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Comparison of Supine and Vertical Bioimpedance Measurements in Young Adults

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ABSTRACT

Topics in Exercise Science and Kinesiology Volume 3: Issue 1, Article 11, 2022. Bioelectrical impedance analysis (BIA) methods estimate health parameters such as phase angle (PhA) and body fat percentage (%BF) from various positional and electrode configurations. PhA and %BF are known biological markers of cellular and physical health, respectively, and can be used to predict various health-related conditions and therefore require accurate assessment. The purpose of this study was to evaluate the effect of body position during BIA by investigating the difference and agreement between PhA and %BF using RJL (supine) and InBody (vertical) analyzers. Thirty-eight young adults (23.4±4.1 yrs.) volunteered and underwent body composition assessments by both analyzers. Difference and agreement in assessments of PhA and %BF between analyzers were assessed using paired samples *t*-tests and Lin's concordance correlation coefficient (r_c), respectively. RJL's PhA (7.15±0.84°) exceeded InBody's (6.11±0.74°), $p<0.001$, and had poor agreement (r_c =0.47). RJL's %BF (23.0±6.8%) was similar to InBody's (23.1±7.4%), $p=0.813$, and had substantial agreement (r_c =0.95). Both analyzers estimated %BF similarly and may be interchangeable for this purpose, thus demonstrating no effect of body position on the estimation of %BF with these BIA devices. An individual's PhA may be underestimated if measured in the vertical position and compared to supine reference values. Current reference values for PhA are based on measurements in the supine position, so until vertical reference values of PhA are available, caution is urged when interpreting PhA from vertical BIA assessments.

KEY WORDS: Phase angle, body fat, measurement, BIA, body position

INTRODUCTION

Bioelectrical impedance analysis (BIA) is commonly used for estimating body composition (body fat (%BF), intracellular water (ICW), extracellular water (ECW), and total body water (TBW)) for clients of all ages. BIA uses one or more weak electrical current(s) to determine the resistance (R) and reactance (Xc) of body tissues to the specific current(s). Muscle and water

have a lower R to electrical current, while fat tissue slows down the current by providing more opposition to its flow. In addition to tracking one's body composition, BIA can provide a measure indicative of muscle quality and function by assessing whole-body phase angle (PhA). PhA is the ratio between the body tissue's R and Xc to an electrical current of 50 kHz (PhA = arctan(Xc/R)*(180/π)) indicating the magnitude of signal delay due to Xc. R is the opposition to a current (amps) as it flows through tissue and is proportional to the drop in the voltage applied as it passes through tissue. Xc is the reciprocal of frequency and capacity and decreases as frequency increases. As a current penetrates a cell membrane, it loses its capacitive properties, and Xc is reduced. Therefore, a high PhA value has a high Xc and low R, whereas a low PhA value has a low Xc and an elevated R. PhA has grown as a tool for assessing physiological variables (2); a low PhA indicates poor cellular health in terms of hydration, membrane integrity, function, and is also associated with a loss of fat-free mass (25,30). Recently, PhA has been shown to have a positive association with running speed (8) and a predictor of mortality following a stay in the intensive care unit (30). This spectrum of applications demonstrates that an accurate assessment of an individual's PhA is important for athletic as well clinical populations alike. Additionally, an accurate measurement of PhA is crucial for tracking changes over time as this can indicate improvements (17) or detriments in an individual's cellular health (23). For example, if the purpose of a training program is to increase fat-free mass, then an increase in PhA is an indication that the individual's training program is working.

