REVIEW ARTICLE

The Development of Body Mass Index (BMI) Device based on Anthropometric Measurements Equation for Adults and Older Persons in Clinical Settings: A Scoping Review

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ABSTRACT

Accurate anthropometric measurements in clinical settings remain challenging. This review article summarised significant studies on anthropometric equations and explored the design and functionality of measurement tools for adults and older persons. A systematic search on PubMed, SCOPUS, Science Direct, and Google Scholar, restricted to human studies in English, following the PRISMA-ScR (2018) guidelines. 20 studies were included in this review. Knee height shows high reliability for height measurement, while mid-upper arm circumference is the strong parameter in measuring weight. Four studies addressed digital BMI devices but noted limited validation across diverse populations. Various methods can be employed to measure height, weight, and BMI when direct measurement is not feasible. Further research on digital or automated anthropometric measurement among hospitalized adults and older persons is necessary to enhance nutritional assessment and management.
Malaysian Journal of Medicine and Health Sciences (2026) 22(1): 1-14. doi:10.47836/mjmhs.v22.i1.1466

Keywords: Height measurement, Weight measurement, Body mass index, Adults, Older persons

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INTRODUCTION

According to the Centers for Disease Control and Prevention (CDC), anthropometric measurements are crucial for assessing the nutritional status of children and adults. The fundamental components of anthropometry include height, weight, head circumference, body mass index (BMI), body circumferences (waist, hip, and limb) to measure adiposity, and skinfold thickness [1]. Among these, body mass index (BMI) is a widely used component of nutrition screening tools due to its affordability, simplicity, and practicality. BMI cut-offs are used to assign a level of malnutrition risk, particularly in hospitalized adults and older persons [2]. Malnutrition is more common in geriatric patients due to factors like advanced age, cognitive decline, comorbid diseases, excessive polypharmacy, depression, and poor appetite, [3,4].

However, the issue of accurately calculating height and weight arises when elderly people experience a decline in their stature [5]. The average height loss for men and women between the ages of 40 and 80 was 3.6 cm and 4.8 cm, respectively, and began around age 40 [6]. Although body weight fluctuates less than height, it still affects BMI calculation [5]. For individuals with severe obesity, especially those who have mobility issues, standard practice frequently fails to provide accurate measurements [7]. In addition, it might be challenging to establish precise estimations or measurements when patients are regularly in emergencies, are immobile, or may not be able to communicate [8]. Recognising the limitations, several surrogate measurements to measure height and weight accurately have been developed. These techniques include the mid-upper arm circumference (MUAC), demi-span, and ulna length [9]. Total arm length is a reliable substitute in older populations [5], and studies indicate that demi-span is especially helpful for determining height when direct measurement is not possible [10].

Other than that, in clinical settings, healthcare professionals employ a variety of techniques to diagnose and assess anthropometric status; however, some diagnostic tools are pricy, non-portable, and emit dangerous radiation [11]. According to the literature, the body of research on anthropometric measurement instruments for determining height, weight, and BMI in adults and older people is lacking, especially for those who are bedridden or have restricted movement. Few research has created automated BMI assessment equipment, by using load cells and ultrasonic sensors, which have proven reliable but are best suited for people who can stand upright without any mobility issues [11,12]. [AIBA3.1][AIBA3.2]Among the drawbacks include its inability to accommodate users weighing 90 kg or more, its suitability for a single user at a time, and its inaccessibility to those with dwarfism, impairments, or mobility disorders [12].

The data currently available on anthropometric formulae for calculating height, weight, and BMI was compiled through a literature survey. This research also examined how BMI measurement tools are developed and their functionality, particularly for adults and older persons.

MATERIAL AND METHODS

The scoping review by Arksey and O'Malley was used as a guide to conduct this review to identify the pertinent data in measuring height, and weight and the development of a body mass index measurement device. This study was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Review (PRISMA-ScR) guidelines (2018) as shown in Fig. 1 [13].

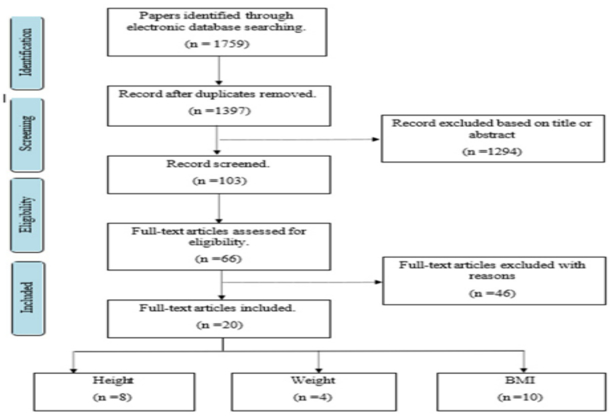

Fig. 1: PRISMA flowchart for article selection

Identifying the research questions

The review questions were: (1) What are the pertinent equations that should be embedded in the body mass index measurement device for adults and older persons?, (2) What are the suitable design criteria for digital body mass index measurement devices for adults and older persons to be used in the medical area?, and (3) What is the functionality and accuracy of the body mass index measurement device for adults and older persons?

