Article:

Alizadehkhaiyat, O, Hawkes, DH, Kemp, GJ et al. (2 more authors) (2014) Muscle strength and its relationship with skeletal muscle mass indices as determined by segmental bio-impedance analysis. European Journal of Applied Physiology, 114 (1). pp. 177-185. ISSN 1439-6319

https://doi.org/10.1007/s00421-013-2764-y

Title

Upper Extremity Strength and its relationship with Skeletal Muscle Mass Indices as Determined by Segmental Bio- impedance Analysis

Running Title

Upper Extremity Muscle Strength and Skeletal Muscle Mass

Authors:

1. Omid Alizadehkhaiyat[1]

2. David H Hawkes[1]

3. Graham J Kemp[2]

3. Anthony Howard[1]

4. Simon P Frostick[1]

Affiliation:

1. Musculoskeletal Science Research Group, Institute of Translational Medicine, University of Liverpool, Liverpool, UK

2. Department of Musculoskeletal Biology II, Institute of Ageing & Chronic Disease, Faculty of Health & Life Sciences, University of Liverpool

Corresponding Author:

Professor Simon P. Frostick

Musculoskeletal Science Research Group,

Institute of Translational Medicine,

University of Liverpool

Liverpool UK, L69 3GA

Phone: +44 151 706 4120 Fax: +44 151 706 5815

Email: s.p.frostick@liverpool.ac.uk

Abstract

Purpose

Despite an increasing interest in using bio-impedance analysis (BIA) for the estimation of segmental skeletal muscle mass (SMM); existing data is sparse. Furthermore, there is a need for better understanding of the influence of SMM on gender-related differences in muscle strength. Hence, study aimed to measure the SMM, determine its correlation with muscle strength, and examine its relation with gender-related differences in muscle strength.

Methods

Segmental and whole body SMM and maximum voluntary contraction in five distinct shoulder planes (forward flexion, abduction in scapular plane, abduction in coronal plane, and internal- and external rotation) were measured in 45 healthy participants (22 males, 23 females) with a mean age of 30.3 years. Independent t-tests and Pearson Correlation test were applied for comparative and correlational analysis, respectively.

Results

All muscle-related parameters including muscle volume, SMM, and SMM index were significantly different between men and women ($p<0.01$). There was a significant gender-related difference ($p<0.01$) in the absolute shoulder strength but not after normalisation to SMM. A strong correlation was found between strength and SMM ($p<0.01$).

Conclusion

BIA provided a convenient method for SMM estimation. SMM parameters may be effectively used for strength normalisation allowing comparisons of individuals with differing genders and body masses.

Key Words: Segmental Bio-impedance; Skeletal Muscle Mass; Muscle Volume; Shoulder Muscle Strength; Muscle Strength Normalisation

INTRODUCTION

The utility of sophisticated imaging techniques for estimating muscle size, such as muscle anatomical cross-sectional area (ACSA) and muscle physiological cross-sectional area (PCSA), is limited by the availability of magnetic resonance imaging (MRI) or computed tomography (CT) equipment. A cheaper and more convenient technique would therefore be desirable. Bio-impedance analysis (BIA) is a safe, non-invasive and convenient technique, originally developed to measure whole body composition using a simple electrode configuration between right wrist and leg. Recent developments in electrode configurations and analysis, backed up with comprehensive validation studies against MRI, ultrasound (US), CT, and dual-energy X-ray absorptiometry (DEXA), have established BIA as a reliable method for the measurement of segmental body composition.[1-7]

There is increasing interest in using BIA techniques for more specific assessment of body composition, including the estimation of skeletal muscle mass (SMM).[5,8,9] The SMM is closely related to mechanical function in many health and sport-related conditions. Segmental BIA estimates the impedance of body segments (e.g. arm, leg, torso, upper arm, lower arm), from which their segmental composition can be calculated. However, this remains a relatively novel approach and lacks an extensive evidence base.

The measurement of SMM has many applications. It can assist, among others, sport physiologists assessing the impact of training programmes by relating muscle mass to exercise performance, $VO2_{max}$ and other physiological parameters; clinicians assessing the effects of catabolic diseases on muscle wasting and the effectiveness of therapeutic regimes in reversing this; and physiotherapists monitoring a individual's progress during rehabilitation and training programs. The estimation of both whole and segmental body composition can thus provide important information on functional capacity and physical performance in both research and clinical settings.

