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Reliability and Accuracy Test of Digital Anthropometry to Monitor Growth and Development in Children

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Abstract

Regular child anthropometry, such as measuring a children height and or length, is a crucial part of pediatric clinical evaluations. Anthropometric measurements of children allow measurement errors caused by weaknesses in measuring instruments, thus affecting the accuracy of measurement results. This review contributes to nursing by providing insights into the reliability and accuracy of digital anthropometric tools, which are essential for ensuring precise growth monitoring in pediatric care. This review assesses the reliability and accuracy of digital anthropometry tools and contributes to nursing by providing insight into the reliability and accuracy of digital anthropometry tools that are important in monitoring child growth and development. Conventional anthropometric methods, while widely used, face limitations in accuracy due to human error and challenges with measuring children. Digital anthropometry offers a promising alternative with potentially higher precision, ease of use, and adaptability, critical for tracking children's health metrics like height and weight against growth standards. The study applied the Joanna Briggs Institute methodology, using PRISMA guidelines for literature reviews, and selected seven studies meeting specific inclusion criteria. Studies reviewed technologies such as Auto Anthro, Bioelectrical Impedance Analysis (BIA), Stunted Early Detection Tool (SEDT), Ultrasonic Sensors, Photogrammetric, and 3D scanners, evaluating validity and reliability with metrics like Technical Error of Measurement (TEM), Concordance Correlation Coefficients (CCC), intraclass correlation, and Bland. Six studies indicated that digital measurements of anthropometry had excellent levels of accuracy and reliability to monitor child growth and development; one study showed less accuracy because it takes more time to test and improve training and ensure the software works as intended. The digital anthropometry used was precise, portable, and not time-consuming, so that digital anthropometry could be an alternative to measuring the nutritional status of toddlers. For nurses, using digital anthropometry improves efficiency in clinical practice by enabling rapid and accurate assessments, reducing human error, and increasing the reliability of growth monitoring, thereby enabling early intervention and better health outcomes for children.

Keywords: *Digital Anthropometry; Measurement, Height; Growth*

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1. Introduction

Height measurements for children are used daily for tracking growth as an indicator of a child's development and health (Rosari et al., 2024). The following sex-specific indicators are then used to compare the measurements to a reference population: weight for age (underweight), height for age (stunting), and weight for height (wasting) (Gupta et al., 2020). Thus, precise anthropometric measures are necessary for screening infant growth, evaluating nutritional status, and providing clinical care data (Gupta et al., 2023). More broadly, anthropometry is the measurement of any part, surface, or volume of the human body (Mocini et al., 2023). There are two kinds of anthropometric measurements: conventional and digital (Kennedy et al., 2022).

Conventional anthropometry is an easy-to-use, low-cost, non-invasive technique that can be used in clinical or epidemiological contexts (Ceniccola et al., 2019). This tool's used to measure the human body at regional and whole body levels using common equipment such as a weight scale, vernier caliper, meter, gauge, compass, and stadiometer (Rumbo-Rodríguez et al., 2021). Anthropometric measurements of children using conventional methods allow for measurement errors caused by human factors (Neale et al., 2021). Children are especially tough to make conventional anthropometric measurements on because they are prone to human error, difficult to hold still, and may not be able to meet the standards (e.g., ability to lie or stand) for manual anthropometry (Gupta et al., 2023). Although it has been widely used for decades, it is cumbersome and heavy (Soller et al., 2023). The manual technique of gathering data also raises the possibility of transcribing errors, which has an adverse effect on the data's accuracy (Mays & Mathias, 2019). Thus, precise and accurate digital measurement tools would be very beneficial for nutritional surveillance and clinical assessment (Neale et al., 2021). If the devices are portable, lightweight, reliable, and have simple data storage and transfer capabilities, health assessment will become more accessible (Soller et al., 2023). In order to improve child clinical evaluation and nutrition surveillance, UNICEF has underlined the need for innovation in the development of height and length measuring instruments (Soller et al., 2023).