Identifying relevant studies

The systematic search was conducted by using electronic databases such as PubMed, SCOPUS, Science Direct, Cochrane, and Google Scholar. Academic journals with full-text accessibility that have been published in the last ten years, from 2014 to 2024, were thoroughly searched for relevant articles. Search terms included "body mass index", "height measurement", "weight measurement", "device", "automated" and "older adults" (for the full search strategy, see Supplementary Table I. Articles were limited to original observational studies with retrospective or prospective cohort, cross-sectional, or case-control study designs. The search was limited to human studies and published in English. Studies in languages other than English were excluded. Studies related to body composition (i.e., Fat-free mass, muscle mass, body fat) and involving aged <18 years were excluded.

During the selection of studies, the data extraction procedure was carried out independently by two researchers, and consensus was reached for all eligible studies. The researchers discussed and examined any disagreements that surfaced during the selection of studies. The reference lists of every article that was retrieved were manually examined for additional relevant research. The abstracts of the studies were screened after their titles. All of the studies that were found to be pertinent during the first screening were read.

Study selection

The reviewed studies were selected after an insightful evaluation of the information about; (1) the pertinent height and weight equation that should be embedded in the body mass index measurement device, (2) the suitable design criteria of digital body mass index measurement device, and (3) the functionality of the body mass index measurement device.

Charting the data

The articles which were identified in electronic databases were exported and stored using the Mendeley software. Next, duplicates were removed from the articles. The eligibility of the remaining complete articles was assessed. Establishing the inclusion and exclusion criteria is a necessary step in the eligibility process. Studies included were the ones with (1) adults or older adults; (2) measurement of human body parts; (3) studies published in English languages; and (4) full-text articles only. Excluded criteria include studies that involved children, animals, and body composition (e.g., fat-free mass, muscle mass). The remaining data were incorporated into this scoping review after the full-text articles that didn't meet the requirements were eliminated. The research was summarised qualitatively including the country, author, year of publication, types of study design, purpose of study, number of subjects or participants, tools or equations used to measure height, weight, and body mass index (BMI), and findings on the measurement tools or equations. All of the findings were summarised in Table I, Table II and Table III.

Table I: Overview of Height Measurement

No.	Country	Study design	Objectives	Participants	Variables	Equation/ Device	Results
1.	Malaysia; Juhanis, (2020)	Cross-sectional	1. To validate the equation for demi-span measurement proposed by Ngoh et al. (2012).	Subjects: n= 118 Age: 30-55 years old	1. Demi Span	1. Ngoh et al. (201): Men: 67.51 + (1.29 x demi span) – (0.12 x age) + 4.13 Women: 67.51 + (1.29 x demi span) – (0.12 x age)	1. The height calculated from the equations and the measured height showed consistent agreement and similarity (r= 0.944 and r= 0.949, respectively). 2. The calculated height led to BMI estimate that was close to the actual BMI (r = 0.997 and r= 0.996, respectively) calculated from the measured height.
2.	Indonesia; Pertiwi, J., (2018).	Cross-sectional	1. To arrange the regression models by combining two predictors (arm span and knee height)	Subjects: n = 136 Age: 60-69 years	1. Arm Span 2. Knee Height	1. Fatmah formula: Women: 28.312 + [0.784 x AS (cm)] Men: 23.247 + [0.826 x AS (cm)] 2. Chumlea formula: Women: 84.88 + [1.83 x KH (cm)] – [0.24 x Age (years)] Men: 64.19 + [2.02 x KH (cm)] – [0.04 x Age (years)]	1. There is a strong positive correlation between arm span and actual height: Men: p value <0.001, r= 0.886 Women: p<0.001; r=0.992 2. There is a very strong positive correlation between knee height and actual height: Men: p<0.001; r=0.989 Women: p<0.001; r=0.986 3. The regression model for combination predictors: Men: p<0.001; R^2 =0.991 Women: p<0.001; R^2 =0.984 4. The height estimated from the arm span-knee height formula: Women: 40.915 + [0.457 x AS (cm)] + [0.818 x KH (cm)] Men: 34.426 + [0.513 x AS (cm)] + [0.813 x KH (cm)]
3.	Singapore; Henry, C. J., (2019).	Cross-sectional	1. To develop predictive models for height and weight in Asian-Chinese adults.	Subjects: n=441 Male: 174 Female: 267 Age: 21-74 years old	1. Knee Height	1. Cereda et al 2010: 60.76 + (2.16 x KH) – (0.06 x Age) + (2.76 x sex) Sex: 0 = women, 1= men	1. The best predictive model for height included arm length, knee height and age: Males: R^2=0.70, standard error of estimate = 3.38 Females: R^2=0.71, standard error of estimate = 3.14 2. Sex-specific equations to predict height (in cm): Males: 64.30 + [2.19 x Arm length] + [0.83 x KH] + [0.22 x Age] Females: 67.83 + [2.08 x Arm Length] + [0.84 x KH] – [0.06 x Age]
4.	Singapore; Yee, W., Lin, L., & Huak, C. (2019).		1. To derive predictive equations to calculate the actual height of bedridden patients on mattresses with different firmness	Subjects: n= 199 - Hospitalised n= 99 Age: 21-80 - Healthy: n= 100	1. Soft mattress 2. Firm Mattress	-	1. The regression equation developed: Firm Mattress (R^2=0.982): Standing height (cm)= 0.993 x Recumbent length – 0.943 Soft Mattress (R^2=0.981): Standing height (cm)= 1.012 x Recumbent length – 4.477
5.	India; Rai, P., (2021).	Cross-sectional	1. To find the accuracy of arm-span in predicting standing height of both males and females in studied population.	Subjects: n= 600	1. Arm Span	1. Regression equation: Stature= (0.868 X AS) + 16.773	1. 87% of height among total population was significantly measured by arm span using regression equation. 2. A positive correlation was found to exist between the arm-span and stature. 3. The correlation coefficient r=0.9, arm span was found to be a strong predictor of stature.

