Room (PAWPER) tape.[6,9] Data on weight estimation using the Broselow tape were done on the western population, and there have been few studies done in Malaysia,[8] Philippines (Castor F, Cu J, unpublished data, 2017), Singapore,[10] and Thailand.[11] To date, there was no literature published on the validation of PAWPER weight estimation systems among the Southeast Asian population. With the conflicting results of the use in extremes of weight and limitation in the study population,[1–10] it is relevant to further determine the accuracy and precision of these pediatric emergency tapes. This study is the first to use both the Broselow and PAWPER weight estimation methods among Filipino children.

1.3 | Goals of this investigation

This study aims to compare the weight determined using one-dimensional and two-dimensional estimation tools with the actual weight of Filipino children admitted in the pediatric emergency department of an urban private tertiary referral hospital.

The Bottom Line

This prospective study compared the accuracy of weight estimation by the PAPWER XL-MAC system and the Broselow tape in Filipino children. The PAWPER XL-MAC system was significantly more accurate than the Broselow tape in all children, but especially the subgroups of underweight, overweight, and obese children. This further reinforces the value of dual length- and habitus-based weight estimation systems.

2 | METHODS

2.1 | Study design and setting

A prospective, observational, cross-sectional study was conducted at the pediatric emergency department of The Medical City in Pasig City, Philippines, between November and December 2019. The Medical City is a tertiary referral hospital with over 25,000 pediatric attendances annually. The study was approved by the institutional review board.

2.2 | Selection of participants

Eligible subjects were determined by their age (1 month to 10 years), height/length (46 cm to 145 cm), and descent (born from both Filipino father and mother). Exclusion criteria included those needing resuscitation, presenting with dehydration along with joint contractures, having congenital anomalies, having endocrine or growth disorders, and being uncooperative. Study participants were a convenience sample of pediatric patients presenting to the pediatric emergency department of The Medical City. A minimum requirement of 190 children was computed based on a level of significance of 5%, 80% power, expected mean difference and SD of Broselow estimated weight and actual weight equal to 0.06 ± 3.8 from a reference article based on Filipino children by Young et al.[12] For PAWPER, Wells et al[13] did not specify a mean difference, which meant we could not provide actual values for the sample size formula. We assume that the expected mean difference and SD of PAWPER would approximate that of Broselow.

2.3 | Data collection and study protocol

Subjects were recruited mostly during day shifts by two investigators (composed of physician or nurse) who underwent a 15-minute lecture to gain familiarity in the proper use of emergency tapes.

Verbal and written consents were acquired from the parent/guardian. The first investigator obtained the demographic information (age, sex) then measured the child's actual length/height (cm) and weight (kg) in light clothing with shoes removed. Regularly calibrated scales were used for children >2 years old capable of standing (Detecto 339 beam medical scale with height rod, Missouri, USA) and infant patients (Detecto 243 mechanical infant scale, Webb City, Missouri, USA). These data were used to determine the body mass index-for-age percentile using the body mass index percentile calculator accessed from the Centers for Disease Control and Prevention (CDC) website.[14]

The second investigator (blinded to the child's actual weight) estimated the weight using the Broselow tape (2011, edition A, Armstrong Medical Industries, Lincolnshire, Illinois, USA) and PAWPER

FIGURE 1 Broselow tape and PAWPER XL-MAC tape

eXtra Length-Mid-Arm Circumference (2016, PAWPER XL-MAC, Mike Wells) tape. The pediatric tapes were secured side by side on a rubber mat with plastic cover pockets (Figure 1). All measurements were done while the child was lying down on the rubber mat with the head positioned on the red marking of the tapes and heels perpendicular to the bed. Weight estimation using Broselow tape was generated by the color-coded segment where the child's heel fell. In the PAWPER XL-MAC method, the habitus category was objectively defined by the mid-arm circumference measured using the initial portion of the tape. The estimated weight was read off the tape from the length segment containing the mid-arm circumference/habitus cutoff values where the child's heel fell. All data were recorded on a secured form for an individual patient.

2.4 | Outcome

The primary outcome was the agreement of estimated weight using Broselow tape and PAWPER XL-MAC compared with the actual weight among Filipino children. The secondary outcome was the comparison of its performance across different age groups and body mass index (BMI) groups.

