RESEARCH ARTICLE

Prediction and discrimination of skeletal muscle function by bioelectrical impedance vector analysis using a standing impedance analyzer in healthy Taiwanese adults

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Abstract

Background: Bioelectrical impedance vector analysis (BIVA) has been used for prediction of muscle performance. However, little is known about BIVA in Asian adults, and even less is known about using standing BIVA devices. Standing impedance analyzer allows quicker and more convenient way to gather data than conventional supine analyzer and is more suitable for clinical practice. This study aimed to investigate the relations between muscle function and BIVA parameters measured with a standing impedance analyzer in healthy Taiwanese adults.

Methods: A total of 406 healthy subjects (age 34.5 ± 17.3 years, body mass index 24.1 ± 4.1 kg/m^2) were recruited for BIVA and handgrip strength (HGS) measurements. Impedance parameters, including resistance (R) and reactance (Xc), were measured and normalized to body size by dividing by height (H). The resulting phase angle (PhA) was calculated. HGS in the dominant, left, and right hands were referred to as HGS_{DH}, HGS_{LH}, and HGS_{RH}, respectively. All subjects were divided into 5 grades according to HGS.

Results: Muscle strength in the dominant, right, and left arms was correlated with variables

in the order of sex, weight, age, height, Xc/H, and R/H (all, $p < 0.001$). Using all 6 variables, the determination coefficients were 0.792, 0.782, and 0.745, respectively, whereas the standard errors of estimates were 56.89, 58.01, and 56.67 N for HGS_{DH}, HGS_{LH}, and HGS_{RH}, respectively. HGS was positively correlated with PhA, and negatively correlated with Xc/H and R/H.

Conclusions: BIVA parameters measured with a standing impedance analyzer and anthropometric variables can predict and discriminate muscle function with good performance in healthy Asian adults.

Introduction

Skeletal muscle is the largest organ in human body, and controls physical activity through the generation of force. The health of skeletal muscle is determined by its mass and function, and is regulated by skeletal muscle protein synthesis and breakdown [1]. Imbalance of the dynamic process of skeletal muscle protein metabolism in response to pathologic conditions and chronic disease may affect muscle mass and function [2] Muscle mass can be indirectly measured by dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA). Muscle function can be expressed in terms of muscle power, muscle strength, and local muscle endurance [3]. Methods for muscle function evaluation include manual muscle testing, electrophysiological studies, and a handheld dynamometer. Handgrip strength (HGS) measurement using a dynamometer is a relatively inexpensive, portable, and simple method which provides information about overall muscle function [4].

The sex- and age-specific reference curves for HGS are well-established for healthy children and adults [5-7]. These reference curves provide normative values for physical fitness in general populations. Deviation of HGS values from the reference values may indicate disease [8] or the aging process [9, 10]. In general population, a lower HSG is associated with higher risk of mortality and morbidity [11, 12]. A study that included 139,691 subjects (age 35-70 years, median follow-up 4.0 years) from 17 countries showed that a lower HGS was associated with a higher risk for all-cause mortality (hazard ratio [HR] = 1.16, 95%

confidence interval [CI]: 1.13-1.20) and cardiovascular mortality (HR = 1.17, 95% CI: 1.11-1.24) [12] . The UK Biobank Study investigated associations between grip strength and disease incidence and mortality in 502,628 subjects (age 40-69 years, median follow-up 7.1 years) [11]. The study found that a lower HGS was significantly associated with both all-cause mortality (HR per 5 kg lower grip strength = 1.20, 95% CI: 1.17-1.23 in women and 1.16, 1.15-1.17 in men) and cardiovascular mortality (HR per 5 kg lower grip strength = 1.19, 95% CI: 1.13-1.25 in women and 1.22, 1.18-1.26 in men).

Malnutrition is defined as a state resulting from lack of uptake or intake of nutrients. According to global consensus statements [13, 14], HGS is one of the recommended tools for assessing nutritional state [13]. Studies have shown that lower HGS is associated with a longer length of hospital stay [15, 16] and higher mortality rate in critically ill patients [17]. HSG has also been used to monitor the outcome of nutritional intervention [18, 19]. Since muscle function may be altered prior to a change in muscular volume during disease progress or intervention, HSG is a more sensitive indicator to changes in nutritional status compared to body composition analysis [20, 21].

Bioelectrical impedance analysis (BIA) can be used to measure tissue electrical properties such as resistance (R) and reactance (Xc) using alternating current. Body fluids are highly conductive, and the resistance of the conductive fluids is defined as R [22]. Xc is the opposition to current flow due to the capacitive nature of cell membranes. Human cells are

surrounded by phospholipid bilayers and act as an electrical insulator and capacitor. Therefore, Xc reflects the integrity of cell membranes, which is correlated with body cell mass [23, 24]. Phase angle (PhA) reflects the relationship of R and Xc, and is calculated as PhA = arctan(Xc/R) [25]. Impedance (Z) is a function of 2 impedance components, R and Xc, and is calculated as $Z^2 = R^2 + Xc^2$ [23]. If the 2 height-normalized impedance components (R/H and Xc/H) are plotted as a bivariate vector in the RXc graph, the length of the vector (Mahalanobis distance) is related to hydration status [24]. Bioelectrical impedance vector analysis (BIVA) is a validated tool for assessing hydration and nutritional status [26]. BIVA has also been validated as a predictor for sports performance [27, 28] and muscular fitness [29].

Currently, BIVA measurements are typically made with subjects in a supine position, and data are acquired at the whole body level. Few studies have examined acquiring BIVA data with subjects standing. Moreover, there is very little published data on muscle function in healthy Asian adults. Consequently, the objective of this study was to investigate the relations between HGS and BIVA in healthy Taiwanese adults using a modified standing impedance analyzer with whole body and segmental modes.

Materials and methods

This cross-sectional study was approved by the Institutional Review Board of the Jen-Ai

Hospital (No. IRB-97-01). Written informed consent was obtained from all subjects. All experiments were conducted at the Jen-Ai Hospital in the Taichung, Taiwan between January 2016 and May 2017.

