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The Relevance of the Technical Error of Measurement in Anthropometry: A Pilot Study from The Nutrifunction Project

La relevancia del error técnico de medición en antropometría: Un estudio piloto del proyecto NutriFunction

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ABSTRACT

Introduction. Anthropometry plays a crucial role in nutritional assessment, especially in clinical and research settings where lack of precision affects data reliability and patient care. However, the accuracy of these measurements is often overlooked when assessing nutritional status and health risks. This study aimed to assess the technical error of measurement (TEM) and evaluate the intra- and inter-observer measurement error of anthropometric measurements performed by the NutriFunction team—an ongoing multicentre study involving hospitalised patients and a comparative sample of community-dwelling individuals.

Methods. Six trained interviewers assessed twelve anthropometric indicators (body weight, body and knee height, hand and middle-finger lengths, hand breadth, mid-arm, waist, and calf circumferences, triceps, calf, and *adductor pollicis* thickness) on eight volunteers following ISAK and other pre-standardized techniques. TEM, relative TEM (%TEM), and coefficient of reliability (R) were calculated.

Results. Most results were adequate for experienced anthropometrists, except for hand breadth (%TEM=1.2) and knee height (%TEM=1.2) for anthropometrist #4, and middle-finger length (%TEM=1.3) for #5 in intra-observer variability (R range=0.6-1.0). Inter-observer variability showed unacceptable %TEM for hand length (%TEM=2.0, 2.5, 1.5) for anthropometrists #1, #2, and #5, hand breadth (%TEM=2.0) for #4, *adductor pollicis* thickness (%TEM=9.9, 14.5) for #1 and #2, and middle-finger length (%TEM=2.0) for #5 (R range: 0.3-1.0). For the beginner standard, intra-observer variability was acceptable across all points, but inter-observer variability was unacceptable for hand length (%TEM=2.5) and *adductor pollicis* thickness (%TEM=14.5) for anthropometrist #2.

Conclusions. Most anthropometric measurements had acceptable TEM values for experienced anthropometrists, meaning that these measurements present the necessary precision for clinical assessment and diagnosis. Anthropometrist #2 should not perform hand length and *adductor pollicis* thickness measurements until further training and a new TEM study are completed. Regular training is essential to minimise errors and safeguard the quality and clinical utility of anthropometric data for assessment, diagnosis and treatment.

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Keywords: Anthropometry; Reliability, intra-observer measurement error; Inter-observer measurement error; Technical error of measurement.

RESUMEN

Introducción. La antropometría es crucial en la evaluación nutricional, especialmente en entornos clínicos e investigativos donde la falta de precisión afecta la confiabilidad de los datos y la atención al paciente. Sin embargo, la precisión de estas mediciones suele pasarse por alto al evaluar el estado nutricional y los riesgos de salud. Este estudio tuvo como objetivo evaluar el error técnico de medición (TEM) y el error intra e inter-observador en las mediciones antropométricas realizadas por el equipo de NutriFunction, un estudio multicéntrico que incluye pacientes hospitalizados y una muestra de individuos que viven en la comunidad.

Metodología. Seis entrevistadores capacitados evaluaron doce indicadores antropométricos: peso corporal, altura corporal y de la rodilla, longitudes de la mano y del dedo medio, anchura de la mano, circunferencias del brazo medio, cintura y pantorrilla, grosor del tríceps, pantorrilla y aductor del pulgar, siguiendo los protocolos de ISAK y otras técnicas estandarizadas. Se calcularon el TEM, el %TEM y el coeficiente de fiabilidad (R).

Resultados. La mayoría de los resultados fueron aceptables para antropometristas experimentados, excepto la anchura de la mano (%TEM=1.2) y la altura de la rodilla (%TEM=1.2) para el antropometrista #4, y la longitud del dedo medio (%TEM=1.3) para el #5 en variabilidad intra-observador (R: 0.6-1.0). La variabilidad inter-observador presentó %TEM inaceptables para la longitud de la mano y el grosor del aductor del pulgar en varios antropometristas (R: 0.3-1.0). La variabilidad intra-observador fue aceptable para principiantes, pero la inter-observador no lo fue para la longitud de la mano y el grosor del aductor del pulgar en el antropometrista #2.

Conclusiones. La mayoría de las mediciones mostraron TEM aceptables, indicando precisión suficiente para evaluación y diagnóstico clínico. El antropometrista #2 necesita entrenamiento adicional antes de medir la longitud de la mano y el grosor del aductor del pulgar. El entrenamiento regular es esencial para minimizar errores y mantener la calidad y utilidad de los datos para evaluación, diagnóstico y tratamiento.

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Palabras clave. Antropometría; Confiabilidad; Error de medición intra-observador; Error de medición inter-observador; Error técnico de medición.

HIGHLIGHTS

- The study identified acceptable intra-observer variability for most anthropometric measurements according to standards advance, except for hand breadth, knee height, and middle-finger length, suggesting these specific measurements require additional training to improve accuracy.
- Unacceptable inter-observer variability was found in hand length, hand breadth, *adductor pollicis* thickness, and middle-finger length. Hand length and *adductor pollicis* thickness had unacceptable %TEM values, even by beginner standards, requiring further training and a new TEM study before reassessment.