CONTINUE

Table I: Overview of Height Measurement (CONT.)

No.	Country	Study design	Objectives	Participants	Variables	Equation/ Device	Results
6.	United Kingdom; Collinson, A., & Madden, A. (2019).		1. To evaluate the relationship between ulna length and height in adults from diverse ethnic groups.	Subjects: n=542	1. Ulna length	1. Elia equation: Men <65 years: 79.2 + 3.60 ulna length Men >65 years: 86.3 + 3.15 ulna length Women <65 years: 95.6 + 2.77 ulna length Women >65 years: 80.4 + 3.25 ulna length (cm)	1. Ulna length and height were significantly associated overall in all groups except one with few participants (P=0.059). 2. Asian Men, (H_p (cm) = 3.26 UL (cm) + 83.58), mean difference from measured (95% confidence intervals) was -0.6 (-2.4, +1.2) 3. Asian Women, (H_p (cm) = 3.26 UL (cm) + 77.62), mean difference +0.5 (-1.4, 2.4) cm. 4. Black Men, (H_p (cm) = 3.14 UL (cm) + 85.80), -0.4 (-2.4,1.7) 5. Black Women, (H_p (cm) = 3.14 UL (cm) + 79.55), -0.8 (-2.8,1.2)
7.	United Kingdom; Finch, H., & Arumugam, V. (2014).		1. To assess the accuracy and reliability of measuring people lying in bed stimulating a patient with contractures.	Subjects: n = 24 Age: 18-65 years old	1. Positions on a hospital bed: - Flexion pattern in side lying - Extension pattern in side lying - Subject positioned to stimulate kyphoscoliosis spine 2. Ulna Length	1. BAPEN MUST Tool	1. The mean of the tape-measured heights was 2.3 cm taller than the 'true' height (95% confidence interval = 4.6 – 9.3) 2. The measurement in all three positions gave an overestimate of the height. 3. Ulna-derived height gave an underestimate (2.2 cm). 4. The estimated reliability between measures (intraclass correlation coefficient) was 0.94 with a 95% confidence interval (0.91-0.96).
8.	Brazil; Tarnowski, M. S., (2018).	Cross-sectional	1. To develop a mathematical formula to estimate the standing body height of critically ill patients with their ulna length (UL) and to evaluate its agreement with the measured height (MH).	Subjects: n = 100 Age: ≥18 years who had their body height estimated before ICU admission	1. Ulna length 2. Knee height	1. Chumlea et al: Men: 64.19 – (0.04 x Age) + (2.02 x KH) Women: 84.88 – (0.24 x Age) + (1.83 x KH	1. Height in cm = 153.492 – (7.97 x sex [male =1, female =2]) + (0.974 x UL [in cm]) 2. There was a significant correlation between MH and UL and between MH and KH. 3. There was no significant difference between the averages of MH and UL height (difference = -0.04 cm, P = 0.96) 4. Mathematical equations based on UL provide good standing height estimation for critically ill patients.
9.	Brazil; Silva, F. M., & Figueira, L. (2017).	Cross-sectional	1. To evaluate the precision of estimated height from UL using the MUST equation and compare it with predicted height from KH, and self-reported height in estimating actual body height in inpatients.	Subjects: n = 472	1. Ulna length 2. Knee height	1. MUST BAPEN tool 2. Chumlea et al. equations: Women: 84.88 - [0.24 x Age] + 1.83 x KH (cm)] Men: 64.19 – [0.04 x Age] + [2.02 x KH (cm)]	1. A significant difference was found when actual height (161.07 ± 8.77 cm) was compared with estimated height from KH (163.64 ± 8.61 cm) and self-reported height (164.54 ± 8.95 cm). 2. No significant difference of 1.07 cm was observed between actual height and estimated height from UL (160.74 ± 7.48 cm), however, the limits of agreement between measures were large (13.69 to 14.39 cm) 3. The difference between actual height and self-reported height was higher in men [-8.50 (-17.00; -2.00) cm] than in women [1.00 (-6.00;8.00) cm]. 4. There was no statistically difference between actual height and estimated height from KH and UL in both women and men.