2.5 | Data analysis

Descriptive statistics were used to summarize the general and clinical characteristics of the participants. Frequency and proportion were determined for nominal variables, while median and range for non-normally distributed continuous variables. Modified Bland-Altman analysis demonstrated a visual comparison of Broselow and PAWPER XL-MAC tapes in estimating actual weight. The bias was determined by the mean percentage error (MPE). A positive MPE indicates an overestimation of weights on the average, and negative MPE indicates underestimation. Limit of agreement (LOA), the range in which 95% of the differences between actual and estimated weights will fall, was also computed. The overall accuracy was determined by calculating the proportion of weight estimations falling within 10% and 20% of the actual measured weight. Subgroup analyses were performed in three age categories (<1 to 2 years, 3 to 6 years, 7 to 10 years) and BMI-for-age categories (underweight, normal, overweight, obese). All valid data were included in the analysis. Missing variables were neither replaced nor estimated. The null hypothesis was rejected at 0.5 α-level of significance. STATA 15.0 (StataCorp. 2017. Stata Statistical Software: Release 15., StataCorp LLC, College Station, Texas, USA) was utilized for the data analysis.

3 | RESULTS

3.1 | Characteristics of study subjects

A total of 220 Filipino children were recruited. Table 1 summarizes the sample population characteristics. Median height and BMI were 103 (53 to 145) cm and 16.42 (12.4 to 34.2) kg/m^2, respectively. Forty-six (20.9%) children had an estimated weight between 15 and 18 kg by Broselow tape.

3.2 | Main results

Body weight measurements derived using Broselow and PAWPER XL-MAC tapes tended to overestimate the actual weight by an average of 0.4% and 1.3%, respectively (Table 2). The Broselow tape yielded a lower MPE (MPE 0.43) as compared with the PAWPER XL-MAC tape (MPE 1.31). However, the PAWPER XL-MAC has a narrower LOA (−15.3 to + 17.9). Performances of both tapes were further stratified by age and BMI-for-age groups (Tables 3 and 4). The PAWPER XL-MAC tape had a higher proportion of weight estimates within 10% of the actual weights (p_{10} 79.6% vs 47.3%) and within 20% of the actual weights (p_{20} 96.8% vs 83.2%). Also, the PAWPER XL-MAC tape had a higher proportion within 10% and 20% of the actual weights, even after subgrouping by age and BMI (Tables 3 and 4). LOA pertains to where 95% of the data points will fall. It was computed as the mean difference (±1.96 SD), an indication of how much the scores can vary in stable

TABLE 1 Demographic profile of patients

	Median (range); frequency (%)
Age	
<1 to 2 years old	76 (34.6)
3 to 6 years old	80 (36.4)
7 to 10 years old	64 (29.1)
Sex	
Male	139 (63.2)
Female	81 (36.8)
Actual weight (kg)	17 (4.5—47)
Estimated weight (using PAWPER XL-MAC tape)	17 (4.5—44)
Estimated weight (using Broselow tape)	17 (4—36)
Actual height (cm)	103 (53—145)
Body mass index-for-age	
Underweight	30 (13.6)
Normal	127 (57.7)
Overweight	24 (10.9)
Obese	39 (17.7)

TABLE 2 Comparison of different weight estimation methods

	MPE	LOA	p_{10}	p_{20}
Broselow tape	0.4	(−29.4 to 30.2)	104 (47.3)	183 (83.2)
PAWPER XL-MAC tape	1.3	(−15.3 to 17.9)	175 (79.6)	213 (96.8)

Abbreviations: LOA, limits of agreement; MPE, mean percentage error. p_{10}, proportion of estimates within 10% of the true weight; p_{20}, proportion of estimates within 20% of the true weight.

patients (ie, smallest detectable change). Ideally, the smaller the LOA, the better; this is achieved with larger sample sizes.

Agreement between Broselow and PAWPER XL-MAC tapes were visually summarized in modified Bland-Altman plots (Figure 2). The percentage error (y-axis) is plotted against the measured weight (x-axis). The broken blue lines represented the MPE, and the solid red lines represent the 95% LOA.

4 | LIMITATIONS

Our study has several limitations. First, the study population was recruited on non-consecutive days through a convenience sampling method, which could have introduced bias in the sample selection by the trained investigators. Second, our sample size may not be enough in representing Filipino children as a whole. Future studies may require a larger sample size and several investigators to assess intra- and inter-observer variability in data collection. Third, the subjects included were children up to 10 years of age and 145 cm in height due to the defined maximum length of the Broselow tape, which limits the applicability of our results to children beyond these age and height/length groups. Fourth, children needing emergent resuscitation were excluded, which can potentially introduce bias as these children may be different from clinically well children in terms of their appearance and habitus.Fifth, securing the pediatric tapes on a rubber mat can result in potential problems in inaccuracy with the Broselow tape caused by the folds between sections. We made sure that the tape is always snugly fitted and flattened on the plastic pockets on the mat before taking measurements.

