Comparison of adult weight estimation methods for use during emergency medical care

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Abstract

Objective: Many emergency drug and fluid doses are weight dependent in adults, but in resuscitation and low-resource settings it can be impractical or impossible to weigh a patient. It is especially important to obtain accurate weight estimation for dose calculations for emergency drugs with narrow therapeutic ranges. Several weight estimation methods have been proposed for use in adults, but none is widely established. The aim of this study was to compare the accuracy of adult weight estimation methods.

Methods: Demographic and body measurement data were obtained from the US National Health and Nutrition Examination Survey (NHANES), and 7 previously published weight estimation methods were used to estimate the weight for each individual. The primary outcomes were the proportions of estimates within 10% and 20% of actual weight (P10, P20). An acceptable accuracy was predetermined to be P10 = 70% and P20 = 95%.

Results: The data set included 5158 adults (51.2% women) with sufficient data to calculate all weight estimation methods. The Lorenz method performed best (P10 = 86.8%, P20 = 99.4%) and met the standard of acceptability across sex and body mass index subgroups. The Mercy and PAWPER XL-MAC methods performed acceptably in non-obese adults.

Conclusion: The ideal weight estimation method should be accurate, rapid, simple, and feasible. This study has demonstrated the accuracy of 7 methods. The Lorenz method performed best but is complex and likely to be difficult to apply in resuscitation settings. Other simpler and quicker methods are at least as accurate as the best methods widely used in children, and there is potential for further calibrating these for use in adults before validation in real-world studies.

KEYWORDS
adult, body weight, body weights and measures, drug prescriptions, emergency medicine, global health, resuscitation

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1 | INTRODUCTION

1.1 | Background

In many emergency situations, it is important to know the weight of the patient to provide safe and effective drug and fluid dosages. This is well recognized in children, for whom medications are routinely dosed by weight, but is also true in adults, for whom a "one size fits all" approach often is used.

In non-emergency settings, in hospitals in high-resource settings, it is usually possible to weigh adult patients. If weighing scales are unavailable, or the patient is unable to stand, patient's estimation of his or her own weight has been found to be the best method to estimate weight (and the clinician estimate has been shown to be poor).[1,2] However, in many emergency situations, patients may not be able to communicate reliably. It has been suggested that all emergency departments (EDs) should have beds capable of weighing patients.[3] However, this is not feasible for pre-hospital or low-resource ED settings, where even simple weighing scales might not be available.

Although there are many weight estimation methods in children,[4] there are none widely validated or used in adults. Simple formulae to estimate weight in adults have been derived from height[5] or mid-arm circumference (MAC).[6] Complex weight estimation models for use in patients with stroke who are unresponsive have been derived from waist and hip circumferences and height and proved superior to visual estimate by the clinician.[2] Two recent studies, from Rwanda and South Africa, found that the PAWPER XL-MAC and Mercy methods, both of which were designed for children, could be used reliably in adults as well.[1,7]

1.2 | Importance

Weight-dependent dosing in adults is especially important for emergency drugs with narrow therapeutic ranges. For example, this includes many anesthetic agents[8] as well as non-titratable drugs, such as the thrombolytic agents used for ischemic stroke. Recent evidence suggested that an error margin in tissue plasminogen activator dose over 10% was associated with a 2.5-fold increase in poor outcome in patients with stroke.[9] Where it is impractical for adult patients to be weighed directly, it is, therefore, important for good emergency care for clinicians to obtain accurate estimates of weight.

1.3 | Goals of this investigation

The aim of this study was to compare the accuracy of 7 previously described adult weight estimation methods. The primary outcome measure for each method was the proportion of estimates within 10% and 20% of actual weight.

The Bottom Line

Often, the critical delivery of the appropriate drug dose in resuscitation hinges on an appropriate weight estimate. After comparing multiple weight estimation methods, the authors found the Lorenz method performed best in a retrospective cohort (n = 5158), followed by the Mercy and PAWPER XL-MAC in the non-obese.

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2 | METHODS

2.1 | Study design and setting

This study was a cross-sectional analysis of publicly available data from the National Health and Nutrition Examination Survey (NHANES). NHANES is a program of studies to assess the health and nutritional status of children and adults in the United States. It is widely used for epidemiological and health science research, and full details of sampling and examination methods are available online.[10] NHANES "demographics data" and "examination data" data sets for the most recent survey (2017–2018) were downloaded and combined according to NHANES guidelines.

