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Original Contribution

Weight estimation in an inner-city pediatric ED: the effect of obesity☆,☆☆,★,★★

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ABSTRACT

Background and Objective: Weight estimation for pediatric resuscitation occurs frequently in emergency departments. Historically, different approaches to estimation have been studied with varied results. With increasing obesity rates among inner-city children, this study aims to determine the best method for pediatric weight estimation in our population.

Methods: This is a prospective, nonblinded, observational study. A total of 324 patients (aged 1 month to 12 years) were enrolled in the study to exceed sample size calculations. The accuracy of 4 methods for weight estimation—the Broselow tape, advanced pediatric life support formulas, the PAWPER tape, and mid-arm circumference formula—were compared across age ranges and body sizes to determine the most appropriate method for our population.

Results: In this inner-city population, 32% of the patients 2 to 12 years of age were found to be overweight or obese. This rate increased to 41% for patients 6 to 12 years of age. In this setting, the PAWPER tape outperformed the other 3 methods, estimating patients' weight within ± 5% of actual weight in 35.2% of our cohort. When compared with the other 3 methods tested, the PAWPER tape was statistically superior with a *P* value less than .02 in each case.

Conclusion: Each of the methods tested in our population performed poorly. Current methods for weight estimation should be used with caution, especially for populations with an increased prevalence of obesity. Efforts should be dedicated to improving or deriving new methods for weight estimation that perform better in this vulnerable population.

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1. Introduction

In pediatric resuscitation, knowing the child's weight is essential for lifesaving interventions such as estimating medication dosages, joules for defibrillation, and the size of airway equipment. Historically, methods for weight estimation have fallen into 2 categories: formulations based on length (ie, the Broselow tape) or age (ie, advanced pediatric life support [APLS] formula) [1–3]. Recent studies have shown these time-honored proxies for weight to be more fallible, with obesity the likely cause of inaccuracy [4–7]. For inner-city populations, especially among racial/ethnic minorities who are more obese than their white, non-Hispanic peers, this can lead to suboptimal emergent care [8,9]. In response to this problem, traditional approaches have been modified and new methods derived for pediatric weight estimation [4,7,10,11].

A promising method for weight approximation is a formula based on mid-arm circumference (MAC) measurement [11]. In the past, MAC has been used as a tool to gauge nutritional status in developing parts of the world [12]. New formulas aim to incorporate MAC alone or MAC in conjunction with humoral length or knee height to estimate weight [10,11,13]. Recent studies have demonstrated the equity of MAC alone with the traditional standard length-based weight estimation in certain populations and the superiority of MAC plus humoral length [10,11].

Separate from MAC, a group from South Africa developed a length-based, habitus-modified weight estimation system called the PAWPER (formal name, not an abbreviation) tape [4]. This tool is rooted in the traditional length-based approach but incorporates a 5-point body habitus scoring system to better estimate patients' weights. During assessment by the developers, the PAWPER tape outperformed the Broselow tape in both accuracy and precision in a cohort of South African children at 2 hospitals [4].

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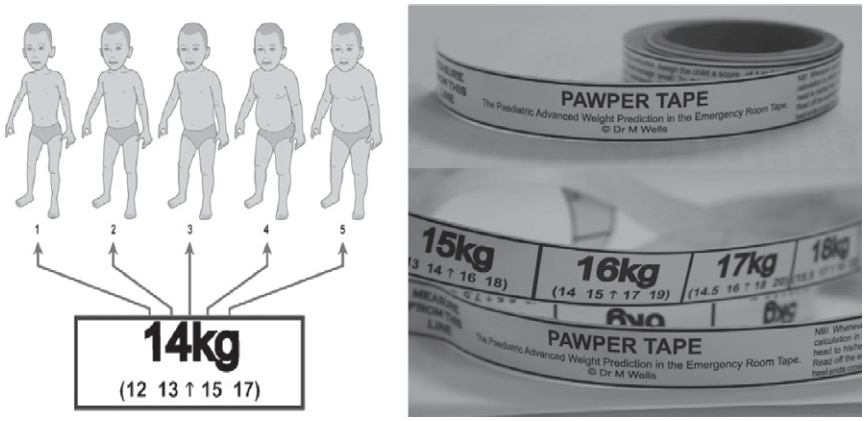

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Fig. 1. The pediatric advanced weight prediction in the emergency department tape [4].

