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Validity and reliability test of an Electric Knee Height Measuring Device (EKHMD) predicting body height and nutritional status

Uji Validitas dan Reliabilitas Alat Ukur Tinggi Lutut Elektrik (AUTLE) sebagai Prediktor Tinggi Badan dan Status Gizi

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ABSTRACT

Background: *Direct height measurement is often difficult in immobilized patients. Knee height measurement becomes an alternative, thus encouraging the development of an electronic knee height measuring device (EKHMD).*
Objective: *The aim of this study was to determine the validity and reliability of the EKHMD in estimating knee height, height, and nutritional status.*
Methods: *This study used a quantitative approach with 30 healthy adults (15 men, 15 women) through purposive sampling. Anthropometric measurements used the EKHMD and a microtoise as standards. Validity was assessed using Pearson or Spearman correlation tests, agreement or accuracy using Bland–Altman plot analysis, and reliability using Cronbach-Alpha.*
Results: *The results of the validity test showed that knee height measurements (r = 0.929), estimated height (r = 0.863 (sitting), r = 0.869 (lying down), and nutritional status (r = 0.952 (sitting), r = 0.970 (lying down) with significance for all variables (p = 0.00) which means that EKHMD correlated strongly with microtoise measurements (p < 0.05). Accuracy analysis using Bland–Altman measurements was in the range of Upper LoA and Lower LoA knee height (2.13 – (-1.43 cm)), estimated height (7.89 – (-9.05) cm (sitting) 0.049 (-0.029) cm (lying down)), and nutritional status (2.35 – (-2.01) (sitting), 0.06 – (-0.023) (lying down)) and Cronbach's Alpha showed high reliability (p > 0.60), knee height (p=0.61), estimated height ((p=0.936 (Sitting), p=0.928 (Lying)), and nutritional status (p=0.983 (Sitting), p=0.984 (Lying)).*
Conclusion: *Thus, EKHMD can be considered as a tool to measure estimated height and nutritional status but still needs to be developed further.*

Kata kunci*: EKHMD, estimated height, immobilization, knee height, nutritional status*

ABSTRAK

Latar Belakang: Pengukuran tinggi badan secara langsung seringkali sulit dilakukan pada pasien imobilisasi. Pengukuran tinggi lutut menjadi alternatif, sehingga mendorong pengembangan alat ukur tinggi lutut elektrik (EKHMD).
Tujuan: Tujuan penelitian ini yaitu menentukan validitas dan reliabilitas EKHMD dalam estimasi tinggi lutut, tinggi badan dan status gizi.
Metode: Studi ini menggunakan pendekatan kuantitatif dengan 30 orang dewasa sehat (15 pria, 15 wanita) melalui purposive sampling. Pengukuran antropometri menggunakan EKHMD dan microtoise sebagai standar. Validitas dinilai menggunakan uji korelasi Pearson atau Spearman, kesepakatan atau akurasi dengan analisis plot Bland–Altman serta reliabilitas menggunakan Cronbach-Alpha.
Hasil: Hasil uji validitas menunjukkan pengukuran tinggi lutut (r=0,929), estimasi tinggi badan (r =0,863 (duduk), r=0,869 (berbaring), dan status gizi (r=0,952 (duduk), r=0,970 (berbaring) dengan signifikansi semua variabel (p=0,00) yang berarti EKHMD berkorelasi kuat dengan pengukuran microtoise (p< 0,05). Analisis akurasi

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menggunakan Bland–Altman pengukuran berada di rentang Upper LoA dan Lower LoA tinggi lutut (2,13 – (-1,43 cm)), estimasi tinggi badan (7,89 – (-9,05) cm (duduk) 0,049 (-0,029) cm (berbaring)), dan status gizi (2,35 – (-2,01) (duduk), 0,06 – (-0,023) (berbaring)) dan Cronbach's Alpha menunjukkan reliabilitas yang tinggi (p > 0,60), tinggi lutut (p=0,61), estimasi tinggi badan ((p=0,936 (Sitting), p=0,928 (Lying)), dan status gizi (p=0,983 (Sitting), p=0,984 (Lying)).
Kesimpulan: Dengan demikian, EKHMD dapat dipertimbangkan sebagai alat mengukur estimasi tinggi badan dan status gizi namun masih perlu dikembangkan lebih jauh lagi.