2.2 | Participants and measurements

The inclusion criteria for this study were adults (18 years and older) with complete data for the following variables: age (years), sex, race/ethnicity, weight (kg), height (cm), mid-arm circumference (MAC; cm), humeral length (HL; cm), waist circumference (WC; cm), hip circumference (HC; cm), and body mass index (BMI; kg/m²). Data were not normally distributed and are presented as medians with interquartile ranges (IQRs). Weights were obtained with digital scales, with patients wearing standard examination gowns and underwear. Standing heights were obtained using a stadiometer. HL, MAC, WC, and HC were obtained with measuring tapes according to NHANES protocols. Participants were excluded if any of these measurements were unavailable.

2.3 | Estimation methods

Previously published weight estimation methods were included only if they used variables available from the NHANES data set. These are summarized in Table 1. The simplest and most accurate of Lorenz's formulae was used.[2] Both the Mercy and PAWPER XL-MAC (PXM) methods were used virtually, with tables of data for the relevant variables rather than the actual tapes.[11] The Mercy method uses MAC and HL, and PXM uses MAC and height.[12,13] Maximum measurements were assumed for those beyond the limits of those methods (Mercy: HL

TABLE 1 Weight estimation methods

Method	Type of method	Variables used	Formula for weight, kg	Reference
Mercy	Tape based	MAC, HL	–	12
PAWPER XL-MAC	Tape based	MAC, height	–	13
Lorenz	Sex-specific formulae	Height, WC, HC	Women: 110.924 + (height × 0.4053) + (WC × 0.325) + (HC × 0.836)	2
			Men: 137.432 + (height × 0.60035) + (WC × 0.785) + (HC × 0.392)	
Crandall	Sex-specific formulae	MAC, height	Women: 64.6 + (MAC × 2.15) + (height × 0.54)	14
			Men: 93.2 + (MAC × 3.29) + (height × 0.43)	
LMS method	Sex-specific data tables	MAC	–	6
Simplified MAC	Single formula	MAC	(MAC × 4) − 50	6
Kokong	Single formula	Height	Height − 100	5

Note: Centimeters (cm) are used throughout for MAC, height, WC, and HC.
Abbreviations: HC, hip circumference; HL, humeral length; MAC, mid-arm circumference; WC, waist circumference;

39 cm, MAC 40 cm; PXM: height 200 cm). The LMS method used sex-specific tables of data for weight according to MAC.[6] For each of the methods, formulae were created in Microsoft Excel to generate weight estimations for all individuals in the study.

2.4 | Outcomes

The primary outcomes were the proportions of estimates within 10% and 20% of actual weight (P10, P20). An acceptable accuracy was defined as P10 > 70%, P20 > 95%.[13] Secondary outcomes were the bias (mean percentage error [MPE]) and limits of agreement (LOA; LOA = MPE ± 1.96 SD) obtained from Bland Altman analysis.[15]

2.5 | Analysis

The McNemar test for comparisons of paired proportions was used to compare the P10 and P20 of different weight estimation methods. Subgroup analysis was performed for sex and BMI. BMI subgroups were defined as not overweight (BMI < 25), overweight (25 ≤ BMI < 30), and obese (BMI ≥ 30). χ^2 tests were used to compare P10 and P20 between subgroups. Bonferroni correction for multiple pairwise comparisons approximated a significant P value <0.001. The sample size was determined by the available data set; 852 paired observations are required to detect a difference in proportions of 1%. MedCalc Statistical Software V.19.6 was used for statistical analysis (MedCalc Software, Ostend, Belgium; https://www.medcalc.org).

2.6 | Ethics

As the study used publicly available data, ethical approval was not sought. No funding was obtained for this project.

3 | RESULTS

3.1 | Characteristics of study subjects

There were 5856 adults in the data set, of whom 5158 had data for all relevant variables. Summary demographic and variable data are presented in Table 2. Only 94 (1.8%) were underweight (BMI < 18.5), and these patients were analyzed together with those within ideal BMI limits as the "not overweight" group.

3.2 | Primary results

P10, P20, MPE, and LOA for each weight estimation method are presented in Table 3.

The Lorenz method achieved P10 > 70% and P20 > 95% accuracy overall and across all subgroups; no other method achieved that accuracy. For P10 and P20 in all adults, each method was significantly different from each other method (P < 0.0005 throughout) except for Mercy versus LMS P20 (P = 0.182). The Kokong formula the worst.