INTRODUCTION

Anthropometry plays a crucial role in nutritional assessment[1,2]. It is employed in nutritional screening, assessment, and monitoring in both clinical and community settings. This method is valuable for detecting deviations from normal nutritional status[3], enabling the identification of under- and overnutrition or its coexistence, and offering insights into body composition by estimating the quantity and distribution of body compartments, such as fat mass and fat-free mass. Though it is not the only method available for evaluating nutritional status, since other techniques, such as bioelectrical impedance analysis (BIA) and dual-energy X-ray absorptiometry (DXA), are also commonly employed and offer valuable insights into body composition[4,5], anthropometry remains widely used due to its low cost, ease of performance, and minimal equipment requirements, making it particularly advantageous in clinical and community settings. Nevertheless, anthropometric measurements can be problematic due to their vulnerability to measurement errors. In this context, they have conceivably two types of impact on the quality of the anthropometric data: those related to the extent to which the 'true' value of a measurement is achieved – the validity; and those associated with the degree to which within-subject variability is present and is due to factors other than the variance of measurement error or morphophysiological variation of the subject – the reliability[3].

Imprecision is the variability of recurrent measurements and is largely attributed to observer error, so the greater the variability between repeated measurements of the same individual by one observer (intra-observer differences) or two or more observers (interobserver differences), the larger the imprecision[6]. Therefore, this indicator can be estimated by carrying out repeated anthropometric measures on the same subjects and calculating the technical error of measurement (TEM), and the relative TEM (%TEM)[3]. The International Society for the Advancement in Kinanthropometry (ISAK) adopted cut-offs of this index for different anthropometric measures in the accreditation of anthropometrists.

Technical measurement errors, particularly skinfolds thickness or waist circumference, have been documented in the literature. These errors often stem from observer variability, site location inaccuracies, or methodological inconsistencies. For instance, Hume and Marfell-Jones[7] emphasised the criticality of accurate site location for skinfold measurements, while Nádas *et al.*[8] detailed the intra-observer and inter-observer variability in waist circumference measurements. These challenges underscore the importance of training and standardisation in anthropometric practices[9-13]. Notwithstanding what was previously mentioned, the literature on methods for assessing the reliability of anthropometric measurements is scarce. Despite various authors' recommendations for anthropometrists to publish error estimates of their measurements[14-16], this information is rarely displayed in studies based on anthropometric measurements[17-19]. Their work is needed in various settings, such as nutritional assessments, monitoring programs, and clinical and epidemiological research involving large-scale cross-sectional or longitudinal studies. This raises the likelihood of measurement errors. Even when trained anthropometrists are involved, slight variations in their techniques can develop over time and should be checked and managed[3].

In this current of thought, the NutriFunction project – New aspects of muscle function related to nutritional outcomes – is an ongoing multicentre study conducted in the north of Portugal that involves a sample of hospitalised patients, and a comparative sample composed of community-dwelling individuals, where data regarding nutritional and functional status will be collected. Within the scope of this project, the authors considered it extremely relevant for the team to conduct a study of technical errors of the measurement in anthropometry – the first step of the NutriFunction before data collection. Since imprecise measurements can weaken observed associations between exposure and health outcomes in both clinical settings and research, recognising these errors highlights the need for improvement, as well as ongoing training, and retraining for the team[3]. This leads to the reduction of variability between various evaluators and/or between measurements and, in turn, to the improvement of anthropometric data collection and its interpretation. After conducting the present study, we will identify the anthropometrists and the measurements that require more training. If there is a need, the team will undergo additional training in order to conduct another study of the technical error of the measurement in anthropometry.

The present study aimed to 1) assess the technical error of measurement and the degree of intra and inter-observer precision for twelve anthropometric measurements performed in normoponderal individuals by the NutriFunction team composed of five evaluators, non-certified at ISAK; and 2) contribute to the awareness and diffusion of the importance of the anthropometrical measurement accuracy.

METHODS

Study setting and sample

This pilot, cross-sectional observational study, involved a convenience sample comprising students, staff, and faculty members, who were recruited via an email invitation sent to the academic community of the Faculty of Nutrition and Food Sciences of the University of Porto (FCNAUP). The anthropometric measurements were extracted from a sample of 8 volunteers (30±13 years) of both genders (6 women and 2 men). All individuals signed an informed consent that included the procedures to be adopted and allowed the publication of the results. The participants' privacy and anonymity were respected in the present study. All procedures were conducted following the Declaration of Helsinki. The NutriFunction project was approved by the Ethics Committee of the FCNAUP (reference 71/2022 and addendum to reference 71/2022, respectively). The primary aim of the NutriFunction is to investigate the relationship between handgrip strength (HGS) and undernutrition, sarcopenia, and frailty. This study encompasses both a cross-sectional investigation within a community setting and a multicentre prospective study involving hospitalised individuals with a wide range of pathologies and diagnoses. Although the study does not target patients with specific diseases, the reason for hospitalisation will be considered in the data analysis, ensuring that relevant clinical and contextual factors are appropriately addressed.