Kata kunci: EKHMD, estimasi tinggi badan, imobilisasi, status gizi, tinggi lutut

INTRODUCTION

Nutritional status assessment is a key component of clinical nutrition services, particularly in determining energy requirements and individualized dietary therapy. One of the main indicators used in this process is body height, which plays an essential role in the calculation of Body Mass Index (BMI), estimation of ideal body weight, and determination of both macronutrient and micronutrient requirements. Direct measurement of body height is not always feasible, particularly in immobilized patients such as geriatric or elderly individuals, post-operative patients, or stroke patients with mobility impairments [1]. As an alternative, knee height measurement has been recommended by the World Health Organization as a reliable method for estimating body height in elderly, bedridden, or immobile patients, as well as in those with leg amputations or spinal deformities. This is because knee height is relatively stable across changes in body position and age [2]. Raditionally, knee height has been measured manually using a knee height caliper, which is considered effective for immobile patients [3]. However, in practice, the use of knee height calipers presents several limitations. These include susceptibility to reading errors, dependence on operator skills, and inefficiency in fast-paced clinical settings, as the device is typically made of wood and metal with a bulky structure that complicates the measurement process [1].

Therefore, there is a need for innovative measurement tools that provide more precise, practical, and user-friendly results for healthcare workers in various clinical conditions. To address this need, the Electric Knee Height Measurement Device (EKHMD) was developed. EKHMD utilizes ultrasonic sensors, servo motors, and an Arduino-based microcontroller to automatically measure knee height. The device was designed using mechatronics principles, with an ergonomic structure that is easy to calibrate. Previous studies have demonstrated that electronic systems in clinical anthropometry can improve accuracy and accelerate assessment processes compared to conventional methods [4]. The development process of Electric Knee Height Measurement Device (EKHMD) included several stages: frame design, integration of electronic systems and programming, and initial functional testing. This innovation is expected to provide an applicable solution for improving the accuracy of body height and nutritional status estimation in immobilized patients, while also supporting the modernization of technology-based nutrition services [1].

Measuring knee height requires a valid and reliability measuring tool capable of measuring accurately and precisely. Validity testing is necessary to ensure that the measuring instruments used are appropriate for the conditions being measured. In addition, validity can also be interpreted as a measurement to determine the precision and accuracy of a measuring instrument with existing standard measurements [5]. Reliability testing of instruments is used to ensure or determine the extent to which the measurement results of an instrument are consistent when measurements are taken two or more times with the same instrument and by the same person. An instrument that is said to be reliable means that it has good consistency when used as a measuring

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instrument because the measurement results are stable and do not change [6]. This study aimed to test the validity and reliability of the results of knee height measuring device as an estimate of body height and nutritional status for immobilized patients compared with the standard measuring instrument for measuring height, such as microtoise.

METHODS

Study design

This study employed a quantitative analytical approach to evaluate the validity and reliability of the Electric Knee Height Measuring Device (EKHMD). The assessment was conducted by comparing knee height measurements obtained from the EKHMD with those measured using a reference method (microtoise) in 30 healthy adult participants aged 18–60 years. Body height was subsequently estimated using the modified Chumlea equation to evaluate the accuracy of the EKHMD in determining body height and nutritional status. Each measurement was performed three times, and the average value was used for analysis. Statistical analysis was conducted to assess the correlation between the two measurement methods.

Data Source and Sampling Procedure

Subjects were selected using purposive sampling to ensure anatomical suitability for knee height measurement and to support initial generalizability to the healthy adult population. A total of 30 healthy adults (15 males and 15 females) participated in this study. Inclusion criteria were adults aged 18–60 years, physically healthy, without musculoskeletal disorders, and able to maintain a sitting position during measurement. Exclusion criteria included lower limb deformities, postural abnormalities, limitations in knee movement, or withdrawal during the study. All participants provided informed consent prior to data collection. Healthy adult participants were selected to minimize anatomical bias and ensure accurate evaluation of the device’s validity and reliability. The age range and inclusion of both sexes were intended to represent typical adult body proportions, while the sample size was sufficient for preliminary instrument testing.

Variables of the Study

The independent variables were knee height measurements obtained using the EKHMD and the reference method (microtoise). The dependent variables included knee height values, estimated body height, and estimated nutritional status derived from the measurements.

