Title

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

Running Title

Skeletal Muscle Mass and Strength

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Abstract

Purpose

Despite increasing interest in bio-impedance analysis (BIA) for estimation of segmental skeletal muscle mass (SMM), published results have not been entirely convincing. Furthermore, a better understanding of the relationship between muscle strength and SMM will be useful in interpreting outcomes of physical/training interventions particularly in groups with diverse body sizes (e.g. men vs women). This study aimed to measure SMM in the upper body (upper extremity and torso), to determine its correlation with muscle strength, and to examine the effects of gender on muscle strength-muscle mass relationship.

Methods

Segmental (upper extremity and torso) SMM and muscle strength in five distinct shoulder planes (forward flexion, abduction in scapular plane, abduction in coronal plane, internal and external rotation) were measured in 45 healthy participants (22 males, 23 females) with mean age 30.3 years. Statistical analysis included independent t-tests, Pearson correlation, and multiple regression analysis.

Results

Men and women differed significantly in body mass (BMI: 25.9 ± 4.3 vs 23 ± 3.6) and SMM ($p < 0.01$). A strong relationship correlation was found between the five shoulder strength measurements and upper extremity SMM ($r = 0.66$-0.80, $p < 0.01$), which was not affected by gender. There was a significant gender difference ($p < 0.01$) in absolute shoulder strength but not after normalisation to the SMM.

Conclusion

BIA-estimated SMM of upper extremity and torso were highly correlated with upper extremity (shoulder) strength independent of gender. SMM may therefore be useful for the normalisation of muscle strength allowing size-independent comparisons of muscle strength in individuals with diverse physical characteristics.

INTRODUCTION

The measurement and monitoring of skeletal muscle mass (SMM) has several applications in the assessment of physical performance. It can assist sport physiologists assessing the impact of training programmes by relating muscle mass to e.g. exercise performance and V_{O2max}, clinicians assessing clinical muscle wasting and its treatment, and physiotherapists monitoring progress during rehabilitation and training programs.

The utility of sophisticated imaging techniques for estimating muscle size, such as muscle anatomical cross-sectional area and muscle physiological cross-sectional area, is limited by the availability of magnetic resonance imaging (MRI) or computed tomography (CT) equipment. A cheaper and readily available 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. State-of-the-art multiple frequency BIA systems, together with recent developments in electrode configurations and analysis software, backed up with comprehensive validation studies against MRI, ultrasound (US), CT, and dual-energy X-ray absorptiometry, have established BIA as a reliable method for the measurement of segmental body composition (Miyatani et al. 2000; Miyatani et al. 2001; Shafer et al. 2009; Salinari et al. 2002; Janssen et al. 2000a; Ishiguro et al. 2006; Chien et al. 2008). Segmental BIA estimates the impedance of body segments (e.g. arm, torso, upper arm, lower arm), from which their segmental composition can be calculated.

There is increasing interest in using BIA techniques for more specific assessment of body composition, including the estimation of SMM, a parameter which is closely related to mechanical function in many health and sport-related conditions (Bracco et al. 1996; Janssen et al. 2000a; Ling et al. 2011). However, this remains a relatively novel approach and lacks an extensive evidence base. Using both BIA and MRI techniques, Janssen et al. determined SMM in a multiethnic group of 388 healthy men and women (aged 18-86 years) and concluded that BIA provided valid estimates of SMM (Janssen et al. 2000a). In another study of 444 healthy volunteers (246 men and 198 women) between 22 and 94 years, Kyle et al. investigated SMM using BIA and dual-energy X-ray absorptiometry and reported BIA as a valid method for estimating SMM, with an error of 5% (Kyle et al. 2003). Miyatani et al. investigated the validity of BIA and ultrasound in estimating upper arm SMM in 26 healthy men and suggested BIA as useful for predicting the SMM of the upper arm with an error of 6% (Miyatani et al. 2000). Despite these encouraging results, concerns remain

regarding the actual accuracy of the BIA technique as an indirect method of SMM estimating. Nevertheless, the method's practicality in many settings and the fact that the error in predicting SMM has been found to be small appear to have outweighed this lack of accuracy (Kyle et al. 2003; Miyatani et al. 2000).