3.3 | Secondary results

In subgroup comparisons of P10, there were significant sex differences with the MAC, Mercy, Crandall, and Kokong formulae (P < 0.0001). BMI subgroups were not significantly different with the MAC formula or LMS method. Of the other methods, the Crandall formula was significantly better in the patients who were obese (P < 0.0005 throughout) than in other BMI groups, but all other methods were significantly less accurate in the patients who were obese.

3.4 | Limitations

A limitation of this study is that it relies on a pre-existing database and is constrained by the methodology and recruitment of that survey.[10]

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TABLE 2 Summary demographic and variable data

N	n (%), or median (IQR)
Total	5158
Women	2640 (51.2)
Age, years	51 (33–64)
Weight, kg	78.8 (66.4–94.4)
Height, cm	166 (159–173.8)
MAC, cm	32.9 (29.5–36.6)
HL, cm	37.2 (35.3–39.3)
WC, cm	98.9 (87.8–110.7)
HC, cm	104.1 (96.6–114)
BMI, kg/m^2	28.4 (24.5–33.4)
Not overweight	1408 (27.3)
Overweight	1643 (31.9)
Obese	2107 (40.8)
Race/ethnicity	
Hispanic	1178 (22.8)
White	1780 (34.5)
Black	1196 (23.2)
Asian	740 (14.3)
Other	264 (5.1)

Note: Figures to 1 decimal place.
Abbreviations: BMI, body mass index; HC, hip circumference; HL, humeral length; IQR, interquartile range; MAC, mid-arm circumference; WC, waist circumference.

The large majority (88%) of participants in this NHANES data set did have measurements of all the variables relevant to this study. We have not attempted to weight the analyses according to US demographics because it was not the aim of this study to validate these methods in a US population. Rather, the subgroup analyses by BMI will provide information more relevant to those who work with different populations. A related limitation therefore is that this particular data set had few participants who were underweight. It is important that any weight estimation is validated in one's own setting; this is therefore a preliminary study to compare the accuracies of different methods with a view to identifying the best methods for calibration and validation.

A further limitation of this study is that it was able to compare only those methods that use body measurements contained in the NHANES data set. This prevented analysis of several methods including knee height, thigh or calf circumference, and subscapular skinfold thickness. Similarly, it was not possible to compare the most commonly used methods of weight estimation: clinician or patient estimate.[4] In 1 study, P10 for the physician estimate of adult weight was 54% and for patient estimate was 86%.[16] Patient estimates have been shown to be superior in adults with the PXM, Mercy, and MAC formulae .[1]

Finally, this study was "virtual" in that it used a pre-existing data set of measurements obtained under ideal conditions. Although virtual studies have been shown to produce similar results to studies obtain-

ing actual body measurements, findings from virtual studies should be validated in a real-life emergency setting.[11]

4 | DISCUSSION

This study presents the accuracy of several adult weight estimation methods. An accurate, rapid, and simple method should provide emergency clinicians with an important tool to provide accurate dosing of critical drugs and fluids. This is especially important in resuscitation settings when direct weighing of the patient is impractical, but also in low-resource settings where weighing scales may not be available.

The Lorenz method was the most accurate overall and in all subgroups and achieved the predetermined standard of acceptability (P10 > 70%, P20 > 95%) throughout. None of the other methods achieved that standard, although both PXM and Mercy reached the standard (or very nearly) in the non-obese group. PXM, Mercy, LMS, and MAC formula methods all achieved overall accuracy comparable with that achieved by the Broselow tape in children, for which P10 ranges from 53% to 65%, which in turn is much better than age-based formulae, all of which are still widely used in children.[6] Neither the Kokong nor Crandall methods achieved the levels of accuracy reported even for age-based rules in children.

Although the Lorenz method displays superior accuracy, it requires 3 separate measurements involving circumferential measurements of the waist and hip and a complex calculation. It has been claimed to take 90 seconds to use this method, which is unlikely to be acceptable in a time-critical resuscitation situation.[17] It is also not clear how much longer it might take in patients who are unconscious or uncooperative, and its accuracy in real-world scenarios is uncertain.[18] Before recommending this method in the resuscitation room, there should be evidence of clinical feasibility and timeliness.