Data Collection

Data collection was carried out from June to July 2025 at the Nutrition Laboratory, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya. All anthropometric measurements were conducted by trained assistants who had undergone standardized training in anthropometric procedures, including operation, calibration, and measurement using the EKHMD. Measurements were taken three times for each participant to ensure consistency, and the average value was recorded for analysis.

Measurement and Instruments

The knee height measurement device (EKHMD) was developed in this study using an ultrasonic sensor to measure the distance between the knee and the plantar surface of the foot. The measurement system consists of an HC-SR04 ultrasonic sensor, an Arduino-based microcontroller, an LCD display, and a calibration module. The device is designed to obtain knee height measurements that are further used to estimate standing height.The device operates based on the time-of-flight principle of ultrasonic waves. The microcontroller triggers the ultrasonic sensor to emit high-frequency sound waves in 40 kHz, which propagate through the air from the sensor

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positioned above the patella toward a base platform placed at the sole of the foot. The reflected waves are received by the sensor, and the time interval between emission and reception is recorded.The measured time is converted into distance values using the speed of sound in air (approximately 340 m/s) with the following formula:

Distance (cm) = (Time × Speed of sound in air) / 2

The division by two accounts for the round-trip travel of the ultrasonic wave from the sensor to the object and back.The calculated knee height is processed by the microcontroller together with user-input variables, including sex and age, using the Chumlea knee height equations (64.19 + (2.02 × knee height) − (0.04 × age) for males and (84.88 + (1.83 × knee height) − (0.24 × age) for females.The final measurement results are displayed on the LCD screen. To improve measurement accuracy, the device is equipped with a calibration feature that allows adjustment of the output values based on manual reference measurements. However, the tool has weaknesses, namely that it requires repeated calibration and cannot store measurement data.

Prior to data collection, the EKHMD was calibrated to ensure measurement accuracy. Calibration was performed by resetting the sensor output to 0.00 cm. Span calibration was conducted using standardized length rods (0–100), with each measurement repeated three times. Measurement error was calculated as the difference between EKHMD readings and standard lengths. Calibration was deemed acceptable when the measurement error did not exceed ±0.5 cm and demonstrated high linearity. All calibration procedures were documented and performed by trained researchers.

Measurement Procedure

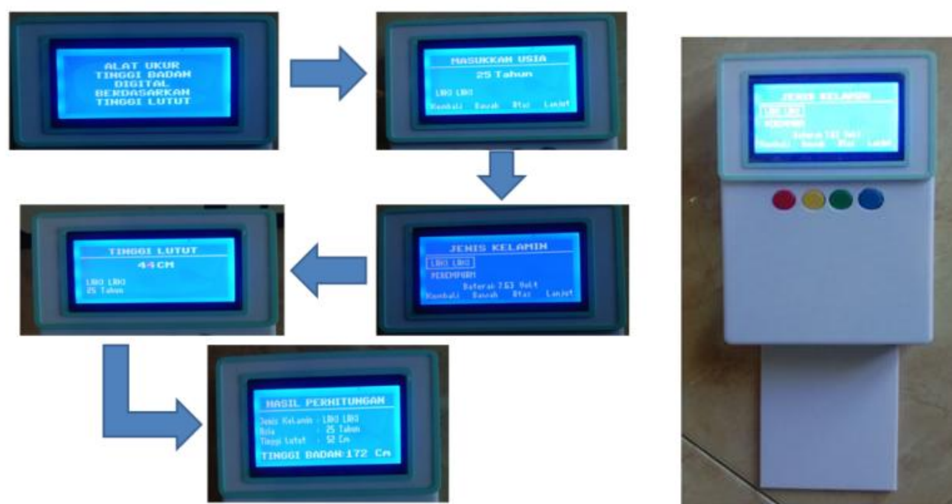

Figure 1. EKHMD tool menu

The measurement procedure was carried out by first turning on the device, setting the subject's age and sex, and positioning the device on the knee with the sensor directed toward the plantar surface of the foot. The device automatically recorded knee height measurements, which were then processed to estimate body height and displayed on the screen. All measurements were conducted under standardized conditions to ensure consistency.

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Ethical Considerations

This study received ethical approval from the Health Research Ethics Commission of STIKES Banyuwangi with the approval number: 278/02/KEPK-STIKESBWI/VII/2024-2025. All participants provided written informed consent prior to participation, and confidentiality of the data was maintained throughout the study.