Muscle strength assessment is used as a key test for muscle function, fitness and physical performance in sports and exercises, musculoskeletal science, and other movement-related activities (Akagi et al. 2009a; Akagi et al. 2009b; Bamman et al. 2000; Jaric 2003). Considering the close relationship of muscle strength in the extremity with muscle mass (Gadeberg et al. 1999; Fukunaga et al. 1992), accurate estimation of segmental muscle mass can improve the interpretation of data on muscle strength (Metter et al. 1999). A better understanding of the relationship between muscle strength and muscle mass can help to interpret the impact of body size on the muscle strength when testing groups with diverse physical characteristics (e.g. man vs woman, athlete vs non-athlete) and provide practitioners (e.g. coaches, athletes, physiologists, nutritionists) with meaningful information in evaluating the outcome of training and intervention procedures, predicting performance in relevant functional movement tasks, and preventing injuries. However, there is inadequate information on the relationship between muscle strength and muscle mass in the extremities and clarity is so far lacking about which measures of muscle mass in vivo best predict muscle strength.

In terms of strength differences, women are about 40-60% and 25-30% weaker than men in the upper and lower body, respectively (Kraemer et al. 2001; Shephard 2000). These gender-related differences in muscular strength have been widely attributed to the smaller absolute muscle mass in women (approximately 60% of that of men) (Janssen et al. 2000b). While several factors such as efficient motor unit utilization, motor learning effect and variations in day-to-day activities can affect regional muscle strength and force production capacity, there is evidence that the capability for expression of strength per muscle unit is equal in men and women (Schantz et al. 1983; Shephard 2000). In equally trained men and women the absolute strength difference has been shown to be almost entirely due to the difference in muscle mass (Bishop et al. 1987; Miller et al. 1993). Studies using different techniques (including BIA) to estimate the muscle mass in both genders have commonly reported significantly more appendicular muscle in men than women in both the upper (torso and arm) and lower body (Abe et al. 2003; Gallagher and Heymsfield 1998;

Gallagher et al. 1997; Janssen et al. 2000b; Miller et al. 1993). (In line with those studies, our results reported below indicate significant gender differences in regional and whole body muscle mass).

Expression of muscle strength relative to different body mass parameters has been used in order to normalise muscle strength and reduce the gender-related difference. Although normalisation of strength measurements to the body mass parameters have been recommended to remove variations in body-size dependence (Bazett-Jones et al. 2011; Hurd et al. 2011; Jaric 2002; Jaric et al. 2002; Keating and Matyas 1996) particularly when comparing study populations with different physical characteristics, most studies report only non-normalised strength data, which subsequently confounds muscle function performance assessments based on muscle strength (Jaric 2002, 2003). Furthermore, differences in the normalisation methods used have precluded comparison of the data reported in different studies. There are a limited number of studies looking at to what extent gender differences in strength can be explained by body composition in general and SMM in particular. In two separate groups of athletes (24 male and 25 female swimmers) and non-athletes (23 male and 25 female), Bishop et al. investigated the upper- and lower-body strength in relation to indices of body mass (FFM and fat-free cross-sectional area) and reported that gender differences in strength were eliminated for handgrip, leg press and leg extension strengths but not for curl and bench press measures (Bishop et al. 1987). In another study of 85 subjects, Hosler et al. used multiple regressions to determine the amount of variance in the strength of arms and legs relative to body composition, following which gender differences were eliminated for the lower extremity strength (Hosler and Morrow 1982). Neither study used the segmental SMM for the normalisation purpose.

In this study, we measured SMM of the upper body (upper extremity and torso) in healthy individuals using a segmental BIA technique. The main aim of this study was to determine whether a relationship exists between BIA-estimated SMM and measures of muscle strength in healthy individuals. A secondary aim was to examine gender effects on this relationship.

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

METHODS

Segmental body bio-impedance and the strength of the shoulder muscle groups were recorded in 45 healthy Caucasian participants (22 males, 23 females). Group demographics are presented in Table 1.

(Table 1 about here)

Bioelectrical Impedance Analysis (BIA)[1]: 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 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 (Bracco et al. 1996; Cornish et al. 1999; Tanaka et al. 2007). The length of the torso and upper extremity 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). Body composition analysis was performed by the associated BIA software (Mi*Stat*, Rayleigh, UK).

