Study on the Development and Validation of Height and Mid Arm Circumference (MAC)-Based Weight Estimation Formula in Neurological Patients of Eastern Nepal.

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Abstract

Introduction: Accurate weight measurement is crucial in clinical settings for medication dosing, nutritional management, fluid balance, diagnostics, and ventilator settings. Traditional weight measurement methods can be challenging for neurological patients, especially those with impaired mobility. This study aims to develop and validate a weight estimation formula using height and mid-arm circumference (MAC) to address these issues.

Materials and Methods:: This cross-sectional study was conducted at the Neurosurgery outpatient department of Neuro Cardio and Multispecialty Hospital in Biratnagar, involving 120 adults aged 18-75 years. Convenience random sampling was used. Data were analyzed using IBM SPSS Statistics 26.0. A linear regression equation was developed to estimate weight based on height and MAC. The validation included R^2 analysis, t-tests, Bland-Altman analysis, percentage error calculation, and scatterplot diagrams.

Results: The simple formula for weight estimation using linear regression equation was derived: Weight (kg) = −73 + 0.32 × Height (cm) + 3 × MAC (cm). Method C (age and gender-neutral) was the most accurate, with an R-squared value of 0.858, a t-value of 2.387, and a p-value of 0.019. In addition, Bland-Altman analysis showed the least bias and limits of agreement (LOA) of -0.996 and -9.95 to 7.97 respectively. Method C also had higher percentages of estimates within 10%, 20%, and 30% of actual weight (83.3%, 96.7%, and 100%, respectively). Scatterplot analysis indicated better linearity for Method C.

Conclusions: Method C is recommended for bedside weight estimation in neurological patients due to its simplicity and precision.

Keywords: Weight, Mid-Arm Circumference, Height, Neurological, Clinical

Introduction

Accurate estimation of patient weight is crucial in Intensive Care Unit (ICU) settings for precise medication dosing, nutritional planning, and clinical assessments. Overestimation risks drug toxicity and increased costs, while underestimation may lead to ineffective treatment.[1] Weight-based dosing influences therapeutic strategies and calculations such as nutritional needs and renal function estimation. Despite its importance, current estimation methods by ICU staff can be unreliable.[2] Many neurological patients cannot communicate their body weight, and physicians often rely on visual estimates.[3] Innovative approaches offer promising alternatives, like anthropometric measurements for weight estimation.[4] Validating such tools for accuracy in adults could significantly enhance clinical decision-making and patient outcomes. Ensuring accurate weight estimation remains pivotal for optimizing medication safety, therapy effectiveness, and overall patient care in critical care environments.[5] This study aims to develop and validate a weight estimation formula using height and Mid-Upper Arm Circumference (MAC) as anthropometric measurements among adults aged 18-75 years. The goal is to enhance the existing research on weight prediction for such critically ill patients.

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METHODS

A descriptive hospital-based cross-sectional study was conducted among 120 adults aged (18-75) years for the development and validation of the weight estimation formula. The study was conducted in the Neurosurgery outpatient department (OPD) of Neuro Cardio and Multispecialty Hospital (NCMH) in Biratnagar-10 from 1st to 31st May 2024. A convenience sampling method was used to select mobile adults.

The sample size was calculated by using the following formula:
Sample size (N) = Z² x p x (1-p) / d²
= 1.962 x 0.90 x (1-0.90)/ (0.05)2
= 138.24 ≈ 138
Where,
N= Sample size
Z= 1.96 at 95% Confidence Interval (CI)
p= prevalence which is taken as 90% from the previous study.3
q= 1-p
d= margin of error, 5%
New sample size in finite population = N / [1+ (N-1) / POP]
= 138 / [1+ (138-1) / 400]
= 102.7
Considering the exclusion cases as 15%, the adjusted sample size was calculated to be 120.

Permission to conduct the study was taken from the operational director and management team of the Hospital. The verbal consent was taken from all the participants before taking their anthropometric measurements and the objective of the study was explained in the vernacular. All the participants in age between (18-75) years attending Neurosurgery OPD, who were mobile with GCS score of 14 and willing to participate in the research were included. Participants with conditions that could affect the anthropometric data like weight, height and mid-arm circumference were excluded. This included those with edema, pregnancy, malnutrition, cognitive impairment, limb abnormalities or any chronic conditions affecting body composition or weight.