Muscle strength, measured as isometric maximum voluntary contraction (MVC), has been a popular, valid, and highly reliable assessment of in vivo force production and a key indicator of fitness and physical performance for several decades.[10-13] Although the relationship between muscle strength and body muscle mass has attracted considerable attention amongst researchers, this relationship is often neglected and there is inadequate clarity about which measures of muscle mass in vivo that best relate to muscle strength. This is an important issue as measures used to estimate muscle mass, particularly segmental measures in the limbs, can influence the interpretation of data on muscle strength relative to SMM.[14] A very few studies have attempted to describe the relationship between muscle volume (MV) in the limbs and strength. Cross-sectional area (CSA), measured in vivo, is generally recommended for measuring muscle size. However, there are indications that MVC is more closely related to MV than CSA at a given site in the limb.[15, 16] It is therefore also reasonable to assume, given the direct relationship between mass and volume; that muscle mass is a superior measure of muscle size in relation to strength. Normalizing strength measurements to body size parameters has traditionally been used to remove variations in body-size dependence,[17-21] particularly when comparing different study populations (i.e. men/women athletes/non-athletes, young/old). However, differences in the normalisation methods preclude comparison of the data reported in different studies.

Using a segmental BIA technique, the study aimed to: 1) compare the muscle composition of the UE and torso in men and women and relate the findings to gender-related differences in shoulder MVC strength, 2) determine whether BIA estimates of muscle volume are potential predictors of muscle strength (strength-size relationship), and 3) establish whether adjusting strength to some specific measures of muscle volume provides an appropriate gender- and size-independent assessment by reducing between-person variability.

METHODS

Segmental body bio-impedance and the MVC of the shoulder muscle groups were recorded in 45 healthy participants (22 males, 23 females). Subjects had a mean age of 30.3 years (+/- 9.3), height 1.7m (+/- 0.1), weight 71.6kg (+/- 15) and body mass index (BMI) of 24.4 (+/- 4.2). Group demographics are summarised in Table 1.

<u>Bioelectrical Impedance Analysis (BIA):</u> Body weight and standing height were measured with subjects dressed in light clothing and barefoot. BMI was calculated by dividing body weight by height squared (kg/m2). Bioelectrical impedance was measured using a multiple frequency Maltron system (Maltron BioScan 920, Rayleigh, UK). Subjects were tested, after a period of 5 minutes rest, supine on a non-conducting surface with their arms abducted away from their trunk and the legs slightly separated. Using a 3-segment configuration, electrodes were attached to the proximal and distal points of upper- and lower extremity in order to separately measure the segmental impedance of the arm, leg, and torso (Figure 1). The precise locations of electrodes were: the dorsal aspect of hand on the third metacarpal bone; dorsal aspect of foot on the third metatarsal bone; over the acromion process of shoulders; and over the greater trochanter of femur. Electrode configuration was in accordance with user's manual and previous work in the field.[8,22,23] The length of the torso, and upper- and lower limbs was measured to the nearest 0.5 cm and used to calculate segmental SMM via an integrated BIA equation (see Analysis section for more details). Routine analysis performed by the BIA software (Mi*Sta*t, Rayleigh, UK) generated broad information on whole body composition.

<u>Shoulder Strength Measurements:</u> Shoulder MVC was measured using a standardised shoulder Nottingham Mecmesin Myometer (Mecmesin Ltd., Slinfold, UK) during five distinct movements: (1) Forward flexion (F.FLEX) with the shoulder at 90° flexion, elbow in extension and the forearm in pronation; (2) abduction in scapular plane (ABD.SP) with the

shoulder at 90° of abduction, elbow in extension and the hand in "full can" position; (3) abduction (ABD) in coronal plane with the shoulder at 90° of abduction and elbow in extension ; and (4&5) external rotation (EXT.ROT) and internal rotation (INT.ROT) with the shoulder in neutral position, the elbow in 90° flexion tucked to the side of the body and the forearm in neutral position. The strap of the myometer was applied to the distal forearm. F.FLEX, ABD.SP, and ABD were measured in standing and EXT.ROT and INT.ROT in seating positions. Participants were instructed and verbally encouraged to build up their strength to a maximum over 3 seconds and then maintain this for a further 2 seconds. The upper body was kept in an upright position throughout the measurement. The myometer has an accuracy of ±0.1% of full-scale and 1000N capacity with real-time digital display screen. The strength was registered in Newton (N) units and average of three consecutive maximal measurements was taken into the analysis.