Importantly, there are multiple bioelectrical impedance devices that report PhA. PhA is typically measured with the client in a supine position on a non-conductive surface with electrodes placed in the standard ipsilateral tetrapolar configuration (21). Algorithm updates to vertical BIA analyzers now provide PhA values computed while the client is standing upright on a weight scale platform having bilateral pairs of electrodes for the feet and holding handles also with embedded bilateral pairs of electrodes. This configuration provides eight points of electrode contact. Based on the manufacturer's descriptions, the InBody 770 (InBody USA, Cerritos, CA), launched in 2014, is one of the first vertical BIA analyzers that is capable of measuring PhA, whereas supine assessments of PhA, such as those performed by BIA analyzers developed by RJL (RJL Systems, Clinton Township, MI), have been available since 1979. Previous researchers, Dellinger et al. (6) and Jensen et al. (12), compared PhA results of the adult men and women in their studies who were assessed in both supine and vertical positions. Their results indicated that PhA is higher with the client in a supine position as opposed to vertical position. Dellinger et al. (6) also reported that there was poor agreement between vertical and supine assessments of PhA between analyzers. PhA increases as the ratio of ICW to ECW increases (20); therefore, it is hypothesized that the body water compartment shifts that occur between vertical and supine positions may result in a greater ratio of ICW to ECW that causes PhA to be higher when assessed in the supine position. Neither Dellinger et al. (6) or Jensen et al. (12) evaluated if the difference in PhA was accompanied by a difference in body water compartments or relative %BF assessed by the BIA devices used in their respective studies. Previous researchers have demonstrated that the shift in body water compartments between vertical and supine positions increased the body's impendence of their participants and that resulted in a higher estimated %BF when assessed in the supine position (14,16,29). Given the number of analyzers now on the market, it is unknown if these observations for PhA and %BF are true for BIA devices not used

in these previous studies. Furthermore, current PhA reference values have been established based on supine assessments and the differences between supine and vertical assessments of PhA may make the use of these values inappropriate when PhA is measured in the vertical position (32). Consequently, a tactile, eight-electrode vertical analyzer (InBody 770) and a supine tetrapolar analyzer (RJL Quantum Legacy) were selected for comparison in the present study. This pairing of analyzers has yet to appear in the published literature. Therefore, the primary purpose of this study was to investigate the difference and agreement between the PhA and %BF assessed by the RJL Quantum Legacy and the InBody 770. A secondary aim of this study was to investigate differences between these analyzers in the measurement of R and Xc as well as their estimations of ICW, ECW, and TBW.

METHODS

Participants

Posted flyers and word-of-mouth recruitment in and around the university community were utilized. All participants (N=38) met the age criterion (between 18 and 45 yrs.) and were free of exclusion criteria capable of modifying or interfering with the electrical current flow. Specifically, the participants had no pacemaker or cardiac defibrillator, amputations or missing appendages, metal surgical implants, known heart or kidney disease, peripheral edema, dialysis treatments, or prescribed/taking diuretic medication. In addition to these, urine pregnancy tests were given to all female participants (n=22) as pregnancy was also an exclusion criterion. All participants provided written informed consent before enrolling in the study, and all procedures were approved by the university's Institutional Review Board for human subject research. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (24).

Experimental Design

Participants reported to the university's exercise physiology laboratory in athletic attire for a single-session assessment after following pre-test guidelines consisting of 1) voiding completely within 30 min of being tested, 2) refraining from eating or drinking within 4 hours of testing, 3) avoiding strenuous exercise within 12 hours of testing, 4) refraining from consuming alcohol within 48 hours of testing. Participants' hydration status was confirmed via urine specific gravity (Refractometer, Model A300, ATAGO Co., Tokyo, Japan) and against the established criterion value ≤ 1.020 (27).

Bioelectrical Impedance Analyses

Participants removed all jewelry prior to testing. Barefoot standing height measurements were taken using a stadiometer (seca gmbh & co. kg, Hamburg, Germany). To allow for body water compartment stabilization each participant was required to stand for 15 minutes prior to assessments of body mass, %BF, and PhA (31) via the segmental multi-frequency (1-1,000 kHz), vertical InBody 770 analyzer. Skin that met the stainless-steel electrodes was prepped with an electrolytic wipe prior to assessment. While barefoot, the participant stepped onto the electrodes embedded into the scale and grasped the electrode-embedded handles, thereby creating the eight-point tactile electrode configuration. The participant was instructed to hold the handles

slightly away from the body so that the arms were not touching the torso per the manufacturer's instructions. Participant age, height, and sex were entered into the analyzer. The InBody 770 assumes the body can be assessed as a whole and segmentally (right arm, left arm, trunk, right leg, and left leg). Estimates of an individual's %BF, ICW, ECW, and TBW were determined via proprietary algorithm(s) incorporating 30 impedance measurements using 6 different frequencies (1kH, 5kHz, 50kHz, 250kHz, 500kHz, 1000kHz) at each of these segments. The estimated %BF, ICW, ECW, and TBW were displayed and recorded. The sum of R in the right arm, right leg, and trunk at 50kHz was used to calculate whole body R. The sum of Xc in the right arm, right leg, and trunk at 50kHz was used to determine whole body Xc. The InBody 770 calculates PhA by use these two summed values of R and Xc and the following equation, PhA = arctan(Xc/R)*(180/π). The displayed values for R, Xc, and PhA at 50kHz were recorded.