The aim of this study is to compare 4 methods of weight estimation in our inner-city population with elevated levels of obesity. The 4 methods are a formula based on MAC, the PAWPER tape, the Broselow tape, and the updated APLS formulas. To our knowledge, no study has compared these 4 methods and very few weight estimation studies have been done among inner-city pediatric populations in the United States.

2. Methods

2.1. Design

The study was conducted as a prospective, nonblinded, observational study at a single institution in an inner-city, pediatric emergency department in the United States. A single investigator recruited a convenience sample of 324 patients. Consent was obtained from all parents and assent for all children older than 8 years. The institutional review board at Jackson Memorial Hospital and the University of Miami approved this study.

2.2. Inclusion criteria

Patients aged 1 month to 12 years were approached for enrollment during a variety of day and night shifts. Children presenting with chronic medical problems except mild to moderate asthma were excluded from enrollment (ie, sickle cell, nephrotic syndrome, malignancy, short gut syndrome, cerebral palsy, etc). Critically ill children requiring immediate attention were excluded.

Study inclusion criteria included minimum and maximum length measurements. This was necessary so that a weight could be derived for both length-based systems. The Broselow tape is the shorter of the 2 methods and accommodates children between 46 and 143 cm. Patients outside this range were excluded.

2.3. Methods for obtaining actual values

Actual weights were obtained during intake by an emergency medical technician or a registered nurse. Children were clothed and weighed on a Health-o-Meter: PELSTAR, LLC, McCook, IL 500KL Medical Scale. If the patient could not stand, they were weighed on a Befour: Befour Inc, Saukville, Wi MX02 Neonatal Scale. These measurements were documented in kilograms. For children able to stand, they were measured with the Health-o-Meter scale. Infants unable to stand were measured with a Grafco: Grahm-Field HEALTH PRODUCTS, INC., Atlanta, GA Paper Infant Measuring Tape. Heights and lengths were documented in centimeters.

The MAC was measured with the child's right arm relaxed and elbow at 90° of flexion. The midpoint between the olecranon and acromion processes was identified and marked. The arm circumference was measured at this point, making sure the tape was flat against the arm without pinching the underlying skin.

2.4. Methods for estimation

For the APLS formula, an age-based formula for weight estimation, we used the following formulas [3]:

- Infants 0 to 12 months of age: weight (kg) = (0.5 × age in months) + 4
- Children 1 to 5 years of age: weight (kg) = (2 × age in years) + 8
- Children 6 to 12 years of age: weight (kg) = (3 × age in years) + 7

Weight estimation based on MAC was done with the previously derived formula [11]:

$$\text{Weight(kg)} = [\text{MAC(cm)}–10] \times 3$$

For the Broselow tape, the patient's height was used to extrapolate where they would plot on the tape.

For the PAWPER tape, the patient's height was used to extrapolate where they would plot on the tape and the body habitus estimation

Table 1
Study population characteristics

Age	Average height (cm)	Average weight (kg)	Average body mass index (kg/m^2)	Average APLS formula estimation	Average PAWPER tape estimation	Average Broselow tape estimation	Average MAC estimation	% Male
0-1 y	62.2	7.5	18.8	6.8	6.6	6.1	15.1	54
1-5 y	97.6	15.9	16.5	13.6	15.5	15.2	20.9	54
6-12 y	128.0	29.8	18.0	29.8	27.4	26.8	31.1	51
0-12 y	99.5	18.3	17.4	17.0	17.2	16.8	22.8	52
Overweight	106.5	22.8	16.5	20.7	20.8	20.1	26.8	38
Obese	121.9	22.5	22.5	23.7	27.1	24.7	39.1	40

Table 2
Obesity rates in study cohort

Age	% Overweight	% Obese	Total overweight and obese
2-5 y (n = 116)	12% (n = 14) [15%)]	12% (n = 14) [8%]	28% [23%]
6-12 y (n-96)	22% (n = 21) [16%]	19% (n = 18) [18%]	41% [34%]
2-12 y (n = 212)	17% (n = 35)	15% (n = 32)	32%

Values in brackets (in percent) indicate US national averages [8]

was made by a single pediatric emergency medicine–trained physician (see picture reference 1 [Fig. 1]).

3. Statistical analyses

The sample size was calculated assuming an effect difference of 11.4% and independent proportions for comparison using a Fisher exact test. The calculated sample size needed to detect statistical significance at a value of $P < .05$ was 322 patients. This test was chosen over McNemar test for paired proportions, as the data set did not fulfill all of the necessary components to use McNemar test. However, because of the paired nature of the data, McNemar test would be expected to give a smaller required sample size. Thus, using Fisher exact test does not reduce the power of the study.