Subjects

Subjects were recruited by community advertisements. Inclusion criteria were healthy Taiwanese adults 18 to 80 years of age. Exclusion criteria were individuals with a pacemaker, metal implants, limb deformities, upper limb neuropathies or arthropathies, those taking medications for chronic conditions and taking vitamin supplements long-term, and those with a history of alcohol abuse and systemic diseases, e.g., malignancy, diabetes, hypertension, hypo- or hyperthyroidism, cardiovascular disease. A total of 406 subjects who met the inclusion criteria and completed each measure were included in the final analysis.

Study design

All subjects were asked to refrain from alcoholic beverages for at least 48 hours and avoid diuretics for 7 days prior to study. Female subjects were not scheduled during menstruation. On the test day, subjects were registered between 1 pm and 5 pm after fasting for 4 hours and were instructed to void, remove all objects which may affect the exam, and change into a light cotton gown prior to measurements.

Anthropometric measurements

Height was measured to the nearest 0.1 cm using a mechanical device (Stadiometer, Holtain, Crosswell, Wales, UK), and weight was measured to the nearest 0.1 kg using an electronic scale (BC-418MA, Tanita Corporation, Tokyo, Japan) by skilled operators with subjects not wearing shoes. Technical errors for height and weight measurements were 0.021% and 0.520%, respectively. Body mass index (BMI) was calculated as weight (kg) divided by height squared (kg/m^2).

Body composition measurements

Body composition measurements were acquired using a DXA scanner (GE, Lunar Prodigy, USA) by experienced radiology technicians. For the examination, subjects were placed supine on the scanning table with the upper limbs stretched and placed flatly on the side of the body, with the feet slightly parallel and the toes facing upwards. The total scan time was approximately 20 min. Regional cut lines were placed using enCore Version 7.0 software according to the manufacturer's protocol. The lean body mass and body fat percentage of the whole body, right arm, and left arm were obtained.

Handgrip strength

A digital handgrip dynamometer (MG4800, Charder Electronical Co., Ltd., Taichung, Taiwan) was used measure HGS, after subjects were given verbal instructions and a brief demonstration. Subjects were instructed to stand upright with their shoulder adducted and neutrally rotated, elbow fully extended, and forearm and wrist neutrally positioned during the study. When correctly positioned, 3-5 second maximum grip strengths were obtained twice for each hand. No verbal encouragement was given during the test. The average values of the 2 trials in the dominant hand, right hand, and left hand were calculated, and represented as HGS_{DH}, HGS_{RA}, and HGS_{LA}, respectively.

To ensure the accuracy of the test, all testers were trained in the test procedures and calibration procedures, and instrument calibration data were recorded to ensure reproducibility of the test. All testers practiced the testing procedure in a subgroup of 35 subjects (age 35.2 ± 12.3 years, body weight 68.3 ± 10.2 kg, height 1.65 ± 0.1 m, BMI 23.9 ± 3.3 kg/m^2) prior to the study assessments. The test-retest reliability intra-class correlation coefficient (ICC) for HGS was r = 0.98 (95% CI: 0.93, 0.99). For criterion-related validity, the MG4800 dynamometer was validated against the standard Jamar dynamometer (J. A. Preston Corporation, Clifton, NJ). The results produced by the 2 devices were highly correlated (r = 0.954 by ICC), and strongly in agreement (bias = 12.0 N, limit of agreement = -58.5 to 85.5 N by Bland-Altman Plot).

Impedance measurements

BIA measurements were carried out with the subject standing on a modified Quadscan 4000 (Bodystat Ltd, Doubles, Isle of Man, UK) with circuit switching switches and measuring lines [30]. The device was calibrated at the beginning of each day using a 500 ohm test resistor provided by the manufacturer, with R and Xc variations within 1% (R = 500 ± 5 ohm, Xc = 0 ± 5 ohm).The reliability and validity of the measuring device have been previously verified [30, 31].

The R, Xc, Z, and PhA for each subject were measured at a single frequency (50 kHz) with 3 modes: whole body (WB), right arm (RA), and the left arm (LA) modes (Figure 1). The method of BIVA used was developed by Professor Antonio Piccoli in 1994 [24]. R and Xc were normalized to height (H), and expressed as R/H and Xc/H, respectively [24]. Then, R/H and Xc/H were used to plot a bivariate RXc graph. The 95% CIs, which represent the mean vector distribution, were calculated for the HGS measurements in the different groups. PhA was defined as arctan(Xc/R).

Statistical analysis

All statistical analyses were performed using SPSS version 19.0 software (SPSS Inc., Chicago, IL, USA). Data were expressed as mean ± standard deviation (SD). The ICC was used to evaluate test-retest reliability. Repeated-measures ANOVA was used to test

differences among group means between men and women. Pearson correlation (r) was used to assess the correlation between 2 variables. Stepwise regression analysis was used to fit possible regression models of muscle strength using sex, body weight, age, height, Xc/H, and R/H as independent variables (F_{in} = 4.00, F_{out} = 3.99). Vector plots and analyses were performed using BIVA Software 2002 [32]. Mean vector lengths of groups were tested using the Hotelling's T-squared test in the BIVA Software 2002. A value of $p < 0.05$ was considered to indicate statistical significance.

Results

The demographic characteristics of the 406 subjects included in the study are presented in Table 1. Impedance parameters, with and without adjustment for height, are shown for the whole body and segmental levels. Mean age of the subjects was 34.5±17.3 years, and mean BMI was 24.1±4.1 kg/m^2. Of the 406 subjects, 235 (58%) were men. Anthropometric indices, HSG, and impedance parameters were significantly greater for men compared to women, except for age and BMI. The majority of subjects were right-handed (94.3%). The mean HGS of the dominant hand was 366.8 ± 108.0 N for men and 251.0 ± 58.5 N for women. The correlation coefficients between muscle mass and function in the dominant hand, right arm, and left arm were 0.866, 0.810, and 0.823, respectively (all, $p < 0.001$).

Possible associations between BIVA variables PhA, R/H, and Xc/H obtained using

whole body and segmental modes were examined (Table 2). All BIVA variables obtained from whole body and segmental modes were very strongly correlated in both sexes (r = 0.910-0.985), except for PhA in males (r = 0.852-0.897). The best association was found with R/H (r = 0.943-0.985). In general, the correlations between whole body and right arm modes were better than the correlations between whole body and left arm modes for all the BIVA variables.