Data Analysis

Data were analyzed using SPSS version 26. The results of the EKHMD and microtoise measurements were tested for validity using the Pearson correlation test (for knee height) or the Spearman correlation test (for estimated body height and Nutritional Status) to determine the relationship between the two types of measurements. The Bland–Altman plot analysis was also applied to assess the level of agreement between them by examining the Limits of Agreement (LoA), calculated using the formula LoA = Difference ± (1.96 × SD). In addition to the validity test, a reliability test was performed using Cronbach's Alpha to evaluate the consistency of the measurement tool when used repeatedly.

RESULTS

This study used the EKHMD, an electronic knee height measuring device that uses sensors to predict the knee height of the person being measured. The device is simple to use: the is placed above the knee, and the sensor measures the knee height. After the knee length is captured, the device processes the measurement data using the Chumlea formula. An overview of the EKHMD and a demonstration of its use can be seen in Figure 2 below.

Image Caption: EKHMD tool and the process of measuring knee height using a tool that is placed above the knee and the tool will capture the height and convert the knee height into body height.

Figure 2. EKHMD tools and demonstration of their use.

The results of the comparative test of knee height measurement, estimated body height, and estimated nutritional status obtained using the EKHMD and microtoise are presented in Tables 1, 2, and 3. Measurements were conducted using two different positions, in which the subjects were assessed while sitting and lying on a mattress.

Table 1 shows that the average knee height was 49.5 ± 2.48 cm in the sitting position and 49.2 ± 2.26 cm in the lying position, with a small mean difference of 0.35 ± 0.91 cm, indicating minimal variation between the two methods. Validity testing using Pearson correlation demonstrated a strong and significant relationship (r=0.929 > r-table=0.361), confirming that measurements in both positions are valid. Reliability testing using Cronbach's Alpha also showed consistent results (α>0.60), indicating stable measurements upon repetition. Bland–Altman analysis revealed limits of agreement ranging from 2.13 cm to –1.43 cm, with most measurements falling within this range. The

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small mean difference (0.35 cm) further indicates good agreement, accuracy, and interchangeability between sitting and lying knee height measurements using EKHMD (Figure 3).

Table 1. Knee Height Measurements in Sitting and Lying Using EKHMD

Knee Height (Mean (cm) + SD)	Methods	
	Sitting Position	Lying Position
Score	49.5 ± 2.48	49.2 ± 2.26
Difference/Error (cm)	0,35 ± 0,91	
Pearson Test	0,00*	
Cronbach's Alpha	0,61**	

*Valid at (p < 0,05)
**Reliable at p > 0,60

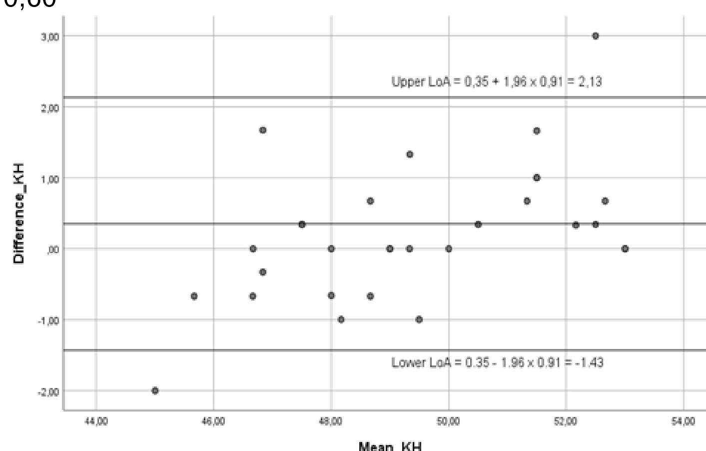

Figure 3. Bland-altman plot Knee Height Measurements in Sitting and Lying Using EKHMD

Table 2. Estimated Body Height Compared with Actual Body Height (Microtoise) and Estimated Body Height (EKHMD)

Body Height (Mean (cm) + SD)	Methods	
	Sitting Position	Lying Position
Estimated (EKHMD)	161.96 ± 9.58	161.37 ± 8.53
Actual (Microtoise)	161.38 ± 7.89	161.38 ± 7.89
Difference/Error (cm)	-0,58±4.32	0,01±0,02
Spearman Test	0,00*	0,00*
Cronbach's Alpha	0,936**	0,928**