To determine statistical differences between the 4 methods' ability to accurately estimate actual weight, defined as within 10% (±5%) of the actual weight, pairwise McNemar tests for paired proportions were performed and Bonferroni correction was applied to adjust for type I error rate. All statistical tests were performed in SAS version 9.3 (SAS Institute, Cary, NC) assuming a type I error rate of 0.05. This information was calculated in collaboration with the Division of Biostatistics, University of Miami Miller School of Medicine.

4. Results

4.1. General study population characteristics

In our study of 324 patients, ages ranged from 1 month to 12 years. The largest cohort fell in between the ages of 1 and 5 years, and overall 52% of the patients enrolled were male. When compared with national statistics for childhood obesity, our population was more overweight and obese (Tables 1 and 2).

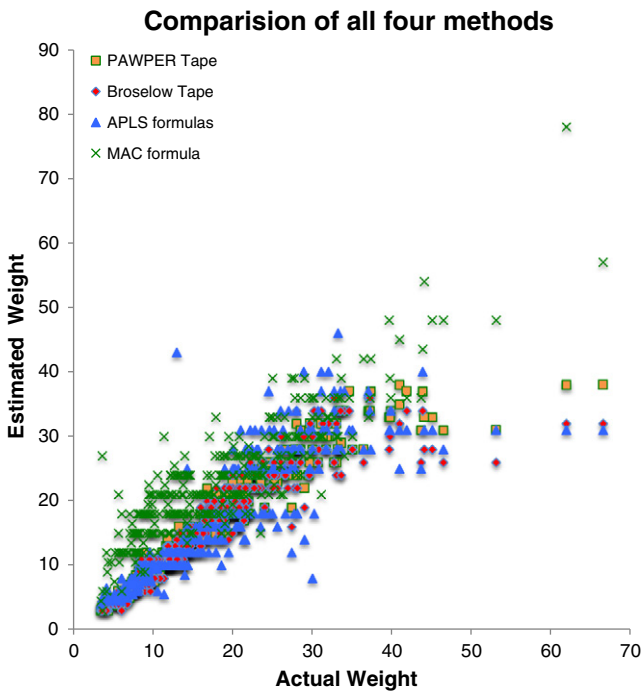

Fig. 2. Graphic displays comparing each of the methods for weigh estimation.

4.2. Comparing methods for estimation

In our population, the PAWPER tape outperformed the other methods; estimating the patients' weight within 10% of actual weight 35% of the time (Fig. 2). Mean error was −1 kg and variance was 1.8 kg. This was statistically better than the second best method, the Broselow tape, with a P value of .01. The Broselow tape was within 10% of actual weight 27% of the time, with a mean error of −1.5 kg and variance of 2.4 kg. Both length-based methods outperformed the APLS formula and MAC formula that were within 10% of actual weight only 17% and 15% of the time, respectively (Tables 3-6).

The MAC formula was the only method to overestimate weight most of the time, overestimating by an average of 4.4 kg. In addition, it outperformed the other methods when applied to the obese portion of our population, as defined by their body mass index.

5. Discussion

In this study, the Broselow tape and APLS formulas, along with 2 newer methods, the PAWPER tape and MAC formula, all demonstrated a large degree of error when estimating a patient's weight. Worsening performance was observed in all but the MAC formula with increasing age and weight of the patient. In this inner-city population, which has a higher proportion of obese children than the national average, this is a large problem (see Table 6).

In 2010, the United States Department of Health and Human Services reported that patients younger than 15 years make up one-fifth of the annual 129 million emergency department visits [14]. Trauma is the most common reason for these visits with non–children's hospitals seeing close to 90% of the total pediatric emergencies [15,16]. In general emergency departments which are infrequently staffed by pediatricians and in the field, where provider comfort with pediatric resuscitation may vary, a rapid and accurate method of weight estimation is a necessity for appropriate care [15].