The results of the multiple regression analyses for HGS using basic indices and height-adjusted BIVA variables (R/H and Xc/H) as predictors are shown in Table 3. The variables were included in the stepwise regression analysis in the following order: sex, weight, age, height, Xc/H, and R/H. Model 1 was the regression model to predict HGS_{DH} from basic indices and whole body mode BIVA parameters. Model 2 was the regression model to predict HGS_{RH} based on basic indices and right hand mode BIVA parameters. Model 3 was the regression model to predict HGS_{LH} from basic indices and left hand mode BIVA parameters. The variance inflation factor (VIF) values were all < 10 (range 1.25-8.26), indicating no multicollinearity. The correlation coefficients between HGS and Xc/H in the whole body, right arm, and left arm modes were 0.663, 0.690, and 0.651, respectively. The correlation coefficients between muscle strength and R/H in whole body, right arm, and left arm modes were 0.773, 0.775 and 0.747, respectively. In general, Xc/H was a better predictor for muscle strsu3ength than R/H in all 3 modes.

The subjects were divided into 5 equal groups depending on their HGS level: group I (the highest 20%), and group II, III, IV, and V, with group V representing the lowest 20%. Graphical comparisons of impedance vectors and confidence ellipses are shown in Figure 2: HGS_{DH} using whole body mode (Figure 2a); HGS_{RH} using right arm impedance measuring mode (Figure 2b); HGS_{LH} using left arm mode (Figure 2c). A significant displacement of the vector was observed between groups with increasing HGS in all 3 models ($p = 0.0001$-0.0112 in the whole body model, $p = 0.0001$-0.002 in the right arm model, $p = 0.0001$-0.0245 in the left arm model). With increasing level of HGS, a decreasing PhA was also noted in all 3 models (Figure 2).

Discussion

The results of this study showed that HGS can be predicted by BIVA parameters of the same limb, and the whole body using a modified standing impedance analyzer. Standing BIA analyzers have attracted a growing interest due to their convenience; however, there are concerns about impedance variability due to fluid shift toward the leg during the day [33, 34]. Our study provides evidence that standing BIVA can be used to predict and discriminate muscle function in healthy adults. BIVA references for the healthy Asian adult population are limited because most BIVA studies have been conducted with Caucasian subjects [24, 27, 35-39]. The current study fills this knowledge gap by providing references ranges for the Asian

population.

Compared to body composition analysis, vector analysis uses height-adjusted raw impedance components (R/H and Xc/H), and involves fewer assumptions and is free of regression equations [28]. Therefore, vector analysis should exhibit less error than body composition analysis using an impedance analyzer, making it a more valuable tool.

Volume-adjusted R and Xc have also been used to construct specific BIVA plots (specific BIVA) [39, 40]. Whole body mode BIVA, with electrodes placed on the ipsilateral arm and foot is the most common BIVA method. Whole body BIVA is well-known to correlate with many diseases, such as renal diseases, critically ill patients, obesity, sarcopenia, and cachexia [36, 37, 41-43]. Segmental vector analysis is a less common BIVA mode; in which upper limb impedance components are acquired using 2 pairs of electrodes attached to the ipsilateral hand and shoulder, which are then divided by the length of the measured extremity [43, 44]. Alternatively, segmental BIVA components may be measured with electrodes placed on the ipsilateral arm and foot, and voltage electrodes on both hands, as done in our study. With this method, the measured values of Xc and R are divided by standing height, which assumes a fixed proportion of limb length to body height.

Maximum handgrip force is mainly determined by the muscle function of the upper limb; therefore, HSG should be associated with BIVA of the ipsilateral limb rather than BIVA of the contralateral limb or the whole body BIVA. Interestingly, whole body Xc/H and

R/H showed similar performance in predicting HGS compared to segmental Xc/H and R/H of the same limb. This may due to the very strong correlation between whole body and segmental Xc/H and R/H in our healthy subjects. However, our results may not be applicable to individuals with diseases, or the general, non-Asian population. Further research is required to explore the used direct measurement of segmental BIVA for the evaluation of regional muscle function.

In this study, a significant migration of the mean vectors with increasing HGS was observed due to decreased Xc/H and R/H in the healthy adults in this study. A similar finding was reported in a study of healthy young adults by Rodriguez-Rodriguez et al [29]. A study of in inpatient subjects showed a different trend for the vector shift; the average vector displaced with increasing HSG due to decreased R/H, but increased Xc/H [25]. Interestingly, our study showed an increase in PhA with increasing HSG in healthy adults using whole body, right limb, and left limb modes, which is consistent with previous studies of healthy young adult [29] and inpatient subjects [25]. Moreover, PhA has been validated as a good predictor of nutritional and functional status [45-47].

In this study, we developed a regression model for HGS using basic indices and BIVA components (Xc/H and R/H). Compared to the regression model for HGS developed using inpatient subjects by Norman et al.[25], the independent variables included in our regression analysis for muscle function were the same, but our models exhibited better

goodness-of-fit (r^2 = 0.745-792) than theirs (r^2 = 0.708). Additionally, the exact order the variables were entered into the equation were different in the 2 studies. In the Norman et al. study, the order was height, age, sex, weight, Xc/H, and R/H; whereas, in our study the order was sex, weight, age, height, Xc/H, and R/H. Although adjusted BIVA components were entered into the models later than the anthropometric indices, correlations between HGS with Xc/H and with R/H were moderate to strong in both studies.

There are limitations of this study that should be considered. First, our study was conducted with healthy Asian adults, and thus the results may not be applicable to different populations or individuals with diseases. Second, migration of the tolerate ellipses in the RXc plots were correlated with group-level differences, and the BIVA method may not be sensitive enough to evaluate vector shifts at the individual level. Third, the segmental BIVA in this study was not measured with electrodes placed on the upper limbs. However, this modified method is more convenient, and yielded good results. Fourth, HGS measured by hand dynamometer may be affected by instrument-, operator- and subject-related errors.

