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Tables 1 and 2 are available in the supplementary files section

Development and Inter-Rater Reliability of an Evidence-Informed Bioelectrical Impedance Measurement Protocol in Adults

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Abstract

Background/Objectives: Bioelectrical impedance analysis (BIA) is widely used in nutritional and body-composition assessment, but raw measurements are sensitive to participant preparation, posture, electrode placement, environmental conditions, operator technique, and analyzer configuration. We developed an evidence-informed operational protocol and evaluated its inter-rater reliability and measurement error for resistance (R), reactance (Xc), and phase angle (PhA) at 50 kHz.

Subjects/Methods: The study comprised protocol development from a broad, traceable literature review followed by a same-session inter-rater reliability study in 80 adults (53 women; 18-59 years). Two trained evaluators independently applied the protocol using supine tetrapolar and standing measurement configurations. Reliability and agreement were assessed using ICC(A,1), technical error of measurement (TEM), standard error of measurement, minimal detectable change (MDC95), Bland-Altman analysis, and mixed-effects models.

Results: ICC(A,1) ranged from 0.951 (95% CI 0.619-0.984) to 0.991 (95% CI 0.898-0.997), with TEM% <3% for all variables. MDC95 values for R, Xc, and PhA were 24.2 ohm, 4.45 ohm, and 0.237 degrees in the supine configuration and 30.0 ohm, 5.19 ohm, and 0.266 degrees in the standing configuration. Proportional bias was detected for supine Xc (P=0.0031) and standing R (P=0.0005).

Conclusions: Standardized BIA assessment produced high inter-rater reliability and low relative measurement error, although systematic and proportional differences remained. Consistent measurement conditions are required when raw bioelectrical variables are used for repeated nutritional and body-composition assessment.

Introduction

Bioelectrical impedance analysis (BIA) is widely used in nutrition and body-composition research because it is non-invasive, portable, and capable of providing primary electrical variables such as resistance (R) and reactance (X_c), from which phase angle (PhA) is derived [1-3]. Although predictive equations can translate impedance measurements into body-composition estimates, their performance depends on the device, population, and reference method [4]. For repeated nutritional assessment, the quality of the raw measurement is therefore fundamental.

BIA measurements are sensitive to posture, fluid redistribution, electrode type and placement, skin and ambient temperature, recent intake and activity, and characteristics of the measurement system [5,8-14]. Differences between analyzers are also well documented, including for raw R, X_c , and PhA [5,6]. Recent discussion in this journal has emphasized that high reliability does not eliminate systematic bias and that stronger standardization is required before small differences are interpreted as biological change [7]. This is particularly relevant as raw bioelectrical variables and bioelectrical impedance vector analysis (BIVA) are increasingly used to characterize hydration, tissue properties, and nutritional status [15-17].

Existing recommendations address many individual sources of variability, but they are dispersed across guidelines, methodological studies, and technical literature. An operational protocol that integrates participant preparation, measurement setup, environmental control, electrode placement, and instrumental verification may improve reproducibility and clarify the magnitude of residual error. The aim of this study was to develop an evidence-informed protocol for standardized measurement of R, X_c , and PhA

at 50 kHz and to evaluate its inter-rater reliability, absolute agreement, and measurement error in adults.

Subjects and Methods

Study design and protocol development

The study comprised two phases and was conducted in the anthropometry laboratory of the Institución Universitaria Escuela Nacional del Deporte, Cali, Colombia, during the second semester of 2025. In Phase I, an evidence-informed BIA protocol was developed. In Phase II, its inter-rater reliability and measurement error were evaluated in adults. Reporting of the reliability phase followed the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) [18].

For Phase I, PubMed/MEDLINE, Scopus, and Web of Science were searched using controlled and free-text terms related to bioelectrical impedance, standardization, measurement conditions, electrode placement, reliability, agreement, and measurement error. Searches included English, Portuguese, and Spanish publications with no lower date limit and were supplemented by reference-list screening. The initial search identified 380 potentially relevant records. After duplicate removal and title/abstract screening, approximately 180 records were retained; approximately 95 were assessed as eligible at full text, and 25 provided direct methodological support for protocol components. This was a broad, traceable evidence review intended for protocol development rather than a prospectively registered systematic review.

Evidence was synthesized into operational recommendations covering pre-analytical participant control, measurement setup, environmental conditions, electrode placement, instrumental verification, and reporting. The strength of support was appraised using

domains adapted from GRADE [19], with a technical-consensus category for recommendations based mainly on guidelines, metrological principles, or operational criteria. A five-participant pilot identified logistical issues and led to minor workflow and recording adjustments without changing the core protocol. The final 19 components are summarized by domain in Table 1; the complete evidence matrix may be found in supplementary material as Supplementary Table S1.