Data was gathered using anthropometric measurements that included height, weight, and mid-upper arm circumference (MUAC). Weight was measured using a calibrated digital weighing machine, with participants standing barefoot in light clothing. The measurement was recorded to the nearest 0.1 kg, and a second reading was taken to ensure accuracy. Height was measured using a stadiometer, with participants standing barefoot on a flat surface, their heels, buttocks, and upper back aligned against the vertical board. Height was recorded to the nearest 0.1 cm. MAC was measured using a non-stretchable adult MUAC tape. The midpoint of the left upper arm was identified by measuring the distance between the shoulder bone (acromion) and the elbow tip (olecranon) and marking the midpoint before measuring. Two readings were taken for all measurements, and the averages were used for analysis.

Descriptive statistics, frequency distributions, and Pearson's correlation coefficients (p) with 95% CIs were calculated. Linear regression was used to develop weight estimation formulas based on MAC, height, age, and sex. Bland-Altman analysis, R-squared values, t-tests, and scatterplot diagrams were used for model validation and to compare the proposed formula with existing ones. In addition, the overall proportions of estimates with errors of 10%, 20%, and 30% were calculated for each method to check its accuracy.
Microsoft Excel 2016 was used to manually code and enter the acquired data sets into the database. Here, qualitative data were coded and transcribed by giving labels to different groups. For additional analysis, it was then moved to IBM SPSS Statistics program (version 26).

RESULTS

A total of 120 adult samples, aged 18 to 75 years, were collected from the Neurosurgery OPD of NCMH in Biratnagar-10. The dataset was analyzed for weight estimation using variables such as age, sex, height, MAC, and actual weight. The mean age of the respondents was 33.76 ± 13.77 years, with a mean height of 157.38 ± 7.76 cm, mean weight of 57.75 ± 12.05 kg, and mean MAC of 27.30 ± 3.33 cm. Significant relationships with actual weight were observed only with age (p = 0.010) and MAC (p = 0.000). No significant relationships were found with height (p = 0.988) and sex (p = 0.264).

Table 1 :The distribution of these variables by age and gender is presented in.

Variables	Frequency	Percentage
Age		
18-32	72	60
33-47	27	22.5
48-62	14	11.7
63-75	7	5.8
Gender		
Male	60	50
Female	60	50
Range	10-52	10-23
Duration of ventilation(days)		
Mean ± SD	6.86 ± 8.37	0.6 ± 1.07
Range	0-24	0-3

Table 1. Distribution by the age and gender of the respondents (n=120)
From the linear regression analysis, the weight estimation formula was:
Weight in kg= -74.417+0.326*Height (cm)+0.059*Age (years)-1.82* Sex (0=female;1=male) +2.925*MAC (cm).

In this formula, all variables were found to be significantly related to weight estimation (p = 0.000), except for age (p = 0.058) and sex (p = 0.091) at a 95% confidence interval. To refine the formula, three models were developed by progressively removing insignificant variables while method D was added as already existing formula for additional validation:

Method A (Linear fit)-All the variables included (-74.417+0.326*Ht.+0.059*Age-1.82*Sex +2.925*MAC)
Method B (Gender neutral)- Gender omitted (-74.417+0.326*Ht.+0.059*Age +2.925*MAC)
Method C (Age and gender neutral)- age and gender omitted (-74.417+0.326*Ht.+2.925*MAC)
Method D (Existing formula)- MAC-based Existing formula (4*MAC-50)
To assess the robustness of the models, we employed R-square (Model-fit), t-test, Bland-Altman analysis and scatterplot diagrams.

Method A had the highest R^2 (0.867), indicating it explained the most variance in weight. Methods B ($R^2 = 0.863$) and C ($R^2 = 0.863$) were also strong but slightly less effective than Method A. Method D had the lowest R^2 (0.800), suggesting it explained less of the variance. A p-value less than 0.05 ($p < 0.05$) indicated significant differences between the methods. Specifically, Method A had a p-value of 0.588, showing no significant difference. Methods B ($p = 0.017$) and C ($p = 0.019$) exhibited significant differences, while Method D ($p = 0.11$) showed a trend toward significance. The p-values suggest that Methods B and C, as well as Method D, had significant biases compared to the baseline, whereas Method A did not, as represented in Table 2.