5 | DISCUSSION

Our study demonstrated the Broselow tape and PAWPER XL-MAC tape overestimated the actual weights. Between the two methods, PAWPER XL-MAC yielded more precise and accurate results. When subdivided among age groups, children 7 to 10 years of age, both tapes tended to have underestimated weights (MPE −2.0 and −2.6) and overestimated (MPE + 2.6 and + 5.7) the weight in children <3 years old. Across BMI-for-age groups, in underweight children, both tapes consistently overestimated (MPE + 19.2 and + 9.3) weight, and in overweight and obese, there was a consistent underestimation (MPE −13.2 and −3.5; MPE −18.6 and −5.5) of weight.

Previous validation studies found the Broselow tape tends to underestimate weight in mid- to high-income areas while overestimating weight among children in the low-income areas.[9,15] A study done by Sahar et al[8] reported that estimated weights using the Broselow tape have a statistically significant mean percentage difference of ≈ 5% among Malaysian children. They found the Broselow tape overestimated the weight of children >0.90 m length (orange and green color code).[8] Among Indian children, a study by Mishra et al[4] stated that as the weight increases, the predictive reliability of weight estimation by Broselow tape decreases; hence, it is less reliable in the subgroup of children weighing >18 kg.[4] The Broselow tape is at risk of weight overestimation error[16,17] because it closely approximates the ideal body weight instead of total body weight.[17] Among underweight children, their total body weight is smaller than their ideal body weight. The improved version of Broselow tape (2011 edition A) was updated from the older version (2007 edition B) to minimize the underestimated weights among children from high-income areas.[18,19] This leads to a greater degree of overestimation when used in areas with a prevalence of underweight children from resource-limited settings.[18–21]

Given the risk of under- or overestimation of a child's weight, the newest generation of weight estimation methods based on length and habitus were developed. These two-dimensional systems include the PAWPER tape, Mercy method, and Wozniak method.[19] A comparison study by Wells et al showed that two-dimensional methods are far more accurate than one-dimensional methods.[5] In a systematic review and meta-analysis of various pediatric weight estimation systems,[22] the PAWPER tape showed an excellent accuracy of 86.9%. PAWPER

TABLE 3 Performance of Broselow and PAWPER XL-MAC weight estimation stratified by age

		Broselow tape				PAWPER XL-MAC tape			
Age	N	MPE	LOA	p_{10}	p_{20}	MPE	LOA	p_{10}	p_{20}
<1 to 2 years	76	2.6	−25.8 to 31.0	39 (51.3)	64 (84.2)	5.7	−12.7 to 24.2	53 (69.8)	69 (90.8)
3 to 6 years	80	0.3	−24.5 to 25.0	45 (56.3)	73 (91.3)	0.2	−11.9 to 12.3	70 (87.5)	80 (100)
7 to 10 years	64	−2.0	−38.1 to 34.4	20 (31.3)	46 (71.9)	−2.6	−16.8 to 11.7	52 (81.3)	64 (100)
Total	220	0.4	−29.4 to 30.2	104 (47.3)	183 (83.2)	1.3	−15.3 to 17.9	175 (79.6)	213 (96.8)

Abbreviations: MPE, mean percentage error; LOA, limits of agreement.
p_{10}, proportion of estimates within 10% of the true weight; p_{20}, proportion of estimates within 20% of the true weight.

TABLE 4 Performance of Broselow and PAWPER XL-MAC weight estimation stratified by BMI-for-age

		Broselow tape				PAWPER XL-MAC tape			
BMI-for-age	N	MPE	LOA	p_{10}	p_{20}	MPE	LOA	p_{10}	p_{20}
Underweight	30	19.2	2.7 to 35.8	3 (10.0)	18 (60.0)	9.3	−7.3 to 25.9	19 (63.3)	5 (83.3)
Normal	127	4.4	−14.3 to 23.2	85 (66.9)	121 (95.3)	2.4	−11.6 to 16.4	108 (85.0)	125 (98.4)
Overweight	24	−13.2	−24.6 to −1.8	9 (37.5)	23 (95.8)	−3.5	−15.9 to 9.0	21 (87.5)	24 (100)
Obese	39	−18.6	−38.0 to 0.8	7 (18.0)	21 (53.9)	−5.4	−18.4 to 7.5	27 (69.2)	39 (100)
Total	220	0.4	−29.4 to 30.2	104 (47.3)	183 (83.2)	1.3	−15.3 to 17.9	175 (79.6)	213 (96.8)