(Figure 1 about here)

Shoulder Strength Measurements: Upper extremity (shoulder) movements and measurements were included in this study for two main reasons, First, according to the kinetic chain principles which consider the whole upper extremity as a single functional unit, the contribution of all shoulder girdle segments (hand, lower arm, upper arm, and scapular muscles) is essential for effective shoulder function and movements used in the study (McMullen and Uhl 2000; McMullen 2004); hence, a configuration of electrode placement allowing estimation of the whole upper extremity composition was considered appropriate to assess the relationship of shoulder muscle strength and SMM. Furthermore, the study also reports the torso SMM and its relationship

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[1] Abbreviations: **BIA**: Bioelectrical Impedance Analysis; **BMI**: Body Mass Index; **FFM**: Fat-Free Mass; **SMI**: Skeletal Muscle Index; **SMM**: Skeletal Muscle Mass.

with shoulder strength as major torso muscles (e.g. pectoralis muscles and serratus anterior) contribute considerably to the optimal shoulder function (Terry and Chopp 2000). Furthermore, most previous studies reported on the lower extremity, and hence detailed information on the upper extremity would be valuable.

Shoulder strength was measured using a standardised shoulder Nottingham Mecmesin Myometer (Mecmesin Ltd., Slinfold, UK) during five distinct movements[2]: (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. (Janssen et al. 2000a): 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. This equation has been validated for several populations including Caucasian, African-American, Hispanic, and Asian populations.(Chien et al. 2008; Janssen et al. 2004; Janssen et al. 2000a) with the required adjustments integrated into the software. The SMM index (SMI) for torso and upper extremity 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-

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[2]Abbreviations: **ABD**: abduction; **ABD.SP**: Abduction in Scapular Plane; **EXT.ROT**: External Rotation; **F.FLX**: Forward Flexion; **INT.ROT**: Internal Rotation.

skeletal muscle tissues.(Chien et al. 2010; Janssen et al. 2004) For strength measurements the data are presented as both absolute values (N) and after normalisation to the whole body and upper extremity SMM.

Differences in body composition and muscle strength (before and after normalisation) were examined between men and women (as groups representing diverse body sizes) using independent t-tests. Pearson correlation coefficients were applied to determine the relationships between key upper body composition variables and muscle strength. A simultaneous multiple regression analysis including gender as a dichotomous variable was performed to determine whether muscle strength-muscle mass relationship is affected by gender. 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 upper extremity in men, women, and full study population. A significant difference was noted for major muscle-related parameters (SMM, and SMI) and FFM between male and female participants ($p \leq 0.01$) but no difference in body FM was seen.

(Table 2 about here)

Table 3 presents and compares the absolute mean values (N) for maximal isometric strength in 5 different shoulder planes and following normalisation to the upper extremity 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. Figures 2A and 2B present one of the shoulder strength measurements (Abduction) in men and women before and after normalization, respectively.

(Table 3 about here)

(Figure 2 about here)

Pearson correlation coefficient analysis (95% confidence interval for r) showed a significant correlation ($p \leq 0.01$) between all upper extremity strength and BIA-related muscle parameters. Collectively, upper extremity

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 3 demonstrates the relations between shoulder strength and SMM in elevation (F.FLEX, ABD.SP, ABD) and rotation (INT.ROT, EXT.ROT) planes. All strength measurements were significantly correlated to each other ($p<0.01$). Simultaneous multiple regression analysis of strength and SMM measurements using muscle strength as dependent variable and gender and SMM as independent variables showed that muscle strength-muscle mass relationship was not affected by the gender ($p = 0.090-0.383$) whereas SMM had a significant effect ($p< 0.001$).

(Figure 3 about here)

DISCUSSION

The study evaluated segmental SMM of the upper extremity and shoulder muscle strength in a group of healthy age-matched men and women with a focus on muscle strength-muscle mass relationship and its implications. This would provide additional information on the BIA-measured SMM of the upper extremity, where existing data are very limited, improve understanding of size- and gender-related differences, and facilitate interpretation of data on muscle strength relative to muscle mass.