BMI, Body Mass Index; MUAC, Mid Upper Arm Circumference; KH, Knee Height; UL, Ulna Length; AS, Arm Span; BAPEN, British Association Parenteral Enteral Nutrition; MUST, Malnutrition Universal Screening Tool; MH, Measured Height; ICU, Intensive Care Unit

Table II: Overview of Weight Measurement

No.	Country	Study design	Objectives	Partici-pants	Variables	Equation/ Device	Results
1.	Singapore; Henry, C. J., (2019).	Cross-sectional	1. To develop predictive models for height and weight in Asian-Chinese adults. 2. To compare the predictive performance of the models with two other models	Subjects: n=441 Male: 174 Female: 267 Age: 21-74 years old	1. Arm circumference 2. Knee height 3. Waist circumference	1. Ross Laboratories (2002): White Women: (KH x 1.01) + (Arm Circumference x 2.81) – 66.04 Black Women: (KH x 1.24) + (Arm Circumference x 2.81) – 82.48 White Men: (KH x 1.19) + (Arm Circumference x 3.21) – 86.82 Black Men: (KH x 1.09) + (Arm Circumference x 3.14) – 83.72	1. The best predictive model for weight included arm circumference, waist circumference and age: Males: R^2=0.79, standard error of estimate = 4.66 Females: R^2=0.78, standard error of estimate = 4.38 2. Sex-specific equations to predict weight (in kg): Males: -16.75 – [0.14 x age] + [0.69 x Arm circumference (cm)] + [0.81 x waist circumference (cm)] Females: -12.86 – [0.15 x age] + [0.69 x Arm circumference (cm)] + [0.81 x waist circumference (cm)]
2.	Indonesia; Katherina, K., (2020).	Cross-sectional study	1. To predict a weight measurement model using an anthropometric index of adult's mid-upper arm circumference and knee height	Subjects: n= 164 Male: 84 Female: 80	1. Mid-upper arm circumference 2. Knee Height	-	1. Mid upper arm circumference was strongly correlated with body weight. 2. Correlation coefficient values in male, female and both sex is 0.874, 0.886 and 0.862, respectively. 3. The resulting equation which is derived by multi linear regression: BW= (2.8 x MUAC) + (1.2 X KH) – (1.25 X Z) – 75.1 R^2 0.841, p-value< 0.001 Z-value: (1: female, 2: male)
3.	United Kingdom; Nathongchai, R., (2020).		1. To translate the adult clinical prehospital method which uses a mid-upper arm circumference (MAC) measurement to estimate body weight (BW) to establish a post mortem computed tomography (PMCT) technique for adult cadaver BW estimation.	Subjects: n = 66 - Males: 45 - Females: 21	1. Mid arm circumference	1. PMCT images: - Toshiba Aquilion 64-slice multidetector CT scanner. 2. MAC measurement: - Osirix MD Version 7.0.2 64-bit. 3. Cattermole et al: - BW of combined sex (kg) = [4 x MAC (cm)] – 50 4. Crandall et al: - BW (kg) = [2.45 x MAC (cm)] + (0.6 x Height) - 105	1. MAC measurements correlated well with actual BW (r=0.75), but correlation was improved to r=0.87 (95% confidence intervals (CI) 0.78 to 0.94, p<0.00001) if 11 cases of a bilateral "quality score" of zero was excluded. 2. Mean estimated BW by using Cattermole equation, was 0.47 kg greater than mean actual BW with limits of agreement of 12.7kg. 3. Use of both height and MAC to estimate BW using Crandall equation results in slightly increased correlation coefficient for estimated vs actual BW that Cattermole equations, r = 0.90 (95% CI 0.82-0.95) and 0.89 (95% CI 0.73-0.93).
4.	United States; Wells, M., (2022)		1. To develop and validate an adult version of the PAWPER XL-MAC tape, using recumbent length and mid-arm circumference (MAC) to predict total body weight.	Subjects: n = 11,520	1. Mid arm circumference	1. PAWPER XL-MAC tape	1. The primary accuracy outcome was achieved in all subgroups except extremes of habitus (severely obese adults). 2. The modified PAWPER XL-MAC model satisfied the primary outcome measures by achieving a P20 in >95% of adults (equivalent to a critical error rate of <5%). 3. The findings were consistent across all lengths, both sexes, all ages, all ethnic groups, and in all habitus types except in severely obese adults. 4. Height and MAC proved to be highly predictive for weight estimation.

[1] KH, Knee Height; MUAC, Mid Upper Arm Circumference; BW, Body Weight; MAC, Mid Arm Circumference; PMCT, Post Mortem Computed Tomography

Table III: Overview of BMI Measurement (CONT.)