Data collection and measurement

In this technical error of measurement study, a Reference Anthropometrist (RA) with extensive experience in all trained measurement procedures, and certified at level 1 by ISAK, was chosen among the project's team. Three registered nutritionists who were research fellows (1, 2, and 3), and two undergraduate students (4 and 5), none of whom certified by ISAK, performed the anthropometric measurements established after a period of theoretical orientation and practical experimentation of the twelve different anthropometric parameters.

The anthropometric measurements performed included weight, measured by a calibrated portable scale (Seca 803, Hamburg, Germany) with a 0.1-kilogram resolution, with the participants wearing light clothes; height, accessed by a calibrated stadiometer (Seca 213, Hamburg, Germany) with a 0.1-centimeter resolution; mid arm, waist, and calf circumferences, measured with a metal tape (Cescorf, Porto Alegre, Rio Grande do Sul, Brazil) with 0.1-centimeter resolution; and triceps and calf skinfold thicknesses and *adductor pollicis* thickness, obtained using a skinfold calliper (Holtain, Tanner/Whitehouse, Pembrokeshire, United Kingdom), with a 0.2-millimeter resolution. Knee height was measured in a supine position, with the knee flexed at 90 degrees, using a segmometer (Cescorf, Porto Alegre, Rio Grande do Sul, Brazil), with 0.1-centimeter resolution. Hand length, hand breadth, and middle-finger length were measured using a calibrated pachymeter (Fervi Equipment SpA, Modena, Italy) with 0.1-centimeter resolution. Weight, height, mid arm, calf, and waist circumferences, triceps and calf skinfold thicknesses, knee height, and hand length followed the procedures recommended by the ISAK[20]. The *adductor pollicis* thickness was measured following the procedure suggested by Lameu *et al.*[21]. Hand breadth followed the method described by ISO 7250-1:2017[22]. At last, the team adapted the procedure described by the second edition of the ISO 7250-1:201 for the index finger length to measure the middle-finger length. This edition describes the index finger length as the "distance from the tip of the second finger to the proximal finger crease on the palm of the hand"[22]. In our work and to measure the middle-finger length, we considered the distance from the tip of the third finger to the proximal finger crease on the palm of the hand. In accordance with ISAK recommendations all parameters were measured on the right side of the body, started with the least invasive anthropometric measurements and followed the anatomical order, prioritising points that are closest to each other[20]. Thus, the order of assessment was: weight, height, mid-arm circumference, hand and middle-finger lengths, hand breadth, *adductor pollicis* thickness, waist and leg circumferences, knee height, triceps and calf skinfolds. For the collection of anthropometric data, a standardised data form was developed in-house based on the ISAK protocol specifically for the NutriFunction project. This form was designed to ensure consistency across evaluators. In total, each volunteer underwent twelve different sets of anthropometric measurements, with each observer performing the measurements twice. When the difference was not as expected, it was measured a third time. To minimise potential influence on results, all measurements were initially taken once, followed by a second reading from both the reference and trainee observers. This approach was carefully chosen to ensure accuracy and consistency while reducing the risk of bias. The RA completed all the anthropometric measurements described before and recorded them on. All anatomical markings were erased, and the volunteers were then measured by the remaining observers. Measurements were recorded on separate forms. Each observer was blind to the other observer's measurements.

These twelve parameters were chosen based on their relevance to the purposes of the NutriFunction project, as well as their frequent use in clinical practice for assessing nutritional status. Given that participants' hand anatomy may influence the obtained HGS values, we considered it prudent to collect anthropometric hand measurements (hand and middle-finger lengths, and hand breadth) to potentially use these values as covariates if necessary. Additionally, as the NutriFunction includes a multicentre prospective study involving hospitalised samples, we collected hand length[23] and knee height[24], which are two critical anthropometric measurements for the indirect estimation of height when conventional height measurement is not feasible, as is frequently the case with hospitalised patients. *Adductor Pollicis* Muscle Thickness (APMT) is a simple, non-invasive, and cost-effective method for assessing muscle mass, that reflects nutritional status, with reduced thickness in undernourished or physically inactive individuals[21]. It can be distinguished from other muscle mass measurements, since is less affected by subcutaneous fat and does not require equations for estimation. APMT is increasingly used as a nutritional indicator in both healthy and sick populations, offering potential for early undernutrition detection and monitoring recovery[21,25]. Almost all the parameters selected for the study correspond to a mix of both the restricted (weight, height, skinfolds, circumferences) and full (hand length) ISAK profile. The remaining anthropometric parameters do not belong to the ISAK protocol.

Coefficient of Reliability calculation

The Coefficient of Reliability (R)[3] is the most widely used coefficient measure of anthropometric precision in population studies, and it has been suggested by Himes[26] that researchers should conduct their reliability studies to establish the necessary levels of R for their specific purposes. This value reveals the proportion of between-subject variance in a measured population free from measurement error. The measure of R can be calculated through the following equation:

$$\mathbf{R = 1 - (TEM^2/SD^2),}$$

where SD^2 is the total inter-subject variance for the study in question. The result value ranges from 0 (unreliable) to 1 (complete reliability). The closer it is to 1, the more accurate the measures are. Measurement values with an $R \geq 0.95$ are generally considered acceptable, meaning that 95% of the variance is due to factors other than measurement error.