The BIA technique and SMM prediction equations applied in this study are supported by broad validation studies (Ishiguro et al. 2006; Janssen et al. 2000a; Miyatani et al. 2000; Miyatani et al. 2001; Stahn et al. 2007; Salinari et al. 2002; Chien et al. 2010). Unlike most studies, our study also reports SMI in addition to absolute SMM in order to provide a better comparison of SMM between individuals of varying genders and body sizes, 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 (Chien et al. 2008; Chien et al. 2010; Janssen et al. 2004; Janssen et al. 2002). The majority of participants in our study were between 19 and 44 years old which minimised 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 (Janssen et al. 2000b).

Significant differences found between men and women for all SMM parameters of whole body, torso, and upper extremity (and also lower extremity, results not reported) highlighted this principal gender-related characteristic. While there are reasonable body of data on whole-body parameters, data on upper extremity

and torso SMM are very limited. Our results on both whole body and segmental parameters are consistent with existing literature (Janssen et al. 2000a; Ling et al. 2011; Shafer et al. 2009; LaForgia et al. 2008; Bracco et al. 1996) 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 upper extremity.

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 (Murray et al. 1985; Bohannon 1997; Schlussel et al. 2008; Sinaki et al. 2001). This difference arises mainly from the strong influence of body size on muscle strength (Hortobagyi et al. 1990; Keating and Matyas 1996). While significant correlations were found between all muscle strength measurements and muscle mass, a further multiple regression analysis showed no significant gender impact on the muscle strength-muscle mass relationship. These strongly indicate that in men and women of similar training status, muscle mass is the biggest factor contributing to the gender differences in strength. In agreement with this, previous studies reported that gender and muscle cross-sectional area account, respectively, for 3% (2% of the variance in leg strength and 1% of arm strength) and 97% of the variance in muscle strength in equally trained men and women (Bishop et al. 1987; Hosler and Morrow 1982). Hence body-size-independent strength measurements are important particularly when comparing persons of different body sizes (e.g. athletes vs on-athletes, men vs women, young vs 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 muscle mass in force-generating capacity of the muscles, suggesting that both genders have similar specific force-producing (Schantz et al. 1983; Shephard 2000). Normalization becomes even more important when addressing size- and gender-related differences in upper extremity strength, as men have more SMM than women in the upper body compared to the lower body (Abe et al. 2003; Janssen et al. 2000b).

Muscle function, athletic profiles, or functional movement performance assessed by muscle strength are likely to be confounded by the effect of body or extremity 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 used in different studies (Akagi et al. 2009a; Bazett-Jones et al. 2011; Jaric 2002, 2003). Bazett-Jones et al. (Bazett-Jones et al. 2011) 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. (Hurd et al. 2011) 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 (Akagi et al. 2009b; Fukunaga et al. 2001). Normalisation of the upper extremity 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 upper extremity, torso and whole body with all upper extremity 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 anatomical cross-sectional area at a given site as an index of muscle mass, recent work suggests that muscle strength and joint torque are more closely related to the muscle mass than anatomical cross-sectional area (Akagi et al. 2009a; Akagi et al. 2009b; Fukunaga et al. 2001). Hence, SMM can be considered as yielding more reliable representative variables for evaluating the muscle strength-muscle mass relationship as well as gender- and the age-related differences in the muscle strength. This is further supported by another finding of the study that gender did not have an effect on muscle strength-muscle mass relationship. Furthermore, MRI and ultrasonic studies have shown that muscle mass is a major determinant of joint torque in upper extremity regardless of athletic training (Fukunaga et al. 2001). A limited number of studies examined whether BIA-

measured muscle parameters can be related to strength developed by specific muscle groups (Elia et al. 2000; Fuller et al. 2002; Miyatani et al. 2001), but no study evaluated this for upper extremity musculature.