Anthropometry is a key method for assessing the nutritional and health status of individuals and populations (Bhattacharya et al., 2019). In various contexts, such as clinical practice, research, and public health, anthropometric measurements are used to monitor growth, detect malnutrition, and assess the risk of chronic diseases (Casadei & Kiel, 2022). As technology advances, portable digital anthropometric measurement tools are increasingly being developed to improve accuracy, efficiency, and ease of use (Mocini et al., 2023). However, significant gaps remain in the literature regarding these tools, particularly concerning their validity, reliability, and standardized use across different populations (Bušić et al., 2020). The lack of strong scientific evidence on their effectiveness may impact their acceptance and implementation in clinical practice and public health policy (Iyamu et al., 2022). For instance, in clinical settings, limited validation data may lead to uncertainty in the interpretation of measurement results, potentially affecting patient diagnoses and nutritional interventions (Holmes & Racette, 2021). Similarly, in public health programs, using tools with unverified accuracy may result in errors in nutrition intervention planning and resource distribution (Kelly et al., 2022).

Research from Mocini et al (2023) revealed a significant void in the industry and scholarly literature for portable digital growth measurement tools. While certain technologies show promise, more investigation is required to evaluate these devices' applicability in other scenarios. To increase the validity and dependability of these devices for general usage, more research and development, as well as commercialization, are necessary. Thus, the purpose of this research is to evaluate the validity and accuracy of digital anthropometry, which is used to measure children's length or height.

2. Method

The study design utilized the Joanna Briggs Institute Methodology Literature Review and Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extensions for Literature Reviews (PRISMA). The literature search was conducted using eight different databases: EBSCO SAGE, Emerald, Scopus, PubMed, Science Direct, Pro Quest, and Springer. The study's publication year was limited to 2015–2023. The research used the PICO methodology (population: children; intervention: digital anthropometry height measurement; comparator: conventional anthropometry; outcome: validity and reliability). The last search was performed on November 27, 2023. This research uses the Zotero application to collect, manage, and analyze, as well as share reference sources.

Eligible studies were primary studies conducted in any country or setting using any study design, provided that the studies involved the use of digital height/height measurement devices in children under 20 years of age. The gray literature search also found relevant product-related information, device manuals and web pages for each identified device. Devices described in gray literature were included in the analysis only if there was evidence to assess the device's validity, reliability, and accuracy. Studies that used standard measuring instruments, such as stadiometers or height meters, were excluded. Book chapters, expert opinions, unavailable full texts, articles in languages other than English, and articles published before 2015 were discarded, and protocol, systematic, scope, or narrative reviews were not included. Nevertheless, references were examined for potentially relevant research results when relevant to the review topic of interest.

Additional studies that may be relevant were investigated by reviewing the references for the included studies. The search was conducted by two researchers (K.Y.A. and H.T.).

3. Results and Discussion

The search returned 677 references: 416 records from the search EBSCO, 116 in SAGE, 32 in Springer, 26 in ScienceDirect, 1 in PubMed, 0 in Scopus, Emerald, and ten from other sources. After screening, 45 records were deemed duplicates and were thus eliminated. After a title and abstract screening, 616 more papers were eliminated from consideration. After the remaining articles failed to produce any meaningful results, nine of them were eliminated. Seven papers were included in our review after a full-text assessment (Figure 1).