Technical error of measurement calculation

Firstly, the absolute TEM was calculated to assess intra and inter-observer variability. This is the most used measure of imprecision and corresponds to the square root of the measurement error variance, according to the following equation:

$$\mathbf{AbsoluteTEM = \sqrt{[(\sum d2)/2N]},}$$

where *d* corresponds to the difference between the two measurements of each subject, and *N* is the total number of subjects evaluated.

Secondly, the absolute TEM was transformed into relative TEM (%TEM) to obtain the error expressed as a percentage and corresponding to the total average of the variable analysed, according to the following equation:

$$\mathbf{\%TEM = (TEM/VAV) \times 100,}$$

where TEM is the technical error of measurement expressed in %, and VAV is the variable average value. This measure is simple to calculate, has no units, and allows direct comparisons of all types of anthropometric measurements.

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Technical error of measurement classification

After calculating the %TEM for intra and inter-observer analysis, the error acceptability ratings for the reference and beginner observers, was classified according to Gore *et al*.[27] **(Table 1)**. The lower the %TEM observed, the better the accuracy of the observer in performing the anthropometric measurements. The standard adopted for the evaluation of the TEM found was the advancers standard – the experienced anthropometrist **(Table 1)**, once the anthropometrists of this study were trainee graduation nutritionists, working as research fellows (1, 2, and 3) and trainee graduation students (4 and 5).

Statistical analysis

The characteristics of the participants are presented for the whole sample as means and standard deviations. To calculate the TEM, %TEM, and R estimates, data were entered and confirmed by three researchers (1, 2, and 3) to reduce entry errors into an Excel spreadsheet (Microsoft Corporation, Redmont, Washington, United States of America), with pre-formulated tables with the TEM, %TEM and R equations.

RESULTS

The error acceptability ratings for the reference and beginner observers was classified according to Gore *et al*.[27] **(Table 1)**.

Table 1. Maximum %TEM values considered acceptable by type of analysis and evaluator experience.

Type of analysis	Beginner anthropometrist	Experienced anthropometrist
Intra-observer %TEM		
Skinfolds	7.5	5.0
Other measurements	1.5	1.0
Inter-observer %TEM		
Skinfolds	10	7.5
Other measurements	2.0	1.5

%TEM: technical error of measurement expressed in %. Adapted from Gore *et al.*[27]

Table 2 describes the physical characteristics of the volunteers, as evaluated by the reference anthropometrist.

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Table 2. Characteristics of the study sample evaluated by the reference anthropometrist.

Anthropometric measurement	Mean	Standard Deviation	Minimum Value	Maximum Value
Weight (kg)	58.7	5.0	59.9	66.5
Height (cm)	165.8	3.7	157.9	168.7
Hand length (cm)	19.1	0.6	18.6	20.1
Hand breadth (cm)	7.3	0.3	6.9	7.8
Middle-finger length (cm)	7.4	0.3	7.0	7.8
Adductor pollicis thickness (mm)	12.7	2.1	8.9	15.5
Mid arm circumference (cm)	26.5	1.3	23.9	27.9
Triceps skinfold (mm)	13.6	3.2	7.8	17.7
Calf circumference (cm)	34.2	1.7	30.9	36.0
Calf skinfold (mm)	12.9	6.0	4.3	19.7
Waist circumference (cm)	71.7	6.6	64.7	84.6
Knee height (cm)	48.9	0.8	47.8	50.0

The intra- and inter-observer reliability for each measurement are presented in Tables 3 and 4. In relation to intra-evaluator relative technical error of measurement results, R values < 95% were observed for hand breadth for anthropometrist #3 (R=0.733), #4 (R=0.921) and for #5 (R=0.944); middle-finger length for anthropometrist #5 (R=0.938) and for adductor pollicis thickness for anthropometrist #2 (R=0.922), #4 (R=0.888) and for #5 (R=0.633). R coefficients ranged from 0.633 to 1.000 (Table 3) for intra-observer reliability; therefore, the highest variation caused by measurement error was 37%, and the lowest was <1%. Regarding the inter-evaluator relative technical error of measurement results, R values < 95% were observed for hand breadth, hand length, middle-finger length, adductor pollicis thickness, and knee height. R coefficients ranged from 0.324 to 1.000 (Table 4), meaning that at the highest, 68% of the variance was caused by measurement error, and at the lowest was <1%.

Table 3. Intra-evaluator relative technical error of anthropometric measurements among five NutriFunction anthropometrists.

