Arm cross-section areas: technical implications and applications for body composition and maximal dynamic strength evaluation

Fernando A.M.S. Pompeu[1], Daniele Gabriel[1], Bianca Gama Pena[1] and Pedro Ribeiro[1]

ABSTRACT

Arm muscular tissue and fat ring areas can be evaluated by anthropometric measures. The objective of this study was to investigate the application of one technique that infers these areas to estimate body adiposity and the maximal strength of upper limbs and trunk, as well as its objectivity. For that, a sample of 40 healthy men (25 ± 6 years; 72.6 ± 9.4 kg) was divided in two groups: VI (n = 30) internal validation and VE (n = 10) external validation. It was determined to VI the muscle area (A_{MB}), fat absolute area (A_{GB}) and fat percentile upper-arm area (A_{PB}) using the values of circumference and triceps skinfold, as well as the sum of seven and eight skinfold thickness (Σ_{8DC}) and the maximal weight lifted in bench press (1-RM) by two evaluators separately (A and B). In VE only A_{MB} and 1-RM were obtained. Multiple and simple regression analyses and *Student t*-test were applied ($\alpha \leq 0.05$). The variance of Σ_{8DC} was explained in 93% (*EPE* = 14.6 mm) from A_{GB} and weight, the A_{MB} explained in 66% (*EPE* = 9 kg) of the 1-RM variance by itself and there was no significant difference between the maximal weight measured and predicted in VE group. Satisfactory intraclass correlations between the evaluators to A_{MB} (*ICC* = 0.99), A_{GB} (*ICC* = 0.96) and A_{TB} (*ICC* = 0.99) were also found. Therefore it may be concluded that the anthropometric technique that infers muscle and fat upper-arm areas can be used with good agreement between evaluators to estimate body adiposity and upper limbs and trunk strength.

Key words: Upper-arm muscle area. Upper-arm fat percentile area. Body adiposity. Limbs and trunk maximal strength. Bench press.

INTRODUCTION

Several valid and precise techniques(1,2) to infer body composition have been developed. These quantifications depend on complex and expensive laboratorial procedures. In face of these difficulties, the accurate study of body composition is yet infeasible or imprecise for a large number of professional from the sports area. The development of simpler, less expensive and precise techniques becomes necessary for field applications. One of the techniques may be the estimation of the fat tissue and the upper arm muscle mass. These inferences are based on anthropometric measures that enable both the resolution of problems related to body adiposity as well as problems related to muscular strength(2).

Himes *et al.*(3) suggested that the inference technique of tissue areas is effective for the prediction of the body fat absolute weight; however, this technique would be ineffective for the estimation of the body density and fat percentile. Until this moment, no similar study was performed with the Brazilian population. These studies are necessary, once the anthropometric inferences of the body composition are population-specific. Thus, doubts with regard to the employment validity of the fat percentile upper-arm area for the estimation of the body adiposity still remain.

The inference anthropometric technique of the muscular area and upper-arm fat proceeds from abstractions derived from calculations of concentric circle areas. However, as the arm is not a perfect cylinder, the fat distribution around it is not homogeneous. Thus, this technique may not be satisfactorily precise. Also considering that the variation between evaluators for the skinfold technique on the estimation of the body adiposity may exceed 200%(4), the validity and objectivity study of the arm tissue areas determination technique is relevant.

The accurate estimation of the upper-arm muscular area should present a good relation with the maximal voluntary strength (FVM)(5). For the measure of the FVM, the free bench press exercise may be employed. The maximal load lifted once (1-RM) in this exercise presents high correlation with the same test performed for other muscular groups of trunk and upper limbs(6). In the practical application field, the FVM indirect estimation may minimize the risks of articular and muscular lesions, besides other possible injuries during the performance of maximal load tests in muscular exercise gyms.