No.	Country	Study design	Objectives	Participants	Variables	Equation/ device	Results
1.	Philipines; White, L. v,. (2019).	Cross-sectional	1. To investigate the feasibility and accuracy of predicting BMI in severely unwell or immobile hospitalised patients, using admission fata from the TB ward.	Subjects: n = 348 Age: 18 years old and above	1. Mid Upper Arm Circumference (MUAC) 2. Ulna limb length 3. Knee Height 4. Demi-Arm Span	-	1. There was a significant interaction between the quadratic MUAC relationship with BMI and sex (LRT p<0.001). 2. The mean difference between predicted and observed heights (95%C CI) was: - 3.09cm (2.59, 3.59) for demi-span, - -0.98 cm (-1.51, -0.44) for knee height - 2.85 cm (2.26, 3.45) for ulna length. 3. Demi-span resulted in the lowest proportion of missed cases (9/294, 3.1%) out of the three limb length measures with none classified as BMI ≥kg/m² when measured BMI was less than 16 kg/m²
2.	Philipines; Baladad, B., (2016)		1. To design and develop an Automated BMI calculation that will display the BMI through height and weight measurement of a person.	Subjects: n = 10 - 4 normal BMI - 4 overweights - 2 underweight	-	Hardware: - Ultrasonic Proximity Sensor - Weight sensor - Gizduino ATMEGA328 - Sensor Amplifier Software: - Windows 7 - SQL Server Management Studio - Microsoft Visual Studio (.NET) - Arduiono (Software)	1. Accuracy of the height and weight: - 5.0 (Linkert Scale) – Excellent 2. Accuracy of BMI measurement: - 5.0 – Excellent 3. System application program easy to use: - 4.8 – Excellent 4. User can easily access the system: - 4.8 - Excellent
3.	Nigeria; Jilantikiri, L. J., (n.d.).	Cross-sectional	1. To develop a digital body mass measuring device for low-resource settings that would be cheap, user-friendly and easy to operate so as to alert users of their nutritional status.	Subjects: n = 8 - 4 males - 4 females	-	Systems: - Ultrasonic sensor - Load cells - Sensor amplifier - Arduino UNO (ATMEGA) microcontroller Software: - C Language	1. Reliability test (root mean square error): - Calculated BMI result from the stadiometer height reading and the designed digital BMI measuring device = 0.32 (Low) 2. This result is more reliable than the BMI result obtained from the wall-mounted-height-measuring meter with an RMSE value of 1.19 3. Nutritional status by digital BMI device: - 5 subjects classified "normal", while two subjects were "overweight" and another one was classified as "obese".
4.	Nigeria; Patrick, O. O., GSJ, A. M. K.-, (2020)		1. To design and fabricate a locally made Arduino-based automated Body Mass Index (BMI) machine with a Liquid Crystal Display (LCD), that works on the principle of Hooke's Law and acoustic ultrasound waves.	Subjects: n = 60	-	1. Arduino-Uno microcontroller 2. Height measurement: Ultrasonic sensor (PING)	1. The values obtained from manual and designed automated BMI machines are relatively agreed with standard errors of 0.01, 0.35, 0.12 for height, weight and BMI respectively.

CONTINUE

Table III: Overview of BMI Measurement (CONT.)

No.	Country	Study design	Objectives	Participants	Variables	Equation/ device	Results
5.	Nigeria; Erinle, T., Olorunfemi, B., & Olorunnishola, A. (2023).		1. To develop an ergonomically anthropometric BMI measuring system for medical check-up and upkeep of the human's body system's health status.	Subjects: n=20		1. Load Cells with Strain Gauge 2. Sonar with Ultrasonic Sensors 3. Liquid Crystal Display 4. Microcontroller Arduino Board 5. Distance ultrasonic sensors from equations: $V= f\lambda$ $\Lambda= vT$ v= Speed of ultrasonic waves λ= wavelength of ultrasonic waves T= period	1. The percentage of humans with BMI normal weight is 80% and that of BMI underweight is 20%. 2. The efficiency of the system is 99.4%.
6.	Sudan; Musa, I. R., Omar, S. M., & Adam, I. (2022).	Cross-sectional	1. To compare MUAC with BMI and propose a MUAC cut off points corresponding to a BMI of <18.5 kg/m^2 (underweight) and ≥30.0 kg/ m^2 (obesity) among Sudanese	Subjects: n=552 Age: 18-60 years old	1. Mid upper arm circumference	-	1. There was a significant positive correlation between MUAC and BMI (r= 0.673, p<0.001) in both females and males, in females (r= 0.639, p<0.001) and in males (r= 0.634, p<0.001). 2. 104 out of 552 participants were normal weight (18.8%). 3. 282 (51.1%) were underweight. 4. 77 (13.9%) were obese. 5. MUAC cut-off corresponding to a BMI <18.5 kg/m^2 (underweight) was ≤25.5 cm in both males and females (Y1= 0.51; sensitivity = 96%; specificity = 54.0%), with a good predictive value (AUROCC = 0.82, 95.0% CI = 0.78 – 0.86). - Females: (Y1= 0.51; sensitivity = 97%; specificity = 54.0%), with a good predictive value (AUROCC = 0.83, 95.0% CI = 0.78 – 0.87) - Males: (Y1= 0.51; sensitivity = 96%; specificity = 56.0%), with a good predictive value (AUROCC = 0.83, 95.0% CI = 0.77 – 0.88).