	NutriFunction anthropometrists														
	#1			#2			#3			#4			#5		
	TEM	%TEM	R	TEM	%TEM	R	TEM	%TEM	R	TEM	%TEM	R	TEM	%TEM	R
Weight	0.163	0.266	0.999	0.120	0.203	1.000	0.022	0.042	1.000	0.515	0.844	0.997	0.077	0.132	1.000
Height	0.155	0.093	1.000	0.074	0.045	1.000	0.022	0.014	1.000	0.045	0.027	1.000	0.081	0.049	1.000
Hand length	0.111	0.593	0.986	0.039	0.210	0.989	0.050	0.266	0.978	0.081	0.445	0.993	0.112	0.599	0.975
Hand breadth	0.032	0.424	0.991	0.032	0.418	0.976	0.045	0.585	**0.733**	0.089	1.158	**0.921**	0.050	0.657	**0.944**
Middle-finger length	0.050	0.676	0.989	0.055	0.727	0.954	0.032	0.413	0.976	0.032	0.423	0.995	0.105	1.347	**0.938**
Adductor pollicis thickness	0.406	3.401	0.979	0.469	4.504	**0.922**	0.100	0.784	0.997	0.500	3.738	**0.888**	0.457	3.141	**0.633**
Mid arm circumference	0.105	0.393	0.995	0.084	0.304	0.998	0.067	0.266	0.999	0.095	0.349	0.998	0.112	0.422	0.998
Triceps skinfold	0.289	1.735	0.978	0.219	1.607	0.997	0.126	1.004	0.998	0.512	2.856	0.950	0.311	1.740	0.989
Calf circumference	0.045	0.125	0.999	0.059	0.171	1.000	0.000	0.000	1.000	0.022	0.062	1.000	0.071	0.205	0.999
Calf skinfold	0.350	2.039	0.988	0.148	1.119	0.999	0.100	1.183	0.999	0.335	1.783	0.995	0.368	2.126	0.997
Waist circumference	0.163	0.219	1.000	0.277	0.377	0.998	0.050	0.077	0.998	0.266	0.359	0.999	0.247	0.345	0.999
Knee height	0.155	0.308	0.997	0.084	0.168	0.997	0.022	0.045	0.999	0.585	1.157	0.975	0.212	0.436	0.992

TEM: technical error of measurement; %TEM: percentage technical error of measurement; R: coefficient of reliability; Bold stands for unacceptable values.

Table 4. Inter-evaluator relative technical error of anthropometric measurements among five NutriFunction anthropometrists compared to the Reference anthropometrist.

	NutriFunction anthropometrists														
	#1			**#2**			**#3**			**#4**			**#5**		
	TEM	**%TEM**	**R**	**TEM**	**%TEM**	**R**	**TEM**	**%TEM**	**R**	**TEM**	**%TEM**	**R**	**TEM**	**%TEM**	**R**
Weight	0.119	0.195	0.999	0.094	0.161	1.000	0.035	0.066	1.000	0.266	0.431	0.998	0.091	0.154	1.000
Height	0.329	0.199	0.994	0.372	0.225	0.991	0.180	0.112	0.997	0.032	0.019	1.000	0.381	0.228	0.959
Hand length	0.369	1.979	**0.643**	0.467	2.477	**0.481**	0.156	0.817	**0.899**	0.224	1.222	**0.600**	0.284	1.481	**0.827**
Hand breadth	0.074	0.999	**0.896**	0.097	0.297	**0.862**	0.103	0.372	**0.620**	0.149	1.976	**0.604**	0.042	0.549	**0.893**
Middle-finger length	0.027	0.373	0.991	0.080	1.062	**0.899**	0.071	0.937	**0.933**	0.035	0.479	0.951	0.156	1.987	**0.452**
Adductor pollicis thickness	1.253	9.889	**0.784**	1.735	14.485	**0.324**	0.000	0.000	1.000	0.338	2.322	**0.639**	0.705	4.968	**0.606**
Mid arm circumference	0.247	0.915	0.951	0.370	1.382	0.953	0.206	0.804	0.990	0.096	0.344	**0.959**	0.079	0.304	0.998
Triceps skinfold	0.222	1.422	0.982	0.520	4.003	0.978	0.452	3.432	0.961	0.522	3.431	0.985	0.635	4.199	0.956
Calf circumference	0.081	0.231	0.993	0.252	0.741	0.980	0.081	0.250	0.997	0.136	0.400	0.955	0.497	0.205	0.995
Calf skinfold	0.567	3.444	0.952	0.375	3.206	0.996	0.261	2.947	0.994	0.081	0.551	0.998	0.216	1.512	0.999
Waist circumference	0.366	0.498	0.997	0.588	0.821	0.993	0.388	0.594	0.958	0.185	0.243	1.000	0.384	0.531	0.998
Knee height	0.432	0.871	**0.840**	0.697	1.418	**0.703**	0.524	1.079	**0.726**	0.376	0.769	**0.692**	0.390	0.791	**0.824**

TEM: technical error of measurement; %TEM: percentage technical error of measurement; R: coefficient of reliability; Bold stands for unacceptable values.

Tables 5 and **6** show the results of the calculations performed for each one of the twelve anthropometric measurements considered in this study. These tables present the relative TEMs of each anthropometrist and for each measurement of the intra-observer **(Table 5)** and inter-observer **(Table 6)** variability analysis and their respective classification.

