A comparison between handgrip strength, upper limb fat free mass by segmental bioelectrical impedance analysis (SBIA) and anthropometric measurements in young males

C H Gonzalez-Correa¹, J C Caicedo-Eraso¹,²,³, D R Varon-Serna¹
¹Research Group on Nutrition and Body Composition, University of Caldas, Colombia
²Research Group on Electrical Bioimpedance, University of Caldas, Colombia
³Department of Systems and Informatics, University of Caldas, Colombia

E-mail: clara.gonzalez@ucaldas.edu.co

Abstract: The mechanical function and size of a muscle may be closely linked. Handgrip strength (HGS) is used as a predictor of functional performing. Anthropometric measurements are used to estimate arm muscle area (AMA) and physical muscle mass volume of upper limb (ULMMV). Electrical volume estimation is possible by segmental BIA measurements of fat free mass (SBIA-FFM), mainly muscle-mass. Relationship among these variables is not well established. We aimed to determine if physical and electrical muscle mass estimations relate to each other and to what extent HGS is to be related to its size measured by both methods in normal (n=43) or overweight (n=12) young males. Regression analysis was used to determine association between these variables. Subjects showed a decreased HGS (65.5%), FFM (85.5%) and AMA (74.5%). It was found an acceptable association between SBIA-FFM and AMA ($r^2=0.60$) but poorer between physical and electrical volume ($r^2=0.55$). A paired Student t-test and Bland and Altman plot showed that physical and electrical models were not interchangeable ($p<0.0001$). HGS showed a very weak association with anthropometric ($r^2=0.07$) and electrical ($r^2=0.192$) ULMMV showing that muscle mass quantity does not mean muscle strength. Other factors influencing HGS like physical training or nutrition require more research.

1. Introduction

Health professionals as nutritionists, sport scientists and physiotherapists need to assess upper limb muscle mass quantity and functionality to monitor progress during nutritional treatments, physical training and rehabilitation. Accurate methods to perform these evaluations as computed tomography (CT), dual energy x-ray absorptiometry (DEXA) or magnetic resonance imaging (MRI), among others, are cumbersome and expensive. Handgrip strength (HGS) test is widely used as a functional parameter and is a good predictor of mortality from all-causes, cardiovascular disease and nutritional status [1]. The test is portable, quick, inexpensive and easy to measure [2]. HGS results may be influenced by the arm muscle mass volume (AMMV) [3]. Traditionally, anthropometric measurements of arm-muscle-area (AMA) or physical upper limb muscle mass volume (ULMMV) have been used to this purpose but errors behind their assumptions limit their use [4]. An alternative is the estimation of electrical ULMMV by segmental BIA (SBIA). Several studies have been performed to study lower limb estimations of body composition due to the importance of these limbs to independent life. Studies of the upper limb, composition, are scarce but equally important in health assessment. Therefore, we wanted to know whether ULMMV estimated by these two methods associate to each
other and to what extent HGS is to be related to its muscle size when measured by both methods in a
group of normal or overweight young males.

2. Materials and methods

2.1. Subjects and data acquisition

The procedures were approved by the Bioethics Committee of the University of Caldas. The purpose
and methods of the study were explained to a sample of 55 young college males. Inclusion criteria
were: being male, aged 18 to 30 years and with no comorbidities. Exclusion criteria were: having
muscle diseases or arthritis, being a smoker, having metal implants or pacemakers or be using
diuretics. All measurements were performed in one session by the same researcher. Relative humidity
and environment temperature were kept stable (63.9±1.5% and 22.4±1.0 °C) by using an electric
heater (BFH416 by Bionaire®) and a dehumidifier (BMD100 by Bionaire®). These variables were
measured with a thermo-hygrometer (13307 by DeltaTrak®, ±0.1 °C). Volunteers were asked to
comply with standardized requirements before the test [5].

2.2. Anthropometric measurements

Height (Heightronic-235 by Seca®, ±0.01 cm) and weight (PP2000 by Icob-Detecto®, ±0.1 kg) were
measured twice. A third measurement was taken if there was a difference greater than 0.5 cm or 0.1 kg
respectively [6]. Subjects were characterized as normal or overweight according to BMI [7]. Mid
upper circumference was measured twice at the mid point length between acromion and olecranon.
The triceps skin fold was measured in the midline of posterior aspect of the arm, at a point midway
between the lateral projection of the acromion process and the inferior margin of the olecranon. AMA
was calculated and the reference values were taken from Frisancho et al, 1974 [8]. For SBIA
measurements the circumferences at the site of voltage-electrodes were measured. The distance-length
between the centers of voltage-detector electrodes were measured accurate to 0.1 cm. Physical
volume (Vp) was calculated as by

\[ Vp = \frac{\pi L}{3}(r_1^2 + r_1r_2 + r_2^2) \]

where L is the distance between the detector electrodes, and \( r_{1,2} \) is the radius of the circumferences of the upper limb at the detector electrodes [9].