Study Limitations

The age range of participants could have had an effect on the SMM due to age-related sarcopenia. However, we believe that this will not have had a great impact on the results because of the dominant age range of the participants in our study, whereas that decrease in muscle mass only becomes appreciable after the fifth decade (Janssen et al. 2000b). Another possible limitation would be the selection of shoulder strength for the purpose of muscle strength-muscle mass relationship in the upper extremity. Based on kinetic chain principles no part of musculoskeletal system functions in isolation, meaning that an optimal shoulder force production (muscle strength) requires all segments of the body particularly those in the upper body (whole upper extremity, shoulder girdle, and torso) working together. This justifies using shoulder strength in this study as the key representative segment for whole upper extremity strength. Finally, the level of physical activity and training of the participants and associated contribution from neural control to the expression of strength was not assessed in our study; this might have affected the relationship between the SMM and strength. Longitudinal studies are needed to examine the accuracy of segmental BIA in identifying changes in extremity SMM. Studies during exercise training and therapeutic interventions are required to determine the validity and sensitivity of the technique.

PRACTICAL APPLICATIONS

BIA technique can be used for estimation of extremity SMM outside of specialized laboratories in sports and exercise fields and clinical settings. Results suggest that BIA-measured SMM parameters may be applied 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. The sensitivity of BIA method to detect changes in SM mass in response to nutritional, exercise, and therapeutic interventions is still to be determined.

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FIGURE LEGENDS:

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

Figure2A. Shoulder muscle strength (Abduction) in men and weomen before normalisation to the SMM.

Figure2B. Shoulder muscle strength (Abduction) in men and weomen after normalisation to the SMM.

Figure3A. Relationships between shoulder strength and Arm SMM in elevation plane and related regression equations (Y=A+BX)[3] . **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; **ARMSMM**: Arm SMM.

Figure3B. Relationships between Arm SMM and shoulder strength in rotation plane and related regression equations (Y=A+BX). **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; **ARMSMM**: Arm SMM.

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[3] In the regression equation is 'Y' is the predicted score, 'a' is the Y intercept, and 'b' is the slope of the line.

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)
Male	30.8±8.2 Range: 19 - 46	1.77±0.05**	81.1±13.7**	25.9±4.3*	52.5±14.8	52.8±4**
Female	29.7±10.4 Range: 20 - 49	1.65±0.06	62.6±9.7	23±3.6	48±13.1	46.3±3.4
Total	30.3±9.3 Range: 19 - 49	1.71±0.08	71.6±15	24.4±4.2	50.2±14	49.5±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.

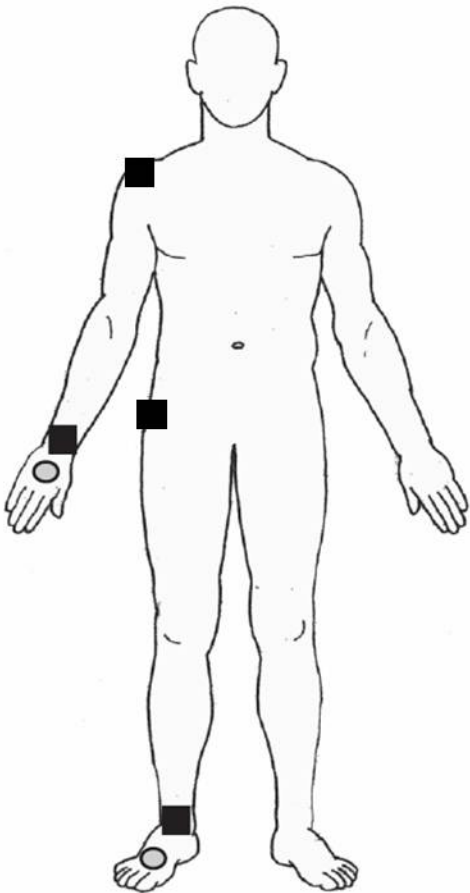**Table2.** Whole body and segmental composition parameters and gender-related comparisons