*Valid at p < 0,05
**Reliable at p > 0,60

Based on Table 2, the average estimated height using the EKHMD tool was 161.96 ± 9.58 cm in the sitting position and 161.37 ± 8.53 cm in the lying position, compared to the actual height of 161.38 ± 7.89 cm. The sitting position showed a slight overestimation with a mean difference of –0.58 ± 4.32 cm, while the lying position was almost identical to the actual measurement with a minimal difference of 0.01 ± 0.02 cm.

Bland–Altman analysis indicated that the sitting position had wider limits of agreement (7.89 to –9.05 cm), whereas the lying position showed much narrower limits (0.049 to –0.029 cm), suggesting higher accuracy in the lying position. Most measurements fell within these limits (Figure 4).

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Spearman correlation analysis showed strong and significant relationships between estimated and actual height in both positions (p=0.00), with r=0.869 (lying) and r=0.863 (sitting), both exceeding r-table (0.361). Reliability testing also demonstrated excellent consistency, with Cronbach's Alpha values of 0.936 (sitting) and 0.928 (lying).

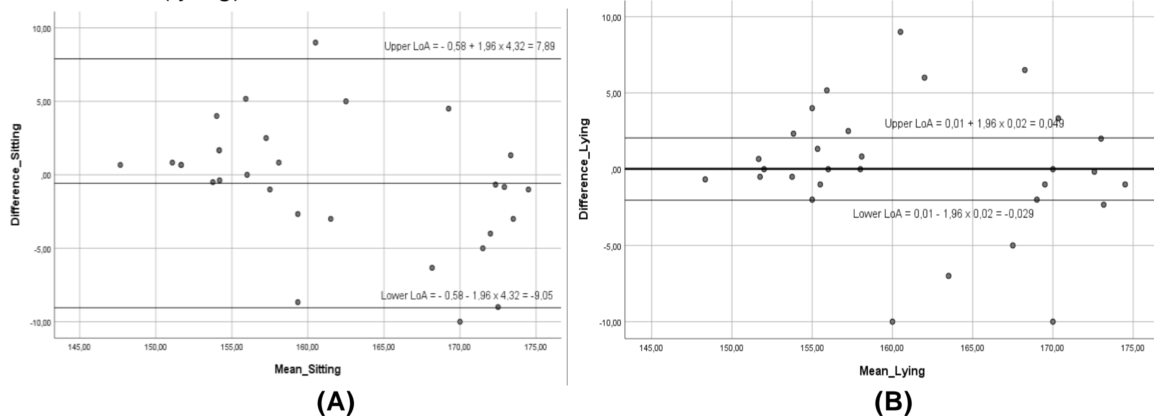

Figure 4. **bland-altman plot Estimated Body Height Compared with Actual Body Height (Microtoise) and Estimated Body Height (EKHMD) by Sitting (A) and Lying (B) Position**

Table 3. **Nutritional Status (BMI) Using Actual body height (Microtoise) and estimated nutritional status (EKHMD)**

Nutritional Status (BMI) (Mean (kg/m^2) + SD)	Methods	
	Sitting Position	Lying Position
Estimated	21.31 ± 4,16 (Normal)	21.46 ± 4,15 (Normal)
Actual	21,48 ± 4,36 (Normal)	21,47 ± 4,36 (Normal)
Difference /Error (cm)	0,17 ± 1,11	0,016 ± 0,02
Spearman Test	0,00*	0,00*
Cronbach's Alpha	0,983**	0,984**
Sensitivity (Sn) (%)	81,8	85,7
Specificity (Sp) (%)	80	87,5

BMI : Body Mass Index (Underweight (BMI < 18,5); Normal (BMI = 18,5 – 22,9), Overweight (BMI = 23 – 24,9); Obesity I (BMI = 25 – 29,9); Obesity II (BMI = ≥ 30) (WHO, 2005)
*Valid at p < 0,05
**Reliable at p > 0,60
*** Good Sn and Sp > 80%

Based on Table 3, BMI was calculated using height from EKHMD and microtoise, and weight from a calibrated digital scale (±0.1 kg). The mean BMI difference was 0.17 ± 1.11 (sitting) and 0.016 ± 0.02 (lying), indicating that the sitting position tended to slightly overestimate compared to the lying position.Spearman correlation showed a strong and significant relationship in both positions (p=0.00), with r=0.970 (lying) and r=0.952 (sitting) > r-table (0.361). Reliability was excellent, with Cronbach's Alpha of 0.983 (sitting) and 0.984 (lying), indicating consistent measurements.