Next, participants assumed a supine position on a soft, non-conductive foam mat for 15 minutes to allow for body water compartment stabilization (31). Standard skin preparation and gel electrode placement for ipsilateral, tetrapolar BIA analysis preceded assessments. The RJL Quantum Legacy uses a tetrapolar wrist-to-ankle electrode configuration to measure R, Xc, and PhA at 50 kHz. The participants' legs were abducted enough to keep the thighs from touching each other. Similarly, the arms were abducted to an approximate 30-degree angle to minimize contact with the torso. Participants remained motionless throughout the duration of the test (15 minutes). The RJL Quantum Legacy measured and displayed the R, Xc, and PhA values from the 50kHz current. The RJL Quantum Legacy calculates PhA using R and Xc measured on the right side using the same equation as the InBody 770 analyzer (PhA = arctan(Xc/R)*(180/π)). According to the manufacturer, the R and Xc values obtained by the RJL Quantum Legacy are predominantly influenced by the arms and legs and discounts the contribution of the torso. The R and Xc values were used in either population-specific or generalized prediction equations provided by the RJL's BC 4 software based on the participant's age, sex, ethnicity, R, Xc, and body mass to estimate %BF, ICW, ECW, and TBW (28). For example, the BC 4's "Obese equation" was selected for participants with a BMI $\geq$ 30 kg/m^2 as this equation was developed from an obese sample (28). Additionally, the BC 4's "Native American equation" was another population-specific %BF prediction equation selected for participants that had a BMI < 30 kg/m^2 and self-identified as being Native American (26). For individuals that did not identify as being Native American and had a BMI $\geq$ 30 kg/m^2, the BC 4's third installment of the National Health and Nutrition Examination Survey (NHANES III) equation was used as a generalized %BF prediction equation (5).

Statistical Analyses

To determine sample size, an *a priori* power analysis was conducted (G*power version 1.9.2, (7) using a conservative estimate of effect size (Cohen's *d* = 0.5) from a prior study examining the effect of body position on PhA (6). It was estimated with an α-level of 0.05, a power of 0.80 (1 – β), that 34 participants would be required to detect differences in PhA between analyzers. To account for the possibility of attrition, inability to screen into the study, or unusable data, 38 participants were recruited and participated in the study.

Data are reported as mean ± standard deviation (SD). Separate two-tailed paired samples *t*-tests were used to determine if there were mean differences amongst the variables of interest (PhA, R, Xc, at 50kHz and estimated %BF, ICW, ECW, and TBW) between bioelectrical impedance analyzers. Bland-Altman 95% limits-of-agreement (LoA) plots were used to quantify the bias and random error between methods of assessing PhA and %BF (3). Acceptable LoA for %BF and PhA was determined to be less than ±3.5% (19) and ±1.0° (1,4), respectively. A line of best fit was superimposed within each plot using simple linear regression analysis of assessment bias between devices (RJL - InBody) and the average value ((RJL + InBody)/2) for PhA or %BF (9). The extent of bias explained by the average PhA or %BF was determined using the coefficient of determination (R^2). Using the RJL Quantum Legacy as the reference method, equivalence between bioelectrical impedance analyzers for the measurement of PhA at 50kHz and estimated %BF were assessed using Lin's concordance correlation coefficient (r_c) (18,22). Of the proposed interpretations of r_c, the categories as identified by McBride (23) for continuous variables were applied a priori where values of <0.90, 0.90–0.95, 0.95–0.99, and >0.99, represented poor, moderate, substantial, and almost perfect agreement, respectively. An alpha of 0.05 was used to determine statistical significance. All analyses were performed using RStudio statistical software package, version 1.3.1073 (R Development Core Team, Vienna, Austria). Data were analyzed for outliers using the *rstatix* package (13). All graphical representations of data were produced in Prism (version 6; GraphPad Software Inc., La Jolla, CA).