Variable	Men (N=22)	Women (N=23)	Total (N=45)
BMI	25.9±4.3*	23.0±3.6	24.4±4.2
Arm 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 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 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.
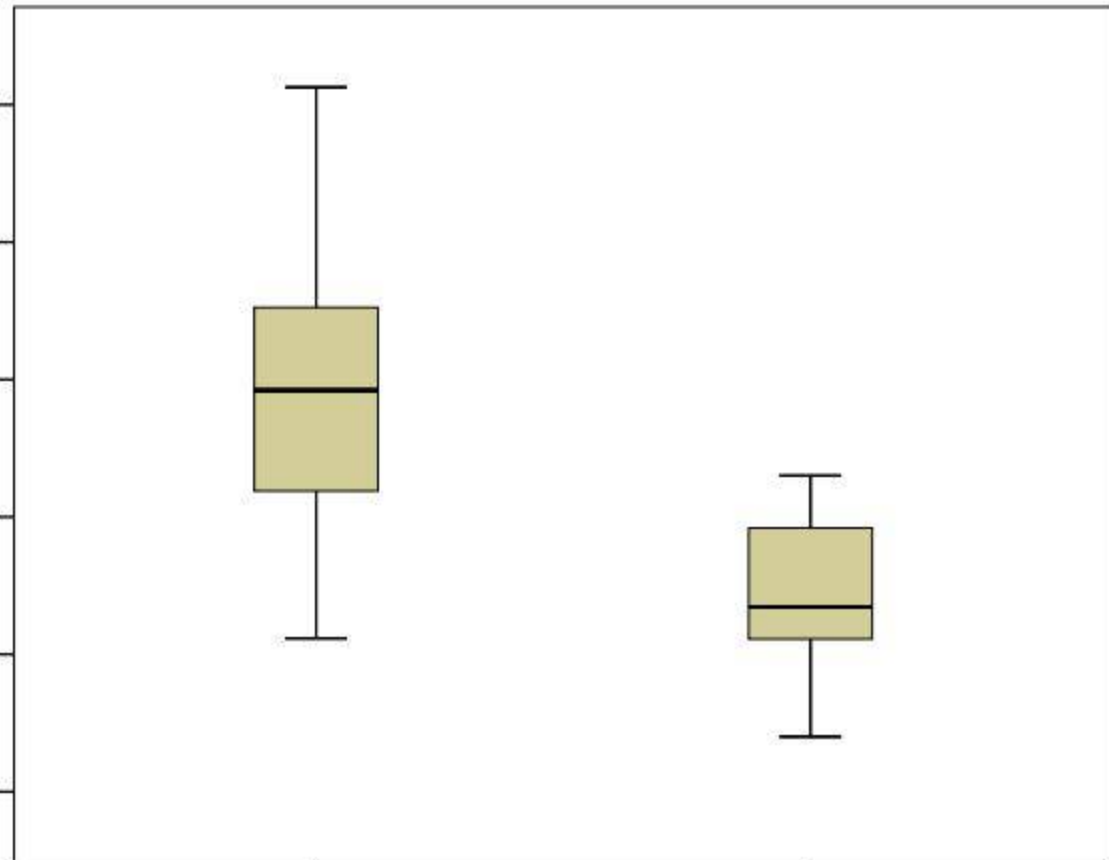
○ Source electrodes

■ Detector electrodes

Figure 3A. Relationship between Arm SMM (kg) and Absolute F.FLEX, ABD, and ABD.SP Strength (N).

- ARMSMM-ABD (3.12+27.04*ARMSMM)
- ARMSMM-F.FLEX (3.42+28.46*ARMSMM)
- ARMSMM-ABD.SP (4.03+26.88*ARMSMM)