Both PXM and Mercy could be further adapted for adults. These methods were designed for children, and with further calibration with adult data, especially the obese, they might achieve accuracies in adults comparable with those obtained in children (PXM: P10 = 79.3%, P20 = 96.9%; Mercy: P10 = 76%, P20 = 98%).[12,13] In contrast to the Lorenz method, measuring height, HL, and MAC are relatively quick and easy in the patient who is supine and unconscious.

The other dual-measurement method, Crandall, was far less accurate. Designed for use in the patients who are obese, with P10 = 72% in the derivation study based on NHANES data (1988–1994),[14] it performed better in this group than in the non-obese group, but even in the obese group did not meet the accepted standard. It might be possible to derive a revised formula based on MAC and height that achieves similar accuracy to PXM or Mercy, and better than the LMS or MAC formula, both of which use only 1 body measurement.

Both the LMS and MAC formulae were also derived using NHANES data (2009–2012) and performed similarly to the derivation study (LMS: P10 = 67.5%, P20 = 94.9%; MAC: P10 = 63.5%, P20 = 92.1%).[6] As the MPE (bias) cannot be improved much more, and with similar LOA to the original study, it is unlikely that further revisions will improve either the trueness or precision of these methods.

TABLE 3 Accuracy of weight estimation methods

	Lorenz	PXM	Mercy	Crandall	LMS	MAC formula	Kokong
All adults, n = 5158							
P10	86.8	59.3	68.2	34.5	65.7	62.3	26.4
P20	99.4	88.4	92.8	63.4	93.4	90.9	53.1
MPE	0.4	−7.1	−3.7	13.9	−1.1	1.3	−18.6
LOA	−12.6 to 13.4	−32.1 to 17.9	−25.7 to 18.3	−13.1 to 41.0	−23.0 to 20.7	−21.7 to 24.2	−63.3 to 26.0
Women, n = 2640							
P10	87	59.4	70.9	18.4	65	59.1	23
P20	99.3	86.9	93.6	40.8	93.4	88.8	47.2
Men, n = 2518							
P10	86.7	59.1	65.4	51.3	66.5	65.6	30
P20	99.6	90	92.0	87.1	93.4	93.1	59.3
Not overweight, n = 1408							
P10	84.3	69.6	78.7	11.2	65.2	63.7	59.7
P20	98.9	96.7	97.2	32.5	92.5	91.6	83.3
Overweight, n = 1643							
P10	89.2	73.8	74.1	26.5	68.4	62.1	31.8
P20	99.6	95.2	96.8	56.1	94.6	90.4	90.2
Obese, n = 2107							
P10	86.7	41	56.6	56.2	64	61.4	0
P20	99.6	77.5	86.9	89.8	93	90.8	3.9

Note: Data are provided as percentages. Figures to 1 decimal place. For simplicity, 95% confidence intervals have not been included; the largest range for any given percentage was ±2.5%.

Abbreviations: PXM, PAWPER-XL MAC method; P10/20, proportion of estimates with 10%/20% of actual weight; MPE, mean percentage error; LOA, limits of agreement.

The other single-measurement method, the Kokong formula, is unlikely to be acceptable for use in most populations. It is essentially the same formula as used for ideal body weight[8] and was validated in a small study of (mostly male) medical students in Nigeria, with no obese individuals included. In that population, P10 was 86%.[5] In our larger, mixed population, it was far less accurate. The LOAs were widest for this method, indicating its inherent imprecision; fine-tuning a height-based formula might improve the MPE, but the overall accuracy will remain poor because of the wide range of weights for a given height.

Good emergency care often requires clinicians to know the weight of their adult patients. This allows correct dosing of drugs and fluids, which is especially important for drugs with narrow therapeutic ranges. In emergency settings, it is often impractical to weight the patient directly, and weight estimation methods are necessary. The ideal adult weight estimation tool should be accurate, simple, and quick to use. This study has demonstrated the accuracy of different methods. The Lorenz method performed best but is the most complex and likely to be most difficult to apply in a resuscitation setting. Other simpler and quicker methods are at least as accurate as the best methods widely used in children, and there is potential for further calibrating these for use in adults before validation in real-world studies.

CONFLICTS OF INTEREST

Professor Wells is the creator of the PAWPER tape, but this is non-profit, and he has no financial conflict of interest.

AUTHOR CONTRIBUTIONS

Both authors conceived and designed the study. Giles N. Cattermole provided the analysis and initial draft, and Mike Wells revised the article.

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