Table 1. Data extraction

Author, Year, Country	Type of Study	Population (Sample Size)	Technology Used	Statistical Analysis	Result		Conclusion
					Reliability	Accuracy	
(Hardy et al., 2018) UK	observational study	53 Children 3-19 years	Bioelectrical impedance analysis (BIA)	StatsDirect V.2.7.2 (Cheshire, UK: Stats Direct) Technical measurement error (TEM), percentage technical measurement error (%TEM), coefficient of reliability (R) with P values, and 95% confidence intervals (CIs) are all indicators of reliability.	The technical error of measurement was used to evaluate reliability (TEM). In standers, the TEM measured height was 0.55 cm, but in non-standers, it was 2.47 cm. 1.57 cm for tibial length and 0.81 cm for knee height were the TEMs for non-standers.		It was possible to measure the body composition and anthropometry of children with exceptional needs. Nonetheless, there are differences in these metrics' dependability for standers and non-standers.
(Conkle et al., 2018) USA	Prospective validation study	474 Children 0-5 years	Auto Anthro Scanner (Occipital, San Francisco, California, United States) White light with structure	Measures of reliability include the intraclass correlation coefficient (ICC), reliability coefficient (R), technical measurement error (TEM), and percentage technical error of measurement (%TEM). Accuracy of the Bland-Altmann plot, paired t-test, and Manner difference (groups)	The total TEM is the sum of the manually measured intra-observer and interobserver TEMs. The total TEM for stature, HC, and MUAC was 0.51 cm, 0.33 cm, and 0.31 cm, respectively, in contrast to the scan values of 0.77 cm, 0.51 cm, and 0.43 cm. The coefficient of reliability based on total TEM was 1.00, 1.00, and 0.99 for height, HC, and MUAC, respectively, generated from manual measures; it was 1.00, 0.99, and 0.98 for data acquired from scans.	The head circumference (mean difference 0.32 and LoA −0.1–0.8), arm circumference (mean difference −0.19 and LoA −0.6–0.2), and height (mean difference 0.59 and LoA −0.1–1.2) were the locations where Bland-Almant plots revealed significant differences ($p<0.001$).	Results show that infant anthropometry produced by Auto Anthro can be trusted.
(Wigati et al., 2022) Indonesia	Qualitative study	Five experts Experts in anthropomet	Stunted early detection tool (SEDT)	Thematic content analysis.	Relative advantage The advantages of portable tools include their ease of use, adaptability to different		The development of the SEDT can be used as a body length measurer

Author, Year, Country	**Type of Study**	**Population (Sample Size)**	**Technology Used**	**Statistical Analysis**	**Result**		**Conclusion**
					Reliability	**Accuracy**	
		ry and health promotion media have over 20 years of experience.	Portable length measurer		environments, and increased likelihood of adoption by potential users. Compatibility The two tools that make up the SEDT are complementary to one another. The child's body length is measured with a length mat to an accuracy of 1 mm. The SEDT discs are then used to classify the measurement data into multiple nutritional status categories based on the LAZ z-score. Complexity Experts believe that since CHWs are used to measuring body length and tracking growth, using SEDT wouldn't be difficult for them. Observability The use of SEDT was simple for CHWs to comprehend.		and stunted early detectors among children under two years old.
(Umiatin et al., 2022) Indonesia	Prospective validation study	5 Children 3-5 year	Sharp IR GP2Y0A21 infrared sensor and HC-SR04 ultrasonic sensor	The Arduino Mega 2560 microcontroller is used to manage the measurement and display of data. The mean ± deviation standard was used to present the measurement data.		In terms of anthropometric height measurement, the IR sensor's average error is 0.33%, whereas the ultrasonic sensor's average error is 2.19%.	Based on these results, the anthropometric system prototype can accurately measure the Height of children under five.
(Penders et al., 2015) Netherland	cross-sectional	54 Children 2-18 year	Photogrammetric, digital camera	IBM SPSS Statistics, Version 20.0 for Windows. For		All measurements have inter-observer correlations of ≥	Photometry of measurement of the body

Author, Year, Country	Type of Study	Population (Sample Size)	Technology Used	Statistical Analysis	Result		Conclusion
					Reliability	Accuracy	
s			Canon EOS 70D	normalcy, use the Shapiro-Wilk test. The two measurement techniques were compared by computing the mean differences with standard deviation and correlation, and interobserver correlation was established using Pearson's correlation coefficient.		0.96, and the mean differences, except for arm span, are 0.3–0.9 cm. The mean differences between manual and photogrammetric measures are between 0.6 and 1.3 cm, with correlations of 0.92 to 0.92, except for sitting height and arm span. The ratios of height to sitting height (r = 0.77), bicarbonate to biiliacum (r = 0.74), and subischial leg length to sitting height (r = 0.75) are correlated amongst approaches.	proportions of a child can be done accurately and reliably.
Glock et al. (2017) German	Cohort study	473 Children 6-17 year	Body laser scanner	Microsoft Excel (version 16.0.6366. 2036, Microsoft, Redmond, Washington) and the statistical software R (version 3.3.1, R core team, Vienna, Austria). For visual data analysis, Bland-Altman plots. The validity of the body	For the intraobserver reliability assessment and the 95% confidence interval, selected measures of conventional anthropometry (CA) are 0.999, while matching body scanner measurements (BS) are 0.999 with OCCC.	The overall CCC for the population was 0.998 (P<0,0001), with a range between 0.987 (male, average weight, 14–17 years old) and 0.997 (male, average weight, 10–13 years old).	It can be used in an epidemiological setting with children and adolescents