2.3. SBIA measurements

Bioelectrical impedance measurements (Hydra 4200 by Xitron Technologies©) were made on the
dominant side of body for three times on a nonconductive surface and after resting for 5 minutes [10].
Subjects were in a supine position with the limbs comfortably abducted. Two current-injection
electrodes (2228 by 3M®) were placed on the dorsal surface proximal to the metacarpal-phalangeal and
the lateral projection of acromion process and the center of two-voltage-detector electrodes were
placed on the mid-line between the prominent ends of the right radius and ulna of the wrist and in the
axillary fold [11]. Raw data of resistance and reactance (800 µA at 50 kHz) were used to calculate
impedance \( Z_{50} \) and estimation of FFM was made by equations for segmental measurements from the
BIA analyzer manufacturer. Because reference values for SBIA-FFM were not available for this
population, we used the FFM mean of our subjects with normal BMI, HGS and AMA as reference.
This value was FFM=2.93 kg. In addition, the values of impedance \( Z_{50} \) were compared with values
from Organ, 1994 [12]. The electrical volume (Ve) was calculated as

\[ Ve = 4\pi (L^2/R) \]

where \( \rho \) is the resistivity of skeletal mass (118 Ω.cm) [9], L is the distance between the detector electrodes and R is
the measured resistance.

2.4. Handgrip strength

HGS was measured on the dominant side 3 times using a hydraulic dynamometer (Baseline®, ±1 kg)
and following the guidelines of the American Association of Hand Therapists [13]. Subjects were
categorized as normal if they had greater than 85% from the reference values extracted from
Mathiowetz [14].
2.5. Statistical methods

Characteristics of the subjects and laboratory conditions were expressed as mean and standard deviation (SD). Subjects with %HGS, FFM, AMA, and $Z_{50}$ out of references values were expressed as percentage. Regression analysis method ($\alpha=0.05$) was used to determine association of SBIA-FFM with AMA and Vp with Ve; and later between %HGS by AMA, SBIA-FFM, Vp and Ve. A paired Student t-test and a Bland and Altman analysis were used to determine significant differences between Vp and Ve ($p<0.05$).

3. Results

Table 1 shows subject’s characteristics and percentage of individuals having decreased or increased values for different variables according to reference values. The data distribution was normal for subjects with normal (n=43) and overweight (n=43) BMI. Except for %HGS, all variables showed significant differences among the 2 groups. When values of $Z_{50}$ for upper limb were compared with values from Organ, 1994 [12], it was found that subjects with normal BMI had more regional fat mass than subjects categorized as overweight (83.7% vs. 58.3%). Figures 1a and 1b show the regression of SBIA-FFM by AMA ($r^2=0.60$) and Vp by Ve ($r^2=0.55$). A paired Student t-test and a Bland and Altman plot (Figure 1c) show that Vp and Ve were not interchangeable ($p<0.0001$). Regression analysis of %HGS by anthropometry showed a very weak association with AMA ($r^2=0.219$) and with Vp ($r^2=0.070$) as well as with electrical variables, SBIA-FFM ($r^2=0.204$) and Ve ($r^2=0.192$).

| Variables         | Mean  | SD   | Normal (A) | Overweight (B) | All (A+B) | Significant differences |
|-------------------|-------|------|------------|-----------------|-----------|------------------------|
| Age (years)       | 19.8  | 1.9  | 43 (78.2%) | 12 (21.8%)      | 55 (100%) | < 0.0001               |
| Height (cm)       | 171.1 | 6.2  | 30 (54.5%) | 6 (10.9%)       | 36 (65.5%) | 0.092                 |
| Weight (kg)       | 66.8  | 8.3  | 39 (70.9%) | 8 (14.5%)       | 47 (85.5%) | 0.002                 |
| BMI (kg/m²)       | 22.7  | 2.3  | 43 (78.2%) | 12 (21.8%)      | 55 (100%) | < 0.0001               |
| %HGS (%)          | 80.9  | 13.2 | 30 (54.5%) | 6 (10.9%)       | 36 (65.5%) | 0.092                 |
| FFM (kg)          | 2.6   | 0.3  | 39 (70.9%) | 8 (14.5%)       | 47 (85.5%) | 0.002                 |
| AMA (mm²)         | 5162.2| 910.4| 35 (63.6%) | 6 (10.9%)       | 41 (74.5%) | 0.003                 |
| Physical volume (L)| 3.3   | 0.4  | 30 (54.5%) | 5 (9.1%)        | 35 (63.6%) | 0.005                 |
| Electrical volume (L)| 1.2  | 0.2  | 31 (56.4%) | 5 (9.1%)        | 36 (65.5%) | 0.009                 |
| Z (Ω)             | 212.9 | 24.0 | 36 (65.5%) | 7 (12.7%)       | 43 (78.2%) | 0.003                 |

*Increased variable; **Decreased variable; #: number of subjects; %All: % of all subjects

Figure 1. (a) Regression of SBIA-FFM by AMA ($r^2=0.60$), (b) Regression of Vp by Ve ($r^2=0.55$), (c) Bland and Altman plot of Ve against Vp.