The intra-observer variability presented acceptable results in all points analysed, except for hand breadth (#4) (%TEM=1.2), knee height (#4) (%TEM=1.2), and middle-finger length (#5) (%TEM=1.3). Unacceptable inter-observer variability was only observed in the hand length for anthropometrists #1 (%TEM=2.0), #2 (%TEM=2.5) and #5 (%TEM=1.5), in hand breadth for anthropometrist #4 (%TEM=2.0), in *adductor pollicis* thickness for anthropometrist #1 (%TEM=9.9) and #2 (%TEM=14.5), and middle-finger length for #5 (%TEM=2.0). The team assessed whether the unacceptable values would meet the criteria based on the standards for the beginner anthropometrist. The analysis confirmed that the intra-observer variability yielded acceptable results across all points examined.

Regarding the inter-observer variability and considering the standard adopted for the beginner anthropometrist, all the anthropometric measurements presented acceptable %TEM results, except for hand length (%TEM=2.5) and *adductor pollicis* thickness (%TEM=14.5) for the anthropometrist #2.

Table 5. Intra-evaluator relative technical error classification among five NutriFunction anthropometrists and according to advancers standard.

Weight		
Anthropometrist	**%TEM**	**Classification**
1	0.266	Acceptable
2	0.203	Acceptable
3	0.042	Acceptable
4	0.844	Acceptable
5	0.132	Acceptable

Height		
Anthropometrist	**%TEM**	**Classification**
1	0.093	Acceptable
2	0.045	Acceptable
3	0.014	Acceptable
4	0.027	Acceptable
5	0.049	Acceptable

Hand length		
Anthropometrist	**%TEM**	**Classification**
1	0.593	Acceptable
2	0.210	Acceptable
3	0.266	Acceptable
4	0.445	Acceptable
5	0.599	Acceptable

Hand breadth		
Anthropometrist	**%TEM**	**Classification**
1	0.424	Acceptable
2	0.418	Acceptable
3	0.585	Acceptable
4	1.158	**Non-acceptable**
5	0.657	Acceptable

Knee height		
Anthropometrist	**%TEM**	**Classification**
1	0.308	Acceptable
2	0.168	Acceptable
3	0.045	Acceptable
4	1.157	**Non-acceptable**
5	0.436	Acceptable

Mid arm circumference		
Anthropometrist	**%TEM**	**Classification**
1	0.393	Acceptable
2	0.304	Acceptable
3	0.266	Acceptable
4	0.349	Acceptable
5	0.422	Acceptable

Waist circumference		
Anthropometrist	**%TEM**	**Classification**
1	0.219	Acceptable
2	0.377	Acceptable
3	0.077	Acceptable
4	0.359	Acceptable
5	0.345	Acceptable

Calf circumference		
Anthropometrist	**%TEM**	**Classification**
1	0.125	Acceptable
2	0.171	Acceptable
3	0.000	Acceptable
4	0.062	Acceptable
5	0.205	Acceptable

Triceps skinfold		
Anthropometrist	**%TEM**	**Classification**
1	1.735	Acceptable
2	1.607	Acceptable
3	1.004	Acceptable
4	2.856	Acceptable
5	1.740	Acceptable

Adductor pollicis thickness		
Anthropometrist	**%TEM**	**Classification**
1	3.401	Acceptable
2	4.504	Acceptable
3	0.784	Acceptable
4	3.738	Acceptable
5	3.141	Acceptable

Middle-finger length		
Anthropometrist	**%TEM**	**Classification**
1	0.676	Acceptable
2	0.727	Acceptable
3	0.413	Acceptable
4	0.423	Acceptable
5	1.347	**Non-acceptable**

Calf skinfold		
Anthropometrist	**%TEM**	**Classification**
1	2.039	Acceptable
2	1.119	Acceptable
3	1.183	Acceptable
4	1.783	Acceptable
5	2.126	Acceptable

%TEM: percentage technical error of measurement.

Table 6. Inter-evaluator relative technical error classification among five NutriFunction anthropometrists compared to the reference anthropometrist and according to advancers standard.

Weight		
Anthropometrist	**%TEM**	**Classification**
1 and RA	0.195	Acceptable
2 and RA	0.161	Acceptable
3 and RA	0.066	Acceptable
4 and RA	0.431	Acceptable
5 and RA	0.154	Acceptable

Height		
Anthropometrist	**%TEM**	**Classification**
1 and RA	0.199	Acceptable
2 and RA	0.225	Acceptable
3 and RA	0.112	Acceptable
4 and RA	0.019	Acceptable
5 and RA	0.228	Acceptable

Hand length		
Anthropometrist	**%TEM**	**Classification**
1 and RA	1.979	**Non-acceptable**
2 and RA	2.477	**Non-acceptable**
3 and RA	0.817	Acceptable
4 and RA	1.222	Acceptable
5 and RA	1.481	**Non-acceptable**

Hand breadth		
Anthropometrist	**%TEM**	**Classification**
1 and RA	0.999	Acceptable
2 and RA	0.297	Acceptable
3 and RA	0.372	Acceptable
4 and RA	1.976	**Non-acceptable**
5 and RA	0.549	Acceptable

Knee height		
Anthropometrist	**%TEM**	**Classification**
1 and RA	0.871	Acceptable
2 and RA	1.418	Acceptable
3 and RA	1.079	Acceptable
4 and RA	0.769	Acceptable
5 and RA	0.791	Acceptable