ARMSMM-EXT.ROT (16.91+27.26*ARMSMM)
ARMSMM-INT.ROT (-.05+44.67*ARMSMM)
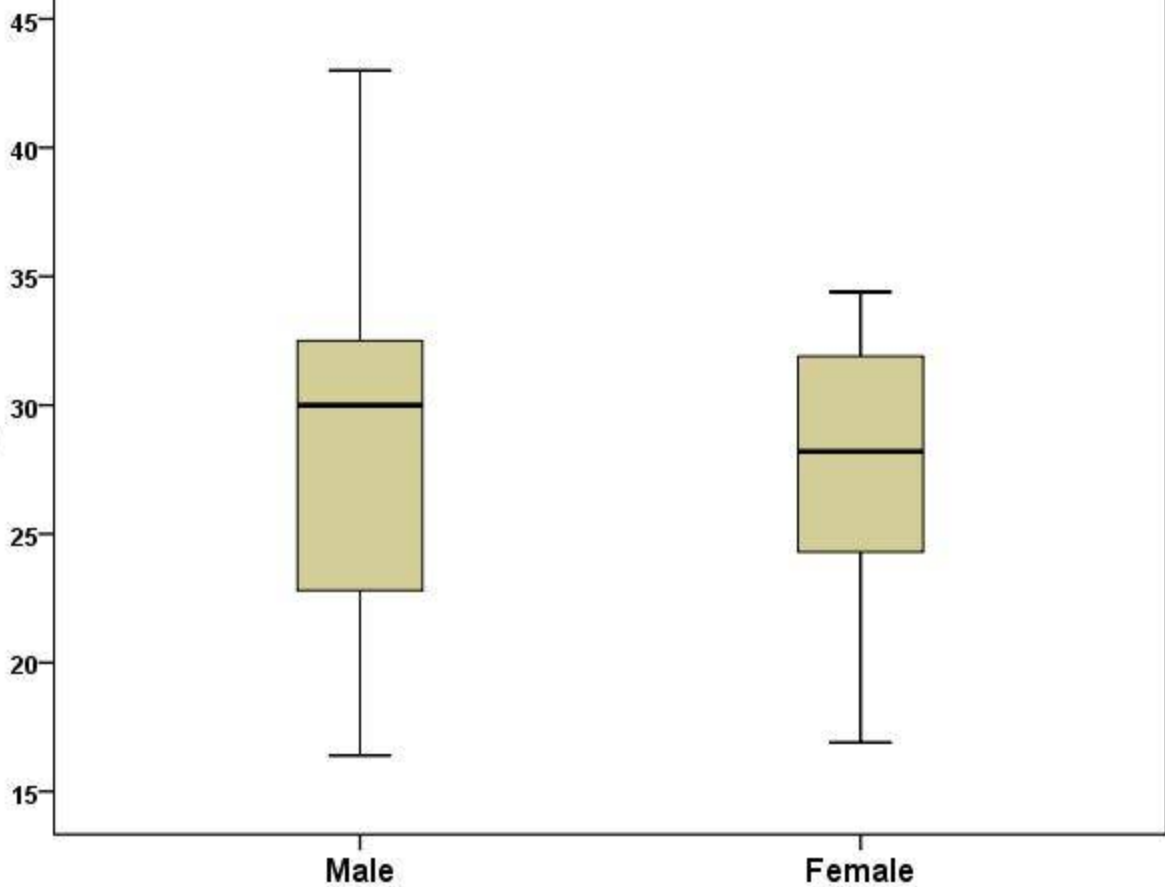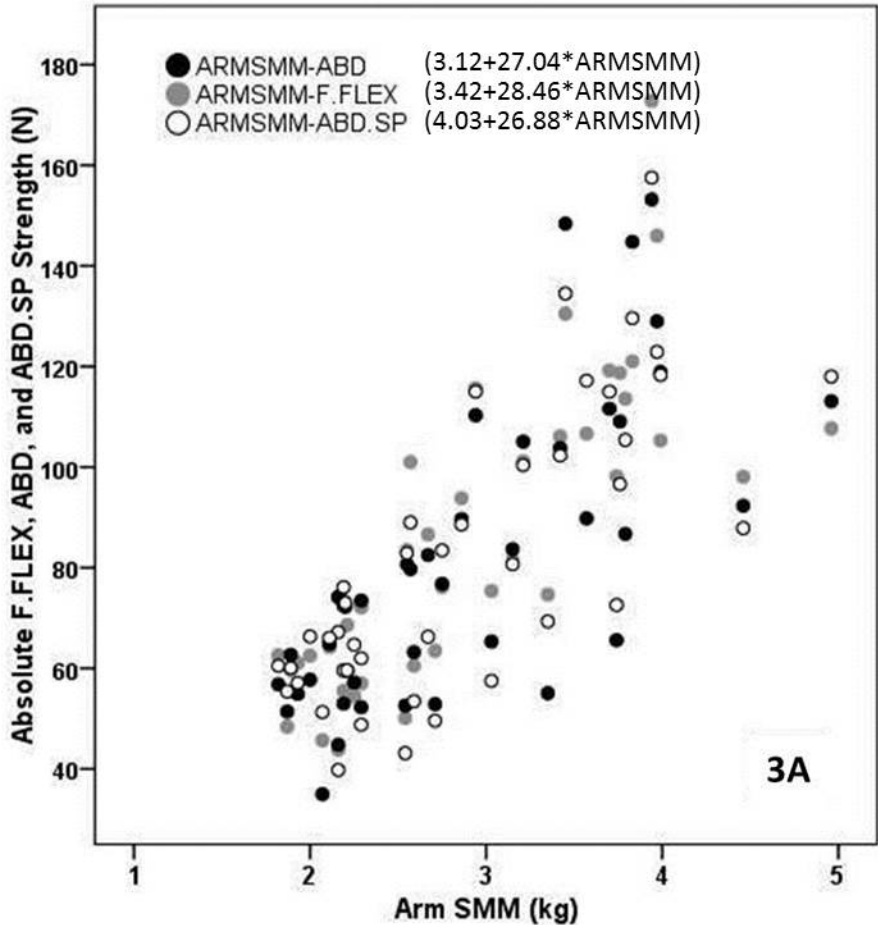
Absolute INT.ROT and EXT.ROT Strength (N) vs Arm SMM (kg)