Conclusions

Our study showed that BIVA parameters measured by a standing impedance analyzer and anthropometric variables can predict muscle function as measured by HGS with good performance in healthy Asian adults. Our results may facilitate clinical applications of

standing BIVA technology in assessing skeletal muscle function.

Competing Interests: Two of the authors (KCH) and (MCH) are employed by Charder Electronic Co, Ltd. This company did not provide KCH and MCH financial support in executing this study. Nor did the company have any additional role in the research funding, study design, data collection and analysis, decision to publish, or preparation of the manuscript. There are no patents, products in development nor marketed products to be declared. The other authors declare no conflict of interest.

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Author contributions

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Funding acquisition: YYC CLL.

Investigation: LWL LPC.

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Supervision: KCH.

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Visualization: LWL LPC KCH.

Writing – original draft: LWL KCH.

Writing – review & editing: LWL HKL YYC CLL KCH.

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Figure legends

Figure 1. Resistance and reactance measurement modes for the respective body segments. (a) Whole body model; (b) Right arm model; (c) Left arm model.

Figure 2. Significant average vector displacement of the handgrip strength (HGS) quintile groups**.** (a) Habitual HGS and whole body impedance measurement mode. (b) Right hand HGS and right upper limb impedance measurement mode. (c) Left hand HGS and left upper limb impedance measurement mode.

Inserted table: HGS: hand grip strength presented as mean ± standard deviation, n (male / female) in the hand grip strength quintile groups: I (the highest quintile), II, III, IV, V (the

lowest quintile) D = Mahalanobis distance between 2 groups defined by the 2 correlated variables. T^2 = Hotelling's T-squared test.

Table 1. Subject demographic and body composition characteristics

	Total (N = 406)	Female (n = 171)	Male (n = 235)
Age (year)	34.5±17.3 (18.7, 79.0)	36.9±18.7 (18.8, 79.8)	32.8±15.4 (18.7, 79.8)
H (m)	1.68±0.10 (1.45, 1.97)	1.61±0.06 (1.46, 1.74)	1.74±0.08 (152, 197)**
Weight (kg)	67.9±14.1 (42.0, 120.0)	60.8±11.9 (42.0, 106.0)	75.3±12.2 (45.0, 120.0) **
BMI (kg/m^2)	24.1±4.1 (16.2, 39.9)	23.5±4.6 (16.2, 38.0)	24.6±3.6 (16.3, 39.9)
HGS_{DH} (N)	366.8±108.0 (86.3, 601.7)	251.0±58.5 (127.5, 402.5)	482.7±82.8 (188.7, 721.0) **
HGS_{RH} (N)	363.5±108.2 (86.3, 601.7)	249.5±58.5 (127.5, 388.2)	482.7±82.8 (188.7, 721.0) **
HGS_{LH} (N)	337.8±99.1 (78.2, 552.3)	231.4±59.3 (112.2, 402.5)	437.7±77.7 (178.9, 638.6) **
Z_{WB} (ohm)	559.6±99.4 (376.7, 908.6)	650.0±96.0 (476.7, 908.6)	514.0±63.7 (376.7, 671.7) **
Z_{RA} (ohm)	312.5±68.0 (203.5, 509.4)	379.4±61.8 (263.6, 509.4)	278.8±40.9 (203.5, 389.9) **
Z_{LA} (ohm)	319.4±70.7 (194.9, 522.3)	386.8±64.7 (268.2, 522.2)	285.5±44.6 (194.9, 423.7) **
R_{WB}	556.5±99.4 (374.6, 905.8)	647.8±96.0 (474.2, 905.8)	510.7±63.4 (374.6, 668.1) **
R_{RA}	311.0±68.1 (202.5, 508.0)	378.1±61.8 (262.5, 508.0)	277.3±40.7 (202.5, 388.4) **
R_{LA}	318.0±70.7 (193.9, 520.9)	385.5±64.8 (267.1, 520.9)	284.0±44.5 (193.9, 422.2) **
Xc_{WB}	58.1±7.7 (40.1, 79.6)	58.4±7.2 (44.9, 79.6)	57.9±8.0 (40.1, 78.9) **
Xc_{RA}	30.1±4.3 (19.9, 40.2)	31.7±3.9 (23.4, 40.0)	29.3±4.3 (19.9, 40.2) **
Xc_{LA}	29.9±4.2 (19.4, 41.2)	31.0±3.9 (23.0, 40.3)	29.3±4.2 (19.4, 41.2) **
R_{WB}/H (ohm/m)	332.1±68.2 (214.6, 595.9)	401.9±62.9 (283.3, 595.9)	297.1±36.7 (214.6, 370.7) **
R_{RA}/H (ohm/m)	185.8±45.8 (116.1, 334.2)	236.4±39.9 (158.1, 334.2)	161.3±23.6 (116.1, 218.2) **
R_{LA}/H (ohm/m)	189.9±47.2 (111.1, 342.7)	239.1±41.6 (160.9, 342.7)	165.2±25.6 (111.1, 237.2) **
Xc_{WB}/H (ohm/m)	34.6±5.0 (22.5, 48.2)	36.3±4.9 (26.4, 48.2)	33.7±4.8 (22.5, 46.5) **
Xc_{RA} /H (ohm/m)	18.0±2.9 (11.1, 25.1)	19.7±2.7 (13.8, 25.1)	17.1±2.6 (11.1, 24.5) **
Xc_{LA} /H(ohm/m)	17.8±2.8 (11.1, 25.1)	19.2±2.7 (14.1, 24.4)	17.0±2.5 (11.1, 25.1) **
PhA_{WB} (°)	6.0±0.8 (3.5, 7.2)	5.2±0.6 (3.9, 6.4)	6.2±0.5 (4.9, 7.2) **
PhA_{RA} (°)	5.5±0.9 (4.1, 8.6)	4.8±0.6 (3.5, 6.1)	6.0±0.7 (4.5, 8.2) **
PhA_{LA} (°)	5.4±0.9 (3.8, 8.2)	4.6±0.7 (3.5, 6.1)	5.9±0.7 (4.9, 8.6) **
$Lean_{WB}$ (kg)	48.0±11.6 (24.7, 82.3)	37.2±4.7 (24.7, 53.4)	55.8±8.0 (33.4, 82.2) **
$Lean_{RA}$ (kg)	2.7±0.9 (1.1, 5.2)	1.8±0.4 (1.1, 3.2)	3.3±0.6 (1.6, 5.1) **
$Lean_{LA}$ (kg)	2.6±0.9 (1.1, 4.9)	1.8±0.5 (1.1, 3.4)	3.2±0.6 (1.7, 4.9) **
BF% (%)	25.3±11.4 (5.1, 54.3)	33.1±9.4 (10.4, 54.3)	19.6±9.2 (5.1, 40.4) **