Participants and evaluators

Eighty adults were recruited by convenience sampling from a university community. The sample included 53 women (66%) and 27 men (34%), with a mean (SD) age of 29.4 (12.0) years and range of 18-59 years. Adults able to remain supine for the required period and providing written informed consent were eligible. Exclusion criteria were pacemakers or other implanted electrical devices for methodological standardization, recent alcohol consumption, edema, diuretic use, or injuries preventing the required posture. The exclusion of implanted devices was procedural rather than an assertion of absolute BIA contraindication [24].

Measurements were performed by two nutritionists with International Society for the Advancement of Kinanthropometry (ISAK) certification (Levels 1 and 2), anthropometric experience, and previous BIA use. Before data collection, both completed eight hours of theoretical-practical training covering participant preparation, electrode placement, operation of both systems, data recording, and supervised practice.

Measurement systems and standardized procedure

The supine configuration used a BIA 101 BIVA PRO analyzer (Akern Srl, Pontassieve, Italy) with disposable BIVATRODE tetrapolar electrodes. The standing configuration

used a seca mBCA 514 (seca GmbH & Co. KG, Hamburg, Germany). R, Xc, and PhA at 50 kHz were obtained from both systems. Device function was verified before each measurement session according to manufacturer procedures. Height, body mass, and waist circumference were measured using a seca 213 stadiometer, seca 874 scale, and Lufkin tape, respectively. Room temperature was controlled at approximately 22 degrees C.

Participants were instructed 24 h before assessment to avoid heavy meals for at least 3 h, intense physical activity for at least 4 h, caffeine and stimulant beverages in the hours before testing, to empty the bladder immediately before measurement, wear light clothing, and avoid body lotions. These controls were selected to minimize known pre-analytical influences [20-23,25,26]. On arrival, adherence was verified, external metal objects and footwear were removed, and body temperature was checked; assessment was postponed at >37.8 degrees C.

Participants rested supine for 10 min on a non-conductive surface with limbs separated from the trunk. For the supine measurement, contact sites were cleaned with 70% alcohol and electrodes were placed on the right hand and foot using a standardized hand-to-foot tetrapolar arrangement with at least 5 cm separation between electrodes. R, Xc, and PhA were recorded, after which the electrodes were removed and the standing measurement was completed. Evaluator 1 always completed the supine then standing sequence first. Evaluator 2 then repeated the complete procedure, including a new 10-min supine rest and electrode placement, in the same configuration order and while blinded to Evaluator 1 readings. Each participant therefore contributed 12 raw values (three variables x two configurations x two evaluators).

Statistical analysis

Analyses were conducted in RStudio version 2026.01.1+403. Inter-rater reliability was assessed separately within each configuration using a two-way absolute-agreement single-measure intraclass correlation coefficient, ICC(A,1), with 95% confidence intervals. Absolute measurement error was characterized using technical error of measurement (TEM), relative TEM (TEM%), standard error of measurement (SEM), and minimal detectable change at 95% confidence (MDC95). Agreement was evaluated using Bland-Altman analysis, with differences defined as Evaluator 1 minus Evaluator 2; mean bias and 95% limits of agreement (LoA) were calculated as bias $\pm$ 1.96 SD of the paired differences. Proportional bias was examined using Pearson correlation and linear regression of paired differences on paired means.

Separate linear mixed-effects models for R, Xc, and PhA included measurement configuration and evaluator as fixed effects and participant ID as a random intercept. Variance components and participant-level ICCs were extracted, and Q-Q plots were used to inspect residual distributions. Statistical significance for correlation analyses was set at $P < 0.05$. The de-identified dataset, data dictionary, and analysis code are available in Zenodo.

Ethics and use of generative AI

The institutional ethics committee of the Institución Universitaria Escuela Nacional del Deporte approved the study (record 320.02-07-2025). Procedures complied with the Declaration of Helsinki and Colombian Resolution 8430 of 1993. All participants provided written informed consent.

During manuscript preparation, ChatGPT (OpenAI) was used to assist with English-language editing and adaptation to journal structure. All scientific content, data, analyses, and interpretations were reviewed and verified by the authors, who take full responsibility for the manuscript. Generative AI was not used to generate, modify, or analyze study data.

Results

Protocol development and participant measurements

The evidence synthesis produced a 19-component operational protocol organized into three domains: participant pre-analytical control, measurement setup and execution, and instrumental/reporting control (Table 1). the complete evidence matrix may be found in supplementary material as Supplementary Table S1.