This necessity led to the creation of the Broselow tape in the 1980s. Initial studies of the Broselow tape found it to estimate weight within 10% of the actual weight 57% of the time [1]. After this study, the Broselow tape became the most widely used tool for weight estimation in the United States. However, more recent studies in a variety of settings have shown the Broselow to estimate weight within 10% of actual weight for 37% to 53% of children [5,10,17]. Our study of an inner-city

Table 3
Mean error

Age	APLS	PAWPER tape	Broselow tape	MAC
0-1 y (n = 65)	−0.75 (66%)	0.87 (78%)	−1.38 (86%)	7.85 (3%)
1-5 y (n = 163)	−2.33 (80%)	−0.43 (56%)	0.69 (59%)	4.99 (6%)
6-12 y (n = 96)	0.02 (38%)	−2.41 (57%)	−3.02 (58%)	1.29 (36%)
0-12 y (n = 324)	−1.32 (65%)	−1.09 (63%)	−1.50 (65%)	4.43 (14%)
Overweight (n = 32)	−2.29 (84%)	−2.19 (97%)	−2.94 (100%)	4.40 (16%)
Obese (n = 35)	−10.62 (100%)	−7.22 (100%)	−9.68 (97%)	4.49 (17%)
Total overweight and obese (n = 67)	−6.64 (93%)	−4.82 (99%)	−6.64 (100%)	4.58 (16%)

Values in parentheses indicates total % of times weight was underestimated.

Table 4
Weight variance in kilograms

	APLS	PAWPER tape	Broselow tape	MAC
0-1 y	1.18 (15.8%)	0.98 (13.1%)	1.42 (18.7%)	7.64 (>100%)
1-5 y	2.63 (16.6%)	1.30 (8.2%)	1.59 (10.0%)	5.27 (33.2%)
6-12 y	6.32 (21.2%)	3.43 (11.5%)	4.4 (14.8%)	3.7 (12.4%)
Overweight	3.90 (23.7%)	2.35 (14.2%)	2.94 (17.9)	4.91 (29.8%)
Obese	10.62 (47.1%)	7.22 (32.0%)	9.90 (43.9%)	6.66 (29.6%)
0-12 y	3.43 (18.7%)	1.86 (10.1%)	2.39 (13.0%)	5.28 (28.8%)

Values in parentheses (in percent) indicate % difference based on mean weight.

Table 6
Method superiority at a statistical significance of ±5% of actual weight

Method	*P*
PAWPER tape > Broselow tape	.011
PAWPER tape > APLS	<.001
PAWPER tape > MAC	<.001
Broselow tape > APLS	.005
Broselow tape > MAC	<.001
APLS > MAC	1

pediatric population in the United States found worsening performance at only 27% of patients' weights being estimated within 10% of actual weight.

Similar to the Broselow tape, the APLS formula taught by the pediatric advanced life support class and used in the United Kingdom performed poorly in our study. Our findings conflict with a recent study done in Australian children where the APLS formula outperformed the Broselow [18]. Because of the growing awareness of the increasingly obese pediatric population, the formula was transitioned from 1 formula for all ages to 3 to better adjust for the obese child [3]. However, even with the 3 formulas, the APLS method was statistically inferior to the Broselow and failed to provide accurate weight estimation within 10% of actual weight 83% of the time in our population.

Current literature suggests that obesity is the main variable influencing incorrect Broselow estimates [4–7]. The PAWPER tape, developed specifically to adjust for the obesity epidemic, outperformed all of the other methods tested within our population yet still gave an incorrect weight value 65% of the time, usually underestimating the actual weight. The most severe underestimations were in obese patients. Although statistically superior to the other methods tested in this study, this amount of error should still be considered suboptimal in pediatric resuscitation.

5.1. Study limitations

Limitations to our study include that a single investigator, at a single institution, performed the data collection, when ideally numerous providers should validate these methods across a number of institutions. In addition, the voluntary participation of the subjects may have unknowingly resulted in sample bias, as is also possible with the exclusion of children with chronic diseases. Being weighed with clothes on may have led to inexact actual weights, but the study was conducted in a very temperate part of the country, so it is unlikely that weight of clothing would cause significant alteration to the patients' actual weight. Finally, it is theoretically possible that the use of dominant vs nondominant upper extremities to assess MAC may have contributed to a discrepancy in data.

6. Conclusion

The Broselow tape, PAWPER tape, APLS formulas, and MAC formula all demonstrated poor accuracy when used to estimate our pediatric population's weight. However, that our results and other studies similar in nature have arrived at different conclusions in varying populations highlights the need for new innovation and invention with regard to a tool for pediatric weight estimation.