Data given as mean ± standard deviation (min, max).; H, height; HGS, hand grip strength; PhA, phase angle; BF%, percentage body fat; R, resistance; Xc, reactance; Lean, lean body mass; R/H, resistance standardized for height; Xc/H, reactance standardized for height; WC, waist circumference.; Subscript R, L, RA, LA, WB, D = right, left, right arm, left arm, whole body, dominant hand respectively.

Table 2. Regression analysis of impedance parameters using whole body and segmental modes

	Dependent Variable	Independent Variable	Intercept	Coefficient	r^2	SEE
Total (n = 406)	Ph_{WB}	PhA_{RA}	0.686±0.127**	0.939±0.022**	0.960	0.240
		PhA_{LA}	1.217±0.142**	0.871±0.025**	0.941	0.290
	R_{WB}/H	R_{RA}/H	64.055±3.784**	1.447±0.020**	0.985	11.885
		R_{LA}/H	66.924±4.291**	1.400±0.022**	0.981	13.560
	Xc_{WB}/H	Xc_{RA}/H	5.434±0.923**	1.623±0.051**	0.962	0.755
		Xc_{LA}/H	1.098±1.001**	0.929±0.056**	0.931	1.829
Female (n = 171)	Ph_{WB}	PhA_{RA}	0.744±0.228**	0.915±0.047**	0.939	0.210
		PhA_{LA}	1.557±0.219**	0.777±0.046**	0.920	0.241
	R_{WB}/H	R_{RA}/H	40.748±11.247**	1.539±0.047**	0.976	13.481
		R_{LA}/H	50.328±12.174**	1.469±0.050**	0.971	14.901
	Xc_{WB}/H	Xc_{RA}/H	2.154±1.859*	1.734±0.094**	0.933	1.779
		Xc_{LA}/H	3.714±2.099*	1.693±0.108**	0.910	2.051
Male (n = 235)	Ph_{WB}	PhA_{RA}	1.339±0.252**	0.838±0.040**	0.897	0.243
		PhA_{LA}	1.992±0.276**	0.751±0.045**	0.852	0.288
	R_{WB}/H	R_{RA}/H	65.642±6.662**	1.443±0.042**	0.959	10.731
		R_{LA}/H	79.702±7.506**	1.322±0.046**	0.943	12.650
	Xc_{WB}/H	Xc_{RA}/H	3.243±1.006**	1.784±0.058**	0.948	1.537
		Xc_{LA}/H	3.443±1.166**	1.776±0.068**	0.932	1.762

Regression coefficient estimate ± SEE; r^2, coefficient of determination.; H, height; PhA, phase angle; R, resistance; Xc, reactance; R/H, resistance standardized for height; Xc/H, reactance standardized for height; Subscript RA, LA, WB = right arm, left arm, whole body, respectively. ; **$p < 0.001$.

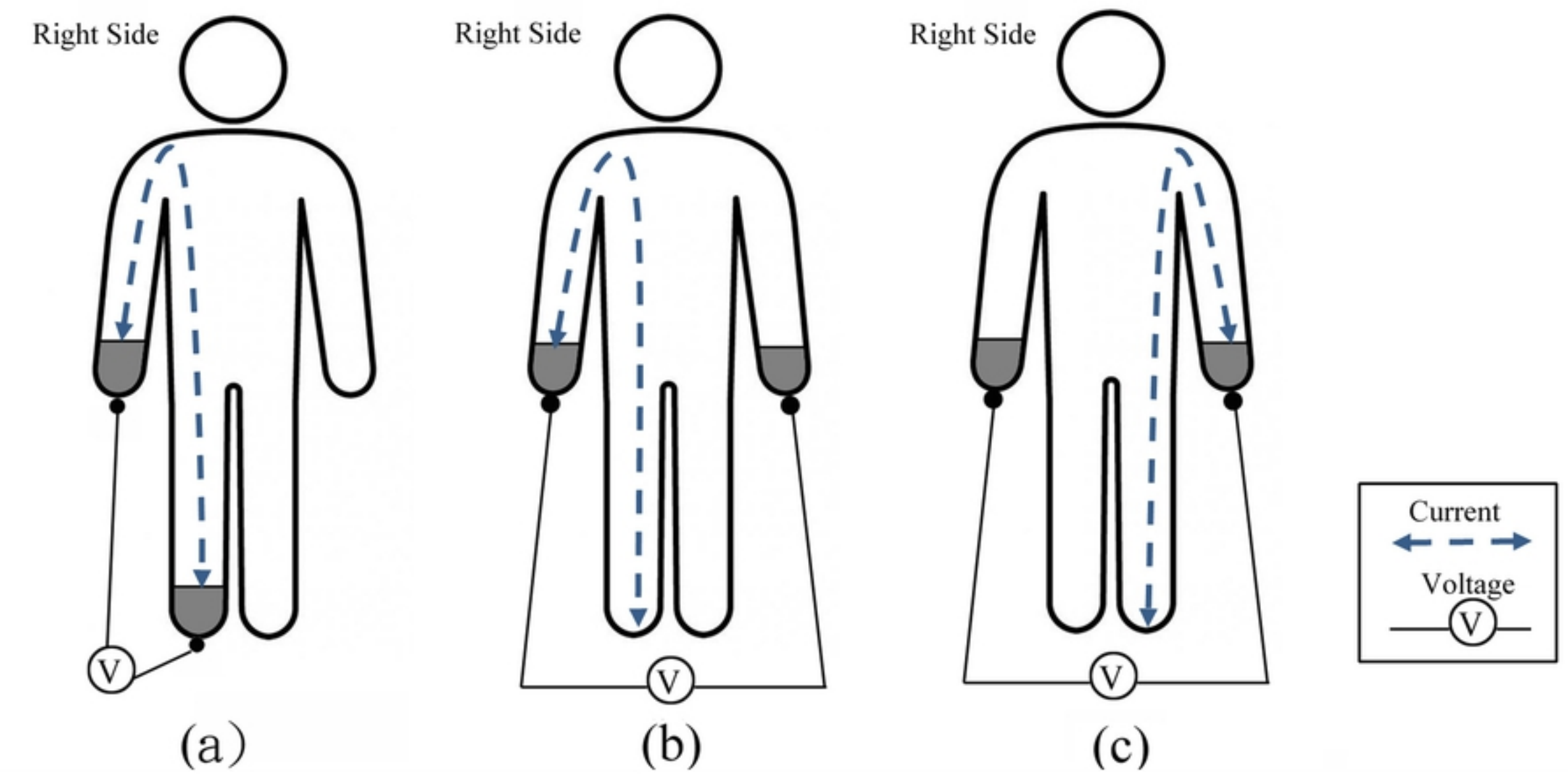
Table 3. Multiple regression analyses for predicting handgrip strength in the dominant, right, and left hands