This study, therefore, had as objectives: a) to determine and to evaluate the relation between the upper-arm fat area (A_{GB}) and other anthropometric variables such as the body adiposity (Σ_{8DC}); b) to verify if the inclusion of the biceps skinfold thickness in the calculation of the A_{GB} improves the relation of this area with body adiposity; c) to evaluate the relation between upper-arm muscular area (A_{MB}) and trunk and upper limbs strength; and d) to assess the subjectivity of the technique on the inference of the upper-arm muscular area (A_{MB}) and upper-arm fat area (A_{GB}).

METHODS

Forty healthy male individuals and students from the Physical Education course (EEFD/UFRJ) who had experience on counter-resistance exercises were volunteers in this study. These individuals were randomly divided into two groups namely: VI (n = 30), internal validation, and VE (n = 10), external validation. Each individual signed a consent form in which all procedures adopted as well as the possible risks were described.

Anthropometry

Two independent evaluators (A and B) measured weight, height, skinfold thickness and the right arm circumference. The arm perimeter was measured at the mid point between the acromion and the olecranon, and the individuals remained at orthostatic position with the upper limb extended and relaxed. The chest, biceps, triceps, medium axillary, subscapular, suprailiac, abdominal, anterior crural and sural skinfold thickness were also measured, followed by standardization proposed by Pollock *et al.*(7). Weight and height

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1. Exercise Physiology Laboratory (LABOFISE) – Department of Biosciences and Physical Activity – Rio de Janeiro Federal University (UFRJ) – Rio de Janeiro.

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Correspondence to: Fernando A.M.S. Pompeu, Av. Brigadeiro Trompowski, 212, Cidade Universitária, Ilha do Fundão – 21941-590 – Rio de Janeiro, RJ. Fax: (21) 2562-6801, e-mail: pompeu@eefd.ufrj.br

were measured according to Gordon *et al.*[8]. For the two last measures, a mechanical balance (FILIZOLA®, Br), for the arm circumference, a metallic measure tape (SANNY®, Br) and for the skinfolds, a skinfold caliper (LANGE®, USA) were used.

The body adiposity was estimated through the sum of skinfold thickness mentioned above. The biceps and triceps (Σ_{7DC}) skinfolds were not employed in this calculation but only the triceps skinfold thickness (Σ_{8DC}), when the two first were included in the calculation of the upper-arm segment area.

Calculation of the arm cross-section area (A_{TB}) and its components

The calculation of A_{TB}, A_{MB}, A_{GB} and A_{PB}, was based on procedures described by Frisancho[9,10], thus:

$$A_{TB} = C^2 \div (4 \times \pi) \qquad \text{(Eq. 1)}$$

where:
A_{TB} = arm total cross-section (cm^2)
C = arm circumference (cm)

The arm muscular area (A_{MB}) is calculated as follows:

$$A_{MB} = [C - (T \times \pi)]^2 \div (4 \times \pi) \qquad \text{(Eq. 2)}$$

where:
A_{MB} = arm transversal muscular area (cm^2)
C = arm perimeter (cm)
T = triceps skinfold (cm)

The arm fat area (A_{GB}) was calculated as follows:

$$A_{GB} = A_{TB} - A_{MB} \qquad \text{(Eq. 3)}$$

where:
A_{GB} = arm fat transversal area (cm^2)
A_{TB} = arm total transversal area (cm^2)
A_{MB} = arm muscular transversal area (cm^2)

Finally, the arm fat percentile area (A_{PB}) was calculated as follows:

$$A_{PB} = (A_{GB} \div A_{TB}) \times 100 \qquad \text{(Eq. 4)}$$

where:
A_{PB} = arm fat percentile area (%)
A_{GB} = arm fat transversal area (cm^2)
A_{TB} = arm total transversal area (cm^2)

In this study, the sum of triceps and biceps skinfold measures were also applied for the determination of A_{MB}. When this procedure was performed, these two measures were not applied in the sum of skinfold measures in order to represent the body adiposity.

Maximal voluntary strength test

The equipments used for the test of a maximal repetition (1-RM) were: a bench with a bar support; other bench for feet support; a long-bar dumbbell (HBL) and free weights (WEIDER®, USA). The last two equipments were previously weighted with the objective of confirming the weight announced by the manufacturer. Prior to the beginning of tests, a specific warm-up in the region to be put in motion was performed. Later, the executions of some repetitions only with the bar were employed for the exercise recognition and corrections. The exercise requested consisted of lifting the HBL held up at the shoulders width with hands in pronation up to the xiphoid process and to elevate it once again up to the elbow complete extension. Three attempts were allowed for the determination of the maximal load, employing the two-minute interval for recovery between attempts.