An ideal weight estimation method would use a single parameter, easily obtained, with a high degree of reproducibility across the spectrum of providers and institutions, and would perform well in all pediatric ages and body sizes. The utility of such a tool would not only be for use in resuscitation in the emergency department but also for primary responders in the field and would be of paramount importance in a mass casualty situation. At this moment, an ideal approach for weight estimation for our pediatric population does not exist. Until a better approach is found, the current methods should be used with caution and an accurate weight obtained as soon as possible during the resuscitation process.

Table 5
Frequency of weight estimation within a certain percentage

Method	±5%	±10%	±20%	±30%
APLS	16.7%	36.4%	65.7%	87.0%
PAWPER tape	35.2%	63.0%	89.2%	96.6%
Broselow tape	27.3%	52.5%	81.4%	95.7%
MAC	14.5%	24.1%	40.1%	52.5%

References

[1] Lubitz DS, Seidel JS, Chameides L, Luten RC, Zaritsky AL, Campbell FW. A rapid method for estimating weight and resuscitation drug dosages from length in the pediatric age group. Ann Emerg Med 1988;17(6):576–81.
[2] Mackway-Jones K, Molyneux E, Phillips B, Wieteska S, editors. Advanced paediatric life support—the practical approach. 4th ed. Oxford: Blackwell; 2005.
[3] Chameides L, Samson RA, Schexnayder SM, Hazinski MF. Pediatric advanced life support provider manual. Am Heart Assn 2011 [Pap/Crds P edition].
[4] Wells M, Coovadia A, Kramer E, Goldstein L. The PAWPER tape: a new concept tape-based device that increases the accuracy of weight estimation in children through the inclusion of a modifier based on body habitus. Resuscitation 2013;84(2):227–32.
[5] Nieman CT, Manacci CF, Super DM, Mancuso C, Fallon WF. Use of the Broselow tape may result in the underresuscitation of children. Acad Emerg Med 2006;13(10):1011–9.
[6] Park J, Kwak YH, Kim DK, Jung JY, Lee JH, Jang HY, et al. A new age-based formula for estimating weight of Korean children. Resuscitation 2012;83(9):1129–34.
[7] Seddon C, Lockitt L, Dhanjal S, Eisenhut M. Validation of advanced paediatric life support formulas for weight calculation in a multiethnic population. ISRN Pediatr 2012;2012:4. http://dx.doi.org/10.5402/2012/869634.
[8] Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of obesity and trends in body mass index among us children and adolescents, 1999-2010. JAMA 2012;307(5):483–90.
[9] Margellos-Anast H, Shah A, Whitman S. Prevalence of obesity among children in six Chicago communities: findings from a health survey. Public Health Rep 2008;123:117–25.
[10] Abdel-Rahman SM, Paul IM, James LP, Lewandowski A. Evaluation of the Mercy TAPE: performance against the standard for pediatric weight estimation. Ann Emerg Med 2013;62(4):332–339.e336.
[11] Cattermole GN, Leung PYM, Mak PSK, Graham CA, Rainer TH. Mid-arm circumference can be used to estimate children's weights. Resuscitation 2010;81(9):1105–10.
[12] Rutishauser IHE. The arm circumference as a public health index of protein-calorie malnutrition of early childhood. (V) Correlations of the circumference of the mid-upper arm with weight and weight for height in three groups in Uganda. J Trop Pediatr 1969;15:196–7.
[13] Lin BW, Yoshida D, Quinn J, Strehlow M. A better way to estimate adult patients' weights. Am J Emerg Med 2009;27(9):1060–4.
[14] National Hospital Ambulatory Medical Care Survey. Emergency Department Summary Tables 2010.
[15] Schappert Susan, Bhuiya Farida. Availability of pediatric services and equipment in emergency departments: United States: 2006. National Health Statistics Reports, 47; 2012.
[16] Rasooly IR, Mullins PM, Alpern ER, Pines JM. US emergency department use by children, 2001-2010. Pediatr Emerg Care 2014;30(9):602–7 [610.1097/PEC.0000000000000204].
[17] Argall JAW, Wright N, Mackway-Jones K, Jackson R. A comparison of two commonly used methods of weight estimation. Arch Dis Child 2003;88(9):789–90.
[18] Graves L, Chayen G, Peat J, O'Leary F. A comparison of actual to estimated weights in Australian children attending a tertiary children's' hospital, using the original and updated APLS, Luscombe and Owens, Best Guess formulae and the Broselow tape. Resuscitation 2014;85(3):392–6.