DATA ANALYSIS

Descriptive statistics are reported as mean $\pm$ standard deviations (SD) and range as appropriate. The parameters of body composition studied are reported as absolute values calculated by the BIA software using established prediction equations. SMM was estimated using the BIA equation described by Janssen et al[5]: SMM (kg) = [0.401 × (height^2/resistance) + (3.825 × gender) - (0.071 x age) + 5.102], where height is in cm; resistance is in ohms; for sex, men =1 and women=0; and age is in years. The equation has been validated in African-American, Hispanic, and Asian populations.[5,7,24] The SMM index (SMI) for whole body, torso, and UE was later calculated by dividing absolute SMM values by height squared (kg/m^2) in order to adjust for stature and the mass of non-skeletal muscle tissues.[24,25] For UE strength measurements the data is presented as both absolute values (N) and after normalisation to the whole body and UE SMM.

Gender-related differences in body composition and muscle strength (before and after normalisation were examined using independent t-tests. Pearson correlation coefficients were applied to determine the relationships between key upper body composition variables and muscle strength. Statistical analysis was performed using the Statistical Package for Social Sciences release 19.0 for Windows (Armonk, NY: IBM Corp.).

RESULTS

Table 2 presents the main BIA results for whole body, torso, and UE in men, women, and full study population. A significant difference was noted for all muscle-related parameters (MV, SMM, and SMI) and fat-free mass (FFM) between male and female participants ($p \leq 0.01$) but no difference in body FM was seen. Segmental MV and SMM were very similar in their value and correlations with other variables indicating that these two parameters may be used interchangeably.

Table 3 presents and compares the absolute mean values (N) for maximal isometric strength in 5 different shoulder planes and following normalisation to the UE and whole body SMM in men and women. Absolute and normalised values were highest for INT.ROT, followed by EXT.ROT, F.FLEX, ABD.SP, and ABD. A significant difference was found between all paired strength measurements ($p \leq 0.01$) except for ABD-ABD.SP. Table 3 also compares the results between male and female participants highlighting a significant difference in absolute ($p \leq 0.01$) in all planes tested but not in normalised strength values.

The correlations between different strength measurements and BIA-related muscle parameters (MV, SMM, and SMI) are summarised in Table 3. Pearson correlation coefficient analysis (95% confidence interval for r) showed a significant correlation ($p \leq 0.01$) between all UE strength and BIA-related muscle parameters. Collectively, UE strength measurements correlated highly to arm SMM (Pearson r: 0.66-0.80) and body (Pearson r: 0.70-0.79) followed by torso (Pearson r: 0.45-0.70). Figure 2 demonstrates the relations between SMM and shoulder strength in elevation (F.FLEX, ABD.SP, ABD) and rotation (INT.ROT, EXT.ROT) planes. There was also a significant correlation between UE strength values and body FFM and lower extremity SMM (results not shown). No correlation was found between UE strength and body FFM%, FM (kg), and FM (%). All strength measurements were also significantly correlated to each other ($p < 0.01$).

DISCUSSION

The study evaluated shoulder muscle strength and segmental body composition in a group of healthy age-matched men and women, and investigated interrelationships between shoulder muscle strength and BIA-measured SMM parameters. This would provide additional information on the BIA-measured SMM of the UE, where existing data is very limited, improve understanding of gender-related differences, and facilitate interpretation of data on muscle strength relative to MV. The majority of participants were between 19 and 44 years old minimising the influence of age-related changes in muscle mass and strength. In a study of whole body SMM in 468 men and women, the SMM was not related to age within the range 18 - 44 years.[26]