Cumulative dependent variables used in model										
Whole body mode for predicting HGS_{DH}										
Sex	Weight	Age	H	Xc/H	R/H	Intercept	SEE	r^2	VIF	β
192.16±10.66**	-	-	-	-	-	294.83± 7.55**	74.79	0.625	3.45	0.42
149.40±10.89**	2.96±0.39**	-	-			114.72± 24.39**	65.67	0.712	2.82	0.23
141.01±10.04**	3.08±0.35**	-1.91±0.30**	-	-	-	166.37± 23.75**	60.00	0.761	1.48	-0.11
118.38±11.97**	2.60±0.37**	-1.55±0.31**	2.18±0.66**	-	-	-165.73±103.70	58.53	0.774	2.66	0.22
126.38±13.79**	2.82±0.42**	-1.50±0.32**	2.23±0.66**	0.78±0.67*	-	-232.56±118.42	57.47	0.784	6.69	0.29
102.90±15.06**	1.95±0.48**	-.96±0.35**	2.65±0.66**	3.42±1.01*	-0.66±0.19**	48.70±117.77	56.89	0.792	7.26	-0.38
Right arm mode for predicting HGS_{RH}										
191.68±10.81**	-	-	-	-	-	291.48±7.66**	75.82	0.617	3.49	0.40
150.38±11.19**	2.86±0.39**	-	-	-	-	117.54±25.07**	67.51	0.698	2.49	0.18
141.73±10.31**	2.98±0.36**	-1.97±0.31**	-	-	-	170.86±24.39**	61.62	0.750	1.25	-0.14
116.69±12.24**	2.45±0.38**	-1.58±0.32**	2.41±0.68**	-	-	-196.57±106.03	59.84	0.765	2.64	0.23
113.27±15.29**	2.39±0.41**	-1.57±0.32**	2.41±0.68**	0.28±0.74*	-	-181.21±113.88	59.97	0.766	5.60	0.18
96.44±15.45**	1.51±0.46**	-1.22±0.33**	2.83±0.67**	2.26±.98*	-0.94±0.25**	-101.23±112.17	58.01	0.782	7.21	-0.34
Left arm mode for predicting HGS_{LH}										
170.26±12.42**	-	-	-	-	-	267.28±7.10**	70.29	0.773	3.55	0.42
134.51±10.56**	2.47±0.37**	-	-	-	-	116.71±23.64**	63.65	0.671	2.58	0.18
126.66±9.79**	2.59±0.34**	-1.78±0.29**	-	-	-	165.05±23.18**	58.55	0.719	1.25	-0.16
111.33±.998**	2.26±0.37**	-1.54±0.32**	1.48±0.66*	-	-	-59.87±102.26	57.95	0.730	2.71	0.18
109.44±14.69**	2.23±0.40**	-1.55±0.31**	1.48±0.66**	-0.15±0.67*	-	-52.12±108.69	58.09	0.730	4.93	0.16
92.39±15.21**	1.43±0.46*	-1.25±0.32**	1.98±0.66*	1.75±0.87*	-0.76±0.23**	-102.47±107.26	56.67	0.745	6.76	-0.31