4. Discussion and conclusion

The study tested the hypothesis that the greater the upper limb muscle mass volume (ULMMV), measured by two methods, the greater %HGS. We also expected that overweight subjects had affected HGS because of muscle fat infiltration [15]. It was remarkable that subjects with normal BMI had decreased %HGS and AMA, and increased arm $Z_{50}$ in a greater proportion than overweight subjects.
We did not measure total body fat; however, according to the two level body composition model, the results suggest that overweight was due to a larger amount of lean body mass and not because a higher fat mass as it was corroborated by Z\textsubscript{50}. Maybe, they had more physical training than subjects with normal BMI but this issue was not addressed in this study. This highlights the need for a nutritional assessment beyond the BMI. The results showed an acceptable association between SBIA-FFM and AMA (\(r^2 = 0.60, r = 0.77\)) and between anthropometric and electrical volume (\(r^2 = 0.55, r = 0.74\)). The former association would suggest a discrete similitude of muscle mass estimations by the two methods as some authors have shown [16] but the methods were not interchangeable. Evaluations of thigh physical and electrical muscle mass volume against DEXA [9] or MRI [17], showed that V\textsubscript{p} correlated with fat mass and Ve was a better predictor of muscle mass volume. This would lead us to suggest using SBIA instead of anthropometry for lean tissue assessment. Nonetheless some studies have found that SBIA tends to underestimate ULMMV in men from 5% [18] up to 20% [19] and more research is required to define the accuracy of SBIA. It appears that subjects with normal and overweight BMI had consistent results for %HGS and ULMMV and that a loss of HGS was accompanied by decreased physical and electrical volumes. Nevertheless, HGS as functional parameter showed a very weak association with SBIA-FFM, AMA, V\textsubscript{p} and Ve parameters, and these variables did not explain satisfactorily the high percentage of subjects with loss of HGS. Therefore, the results suggest that muscle mass quantity does not mean muscle strength, agreeing with some authors [20]. Other variables, like physical training or nutrition could explain the loss of HGS and prospective studies to exam the association between loss of muscle mass and physical function may be warranted. Many studies have been performed to exam and associate lower limb composition and muscle strength and have shown little association between muscle mass size and function but fewer studies have made for upper limb. This study suggests that results for upper limb are similar to those examining lower limb.

References

[1] Gale CR, Martyn CN, Cooper C, Sayer AA 2007 Int J Epidemiol 36 228-35
[2] Bohannon RW 2008 J Geriatr Phys Ther. 31(1) 3-10
[3] Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinková E and Zamboni M 2010 Age Ageing 39 (4) 412-23
[4] Lukaski HC 1996 Human Body Composition. Chapter 6. (Human kinetics Ed)
[5] Gonzalez-Correa CH, Caicedo-Eraso JC 2012 J. Phys. Conf. Ser. 407 012018
[6] Lohman TG, Roche AF and Martorell R 1988 Anthropometric standardization reference manual
[7] WHO, 2011 Global status report on non-communicable diseases 2010 Annex 4
[8] Frisanche AR, 1974 Am J Clin Nutr. 27(10) 1052-8
[9] Lukaski HC 2000 Ann N Y Acad Sci. 904 154-8
[10] Xitron Tech 2007 Hydra ECF/ICF (Model 4200) Operating Manual
[11] Chumlea WC, Baumgartner RN and Roche AF 1988 Am J. Clin Nutr. 48 (1)7-15
[12] Organ LW, Bradham GB, Gore DT, Lozier SL 1994 J. Appl Physiol. 77 (1) 98-12
[13] Innes E 1999 Aust Occup Ther J. 46 (3) 120-40
[14] Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M and Rogers S 1985 Arch Phys Med Rehabil. 66 (2) 69-74
[15] Delmonico MJ, Harris TB, Visser M, Park SW, Conroy MB, , Boudreau R, Manini TM, Nevitt M, Newman AB and Goodpaster BH 2009 Am J. Clin Nutr. 90(6) 579-85
[16] Casanova M, Rodríguez I, Rico S and Casanova M 2004. An Pediatr. 61(1) 23-31
[17] Stahn A, Terblanche E and Strobel G 2007 J Appl Physiol. 103 (4) 1428-35.
[18] Mally K, Trentmann J, Heller M and Dittmar M 2011 Eur J Appl Physiol. 111 (8)1879-87
[19] Jung-Jui C, Meng-Feng K, Chih-Lin C, Hsueh-Kuan L, Ming-Chang W, Yu-Yawn C and Kuen-Chang Hsieh 2011 Acad. J. 6 (24) 5131-7
[20] Visser M, Deeg DJ, Lips P, Harris TB and Bouter LM 2000 J Am Geriatr Soc 48 (4)381-6