Statistical analysis

The descriptive statistics with average and standard deviation and the *Student t-test* for independent samples were employed for the comparison between groups. For the VE group, the paired *Student t-test* was employed in order to compare the result of the 1-RM measured to the result predicted from the formula deduced for group VI. For the study of the objectivity of $A_{MB,}$ A_{GB} and A_{TB} and for the inclusion of the biceps skinfold in the method, the multiple and linear regression analysis and the calculation of the coefficient of the intraclass correlation (*ICC*) were employed. The level of significance adopted in this study was $\alpha \leq 0.05$. The calculations for this study were performed with the *SPSS for Windows*® applicative.

RESULTS

No significant differences between the anthropometric variables and the load of 1-RM of groups VI and VE (tables 1 and 3) were observed. A matrix of correlation for the parameters studied in group VI was presented in table 2. The body adiposity, determined through the eight skinfold thickness, was explained in 84% by the arm fat area (figure 1). This prediction may be improved through the inclusion of the variable weight, what increased the determination correlation up to 88.2% (Eq. 5). The inclusion of other variable did not improve this model significantly.

$$\Sigma_{8DC} = -22.477 + 3.505\,(A_{GB}) + 0.786\,(\mathit{weight}) \qquad \text{(Eq. 5)}$$

$$r = 0.93 \text{ and } EPE = 14.6 \text{ mm}$$

Applying the equation above (Eq. 5) for data from group VE, non-significant differences were observed between values measured (104.1 ± 31.3 mm) and predicted (95.4 ± 18.7 mm).

The inclusion of the biceps skinfold (A_{GBTB}) did not improve significantly (n = 30, $r = 0.90$, $EPE = 16$ mm, $\Sigma_{7DC} = 23.972 + 3.974A_{G\text{-}BTB}$) the predicting power of the sum of seven skinfold thickness

TABLE 1
Anthropometric data from internal validity group (VI)

Variables	n	Minimum	Maximum	Average	Standard deviation
Age (years)	30	18	45	25	6
Weight (kg)	30	52.9	94.6	72.7	10.0
Height (cm)	30	161.5	197.0	173.8	8.0
CIRC (cm)	30	24.0	34.5	30.3	2.6
1-RM (kg)	30	50.0	112.0	81.6	15.6
Σ_{8DC} (mm)	30	40	184	89	38
Σ_{7DC} (mm)	30	38	175	85	38
A_{TB} (cm^2)	30	45.8	94.7	73.5	12.5
A_{MB} (cm^2)	30	41.1	82.1	57.9	9.3
A_{GB} (cm^2)	30	4.7	38.2	15.6	8.3
A_{PGB} (%)	30	9.9	41.7	20.5	8.7

Where: CIRC = arm circumference, 1-RM = one maximal repetition in free bench press, Σ_{7DC} = sum of subscapular, suprailiac, abdomen, axillary, chest, thigh and leg skinfolds, Σ_{8DC} = sum of subscapular, suprailiac, abdomen, axillary, chest, thigh and leg skinfolds, A_{TB} = arm total area, A_{MB} = arm muscular area, A_{GB} = arm fat area and A_{PGB} = arm fat percentile area.