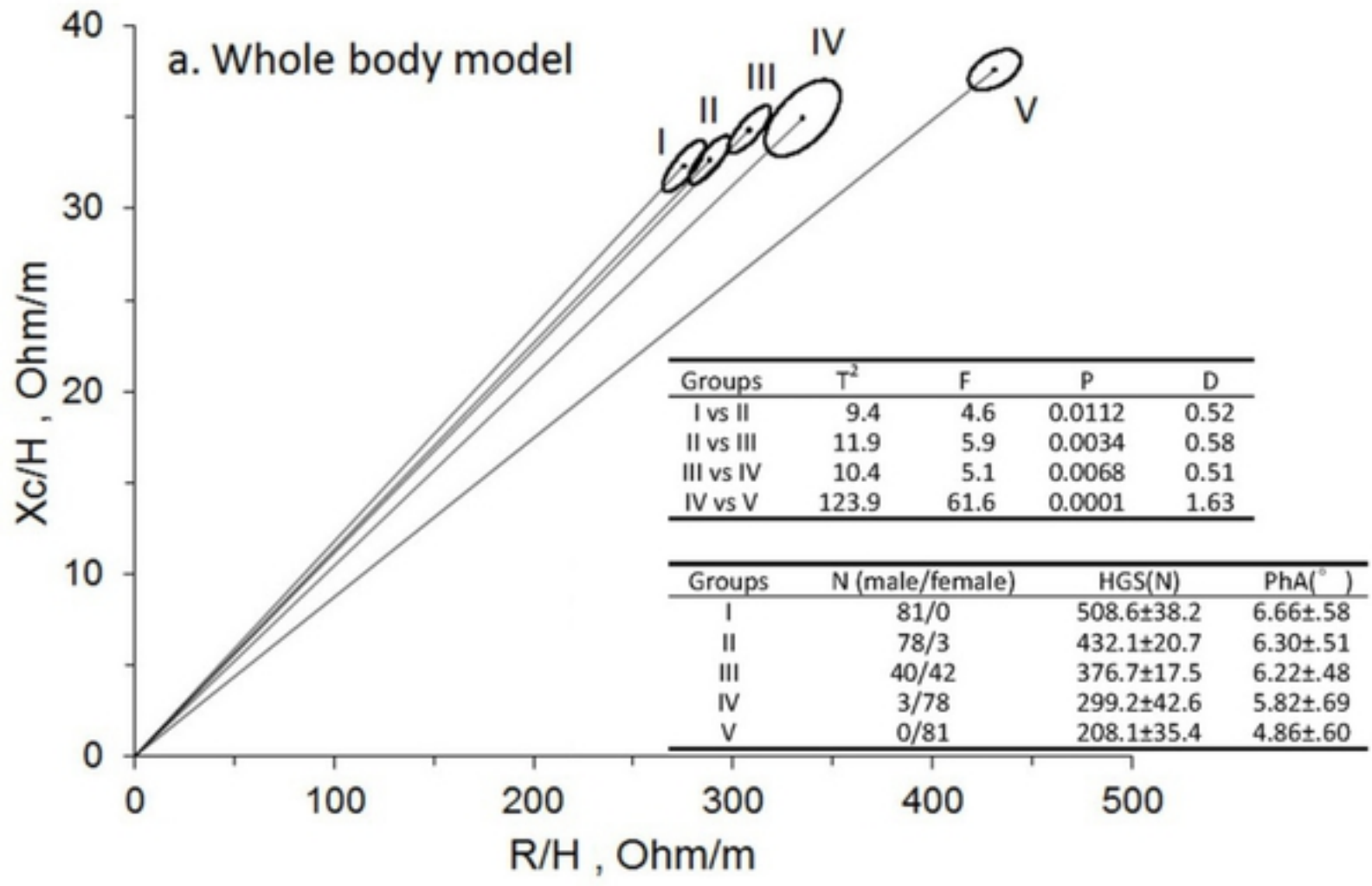
Regression coefficient estimate ± SEE; r^2, coefficient of determination; H, height;

β, standardized coefficient; B, unstandardized coefficients; VIF, variance inflation factor; SEE, standard error of estimate.

Using all 6 variables, the determination coefficients were 0.792, 0.782, and 0.745, respectively, whereas the standard error of estimates were 56.89, 58.01, and 56.67 N for the dominant, right, and left arms, respectively.; **$p < 0.001$.