Mid arm circumference		
Anthropometrist	**%TEM**	**Classification**
1 and RA	0.915	Acceptable
2 and RA	1.382	Acceptable
3 and RA	0.804	Acceptable
4 and RA	0.344	Acceptable
5 and RA	0.304	Acceptable

Waist circumference		
Anthropometrist	**%TEM**	**Classification**
1 and RA	0.498	Acceptable
2 and RA	0.821	Acceptable
3 and RA	0.594	Acceptable
4 and RA	0.243	Acceptable
5 and RA	0.531	Acceptable

Calf circumference		
Anthropometrist	**%TEM**	**Classification**
1 and RA	0.231	Acceptable
2 and RA	0.741	Acceptable
3 and RA	0.250	Acceptable
4 and RA	0.400	Acceptable
5 and RA	0.205	Acceptable

Triceps skinfold		
Anthropometrist	**%TEM**	**Classification**
1 and RA	1.422	Acceptable
2 and RA	4.003	Acceptable
3 and RA	3.432	Acceptable
4 and RA	3.431	Acceptable
5 and RA	4.199	Acceptable

Adductor pollicis thickness		
Anthropometrist	**%TEM**	**Classification**
1 and RA	9.889	**Non-acceptable**
2 and RA	14.485	**Non-acceptable**
3 and RA	0.000	Acceptable
4 and RA	2.322	Acceptable
5 and RA	4.968	Acceptable

Middle-finger length		
Anthropometrist	**%TEM**	**Classification**

Calf skinfold		
Anthropometrist	**%TEM**	**Classification**

1 and RA	0.373	Acceptable	1 and RA	3.444	Acceptable
2 and RA	1.062	Acceptable	2 and RA	3.206	Acceptable
3 and RA	0.937	Acceptable	3 and RA	2.947	Acceptable
4 and RA	0.479	Acceptable	4 and RA	0.551	Acceptable
5 and RA	1.987	**Non-acceptable**	5 and RA	1.512	Acceptable

%TEM: percentage technical error of measurement; RA: reference anthropometrist.

DISCUSSION

This study reports the intra- and inter-observer measurement error of twelve anthropometric measurements, including weight, height, lengths, circumferences, and skinfold measurements, and for five anthropometrists, using multiple reliability statistics such as TEM and the R-value. Most %TEM values were considered acceptable for advanced anthropometrists' standards, except for hand length, hand breadth, middle-finger length, *adductor pollicis* thickness, and knee height. Thus, the variation verified between measurements performed by these anthropometrists in two different moments suffers no influence or little influence on the systematic error and emphasises the acceptability of using routinely collected anthropometric measurements to evaluate body composition.

Our findings align with those described by Ulijaszek and Kerr[3], who showed that a comparison of studies revealed a clear order in the precision of different anthropometric measures, being the weight and height the most precisely measured. They also refer that waist circumference show strong between-observer differences, recommending to be carried out by one observer, wherever possible[3]. In the present study, the %TEM determined for waist circumference presented acceptable values for experienced anthropometrists, ranged between 0.1 and 0.4%, while for inter-evaluator errors, the %TEM oscillated between 0.2 and 0.8%. Although skinfold measurements are the most susceptible to technical measurement errors[3], in the present study, for intra-evaluator errors, the resulted %TEM for triceps and calf skinfolds ranged between 1.0 and 2.9%, while for inter-evaluator errors, the %TEM ranged between 0.6 and 4.0%. All these values are acceptable for experienced evaluators and were similar to those found by Perini *et al.*[28], where the intra-evaluator %TEM determined oscillated between 3.0 and 5.7, while for inter-evaluator errors, the %TEM ranged between 1.7 and 5.8%.

The intra-observer TEM results classified as non-acceptable for experienced evaluators were found for hand breadth, middle-finger length, and knee height. The fact that these anthropometric measurements are used less frequently in the assessment of nutritional status, compared to weight, height, circumferences, and skinfolds, may have led to these intra-observer TEM differences.

Conversely, in the inter-evaluator analysis, *adductor pollicis* thickness and hand length were the anthropometric measurements most classified with TEM results as non-acceptable. The lack of training due to the fact that *adductor pollicis* thickness was not frequently used by these anthropometrists could have resulted in the skinfold calliper not being applied at the correct anatomical site due to the absence of an anatomical point marking and the participant's position during the measurement. According to Gonzalez *et al*.(29), it is crucial to point out that investigations that recognise discrepant *adductor pollicis* thickness values relative to the references may be based on improper anatomical point clamping, as well as other methodological inadequacies.