CONTINUE

Table III: Overview of BMI Measurement (CONT.)

No.	Country	Study design	Objectives	Participants	Variables	Equation/ device	Results
7.	Indonesia; Faradisa et al., (2022)	N/A	1. To create a device with a system that can determine the value and category of Body Mass Index (BMI) automatically using fuzzy logic to maintain nutritional status.	Subjects: n = 5 Age: 22-23 years old	-	1. Mamdani fuzzy logic 2. Ultrasonic sensor: HCSR-04 3. Arduino Mega Uno	1. No significant differences between the BMI test taken using the system with MATLAB test and manual calculations.
8.	Australia; McDougall, K. (2018).	Cross-sectional	1. To compare standing height, estimated current height and demi-span estimated height and examine their impact on body mass index (BMI) classification.	Subjects: n =104 Age: 19-64 years old.	1. Demi span	1. Bassey's formula: Females= (1.35 x DS cm) + 60.1 Males= (1.4 x DS cm) + 57.8 2. Estimated current height	1. The limits of agreement (95% confidence interval) for estimated current height compared with standing height were +9.9 cm and -7.9 cm, in contrast to +8.7 cm and -14.3 cm for demi-span estimated height. 2. Demi-span underestimated height when compared with standing height in both age groups, 19-64 years (mean ± SD) 3.0 ± 6.5 cm (P=0.001, n = 68) and ≥ 65 years age group 4.0 ± 6.0 cm (p<0.001, n = 36), resulting in a significantly greater mean BMI (analysis of variance P<0.001, P=0.02). 3. In the 19-64 and ≥ 65 years age groups, 3% (n = 2) and 10% (n=4) of patients, respectively, had a different BMI classification using demi-span estimated height compared with standing height.

[1]TB, Tuberculosis; MUAC, Mid Upper Arm Circumference; BMI, Body Mass Index; LRT, Likelihood Ratio Test; CI, Confidence Interval; SQL, Structured Query Language; RMSE, Root Mean Square Error; YI, Youden Index; AUROCC, Area Under Receiver Operating Characteristic Curve; DS, Demi Span; SD, Standard Deviation

Study quality assessment

The study quality appraisal was evaluated by using the adapted version of the Newcastle-Ottawa Scale (NOS) (Supplementary Table II. This scale is used to assess the quality for cross-sectional studies due to its versatility and broad application in evaluating the methodological quality of observational research, the NOS was chosen to allow for a consistent assessment across investigations [14]. Comparability (study design and analysis), outcome (outcome assessment and statistical testing), and selection (sample representativeness, sample size, non-response, and exposure ascertainment) are the three domains in which the tool assesses the quality and risk of bias in cross-sectional studies. Up to five points are awarded for the selection domain, and research with well-defined samples and target groups receive better marks. Studies that account for at least two significant confounders can receive up to two points in the comparability domain. Studies with consistent results and established measurement instruments receive up to three points in the outcome domain. A very good study receives the highest possible score (9–10), a good study receives a score of 7–8, a fair study receives a score of 5–6, and an unsatisfactory study receives a score of 0–4. The included studies are consistently evaluated for quality using this modified Newcastle-Ottawa Scale (NOS).

Collating, summarizing and reporting the results

Table II provides an overview of the review's significant findings and data. The table has been modified to align with the study's objectives. The elements extracted from the findings were regarding the tools and equations to measure height and weight and the device or system that were developed to measure or categorize body mass index.

RESULTS

The electronic search of the literature yielded 1759 potentially relevant articles. After the removal of duplicates, the number of articles left was 1397. 1294 articles were excluded based on screening based on the title and the abstract. 103 articles were screened and 66 articles were screened at the full-text level. 46 articles were excluded from the study related to body composition (i.e body fat, fat-free mass, muscle mass), aged <18 years old, and unable to assess the full text. Therefore, 20 studies remained for data extraction as shown in Figure 1. At baseline, the studies' sample sizes varied from 8 to 11,520 participants. This study summarised the findings of the pertinent data of height, weight, and body mass index measurement, together with the digital body mass index measurement devices and systems, as outlined in Table I, Table II and Table III.

Height measurement

The included studies in this review identified nine studies of different height measurements that involved body parameters, equations, and tools such as hospital beds [10,15-21] (Table I). The anthropometric parameters to measure height include demi span, knee height, arm span, and, ulna length. Among the identified parameters, knee height and ulna length are the most frequently used and showed high reliability and accuracy in estimating height among adults and older persons [15,16,18-21]. However, a study conducted in Malaysia determined that the demi-span measurement was reliable and effective for estimating height in Malaysian adults [10].