Traditional methods for the quantification of SMM such as CT and MRI (by means of CRA) are not practical for the majority of research and clinical set-ups because of associated costs, training requirement, and time issues. Therefore, establishing BIA as an alternative technique would be very useful. Using a BIA technique, which is robustly supported by comprehensive validation studies,[1,2,4-6,25,27] provided a convenient measurement of SMM in the study. Amongst many BIA equations developed for evaluating lean body mass, there have been few equations for predicting SMM. That used in our study was based on principles developed and validated in the pioneering work of Jenssen et al.[5]. We also report SMI values in addition to absolute SMM in order to provide a better comparison of SMM between the genders, as the index adjusts for physique and the mass of non-skeletal muscle tissues. This index has been used in several epidemiological studies and studies of age- and gender-related changes in muscle mass and function.[7,24,25,28]

Significant differences found between men and women for all SMM parameters of whole body, torso, and UE (and also lower extremity, results not reported) highlighted this principal gender-related characteristic. While there is a reasonable body of data on whole-body parameters, data on UE and torso SMM are very limited. Our results on both whole body and segmental parameters are consistent with existing literature.[3,5,8,9,29] supporting the applicability of BIA for estimating SM parameters in various fields of research on human body composition as well as its relation to muscle function and physical performances (e.g. metabolic diseases associated with muscle wasting, ageing and sarcopenia, sports performance and training-induced changes, muscle rehabilitation and conditioning). Reviewing the literature, we were not able to find any comparable SMI data for the UE.

Significant difference in muscle strength between men and women was expected as gender-related strength differences have been widely recognised in the literature for main body muscle groups including shoulder.[30-33] This difference arises mainly from the strong influence of body size on muscle strength.[21,34] Hence body-size-independent strength measurements are important particularly when comparing persons of different body sizes (e.g. athletes/non-athletes, men/women, young/old), or in long-term treatment follow-ups where a change in body mass is expected during the data collection period. In the present study, normalisation of shoulder strength to the SMM of the arm and whole body eliminated body-size dependence and effectively removed the influence of body mass on force and torque. This highlights the fundamental influence of MV in force-generating capacity of the muscles, suggesting that both genders have similar specific force-producing potential. Normalization becomes even more important when addressing gender-related differences in UE strength, as men have more SMM than women in the upper body compared to the lower body.[26]

Muscle function, athletic profiles, or functional movement performance assessed by muscle strength are likely to be confounded by the effect of body or limb muscle mass indicating the importance of using body-size-independent indices of muscle strength. However, there is no consensus on the method by which strength measurements are best normalized, and as a result, conventional normalization to different measures of body size has been applied by different studies.[10,13,17,19] Bazett-Jones et al[17] examined various normalisation methods for the hip strength and described force normalization to body mass as the most effective body-size-independent measure. In a study of shoulder rotation strength, Hurd et al[18] compared normalization techniques using a spectrum of anthropometric parameters and reported the body weight as the most effective parameter for strength normalisation.

The normalisation method used in the present study is based on the principle that force-generating capacity of muscles is direct proportional to their SMM.[11,35] Normalisation of the UE strength (i.e. a body segment) directly to the related segmental SMM or alternatively to whole body SMM would provide a more pragmatic body-size-independent strength assessment. This was supported by the strong correlation of BIA-estimated SM parameters for UE, torso and whole body with all UE strength measurements. This may have important research and clinical implications as the estimation of functional performance from tests of muscle strength needs to be based on normalized muscle strength to avoid the impact of body size on the outcome. While majority of previous studies examining the relation between muscle strength/function and muscle mass used anatomic CSA (ACSA) at a given site as an index of muscle size, recent knowledge suggests that muscle strength and joint torque are more closely related to the MV than ACSA.[10,11,35] Hence, SMM can be considered as more reliable representative variables for evaluating the size–strength relationship as well as gender- and the age-related differences in the muscle strength. Furthermore, MRI and ultrasonic studies have shown that MV is a major determinant of joint torque in UE regardless of athletic training.[35] A limited number of studies examined whether BIA-measured muscle parameters can be related to strength developed by specific muscle groups,[2, 36, 37] but no study evaluated this for UE/shoulder musculature.

CONCLUSION

BIA provided a convenient method for whole body and segmental SMM estimation. Our results suggest that BIA-measured SMM parameters may be effectively used for the normalisation of muscle strength and removing body-size dependence. This readily accessible approach can facilitate the identification of differences in strength between individuals with diverse physical characteristics and improve interpretation of the data. Furthermore, strong correlations between SMM and muscle strength indicated that BIA may be used as an outcome tool for muscle function assessment by assessing relations between muscle volume and strength capability. Future studies should evaluate the methods discussed in this study to further support the normalisation technique applied.