Table 2: Model fit and paired t-test comparison of different Methods (A to D) (n=120)

Methods	R-square (R2)	Paired t-test	
		t-value	p-value
Method A (Linear fit)	0.867	-0.543	0.588
Method B (Gender neutral)	0.863	-2.425	0.017
Method C (Age and gender-neutral)	0.858	2.387	0.019
Method D (Existing formula)	0.800	2.594	0.011

p-value significant (<0.05)

Method A (0.248) had a low bias and a relatively narrow range of Limits of Agreement (LOA) from -9.55 to 10.05, suggesting better agreement with the actual weight measurements with relatively tight range of error. Method C while having a slightly wider LOA (-9.95 to 7.97), offers the least bias (-0.996), indicating less systematic error. Methods B had a similar bias of 0.995 and narrow LOA ranges of -7.81 to 9.79. Method D (-3.48) showed the largest bias and the widest LOA range from -32.33 to 25.37, indicating poorer agreement with the actual measurements.

Method A demonstrated high accuracy, with 79.2% of estimates within ±10%, 97.5% within ±20%, and 99.2% within ±30% of the actual weight. Methods B and C performed slightly better, with 96.7% of estimates within ±20%, and 100% within ±30% of the actual weight, respectively. Comparatively, Method C demonstrated the highest precision, with 83.3% of estimates within ±10% of the actual weight, compared to 82.5% for Method B. Method D was the least accurate, with only 55.8% of estimates within ±10%, 79.2% within ±20%, and 84.2% within ±30% of the actual weight, as shown in Table 3.

Table 3: Accuracy of different weight estimation methods (A to D) (n=120)

Methods	Bland-Altman Analysis		Percentages of estimates lying in x% of actual weight		
	Bias	Limits of Agreement (LOA)	Within 10%	Within 20%	Within 30%
Method A (Linear fit))	0.248	-9.55 to 10.05	79.2	97.5	99.2
Method B (Gender neutral)	0.995	-7.81 to 9.79	82.5	96.7	100
Method C (Age and gender neutral)	-0.996	-9.95 to 7.97	83.3	96.7	100
Method D (Existing formula)	-3.48	-32.33 to 25.37	55.8	79.2	84.2

The visual representation of bias and LOA for each method was illustrated using a Bland-Altman plot, as shown in Figure 1.

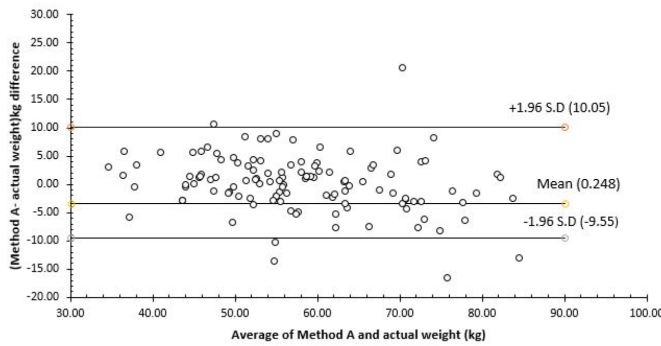

Figure 1 (A)- Bland-Altman Plot for Method A.

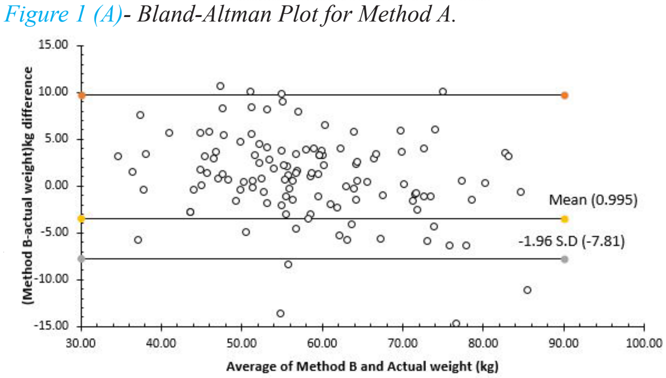

Figure 1 (B)- Bland-Altman Plot for Method B.

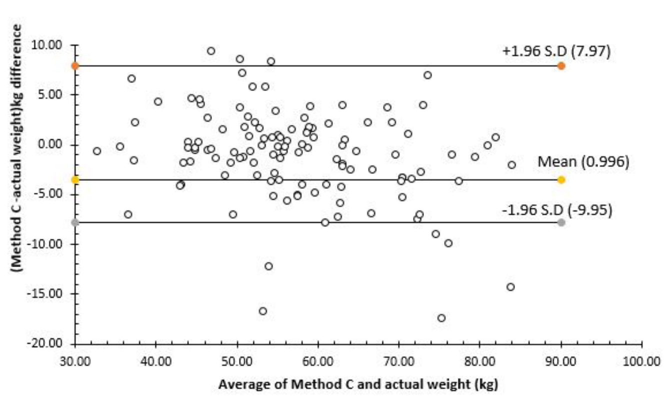

Figure 1 (C)- Bland-Altman Plot for Method C.