Bland–Altman analysis showed wider limits of agreement in the sitting position (2.35 to –2.01) and narrower limits in the lying position (0.06 to –0.023), with mean differences of –0.17 (sitting) and 0.016 (lying). Most data fell within these limits, indicating good agreement, especially in the lying position (Figure 5).

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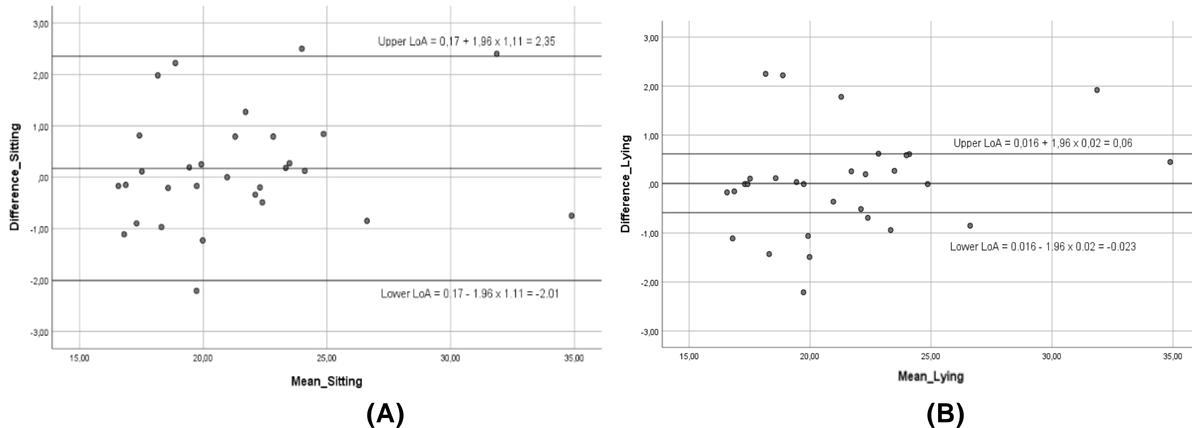
Sensitivity and specificity analysis further confirmed better performance in the lying position (85.7% and 87.5%) compared to the sitting position (81.8% and 80.0%). Overall, EKHMD is accurate and reliable for BMI estimation, with higher diagnostic accuracy in the lying position.



(A) (B)

Figure 5. Nutritional Status (BMI) Using Actual body height (Microtoise) and estimated nutritional status (EKHMD) by Sitting (A) and Lying (B) Position

DISCUSSION

These findings are important because even small errors in height estimation can lead to significant misclassification of nutritional status. Therefore, the demonstrated agreement between EKHMD-derived height and microtoise measurements highlights its potential utility as a practical and clinically meaningful assessment too. Previous anthropometric studies have emphasized the importance of standardized posture during knee height measurements. Measurements taken in the lying position are considered more stable due to reduced axial loading and increased muscle relaxation, which minimizes postural variability and measurement error [7], [8]. The error results of height estimation using EKHMD are sitting (-0.58 cm) and lying (0.01 cm) when compared with standard measurements using a microtoise. This difference or error is much smaller when compared with previous research where the difference in height measurements using knee height was 2.26-5.73 cm [9] and other research where height estimation using knee height had a difference of up to 10.25 cm [3].

The EKHMD showed evidence of validity and reliability based on the results obtained in this study. The validity analysis indicates that the measurements were comparable to the reference method, while the reliability analysis suggests consistency of repeated measurements under similar conditions [10]. The reliability of a measurement instrument is essential, as it guarantees the accuracy and consistency of results across various conditions, including those involved in health assessments through anthropometric measurements [11]. The use of valid and reliable instruments is essential to minimize bias in manual anthropometric measurements. Although anthropometric assessment may appear straightforward, it carries a considerable risk of error due to variations in examiner skill, equipment quality, and procedural understanding. Inaccurate measurements or misinterpretations by examiners can lead to erroneous nutritional diagnoses. Such misinterpretations commonly arise from reading errors and are further influenced by the examiner's level of expertise, which is often affected by insufficient training and procedural challenges encountered during measurement [12].