RESULTS

Data met the assumptions of the *t*-test by displaying normality using the Shapiro–Wilks's test and homogeneity of variance by reviewing the ratio of the raw score variances. Case diagnostics indicated no influential outliers in the data set. All participants met the hydration status requirement. Table 1 shows the descriptive characteristics of the sample. The majority (52.6%; n=20) of the participants in this study were White, 26.3% (n=10) were Hispanic, 13.2% (n=5) were Black, and 7.9% (n=3) were Native American.

Table 1. Participant demographics (Mean ± SD)

	Men (n = 16)	Women (n = 22)	Total (N = 38)
Age (years)	24.2 ± 3.9	22.8 ± 4.3	23.4 ± 4.1
Height (cm)	177.7 ± 4.7	167.7 ± 9.0	171.9 ± 8.9
Body Mass (kg)	78.8 ± 10.2	65.5 ± 12.1	70.9 ± 13.2
Body Mass Index (kg/m^2)	25.0 ± 4.6	23.1 ± 1.5	23.8 ± 3.3

Table 2 shows the comparisons between analyzers for variables obtained via BIA. No significant between-method difference was observed for %BF (p = 0.813). A significant between-method difference was observed for PhA and Xc assessed at 50kHz with the values from the RJL Quantum Legacy analyzer being the larger of the two (both p < 0.001). R at 50kHz was significantly lower when measured by the RJL Quantum Legacy compared to the InBody 770 (p < 0.001). ICW was significantly greater (p = 0.021), and ECW was significantly lower (p = 0.019) when estimated with the RJL Quantum Legacy compared to the InBody 770. No difference was observed in TBW between analyzers (p = 0.507). The coefficient derived from Lin's concordance correlation revealed that on average there was poor agreement in the assessment of PhA

between the RJL Quantum Legacy and the InBody 770, r_c = 0.47, 95% CI (0.32 to 0.59]). The coefficient derived from Lin's concordance correlation revealed that on average there was substantial agreement in the assessment of %BF between the RJL Quantum Legacy and the InBody 770, r_c = 0.95, 95% CI (0.89 to 0.97).

Table 2. Participants' physiological characteristics presented as mean ± SD (N = 38)

Bioelectrical Impedance Analyzer	**BF (%)**	**PhA (◦)**	**R (Ω)**	**Xc (Ω)**	**ICW (L)**	**ECW (L)**	**TBW (L)**
RJL Quantum Legacy	23.0±6.8	7.15±0.84*	560.4±93*	69.6±8.1*	20.7±4.8*	16.3±2.9*	37.0±7.6
InBody 770	23.1±7.4	6.11±0.74	616.3±86	65.5±6.6	19.3±3.4	17.5±3.0	36.8±8.3

BF = body fat, PhA = phase angle, R = resistance, Xc = reactance, ICW = intracellular water, ECW = extracellular water, TBW = total body water. Values assessed by the RJL were measured at 50kHz. %BF, ICW, ECW, and TBW were estimated by the InBody 770 via proprietary algorithm(s) incorporating 30 impedance measurements using 6 different frequencies (1kH, 5kHz, 50kHz, 250kHz, 500kHz, 1000kHz). InBody values for PhA, R, and Xc were the sum of measured values at 50kHz for the right arm, right leg, and trunk. *p < 0.05 significantly different from the InBody 770 analyzer.

Figure 1 shows the results of the Bland-Altman plots with simple linear regression analyses to evaluate the individual methodological variability for bias when compared to the participant's average %BF (Figure 1A) and PhA (Figure 1B). Of the individual differences between devices, 95% fell within the LoA indicating that differences were normally distributed. The LoA for methodological bias in %BF was -4.9% to 4.8% which exceeded the acceptable range of ±3.5% determined *a priori* at (Figure1A). The LoA for methodological bias in PhA was 0.22 to 1.90° and exceeded the acceptable range of ±1.0° determined *a priori* (Figure1B). Simple linear regression analyses of the Bland–Altman plots indicated no significant systematic bias between analyzers for %BF, 95% CI (-0.20 to 0.02%); $F(1, 36) = 2.62$, $p = 0.114$ (Figure1A) or PhA, 95% CI (-0.06 to 0.30°); $F(1, 36) = 1.92$, $p = 0.175$ (Figure1B).