All 80 participants completed measurements by both evaluators in both configurations, yielding 320 evaluator-by-configuration assessments. Across all observations, R ranged from 405.3 to 968.3 ohm, Xc from 44.7 to 92.5 ohm, and PhA from 4.2 to 8.3 degrees. Mean (SD) values were 593.1 (91.4) ohm, 64.7 (8.1) ohm, and 6.19 (0.67) degrees in the supine configuration, and 661.4 (103.7) ohm, 66.3 (8.5) ohm, and 5.80 (0.72) degrees in the standing configuration.

Inter-rater reliability, agreement, and measurement error

Inter-rater reliability was high for all raw variables (Table 2). ICC(A,1) ranged from 0.951 (95% CI 0.619-0.984) for standing Xc to 0.991 (95% CI 0.898-0.997) for supine R. TEM% was <3% for every variable and configuration. MDC95 values for R, Xc, and PhA were 24.2 ohm, 4.45 ohm, and 0.237 degrees, respectively, in the supine configuration and 30.0 ohm, 5.19 ohm, and 0.266 degrees in the standing configuration.

Using Evaluator 1 minus Evaluator 2 as the difference, mean biases were -9.25 ohm, -1.66 ohm, and -0.045 degrees for supine R, Xc, and PhA, and -12.48 ohm, -1.97 ohm, and -0.050 degrees for the corresponding standing measurements. Proportional bias was detected for supine Xc ($P=0.0031$) and standing R ($P=0.0005$), but not for the other variables ($P=0.0544-0.8323$). Bland-Altman plots are shown in Figure 1.

In mixed-effects models, the standing versus supine configuration contrast was +68.28 ohm for R, +1.66 ohm for Xc, and -0.39 degrees for PhA. Evaluator 2 versus Evaluator 1 contrasts were +10.86 ohm, +1.81 ohm, and +0.048 degrees, respectively. Participant-level ICCs after accounting for configuration and evaluator were 0.985 for R, 0.957 for Xc, and 0.968 for PhA; full model estimates and variance components are provided as Supplementary Table S2.

Discussion

The present study integrated dispersed methodological evidence into a 19-component BIA measurement protocol and then quantified residual inter-rater variability under controlled conditions. Relative reliability was high for R, Xc, and PhA in both tested configurations, but Bland-Altman analyses identified systematic and proportional differences for selected outcomes. The principal implication is that high ICCs should not be interpreted as absence of measurement error or as evidence of interchangeability. This distinction is consistent with recent emphasis on systematic bias and standardization in BIA research [7].

The protocol addresses three linked sources of uncertainty. First, participant preparation and environmental control reduce transient physiological influences on impedance. Postural fluid redistribution, skin and ambient temperature, intake, and electrode-skin

conditions can alter raw measurements [8-14]. Second, anatomical precision and electrode characteristics are especially relevant for Xc and PhA [9,27]. Third, metrological verification and transparent reporting are necessary because analyzers, cables, electrodes, frequency, posture, and system geometry contribute to observed values [14,28,30,31]. The objective is therefore not to create a device-independent value, but to make measurement conditions explicit and reproducible.

The error metrics complement the ICC. TEM% remained below 3%, yet MDC95 ranged from 24.2 to 30.0 ohm for R, 4.45 to 5.19 ohm for Xc, and 0.237 to 0.266 degrees for PhA. These values indicate the magnitude of within-session change required to exceed expected measurement error under the tested conditions; they do not establish clinical or physiological importance. A similar distinction between precision and meaningful change is increasingly emphasized when repeated BIA is used for monitoring [29]. For longitudinal nutritional assessment, measurements should therefore use the same analyzer, posture, configuration, preparation conditions and, where feasible, evaluator. Differences between the supine and standing measurements should be interpreted as configuration contrasts rather than isolated device effects. Device, posture, electrode geometry, and measurement order were linked in the study procedure and cannot be separated statistically. Previous studies likewise show that raw BIA values and PhA depend on analyzer configuration and posture [5,6,27,28]. The fixed evaluator order creates a related limitation: the small Evaluator 1-Evaluator 2 differences cannot be attributed exclusively to operator effects because time and sequential fluid redistribution may also have contributed.

Other limitations should constrain generalization. The study involved two trained evaluators at one center, used convenience sampling from a university community, and was predominantly female. It evaluated same-session inter-rater reliability, not between-day test-retest reliability or intra-rater repeatability. The 19 protocol components were implemented as a bundle; the study does not estimate the independent contribution of each component. No criterion method was used, so the results address reliability and agreement of raw bioelectrical variables rather than criterion validity of body-composition estimates. Finally, the results should not be extrapolated directly to clinical populations, athletes, or other analyzer configurations without external validation. In conclusion, an evidence-informed standardized procedure yielded high inter-rater reliability and low relative measurement error for R, Xc, and PhA within both evaluated BIA configurations, while systematic differences remained detectable. Consistent participant preparation, measurement setup, analyzer configuration, and operator procedures are therefore essential when raw bioelectrical variables are used in nutritional and body-composition research. Multicenter and longitudinal studies are needed to establish external reproducibility and change-detection performance.