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Anthropometric measurements are widely used to assess the health status of individuals by evaluating physical conditions based on body height and weight. Body height plays an important role in estimating an individual's condition and in calculating nutritional status across all age groups, from children to older adults. However, in clinical settings, direct height measurement is not always feasible, such as in patients with fractures, paralysis, skeletal deformities (scoliosis, kyphosis, and lordosis), amputations, or in the elderly [13]. In such cases, alternative methods are needed to estimate body height, one of which is knee height measurement. The measurement is taken from the patient's lower limb and then applied to the Chumlea formula to estimate body height. Previous research by Intan demonstrated that there were no significant differences between actual height and estimated height derived from knee length. Similarly, Rahayu also reported that actual height measured using a microtoise did not differ significantly from height estimated through knee height. These findings support the use of knee height measurement as a reliable alternative for estimating body height when direct measurement is not possible [14].

Previously, knee height measurements using a knee height caliper were considered impractical. Therefore, this study introduced an innovation by developing the Electric Knee Height Measurement Device (EKHMD), which utilizes an electronic system and sensors to measure knee height. Measurements with EKHMD were performed in two positions, sitting and lying down, to ensure that the device could function reliably and valid under both conditions. The absence of significant variation is likely due to the fact that body position does not substantially affect knee length [1]. The accuracy of EKHMD is supported by its use of ultrasonic sensors that automatically capture and display measurements on an LCD, ensuring consistent and standardized results. In contrast, manual anthropometric tools are more dependent on operator skill and are prone to errors such as misreading, low precision and sensitivity, inadequate training, calibration issues, and practical limitations like large size and weight[15].

The use of an electronic body height measurement device offers notable advantages, particularly in terms of efficiency, measurement time, and accuracy. Moreover, electronic devices are generally well-accepted due to their ease of use, practicality, and sustainability in application [16]. Accurate assessment of nutritional status plays a crucial role in reducing the risk of malnutrition, particularly in elderly patients. Those with an appropriate nutritional status are less likely to develop malnutrition during hospitalization, as precise nutritional diagnosis facilitates timely and appropriate implementation of nutrition therapy [17]. Furthermore, nutritional status is closely associated with disease outcomes, especially in hospital care. Poor nutritional status has been linked to increased risks of health complications and adverse clinical outcomes in patients [18].

The results of the EKHMD tool's validity and reliability test for estimating body height and nutritional status compared to height measured with a standard manual tool such as a microtoise indicate whether the two measurements are valid and reliable. Validity indicates the extent to which a tool delivers accurate results compared to standard measurements. A tool is considered valid if it accurately measures the variables it intends to measure [19].Anthropometric measurements such as body height, body weight, and knee height are essential, as inaccuracies in these parameters may lead to misinterpretation of nutritional status. Such errors can subsequently result in inappropriate decision-making and ineffective planning of nutrition programs for patients [20]. The use of microcontroller-based technology represents a new breakthrough in the development of automatic devices, such as electronic knee height measurement tools. This innovation facilitates faster, easier, and more accurate measurements, thereby improving efficiency and reducing the time required for knee height assessment [21]. The

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EKHMD tool in this study has the advantage of being very easy to use, a tool that has never been similar before, practical and easy to carry anywhere, lightweight and can be easily stored. However, the EKHMD has disadvantages: the tool cannot store measurement results, the shape is still less attractive, and it has not been tested whether race will affect the measurement. The implications of this study are that the tool will be used by nutritionists to help determine height through knee height more quickly and practically. Estimating height in immobilized patients will be easier for nutritionists. In addition, the EKHMD tool can be used as a learning medium for lecturers and nutrition students for anthropometric measurements and further in-depth research on this tool.

CONCLUSION

The results of the study showed that EKHMD has good validity and reliability supported by the Bland–Altman plot, which shows that most of the test results are within the upper and lower limits of agreement (LoA), indicating that the measurements from both methods are very suitable and can be used interchangeably. Suggestions for further research involving more diverse participants and larger sample sizes is recommended to strengthen the validity of the findings.

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