Additionally, hand length was the other anthropometric measurement most classified with inter-observer %TEM values as non-acceptable. This measurement is relevant in situations where obtaining an accurate height is not possible(23), such as in participants with visible kyphosis, or when it is impossible to measure standing height due to the participant's paralysis, mobility, or balance limitations. This is important in the NutriFunction study since we will collect data from both community-dwelling living participants and hospitalised patients. The hand length represents the distance between the mid-points of the distal transverse crease of the wrist to the most anterior projection of the skin of the middle finger. Among the known publications that report %TEM for hand anthropometry, we highlight Weinberg *et al*.(30) that showed a very high degree of precision (TEM < 2 mm, %TEM < 1%, and R > 0.95 for hand and middle-finger lengths). In the present study, and considering the reference anthropometrist, we detected unacceptable inter-observer variability in the hand length for anthropometrists #1, #2, and #5, with %TEM values ranging between 0.8 and 2.5%. Weinberg *et al*.(30) state that there is disagreement in the literature regarding the choice of wrist landmarks for hand measurements; therefore, not all studies collecting anthropometric data on the hands use the same landmarks. Although we used a standardised procedure in our study, the evaluators might have incorrectly chosen a different landmark because it was more easily identifiable or easily confused with the correct one. Consecutively, the pachymeter may have been placed at the wrong anatomical point leading to these inter-observer TEM differences.

By periodically calculating the TEM, intra- and inter-evaluator variations can be quantified. In the present study, the attainment of the intra- and inter-evaluator TEM indicated the need for technique improvement for anthropometrists #1, #2, #4, and #5 in the following measurements: hand length, hand breadth, middle-finger length, knee height, and *adductor pollicis* thickness. Since the improvement of the anthropometric measurement technique is directly related to the number of evaluations performed by the anthropometrist(3,31), these evaluators will be encouraged to engage in technical improvement sessions based on detailed standardized measurement protocols and subsequently perform new TEM calculations.

Since that the previously discussed results were categorised according to advanced anthropometrists' standards, the team verified if the unacceptable values would be acceptable, considering the standards adopted for the beginner anthropometrist. Thereby, we confirmed that the intra-observer variability presented acceptable %TEM results in all points analysed. However, regarding the inter-observer variability, unacceptable %TEM results remained for hand length (%TEM=2.5) and *adductor pollicis* thickness (%TEM=14.5) for the anthropometrist #2. Therefore, the anthropometric measurements should not be performed by anthropometrist #2 until further training is completed and a new technical error of measurement´ study is conducted, resulting in acceptable values.

We conducted anthropometric measurements following standardized procedures and reference guidelines. We used identical measurement instruments that were previously calibrated. Furthermore, we employed universal and common error estimation methods, enabling comparison with the results of other studies which strengthen the present study findings. These points highlight the aspects that enhance the reliability and comparability of the data obtained. One of the limitations of this study is the use of a convenience sample, consisting of students, staff, and faculty members. This may limit the generalisability of the findings to other populations. Additionally, the study's inability to stratify the technical error of measurement by sex represents another notable limitation. This was due to the limited number of male participants in our sample (n = 2), which prevented meaningful statistical analysis. We acknowledge that differences in physiognomy and body composition between men and women may influence the TEM, potentially affecting the comparability of certain measurements. This limitation should be considered when interpreting the findings, and future studies should aim to include more balanced samples to enable a more robust analysis by sex. Although this study enables us to evaluate the reliability of human measurements, it does not address potential errors stemming from anthropometric equipment or measurement techniques. While the findings reflect internal validity, caution is advised when generalising externally, as measurements can heavily depend on the operator and the instruments used.

Technical error of measurement was not stratified by body composition since our convenience sample consisted entirely of normoponderal individuals. We acknowledge that different body composition profiles, such as individuals with overweight, and obesity may influence TEM due to anatomical and physiological variations associated with these conditions. TEM is expected to be higher in subjects with higher degree of adiposity and so, it is possible that especially less trained anthropometrists need to train more to successfully conduct anthropometric measurements among individuals with overweight and obesity. Future studies should therefore address this issue by including analyses of TEM stratified by body composition to explore potential variations within broader groups.

At least, comparing the technical measurement error of a level 3 anthropometrist versus several level 1 anthropometrists would be an interesting analysis to understand variations related to training and experience. However, this type of analysis was beyond the scope of the current study and moreover only the reference anthropometrist held a level 1 ISAK certification, and no other certified anthropometrists were available to facilitate such a comparison. This aspect should be considered in future studies.

CONCLUSIONS

In the present study, the accomplishment of the intra and inter-evaluator TEM results allowed us to indicate the necessity of the technique improvement of four anthropometrists in the following anthropometric measurements – hand length, hand breadth, middle-finger length, knee height, and *adductor pollicis* thickness. Hand length and *adductor pollicis* thickness presented unacceptable TEM values for the standard adopted by beginner anthropometrist and should not be performed by anthropometrist #2 until a new technical error of measurement study is conducted and resulting in acceptable values. The method presented was of easy execution and permitted analysing the performance of the NutriFunction team. For improvement purposes, efforts should focus on lowering TEM values. Training and periodic quality control will enable the team to achieve greater accuracy and reliability in their anthropometric measurements.

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COMPETING INTERESTS
The authors state that there are no conflicts of interest when writing the manuscript.

AUTHORS' CONTRIBUTIONS
T.A., N.B, R.G., A.S.S., J.M., A.R.S.S., and R.V. contributed to the creation and design of the study; M.C.R conducted the literature search, performed the analyses, and wrote the original manuscript; M.C.R., M.R., R.V., B.R., M.L. and T.A. participated in the technical error of measurement data collection; and all authors critically reviewed this and previous versions of the paper.

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DATA AVAILABILITY
Data will be provided on request to the corresponding author.

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