Author, Year, Country	**Type of Study**	**Population (Sample Size)**	**Technology Used**	**Statistical Analysis**	**Result**		**Conclusion**
					Reliability	**Accuracy**	
				scanner using concordance correlation coefficients (CCC). Overall CCC (OCCC) was used to assess the intra-observer reliability of both techniques by calculating the three single measurements of each triplet.			
Leidman et al., (2022) United States	Prospective validation study	539 Children 6-59 month	Automated 3D Imaging, Samsung Galaxy 8 phone loaded with custom software, AutoAnthro and an Intel RealSense 3D scanner.	The significance of differences statistically using the Kruskal-Wallis. The fraction of outlier values, SD, and digit preference ratings are used as standard indicators to assess the quality of anthropometric measurements. The accuracy of the measurements using Bland-Altman plots.		The availability of scan-derived metrics was correlated with the children's demographics (age and sex), height, and MUAC; the team was significantly correlated (P<.001). For height and MUAC, respectively, the average bias of scan-derived values in cm was −0.5 (95% CI −2.0 to 1.0) and 0.7 (95% CI 0.4–1.0). The 95% LoA for stature ranged from -23.9 to 22.9 cm. The 95% LoA for MUAC ranged from -4.0 to 5.4 cm.	Scan-derived measurements were not sufficiently accurate for the widespread adoption of the current technology.

The measurement results below indicate minimum and maximum values, as the values vary depending on the body part measured and the technique used. Two of the seven studies (Conkle et al., and Glock et al.) addressed reliability and accuracy; three (Umiatin et al., Penders et al., and Leidman et al.) addressed accuracy; and two (Hardy et al., and Wigati et al.) addressed reliability only.

Reliability

Four of the seven studies (Hardy et al., Conkle et al., Wigati et al., and Glock et al.) showed greater reliability after repeated measurements. The observed reliability was performed on the same subject by one or more operators. The reliability of the 2 studies (Hardy et al., and Conkle at al.) was expressed in Technical Error of Measurement (TEM) and % TEM. According to the ISAK protocol, if TEM < 2 cm and % TEM < 1.5%, anthropometric measurements are considered reliable (Mocini et al., 2023). One study (Glock et al.) used overall concordance correlation coefficients (OCCC) to express reliability; measurements were considered reliable if the CCC value (P ≤ 0-05) and 95% CI (Smith et al., 2023). One study (Wigati et al.) used qualitative data from five experts which discusses relative advantages, compatibility complexity and observability.

Hardy et al., using bioelectrical impedance analysis (BIA), found that the height and supine length TEMs were 0.55 cm for standers and 2.47 cm for non-standers, respectively. For non-standers, the TEMs for knee height and tibial length were 0.81 and 1.57 cm, respectively. Indicating that digital anthropometry is reliable. Conkle et al. used an Auto Anthro scanner (Occipital, San Francisco, CA, USA) with the total TEM for height being 0.77 cm. The reliability coefficient based on the total TEM was 1.00, indicating the measurements obtained from the scan were reliable.

Wigati et al. conducted a qualitative study by interviewing five anthropometric experts. The SEDT prototype consists of two tools: a long mat to measure children's height and a circular disk that helps CHWs classify children's nutritional status according to the length-for-age Z-score. Most experts agree that the SEDT is a good instrument for the early detection of stunting in children under 24 months. Glock et al. used a body laser scanner with corresponding body scanner measurements (BS) of 0.999 (CCC ≥ 0.9), indicating "very good" intra-observer reliability (OCCC ≥ 0.9).