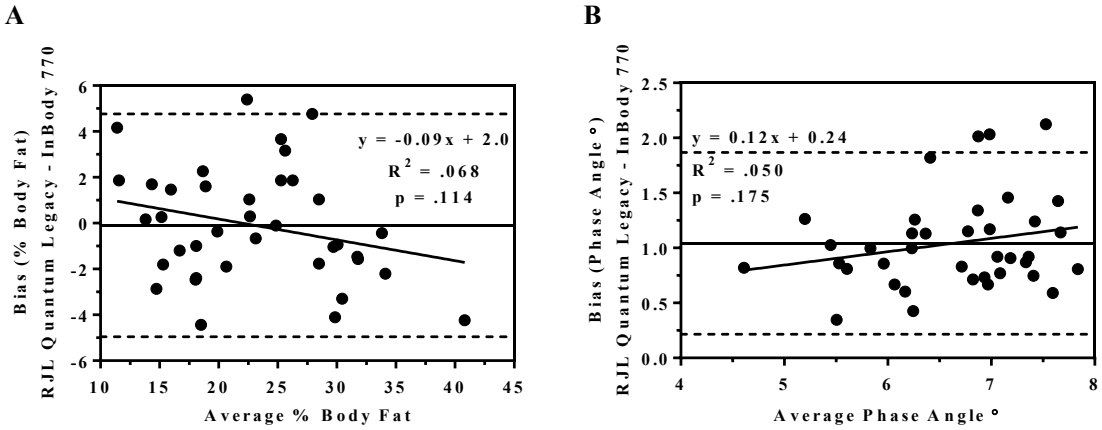

Figure 1. Bland and Altman plots of individual %BF (A) and phase angle (B) assessed by two bioelectrical impendence analyzers (N = 38). The vertical axes represent methodological bias for the differences in %BF and phase angle assessed by the two analyzers. The horizontal axes represent the average %BF and phase angle ((RJL + InBody)/2) in panels A and B, respectively. The solid horizontal lines are the mean differences (bias). The dashed lines denote the upper and lower LoA (bias ± (1.96×SD of the bias)). R^2 represents the amount of variance explained by the average %BF or phase angle.

DISCUSSION

The purpose of this study was to investigate the difference and agreement between PhA and %BF assessed by the RJL Quantum Legacy and the InBody 770. A secondary aim of the study was to investigate differences between these analyzers in the measurement of R and Xc as well as their estimations of ICW, ECW, and TBW. Our main findings were that the body positions used by the different devices had a significant effect on measurements of PhA, R, Xc, and estimations ICW and ECW, but not %BF and TBW estimations. While previous researchers have demonstrated that %BF is higher when assessed in the supine compared to vertical position (14,16,29), there was no significant difference and substantial agreement ($0.95 \geq r_c \leq 0.99$) for %BF estimated by the two analyzers at the group level in the current study (Table 2). At the individual level, 84% (32/38) of the participants were within acceptable LoA for bias in %BF (total error ≤ ±3.5%) between the RJL Quantum Legacy and InBody 770 (Figure 1A); hence, both analyzers estimated %BF similarly, suggesting that they may be interchangeable for this purpose (19,22). The discrepancies between our findings and those of previous researchers may be partially explained by the devices used in their studies (Bodystat 500, Douglas, Isle of Man, UK, (29), Xitron 4000, Xitron Technologies Inc., San Diego (16) TBF 215GS, Tanita, Japan (14) STA/BIA, Akern, Italy (14)) compared to those used in the current study (InBody 770 and RJL Quantum Legacy). Although speculative, newer BIA devices were used in the current study, so it is likely that technological advancements have been made to lessen the impact of body position when estimating %BF. Future researchers should test this hypothesis by comparing the effect of body position on %BF between newer (e.g., RJL Quantum Legacy) and older (e.g., Xitron 4000) BIA devices.