Variations were observed in the anthropometric equations used in these studies across different ethnic groups, including equations by Fatmah, Chumlea, Cereda et al (2010), Elia, BAPEN MUST tool, and Ngoh et al (2012). The Chumlea equation is frequently used to measure height [15,20,21]. Despite the extensive use of Chumlea equation, only one study was found that validated an equation to be used for Malaysian adults [10]. It was found that the height calculated from the equations proposed by Ngoh et al., (2012) and the measured height showed consistent agreement and similarity (r=0.944 and r=0.949, respectively) among the 30-55 years old Malaysian adults [10,22].

Weight measurement

A total of four studies in this review explained the anthropometric measurement of weight [16,23-25] (Table II). These studies utilized a range of variables including mid-upper arm circumference, and knee height. Equations such as Ross Laboratories (2002), Crandall et al and Cattermole et al were commonly applied [16,23-25]. Additionally, tools like the PAWPER XL-MAC tape and post-mortem computed tomography were identified for measuring weight [25].

Several studies demonstrated that weight measurement incorporating mid-upper arm circumference provided higher accuracy [23,24]. One study found that uses mid-upper arm circumference, had high correlation coefficient values in males, females, and both sexes 0.874, 0.886, and 0.862, respectively, indicating strong reliability [23]. This review showed that the Ross Laboratories equation was the best predictive model for weight in Asian populations [16].

In addition, according to one study, using PAWPER XL-MAC tape produced consistent results in all lengths, both sexes, all ages, all ethnic groups, and all habitus types—except for extremely obese adults, highlighting the need for the advancement of measuring tools to enhance the accuracy and reliability of the anthropometric data [25].

Body mass index measurement

The majority of the studies included in this review concentrate on utilizing body parameters such as mid-upper arm circumference, ulna limb length, knee height, and demi span as presented in Table III [26-29]. Mid-upper arm circumference was commonly employed in BMI measurement [26,28]. This review highlighted the positive correlation of BMI with MUAC.

Digital body mass index devices and systems integrated with formula and computing languages were also identified. The Arduino Uno is the most popular microcontroller found in BMI measurement equipment [12, 30-32]. Several studies demonstrated that digital BMI measurement devices and systems provided higher accuracy and efficiency [11,12, 30-32]. One study found that the efficiency of the system of BMI measurement is 99.4% [30].

This review also demonstrated that more accurate body mass index measurements were possible with digital systems and devices that integrated sensors and software. The validity of the systems and devices covered in this review, however, appears dubious because they were tested on older adults and healthy adults, not a diverse population.

DISCUSSION

Adults and older persons with physical disabilities, and weak condition can have their height and weight measured differently. Many attempts have been undertaken over the years to create a trustworthy anthropometric formula or method for estimating body mass index, weight, and height using different body part measurements. This is because anthropometry measurements are frequently used to assess nutritional status, particularly in hospitalized patients and older adults [33]. This scoping review gathered studies on the anthropometric measurements of height, weight, and body mass index for adults and older persons in hospitals. It also assembled information regarding automated or digital body mass index measurement devices and systems for adults and older persons. In addition, our findings provide insight into these methods' accuracy, reliability and applicability in different populations.

The results indicated that various available ways can be used to measure height and weight specifically when direct measurement is not feasible. This is mainly because estimating the height of older adults is essential, however, it is difficult to directly measure their height owing to the changes in their body posture, loss of height in the vertebrae, kyphoscoliosis, and arthritis [34]. One of the particularly common types of arthritis is osteoarthritis (OA) [35]. It was noted that OA is closely linked to aging [36]. This condition also affects the feasibility of direct measurement as the cause of OA may be biological aging which is due to cartilage thinning, weak muscle strength, poor proprioception, and oxidative damage, they make a joint less resilient to adversity [37].

The review identified several reliable methods for measuring height, including using body parameters such as demi span, knee height arm span, and, ulna length [10,15-21]. Knee height and ulna length are found to be the most common parameters used to estimate height in adults and older persons [15,16,18-21]. It was found that there is a solid positive correlation between knee height and actual height (Men: $p<0.001$; $r=0.989$, Women: $p<0.001$; $r=0.986$) [15]. This is consistent with previous research that found knee height showed the highest correlation and the least amount of error, making knee height suitable to be used in estimating height [38].

However, some studies highlighted the other parameters as the best in estimating the height. A study in Singapore concluded that the best predictive height included arm length, knee height, and age with the standard error of estimate for males and females being 3.38 and 3.14, respectively [16]. Meanwhile, a study in Malaysia that involved Malaysian adults found that the demi-span measurement was reliable in estimating height [10]. This is consistent with a different Malaysian study that discovered that demi-span enables older Malaysians to measure their height with some degree of accuracy. A similar finding discovered men's height can be predicted by demi-span, knee height, and age [39].