Data Availability Statement

The anonymized dataset supporting the findings of this study, together with the data dictionary and analysis code, is openly available in Zenodo at <https://doi.org/10.5281/zenodo.22287242>.

Conflict of Interests Statement

The authors of this study declare no conflict of interest.

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None.

Author Contributions

Conceptualization, M.S.; methodology, M.S., D.G. and J.P.S.; formal analysis, D.G.; investigation, M.S. and B.B.-A.; data curation, D.G.; writing-original draft preparation, M.S., B.B.-A. and E.R.-Q.; writing-review and editing, D.G., E.R.-Q., F.E. and B.B.-A.; supervision, F.E. All authors have read and approved the manuscript.

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Ethical Approval

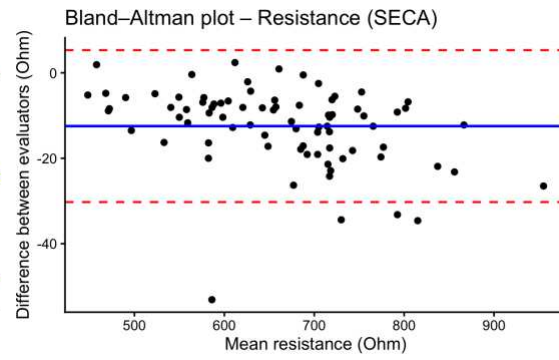
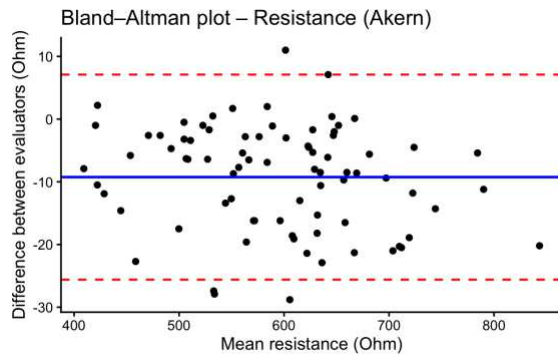
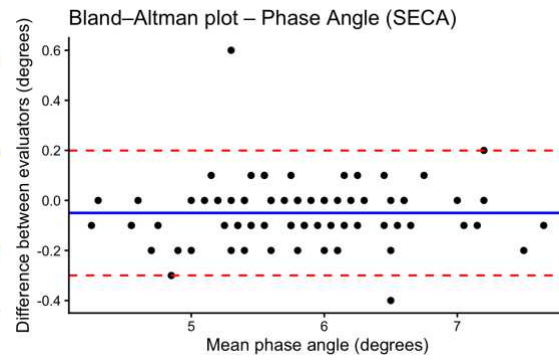
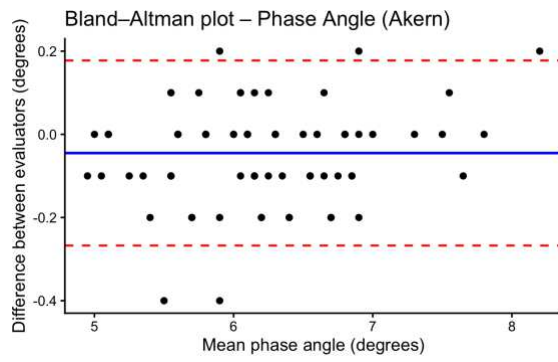
The study was conducted in accordance with the Declaration of Helsinki and was approved by the institutional ethics committee of the Institución Universitaria Escuela Nacional del Deporte (approval record 320.02-07-2025). All participants provided written informed consent.

Competing Interests

The authors declare no competing interests.

374 **Figure Legends**

375 Figure 1. Bland-Altman plots of inter-rater agreement for resistance (R), reactance (Xc),
376 and phase angle (PhA) at 50 kHz in the supine and standing bioelectrical impedance
377 measurement configurations. Differences are defined as Evaluator 1 minus Evaluator 2.
378 The solid line indicates mean bias and dashed lines indicate the 95% limits of agreement.



Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Table1.Operationaldomainsoftheevidenceinformedbioelectricalimpedancemeasurementprotocol.pdf](#)
- [SupplementaryTableS1.pdf](#)
- [Table2.Interraterreliabilitymeasurementerrorandagreementbymeasurementconfiguration.pdf](#)
- [TableS2.pdf](#)