Most of them included studies (Hardy et al., Conkle et al., Wigati et al., and Glock et al.) reported good reliability of digital anthropometry. According to the International Society for the Advancement of Kinanthropometry (ISAK) protocol, the acceptable TEM is 2 cm (Mocini et al., 2023). All %TEM values < 2% and R coefficients > 99% mean that intra- and inter-observer reliability are acceptable and have high reliability. This supports the acceptability of using routinely collected length and height measurements (Carsley et al., 2019). In addition to stating reliability, a measurement is considered reliable if the CCC value (P ≤ 0-05) and 95% CI (Smith et al., 2023). The degree to which people in a sample hold their position over multiple assessments is known as relative reliability, and it is represented by the intraclass correlation coefficient (ICC) and reliability coefficient R (Mocini et al., 2023).

The use of bioelectrical impedance analysis (BIA) is reliable; this is in line with research conducted by Lewis et al., (2023) showing the BIA calibration equation for a group of stunted children with relatively low prediction errors. This can help evaluate large-scale trials in the same population. Anthropometric and body composition measurements are feasible for children with special needs (Duran et al., 2019). However, the reliability of these measures differs between non-standers and standers and should be considered when choosing the appropriate measure (Jefferds et al., 2022).

The results of the research analysis conducted by Wigati et al. provide extensive information about the potential of SEDT, and most experts agree that the SEDT prototype consists of two tools, namely a long mat to measure children's height and a circular disk, a good instrument for early detection of stunting (Widodo & Sulistiyanti, 2022). In another study, a stunting detection tool applied to 6-month-old babies provided a valid prediction of the risk of stunting at the age of 3 years (Hanieh et al., 2019). An ultrasonic HC-SR04 sensor and a sharp IR GP2Y0A21 sensor can be used to measure height (Ardianto et al., 2022).

Digital anthropometry is less time-consuming and more reliable than conventional anthropometry (Kim et al., 2022). Body image scanners are used in industry and research to reliably deliver a multitude of anthropometric measurements in seconds (Ashby et al., 2023). Different equipment and methods can be used to obtain body measurements with different levels of precision and reliability (Nieberle et al., 2023). However, digital anthropometry has several limitations due to technical and human variability. Technical variability is affected by the characteristics of 3D scanning hardware and the performance of data acquisition, visualization, landmark, and measurement extraction software (Mocini et al., 2023).

Based on observations in this review, the use of bioelectric impedance analysis (BIA) shows the best reliability results. Besides being reliable, this digital anthropometry can be used for children with special needs. However, the reliability of this measurement differs between standing and non-standing.

Accuracy

Most studies (Conkle at al., Umiatin et al., Penders et al., Glock et al., and Lediman et al.) evaluated the accuracy of digital anthropometry. Conkle et al. measured 82 children aged 1 month, showing a 0.825 (0.689 to 0.961) measurement difference in cm, µ (95% CI), -0.412 to 2.062 (95% limits of agreement in cm), with a p value of 0.091, while in 392 children aged 1-59 months showed 0.571 (0.505 to 0.636), -0.756 to 1.897, with a p value of 0.919. Research conducted by Umiatin et al. showed an average error of 0.33% for the sharp IR GP2Y0A21 sensor for height measurement. The HC-SR04 ultrasonic sensor shows an average sensor error of 2.19%.

Research conducted by Penders et al. showed all correlations between the manual and photogrammetric calculated ratios were ≥ 0.70 (p ≤ 0.001) for both observers. While research conducted by Glock showed a total CCC of 0.998 for the whole population and a range between 0.987 (male, normal weight, 14–17 years old) and 0.997 (male, normal weight, 10–13 years old) for body height without major influence of age, weight, or sex. Leidman et al. used Auto Anthro technology for height measurement, and the results showed that the average bias of measurements obtained from scanning in cm was -0.5 (95% CI -2.0 to 1.0) for height. The 95% LoA for stature ranged from -23.9 to 22.9 cm. The 95% LoA for MUAC ranged from -4.0 to 5.4 cm.