REFERENCES

1. Miyatani M, Kanehisa H, Fukunaga T. 2000. Validity of bioelectrical impedance and ultrasonographic methods for estimating the muscle volume of the upper arm. European journal of applied physiology 82: 391-6.

2. Miyatani M, Kanehisa H, Masuo Y, et al. 2001. Validity of estimating limb muscle volume by bioelectrical impedance. J Appl Physiol 91: 386-94.

3. Shafer KJ, Siders WA, Johnson LK, et al. 2009. Validity of segmental multiple-frequency bioelectrical impedance analysis to estimate body composition of adults across a range of body mass indexes. Nutrition 25: 25-32.

4. Salinari S, Bertuzzi A, Mingrone G, et al. 2002. New bioimpedance model accurately predicts lower limb muscle volume: validation by magnetic resonance imaging. American journal of physiology. Endocrinology and metabolism 282: E960-6.

5. Janssen I, Heymsfield SB, Baumgartner RN, et al. 2000. Estimation of skeletal muscle mass by bioelectrical impedance analysis. J Appl Physiol 89: 465-71.

6. Ishiguro N, Kanehisa H, Miyatani M, et al. 2006. Applicability of segmental bioelectrical impedance analysis for predicting trunk skeletal muscle volume. J Appl Physiol 100: 572-8.

7. Chien MY, Huang TY, Wu YT. 2008. Prevalence of sarcopenia estimated using a bioelectrical impedance analysis prediction equation in community-dwelling elderly people in Taiwan. Journal of the American Geriatrics Society 56: 1710-5.

8. Bracco D, Thiebaud D, Chiolero RL, et al. 1996. Segmental body composition assessed by bioelectrical impedance analysis and DEXA in humans. J Appl Physiol 81: 2580-7.

9. Ling CH, de Craen AJ, Slagboom PE, et al. 2011. Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. Clin Nutr 30: 610-5.

10. Akagi R, Takai Y, Kato E, et al. 2009. Relationships between muscle strength and indices of muscle cross-sectional area determined during maximal voluntary contraction in middle-aged and elderly individuals. Journal of strength and conditioning research 23: 1258-62.

11. Akagi R, Takai Y, Ohta M, et al. 2009. Muscle volume compared to cross-sectional area is more appropriate for evaluating muscle strength in young and elderly individuals. Age and ageing 38: 564-9.

12. Bamman MM, Newcomer BR, Larson-Meyer DE, et al. 2000. Evaluation of the strength-size relationship in vivo using various muscle size indices. Medicine and science in sports and exercise 32: 1307-13.

13. Jaric S. 2003. Role of body size in the relation between muscle strength and movement performance. Exercise and sport sciences reviews 31: 8-12.

14. Metter EJ, Lynch N, Conwit R, et al. 1999. Muscle quality and age: cross-sectional and longitudinal comparisons. The journals of gerontology. Series A, Biological sciences and medical sciences 54: B207-18.

15. Gadeberg P, Andersen H, Jakobsen J. 1999. Volume of ankle dorsiflexors and plantar flexors determined with stereological techniques. J Appl Physiol 86: 1670-5.

16. Fukunaga T, Roy RR, Shellock FG, et al. 1992. Physiological cross-sectional area of human leg muscles based on magnetic resonance imaging. Journal of orthopaedic research : official publication of the Orthopaedic Research Society 10: 928-34.

17. Bazett-Jones DM, Cobb SC, Joshi MN, et al. 2011. Normalizing hip muscle strength: establishing body-size-independent measurements. Archives of physical medicine and rehabilitation 92: 76-82.

18. Hurd WJ, Morrey BF, Kaufman KR. 2011. The effects of anthropometric scaling parameters on normalized muscle strength in uninjured baseball pitchers. Journal of sport rehabilitation 20: 311-20.

19. Jaric S. 2002. Muscle strength testing: use of normalisation for body size. Sports Med 32: 615-31.

20. Jaric S, Kukolj M. 2002. Evaluation of methods for normalizing muscle strength in elite and young athletes. The Journal of sports medicine and physical fitness 42: 141-51.

21. Keating JL, Matyas TA. 1996. The influence of subject and test design on dynamometric measurements of extremity muscles. Physical therapy 76: 866-89.