At the group level, supine assessments of PhA measured via the RJL Quantum Legacy were significantly greater (+1.04°) than when measured in the vertical position with the InBody 770 (Table 2). Also, equivalency testing via Lin's concordance correlation revealed that there was poor agreement ($r_c < 0.90$) between the RJL Quantum Legacy and InBody 770 in the assessment of PhA, suggesting that these devices are not interchangeable for the purpose of assessing PhA (22). In addition to the group response, the Bland-Altman plot (Figure 1B) revealed that the devices used in this study have poor agreement in their ability to assess PhA as the LoA exceeded the *a priori* limit of ±1.0° for 18 of the 38 participants (1,4). Furthermore, the Bland-Altman plot showed that the RJL Quantum Legacy analyzer measured a greater PhA value for all participants in the current study. This further supports the effect of body position during the assessment of PhA (Figure1B). These findings support the results of Jensen et al. (12) who used supine and vertical configurations of the mBCA 514/515 (seca gmbh and co, Hamburg, Germany) and Dellinger et al. (6) who used the SFB7 (ImpediMed®, Carlsbad, CA), mBCA 515/514, and the Quantum V (RJL Systems, Clinton Township, MI) analyzers, and observed differences between vertical and supine assessments of PhA such that it is 0.80° to 1.1° greater when measured in the supine compared to vertical position. The current study builds on these previous findings by extending them to other vertical and supine analyzers such as the InBody 770 and the RJL Quantum Legacy, respectively.

Building upon previous findings that observed a significant difference between PhA between vertical and supine assessments (6,12), the current study supports that the difference in PhA between vertical and supine assessments observed in this study is likely a result of body water compartment shifts and stabilization that occurs in the different positions. When an individual moves to a supine position body water compartments stabilize so that the volume of intracellular water is greater, and the volume of extracellular water is lower in the supine compared to vertical position (10). Our results support this hypothesis by demonstrating that ICW is significantly increased, and ECW is significantly decreased after transitioning from a vertical to supine position (Table 2). Researchers have shown that an increase in the ratio of ICW to ECW increases PhA (20), and the results of the current study support this observation by indicating that an increase in ICW/ECW corresponds with an increase in Xc and a decrease in R which equates to a higher PhA value (Table 2). Additionally, a limitation of supine tetrapolar analysis is that it relies primarily on the contribution of R and Xc from the arms and legs and discounts the contribution of the torso, which may be a contributing factor to the difference we observed between vertical and supine assessments of PhA since the vertical InBody 770 analyzer uses values of R and Xc that were summed from the right leg, right arm, and torso to calculate PhA (2,15). Manufacturers of supine tetrapolar BIA devices should consider addressing this limitation by increasing the contribution of the torso towards R and Xc. Despite this limitation, a recent systematic review by Mattiello et al. (21) indicated that vertical assessments of PhA are rarely used and, consequently, reference values for PhA are based on supine assessments (1,5). Based on the manufacturer's descriptions, the InBody 770, launched in 2014, is one of the first vertical BIA analyzers that is capable of measuring PhA, whereas supine assessments of PhA, such as those performed by BIA analyzers developed by RJL, have been available since 1979. It is likely for this reason that reference values for PhA are based on supine assessments.

Our results, and those by previous researchers (6,12), demonstrate that PhA is underestimated when measured in the vertical compared to supine position. These findings are of clinical and practical importance since reference values have only been established for PhA assessed in the supine position (21), therefore, an individual's PhA may be misclassified if it was measured in the vertical position but is compared to supine reference values. For example, we observed that the InBody 770 (vertical assessment) underestimates PhA by 1.04° on average compared to the RJL Quantum Legacy (supine assessment); therefore, participants in the current study with a PhA between 5-6° (Table 2) as assessed in the supine position could be identified as being at risk for having a condition characterized by muscle wasting, sarcopenia (PhA ≤ 4.55° and 4.25° for men and women, respectively), when assessed in the vertical position (11). To avoid future misclassification of PhA assessed in the vertical position, future researchers should develop a conversion factor for transforming vertical to supine PhA values, or reference values that are specific to the body position of the assessment. While the current study was underpowered to perform sub-analyses based on participant characteristics, future research using larger sample sizes may be warranted to evaluate the effect of characteristics such as race/ethnicity, age, and BMI category on the difference in PhA or %BF between the two devices evaluated in the present study (RJL Quantum Legacy and the InBody 770).

The InBody 770 may be an equivalent alternative to the RJL Quantum Legacy for estimating %BF, but due to differences in body water compartment stabilization between supine and vertical positions, the supine assessment (RJL Quantum Legacy) will produce a greater PhA than the vertical assessment (InBody 770). Therefore, postural differences should be considered when comparing PhA assessments and, until vertical reference values or conversion formulas are developed, avoid using when using reference values to classify and individual based on PhA assessed in the vertical position.

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