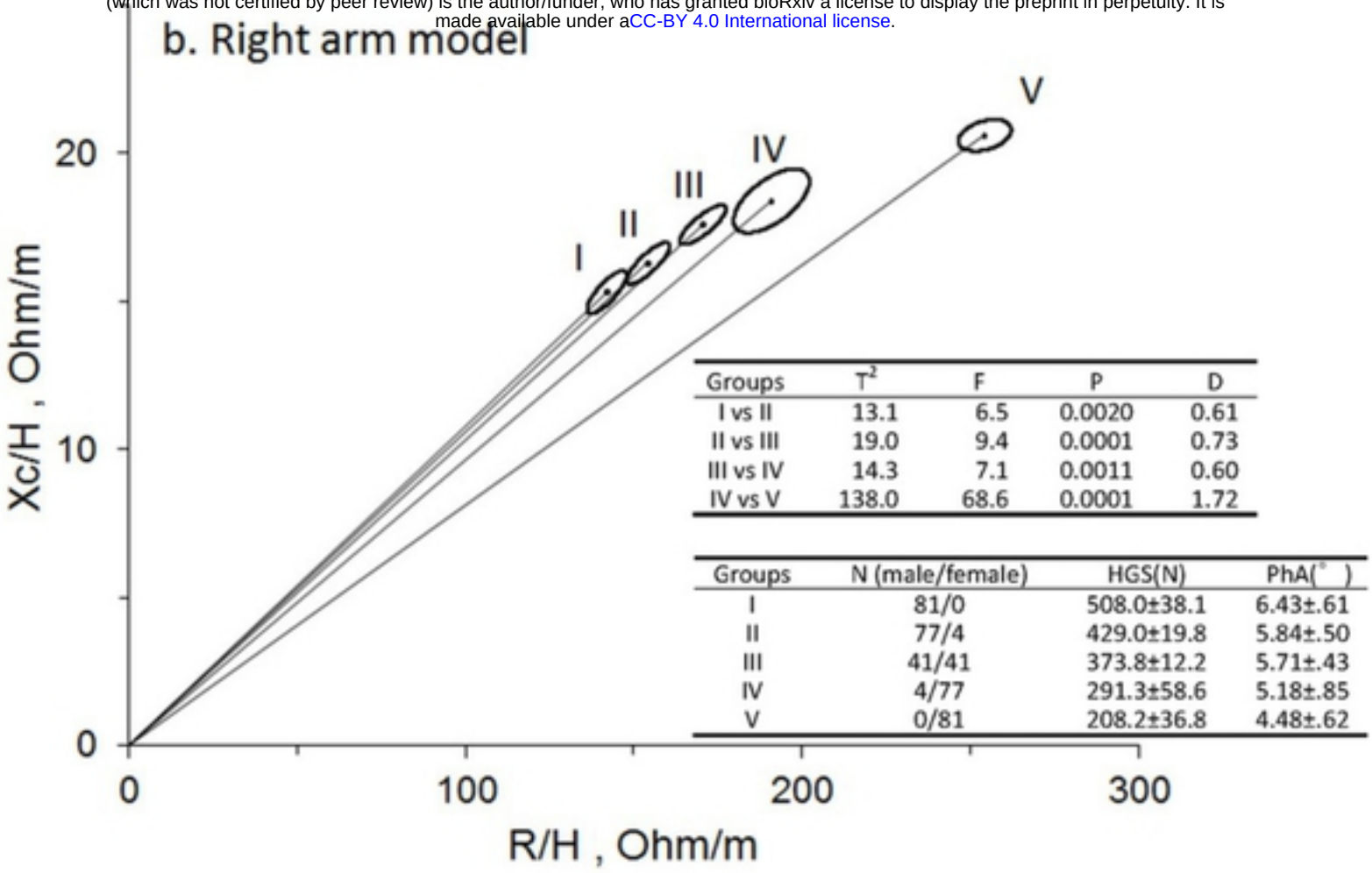


Figure



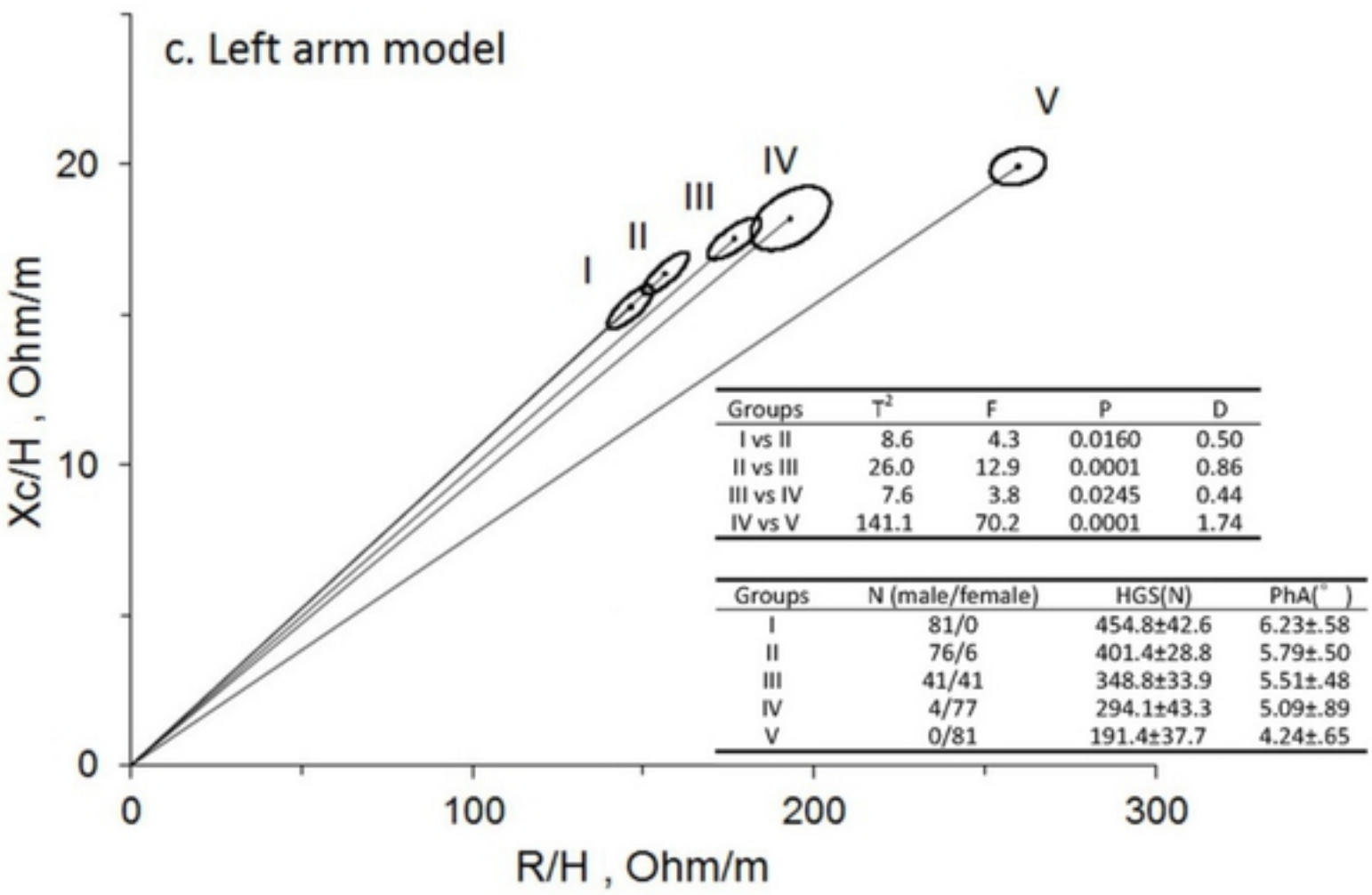
Groups	T^2	F	P	D
I vs II	9.4	4.6	0.0112	0.52
II vs III	11.9	5.9	0.0034	0.58
III vs IV	10.4	5.1	0.0068	0.51
IV vs V	123.9	61.6	0.0001	1.63

Groups	N (male/female)	HGS(N)	PhA(°)
I	81/0	508.6±38.2	6.66±.58
II	78/3	432.1±20.7	6.30±.51
III	40/42	376.7±17.5	6.22±.48
IV	3/78	299.2±42.6	5.82±.69
V	0/81	208.1±35.4	4.86±.60



Groups	T^2	F	P	D
I vs II	13.1	6.5	0.0020	0.61
II vs III	19.0	9.4	0.0001	0.73
III vs IV	14.3	7.1	0.0011	0.60
IV vs V	138.0	68.6	0.0001	1.72

Groups	N (male/female)	HGS(N)	PhA(°)
I	81/0	508.0±38.1	6.43±.61
II	77/4	429.0±19.8	5.84±.50
III	41/41	373.8±12.2	5.71±.43
IV	4/77	291.3±58.6	5.18±.85
V	0/81	208.2±36.8	4.48±.62



Groups	T^2	F	P	D
I vs II	8.6	4.3	0.0160	0.50
II vs III	26.0	12.9	0.0001	0.86
III vs IV	7.6	3.8	0.0245	0.44
IV vs V	141.1	70.2	0.0001	1.74

Groups	N (male/female)	HGS(N)	PhA(°)
I	81/0	454.8±42.6	6.23±.58
II	76/6	401.4±28.8	5.79±.50
III	41/41	348.8±33.9	5.51±.48
IV	4/77	294.1±43.3	5.09±.89
V	0/81	191.4±37.7	4.24±.65

Figure