22. Cornish BH, Jacobs A, Thomas BJ, et al. 1999. Optimizing electrode sites for segmental bioimpedance measurements. Physiological measurement 20: 241-50.

23. Tanaka NI, Miyatani M, Masuo Y, et al. 2007. Applicability of a segmental bioelectrical impedance analysis for predicting the whole body skeletal muscle volume. J Appl Physiol 103: 1688-95.

24. Janssen I, Baumgartner RN, Ross R, et al. 2004. Skeletal muscle cutpoints associated with elevated physical disability risk in older men and women. American journal of epidemiology 159: 413-21.

25. Chien MY, Kuo HK, Wu YT. 2010. Sarcopenia, cardiopulmonary fitness, and physical disability in community-dwelling elderly people. Physical therapy 90: 1277-87.

26. Janssen I, Heymsfield SB, Wang ZM, et al. 2000. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. J Appl Physiol 89: 81-8.

27. Stahn A, Terblanche E, Strobel G. 2007. Modeling upper and lower limb muscle volume by bioelectrical impedance analysis. J Appl Physiol 103: 1428-35.

28. Janssen I, Heymsfield SB, Ross R. 2002. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. Journal of the American Geriatrics Society 50: 889-96.

29. LaForgia J, Gunn S, Withers RT. 2008. Body composition: validity of segmental bioelectrical impedance analysis. Asia Pacific journal of clinical nutrition 17: 586-91.

30. Murray MP, Gore DR, Gardner GM, et al. 1985. Shoulder motion and muscle strength of normal men and women in two age groups. Clinical orthopaedics and related research 268-73.

31. Bohannon RW. 1997. Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. Archives of physical medicine and rehabilitation 78: 26-32.

32. Schlussel MM, dos Anjos LA, de Vasconcellos MT, et al. 2008. Reference values of handgrip dynamometry of healthy adults: a population-based study. Clin Nutr 27: 601-7.

33. Sinaki M, Nwaogwugwu NC, Phillips BE, et al. 2001. Effect of gender, age, and anthropometry on axial and appendicular muscle strength. American journal of physical medicine & rehabilitation / Association of Academic Physiatrists 80: 330-8.

34. Hortobagyi T, Katch FI, Katch VL, et al. 1990. Relationships of body size, segmental dimensions, and ponderal equivalents to muscular strength in high-strength and low-strength subjects. International journal of sports medicine 11: 349-56.

35. Fukunaga T, Miyatani M, Tachi M, et al. 2001. Muscle volume is a major determinant of joint torque in humans. Acta physiologica Scandinavica 172: 249-55.

36. Elia M, Fuller NJ, Hardingham CR, et al. 2000. Modeling leg sections by bioelectrical impedance analysis, dual-energy X-ray absorptiometry, and anthropometry: assessing segmental muscle volume using magnetic resonance imaging as a reference. Annals of the New York Academy of Sciences 904: 298-305.

37. Fuller NJ, Fewtrell MS, Dewit O, et al. 2002. Segmental bioelectrical impedance analysis in children aged 8-12 y: The assessment of regional body composition and muscle mass. International journal of obesity and related metabolic disorders 26: 692-700.

Table1. The participant demographics and gender-related comparisons

Gender	**Age** (Years)	**Height** (m)	**Weight** (kg)	**BMI** (kg/m^2)	**Arm Length** (cm)	**Torso Length** (cm)	**Leg Length** (cm)
Male	30.8±8.**2**	1.77±0.05**	81.1±13.7**	25.9±4.3*	52.5±14.8	52.8±4**	91.7±5.4*
Female	29.7±10.4	1.65±0.06	62.6±9.7	23±3.6	48±13.1	46.3±3.4	88.3±5.3
Total	30.3±9.3	1.71±0.08	71.6±15	24.4±4.2	50.2±14	49.5±5	90±5.5

Data are expressed as means ± SD**. BMI:** Body Mass Index. *Significant gender-related difference by independent t-test at $P< 0.05$ by independent t-test. ** Significant difference between male and female participants at $P< 0.01$ by independent t-test.