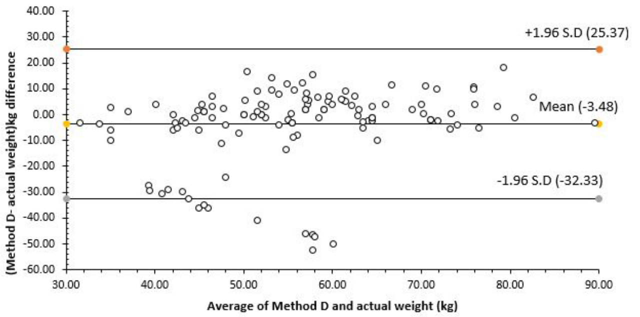

Figure 1: Bland-Altman plot for each Method (A to D) for adults (18-75) years

The scatterplot analysis was conducted for each method, with Method C showing a more linear relationship and the least spread of data points around the line of best fit, whereas Method D exhibited the greatest spread of data points, as shown in Figure 2.

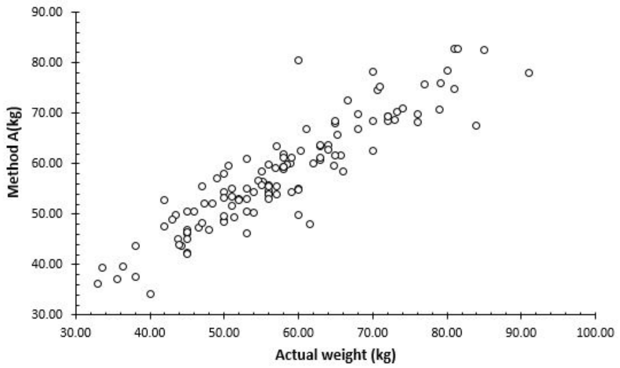

Figure 2 (A): Scatter plot diagram of actual weight vs weight estimation by Method A.

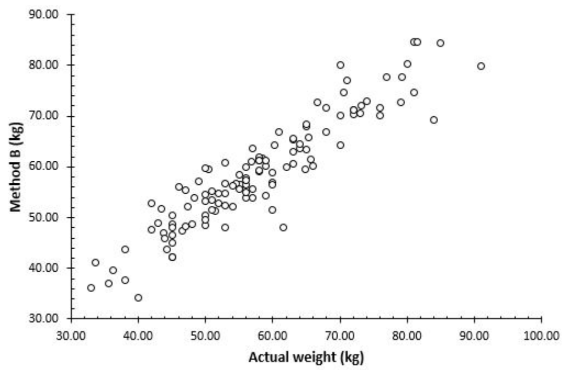

Figure 2(B): Scatter plot diagram of actual weight vs weight estimation by Method B

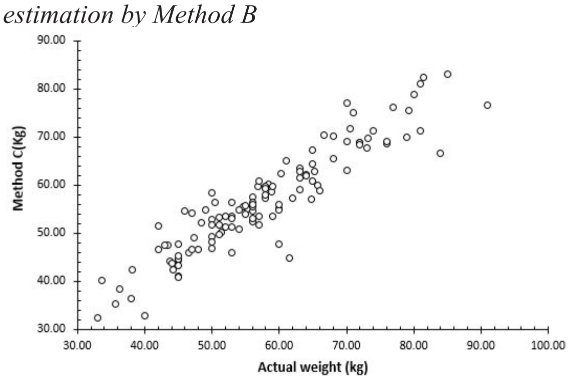

Figure 2(C): Scatter plot diagram of actual weight vs weight estimation by Method C

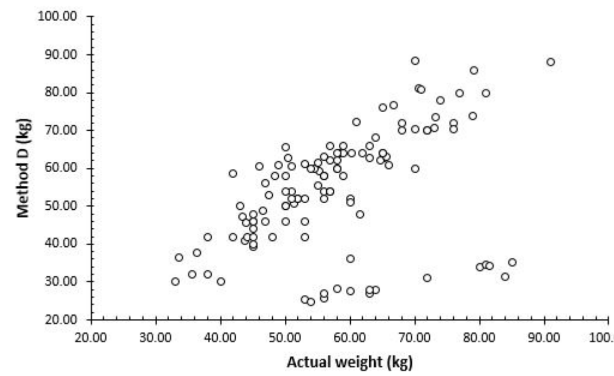

Figure 2(D): Scatter plot diagram of actual weight vs weight estimation by Method D

Figure 2: Scatter plot diagram of actual weight vs weight estimation by Methods (A to D) for adults aged (18-75) years