Systematic error or bias depends on accuracy, accuracy is classified based on correlation at a mean level; linear regression, concordance correlation coefficient (CCC), Pearson's correlation coefficient, and paired t-tests (Parker et al., 2020). For the latter, computations of the root mean square error (RMSE), standard error of the estimate (SEE), and coefficient of determination (R2) are required (Mocini et al., 2023). For methods of agreement (association) and identity where more than two operators and/or repeated measurements are involved, CCC seems to be a good description. Although CCC does not rely on ANOVA assumptions, ICC does; both indices simultaneously consider accuracy and precision evaluations (Wen & Gallas, 2022). Agreement or concordance, at an individual level; the Bland-Altman plot plots the difference between the arithmetic mean (M) of each pair of measurements, the total mean difference (bias), and the 95% limits of agreement (LoA), along with the corresponding confidence intervals, to compare the degree of agreement between two different technologies (Gerke, 2020) (Bahiraei et al., 2023).

Research conducted by (Conkle at al., Umiatin et al., Penders et al., Glock et al., and Lediman et al.) evaluated the accuracy of digital anthropometry. The use of the Auto Anthro system to capture 3D scans in children aged <5 years to calculate anthropometric measurements is generally as acceptable as manual anthropometric measurements (Jefferds et al., 2022). However, research conducted by Leidman et al. showed that the measurement results were less accurate. This is in line with research conducted by Bougma et al. (2022) showing that the overall evaluation of the effectiveness of using Auto Anthro scanning technology to measure anthropometric measurements of children <60 months in Guatemala, Kenya, and China through population-based surveys and surveillance systems found many poor quality results. In another study, it was suggested that anthropometric experts were not ready to abandon manual equipment for 3D scanners due to difficulties in measuring uncooperative children (Conkle et al., 2019).

With the development of portable camera technology (particularly cameras integrated into smart phones), image-based approaches to measuring infant body length are being developed (Sommer et al., 2020). The use of digital photogrammetry techniques has increased rapidly to meet the needs of many applications in various fields (Hadi & Khalaf, 2022). In another study, measuring human body segments through digital photogrammetry showed a good fit with the same accuracy (Soller et al., 2023). The infant body length measurement instrument involves a body length sensor that is described through a regression equation approach and processed using an Arduino Mega 2560 microcontroller (Chabibah et al., 2023). Validation of ultrasonic sensors as body length detectors shows accurate regression values (Gubawa et al., 2021).

Conventional anthropometry used widely in medical practice and epidemiological studies to assess a person's health (Minetto et al., 2023). However, traditional techniques reduce the complex shape of the human body to a series of simple size measurements and derive health indices, such as body mass index, height, and length (Kennedy et al., 2022b). The use of digital anthropometry, such as three-dimensional (3D) imaging, can capture detailed and accurate measurements of the human external shape and has the potential to surpass traditional measurements in healthcare applications (Thelwell et al., 2022). Additionally, the use of auto-anthropometry generated by the mobile app is accessible and cost-effective, with the potential to assess clinically relevant anthropometry without the presence of a trained technician (Graybeal et al., 2023).

Accurate digital anthropometric measurements can help identify underlying medical, nutritional, or social problems in children (Sommer et al., 2020). Besides that, the use of this digital anthropometric measuring instrument can detect stunting early, is easy to use, easy to carry, or portable, so it has the potential to be used by ordinary people through community empowerment at Integrated health post (Siswati et al., 2023).

Based on observations in this review, the use of anthropometric body laser scanners shows the best accuracy results. The laser body scanner can also provide detailed body composition information. In addition, the body laser scanner can be used for anthropometric measurements in adolescents.

This review shows high reliability and accuracy in digital anthropometry. This is supported by measurements that are carried out precisely, thoroughly, careful data processing to the evaluation of measurement results that are carried out properly.

4. Conclusions

This research reveals a substantial gap in the availability of instruments for measuring children's length and height. Under certain circumstances, digital anthropometry is more appropriate than traditional approaches because of its high reliability and speed of measurement detection. The primary goal of this study, which was to present current data on the accuracy and dependability of digital anthropometry, was accomplished. This review provides up-to-date information on the state of digital anthropometry to identify how technology can be appropriately selected and incorporated into everyday clinical practice. Recommendations for further research are to explore the long-term impact of adopting digital anthropometry on pediatric growth monitoring, including health outcomes, cost-effectiveness, and user satisfaction among healthcare providers. Future studies should also examine training requirements for nurses to optimize the use of digital anthropometry in clinical settings. Ensuring that nurses are well-equipped with the knowledge and skills to utilize these tools effectively will maximize their benefits in pediatric care.

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