Table2. Whole body and segmental composition parameters and gender-related comparisons

Variable	Men (N=22)	Women (N=23)	Total (N=45)
BMI	25.9±4.3*	23.0±3.6	24.4±4.2
Arm MV (L)	3.3±0.6**	2.1±0.3	2.7±0.8
Arm SMM (kg)	3.5±0.6**	2.2±0.3	2.9±0.8
Arm SMI (kg/m^2)	1.1±0.2**	0.8±0.1	1.0±0.2
Torso MV (L)	4.2±0.8**	2.9±0.5	3.5±0.9
Torso SMM (kg)	4.4±0.8**	3.0±0.5	3.7±1.0
Torso SMI (kg/m^2)	1.4±0.2**	1.1±0.2	1.3±0.3
Body Volume (L)	77.9±14.1**	60.6±10.2	69.1±14.9
Body SMM (kg)	31.2±4.7**	20.8±2.5	25.8±6.4
Body SMI (kg/m^2)	11.1±2.7**	8.6±1.9	9.8±2.6
Body FFM (kg)	60.5±7.3**	44.2±3.8	52.1±10.0
Body FFM (%)	75.4±7.4	71.5±6.8	73.4±7.3
Body FM (kg)	20.7±8.9	18.4±7.0	19.5±8.0
Body FM (%)	24.6±7.4	28.5±6.8	26.6±7.3

Data are expressed as means ± SD**. BMI:** Body Mass Index; **SMM**: Skeletal Muscle Mass; **MV**: Muscle Volume; **SMI**: Skeletal Muscle Index. **FFM:** Fat-Free Mass; **FM:** Fat Mass. *Significant gender-related difference by independent t-test at $P< 0.05$. **Significant gender-related difference by independent t-test at $P< 0.01$

Table3. Absolute and normalised shoulder strength measurements and gender-related comparisons

Variable	Men	Women	Total
F.FLEX (N)	105.2 ±25.6*	63.0±12.4	83.6±29.1
F.FLEX/Arm.SMM	30.5±6.1	28.8±4.9	29.7±5.6
F.FLEX/Body.SMM	3.4±0.7	3.1±0.7	3.2±0.7
ABD	98.8±29.2*	60.1±13.0	79.4±29.7
ABD /Arm.SMM	28.6±7.2	27.7±4.9	28.2±6.1
ABD /Body.SMM	3.2±0.8	2.9±0.7	3.0±0.7
ABD.SP	99.7±27.0*	60.4±11.8	79.6±28.5
ABD.SP /Arm.SMM	28.8±6.6	27.9±5.1	28.4±5.9
ABD.SP /Body.SMM	3.2±0.7	2.9±0.6	3.1±0.7
INT.ROT	157.6±40.1*	95.1±18.3	127.1±44.3
INT.ROT/Arm.SMM	45.4±9.1	43.2±7.2	44.4±8.2
INT.ROT/Body.SMM	5.1±1.0	4.6±0.8	4.9±1.0
EXT.ROT (N)	114.6±31.6*	73.7±15.8	92.7±31.8
EXT.ROT/Arm.SMM	33.2±7.8	33.9±7.3	33.5±7.5
EXT.ROT/Body.SMM	3.7±0.8	3.6±0.8	3.6±0.8

Data are expressed as means±SD**. F.FLEX**: Forward Flexion; **ABD**: Abduction; **ABD.SP**: Abduction in the Scapular Plane; **INT.ROT**: Internal Rotation; **EXT.ROT**: External Rotation; **SMM**: Skeletal Muscle Mass.*Significant difference between males and females at $P< 0.01$ by independent t-test.

FIGURE LEGENDS:

Figure1. Schematic representation of the electrode placement for the 3-segment (UE, torso, and lower extremity) bioelectrical impedance analysis (BIA)

Figure2A. Relationships between Arm SMM and shoulder strength in elevation plane. **SMM**: Skeletal Muscle Mass; **F.FLEX**: Forward Flexion; **ABD**: Abduction; **ABD.SP**: Abduction in the Scapular Plane; **INT.ROT**: Internal Rotation; **EXT.ROT**: External Rotation

Figure2B. Relationships between Arm SMM and shoulder strength in rotation plane. **SMM**: Skeletal Muscle Mass; **F.FLEX**: Forward Flexion; **ABD**: Abduction; **ABD.SP**: Abduction in the Scapular Plane; **INT.ROT**: Internal Rotation; **EXT.ROT**: External Rotation