Abbreviations: BMI, body mass index; LOA, limits of agreement; MPE, mean percentage error.
p_{10}, proportion of estimates within 10% of the true weight; p_{20}, proportion of estimates within 20% of the true weight.

tape has 3 versions: Original PAWPER tape, PAWPER XL tape, and PAWPER XL-MAC tape. The first two versions (developed in 2009 and 2014 respectively) both use visual habitus assessment as compared with the newest PAWPER XL-MAC (2016), which objectively uses the mid-arm circumference instead of using visual habitus in defining weight.[19]

PAWPER XL-MAC was validated through a combined survey dataset of the National Health and Nutrition Examination Survey (NHANES) from theUnited States.[23] Although it was labeled as the most accurate method for weight estimation by surpassing predetermined acceptable outcome criteria, its performance amongst extremely obese and underweight children still needs to be validated for its accuracy to remain clinically consistent.[19] A study by Garcia et al[24] demonstrated that PAWPER tape has a lower accuracy of 50% in children with above-average habitus compared to its overall accuracy of 64%. This was supported in another study by Wells et al,[19] which reported that even the improved version of PAWPER XL-MAC tape performed the most accurate weight estimation in all habitus groups except in severely underweight and obese children from low- and middle-income countries. However, these results were contrasted in our study that yielded a 100% accuracy for the PAWPER XL-MAC tape among overweight and obese Filipino children.

A reliable weight estimation method should be accurate and easy to use.[17,19] These are the requirements defined by Luten et al as

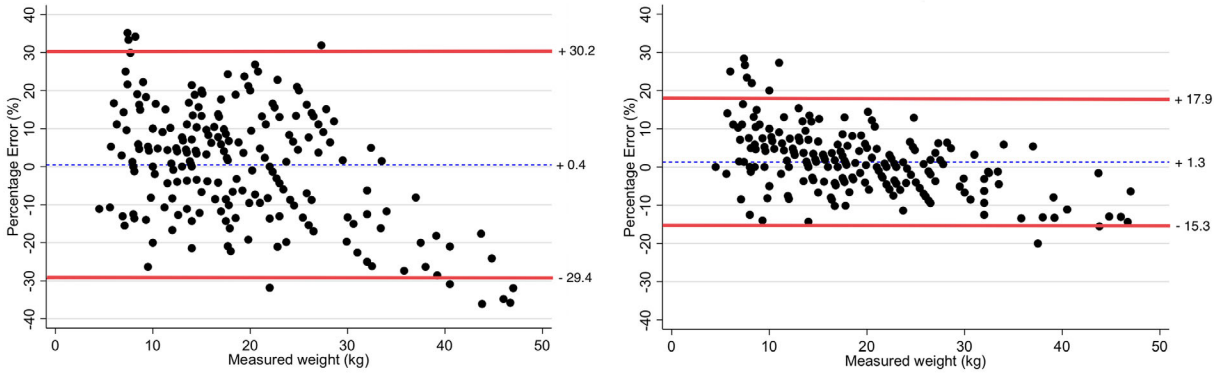

FIGURE 2 Modified Bland-Altman plot depicting agreement between estimated and actual weight: (A) Broselow tape and (B) PAWPER XL-MAC tape. Broken blue lines indicate the mean percentage error while solid red lines indicate the 95% limits of agreement

"sophistication of simplicity."[19] These are also the same features that a PAWPER XL-MAC tape fulfills by giving a direct weight estimation based on easily measured anthropometric parameters without requiring the use of any formula or calculations. Ease of using weight estimation tapes can be beneficial during resuscitation. Still, it is also important to take note that these tapes tend to under- and overestimate in extremes of age and weight. Hence, prudent use of these tools is recommended in these populations.

In conclusion, our study has demonstrated that among Filipino children attending our pediatric emergency department, the PAWPER XL-MAC tape performed a more accurate and precise weight estimation compared to the Broselow tape. Both tapes tend to overestimate weight among younger and underweight children while underestimating weight among children ages 7 to 10 years old and overweight or obese children.

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AUTHOR CONTRIBUTIONS

Both authors substantially fulfilled all authorship criteria defined by the International Committee of Medical Journal Editors: conceptualization of study design, analyzation of data, drafting the article, and approval and agreement of the final version.

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