3B
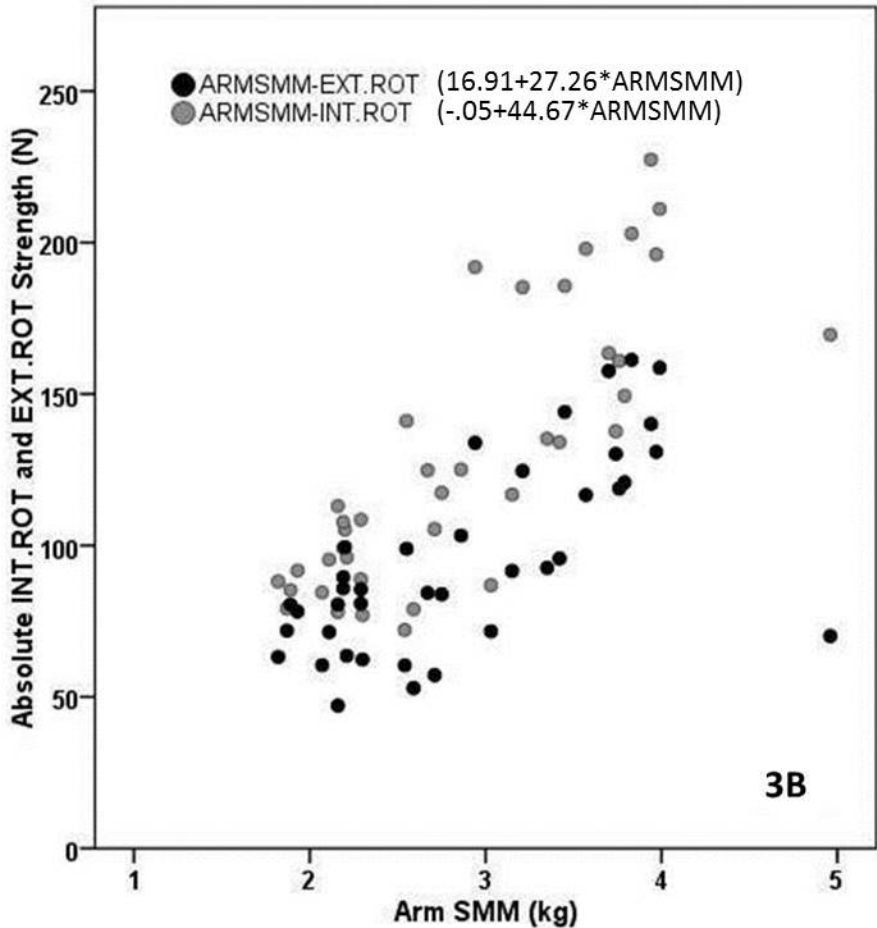
Alphabetic list of abbreviations

ABD	Abduction
ABD.SP	Abduction in Scapular Plane
BIA	Bio-Impedance Analysis
BMI	Body Mass Index
EXT.ROT	External Rotation
F.FLEX	Forward Flexion
FFM	Fat-Free Mass
INT.ROT	Internal Rotation
MRI	Magnetic Resonance Imaging
SMI	Skeletal Muscle Index
SMM	Skeletal Muscle Mass