In addition, this scoping review identified the validation of the equation to estimate height by using demi-span for Malaysian adults aged 30-55 years old [10]. It was found that the height calculated from the equations proposed by Ngoh et al. (2012) and the measured height showed consistent agreement and similarity ($r= 0.944$ and $r= 0.949$, respectively). The agreement analysis of measured height and demi span equivalent height new, as a proxy for maximum adult height in people aged ≥65 years, according to a nationally representative cross-sectional study conducted in England [40]. This aligns with a study on adults in Thailand that stated demi span, sitting height and knee height are all reliable indicators of height [41].

Studies on weight measurement demonstrated that body parameters such as arm circumference, waist circumference, mid-upper arm circumference, and knee height can be used in estimating body weight. One research suggested that the best predictive model for weight included arm circumference, waist circumference, and age [16]. However, this finding is contradicting with a study by Katherina K., (2020) that found mid-upper arm circumference (MUAC) was strongly correlated with body weight. Another study showed that there is a strong correlation between weight and MUAC in both adults and children [42]. This is supported by the new body weight estimation equations developed by Guerra et al. (2021) that were cross-validated on a large sample of older adults, including participants in both younger and older age groups. It is recommended to estimate body weight using the equation containing five predictor variables (height, calf circumference (CC), waist circumference (WC), mid-upper arm circumference (MUAC), and triceps skinfold thickness (TST) [43].

BMI measurement studies revealed that MUAC can be used to estimate body mass index among adults and older persons. The quadratic MUAC relationship between BMI and sex significantly interacted [28]. A cross-sectional study involving 552 Sudanese adults found a significant positive correlation between MUAC and BMI [44]. This evidence is backed by a study confirming that MUAC is a parameter that strongly correlates with BMI and can be used in addition to it or in situations when a patient cannot be weighed [26]. MUAC has been used as a nutritional metric in many studies on a range of population groups, including the elderly, hospitalised patients, newborns, preschoolers, schoolchildren, pregnant women, and nursing mothers [45-47].

This review also revealed the digital BMI measurement devices, including BMI measurement systems which enhanced the precision of BMI estimation. All of the devices and systems used Arduino Uno microcontroller. The Arduino microcontroller is an open-source device that is simple to program, erase, and reprogram at any time making it a practical tool to be used [48]. An automated BMI calculation was created using Arduino software as the result of a study carried out in the Philippines, and the system and measurement were extremely accurate [12]. Another study that creates a system to determine the value and category of the BMI use fuzzy logic as fuzzy logic method is one that can be used to determine nutritional status [32].

Four studies in the review found to developing an automatic BMI measurement device by using Arduino and measuring the height with ultrasonic sensors together with a load cells gauge to measure the weight [11,12,30,31,]. A study by Jilantikiri found that the BMI calculated by using the device is more reliable than the BMI result obtained from the wall-mounted height measuring meter. This is aligned with a study from Nigeria that stated the standard measurement errors of the measurement is relatively low with 0.01, 0.35 and 0.12 for height, weight and BMI [31]. Other than that, the efficiency of the measuring system that is connected with the automated BMI measurement device is found to be 99.4% efficient [30].

Moreover, this review also shows how crucial a precise body mass index assessment is for determining a person's current state of health, identifying possible health hazards, and directing dietary and therapeutic measures. This review also highlighted the importance and the need for the advancement of health technology that is cost-effective and widely accessible in bridging the gaps in healthcare and advocating for universal health coverage. Following the Sustainable Development Goals- Goal 3, which emphasizes promoting well-being and guaranteeing healthy living for all individuals at all ages, an accurate BMI assessment aids in individualised health programs and the early detection of obesity or malnutrition.

From the review, one significant limitation of the devices and systems reviewed is that they have been primarily tested on healthy individuals, thereby limiting their generalizability to other populations that are bedridden or incapable of standing straight. Therefore, the functionality, accuracy, and reliability of these BMI measurement tools in bedridden, physically disabled, and severely obese individuals are debatable. These limitations highlight the need for the further advancement of BMI measurement tools that can provide accurate data across diverse groups, specifically in clinical settings ultimately improving health assessments and interventions for those who are currently underrepresented in research.

CONCLUSION

In conclusion, results from this scoping review provide an overall summary of the measurements of height, weight, and body mass index available, particularly in individuals for whom direct measurement is not feasible. Knee height and demi span are found to be a strong parameter in measuring height while mid-upper arm circumference is important in estimating body weight and body mass index. Overall findings in this review suggested the usage of digital or automated body mass index measurement devices can enhance measurement accuracy. In addition, appropriate anthropometric measurements may be one of the strategies for managing and combating nutritional issues in hospitalized adults and older persons.

ACKNOWLEDGEMENT

This work was supported by Dana Penyelidikan Universiti (UNISZA/2022/DPU2.0/24) (R0423). We extend our gratitude to everyone who contributed to the development and writing of this article.

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