DISCUSSIONS

In acute medical settings, accurate body weight is essential for the proper dosage of numerous pharmacological treatments.6 Often, emergency patients are unable to provide their weight. Body weight is also a critical parameter in many medical procedures and is used in various clinical scenarios, including calculating nutritional needs, administering drug doses, conducting resuscitations, estimating pulmonary tidal volume, and performing hemodynamic evaluations.[7,8]

The study highlighted a significant correlation between weight and both age and Mid-Upper Arm Circumference (MAC), but no significant correlation with sex and height. Aging is commonly linked to decrease in total lean body mass, which can lead to a reduction in muscle strength, mobility, and overall physical function. In adults, weight tends to stabilize after reaching adulthood, though lifestyle, diet, and physical activity can still affect it.[9] MAC generally shows a positive correlation with weight, as both metrics can indicate overall body mass and muscle development. Higher body weight is generally linked to a larger MAC, which indicates greater muscle or fat mass. As people age and experience muscle loss (sarcopenia), weight may fluctuate, potentially leading to a decrease in MAC if weight loss or significant muscle reduction occurs.[10]

With the help of linear regression model through IBM SPSS, we derived MAC and height-based equation given by; weight (kg)=-74.417+0.326* height (cm)+2.925*MAC (cm) where the coefficients of the variables were rounded off to give the simplified version, weight (kg)=-73+0.32*height+3*MAC

In our linear regression model, we found that estimated weight was significantly related to MAC and height, but not to age and sex. To identify the best model, we created three variations by progressively removing less significant variables: Method A that included all variables which is age, sex, MAC and height, Method B, which is gender-neutral, and Method C, which is both gender- and age-neutral. Method D represents an existing MAC-based formula for weight estimation using MAC as the only variable. This established formula was also compared with the models derived from our linear equation for additional validation.

Height is frequently utilized in weight estimation methods for both adults and the elderly.[11,12] This underscores its relevance for accurate weight estimation, as demonstrated in our study. MAC has long been used as an indicator of nutritional status in children under five years old, particularly in resource-limited settings.[13] The World Health Organization (WHO) classifies a MAC of less than 11.5 cm as indicative of severe acute malnutrition (SAM). MAC is also used to assess nutritional status in pregnant women, with a cutoff value of less than 23.5 cm.[14,15] Historically, MAC has been correlated with weight and has been used to estimate weight in children, new-born, and now it is also used to estimate weight of adults in many studies along with other anthropometric variables.[16,17,18] Our study's height and MAC-based formula was validated through various statistical analyses, including model fit evaluation, R-squared values; paired sample t-tests; Bland-Altman analysis; percentage error assessments, and scatterplot diagrams.

The analysis shows that Method C—which is gender- and age-neutral—is the most effective approach for estimating weight. It has the highest percentage of estimations within 10% (83.3%), 20%, and 30% of the actual weight (96.7% and 100%, respectively), and a virtually zero bias (-0.996) with a tight LOA of -9.95 to 7.97 (Table 3). Furthermore, a strong linear relationship was displayed in the scatterplot using Method C, suggesting consistent performance across several data points (Figure 2). The paired t-test for Method C shows a significant difference (p= 0.019) from actual weights while having a slightly lower R-square (0.858) than Method A (Table 2). Nevertheless, it provides the best overall balance of accuracy, precision, and consistency.

Numerous studies indicate that healthcare providers often struggle with accurately estimating patient weights. One study found that providers could estimate within 5% of the true weight in only 33% of cases, and this accuracy did not improve with experience or specialization.[19] An ideal method for bedside weight estimation should be straightforward, quick, and highly accurate.20 Therefore, we propose that the formula developed in this study, which uses only height and MAC, offers a simplified and efficient solution for estimating the weight of bedridden patients in a very short time.

CONCLUSIONS

This study developed a weight estimation formula using height and Mid-Upper Arm Circumference (MAC) for adults aged 18-75 years [weight (kg) = -73 + 0.32* height (cm) + 3*MAC (cm)]. The formula was rigorously validated and provides a reliable estimate of body weight, which is particularly useful for bedridden patients, including those with neurological conditions who may face difficulties with traditional weight measurements. For Neurological patients in ICU or rehabilitation settings, this formula offers a practical tool for nutritional assessment and care management. Given the study's limited sample size, further research with larger and more diverse populations is recommended to refine the formula and assess its applicability across different patient groups. Future studies should also explore additional variables to enhance the accuracy of weight estimation.

Conflict of Interest: None.

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