TABLE 2
Correlation matrix for data from group VI

	Age	Weight	Height	CIRC	1-RM	Σ_{7DC}	Σ_{8DC}	A_{TB}	A_{MB}	A_{GB}	A_{PGB}
Age	1.00	0.20	–0.27	0.30	–0.11	0.33	0.32	0.33	0.13	0.34	0.23
Weight		1.00	0.51**	0.71**	0.24	0.72**	0.74**	0.71**	0.33	0.69**	0.60**
Height			1.00	0.00	–0.04	0.10	0.12	–0.00	–0.04	0.05	0.07
CIRC				1.00	0.62**	0.61**	0.62**	0.99**	0.75**	0.66**	0.48**
1-RM					1.00	–0.09	–0.11	0.60**	0.81**	–0.01	–0.15
Σ_{7DC}						1.00	0.99**	0.61**	0.01	0.90**	0.87**
Σ_{8DC}							1.00	0.62**	0.01	0.92**	0.88**
A_{TB}								1.00	0.74**	0.67**	0.48**
A_{MB}									1.00	0.00	–0.22
A_{GB}										1.00	0.97**
A_{PGB}											1.00

** Significant correlation for the level of 0.01 (2-talhada). CIRC = arm circumference, 1-RM = one maximal repetition in free bench press, Σ_{7DC} = sum of subscapular, suprailiac, abdomen, axillary, chest, thigh and leg skinfolds, Σ_{8DC} = sum of subscapular, suprailiac, abdomen, axillary, chest, thigh and leg skinfolds, A_{TB} = arm total area, A_{MB} = arm muscular area, A_{GB} = arm fat area and A_{PGB} = arm fat percentile area.

TABLE 3
Anthropometric data from external validation group (VE)

Variables	n	Minimum	Maximum	Average	Standard deviation
Age (years)	10	21	24	23	1
Weight (kg)	10	62.9	81.8	71.9	7.1
Height (cm)	10	158.5	183.5	173.2	7.5
CIRC (cm)	10	26.5	33.5	29.8	1.9
1-RM (kg)	10	68.0	112.0	84.2	16.2
Σ_{8DC} (mm)	10	60	156	104	31
A_{TB} (cm²)	10	55.9	89.3	73.1	10.5
A_{MB} (cm²)	10	39.9	74.8	55.7	10.6
RM_P (kg)	10	57.2	104.6	78.8	14.2
A_{GB} (cm²)	10	10.1	27.2	17.4	6.0
A_{PGB} (%)	10	14.1	39.2	24.8	8.0
$\Sigma 8DC_{P1}$ (mm)	10	66.4	137.6	96.9	25.1
$\Sigma 8DC_{P2}$ (mm)	10	77.4	122.4	95.4	18.7

CIRC = arm circumference, 1-RM = one maximal repetition in free bench press, Σ_{7DC} = sum of subscapular, suprailiac, abdomen, axillary, chest, thigh and leg skinfolds, Σ_{8DC} = sum of subscapular, suprailiac, abdomen, axillary, chest, thigh and leg skinfolds, A_{TB} = arm total area, A_{MB} = arm muscular area, A_{GB} = arm fat area, A_{PGB} = arm fat percentile area, Σ_{8DCP1} = sum of 8 skinfolds predicted from A_{GB} and Σ_{8DCP2} = sum of 8 skinfolds predicted from A_{GB} and body weight.

(Σ_{7DC}). The data predicted for Σ_{7DC} (106 ± 39 mm) from A_{GBTB} were significantly higher; however, these values presented strong association ($r = 0.99$).

When data from all subjects ($n = 40$) measured by two evaluators (A and B) are compared to each other, a non-significant difference was observed for A_{TB} (A = 73.3 ± 12.0 cm² and B = 72.9 ± 11.8 cm²). This parameter presented good correlation between evaluators (*ICC* = 0.99, *EPE* = 3.20 cm², y = 2.12 + 0.977x). However, a small but significant difference between evaluators for A_{MB} (A = 57.7 ± 9.9 cm² and B = 57.0 ± 10.3 cm²) was observed. This area (A_{MB}) was also strongly associated between evaluators (*ICC* = 0.99, *EPE* = 2.11 cm², y = 11.208 – 0.110x). Finally, the A_{GB} was not different between evaluators (A = 15.5 ± 8.0 cm² and B = 15.9 ± 7.2 cm²) and also presented correlated measures (*ICC* = 0.96, *EPE* = 8.01 cm², y = 7.280 – 0.110x).

In figure 2, it is observed that the A_{MB} presented good correlation with the load of 1-RM test in the free bench press exercise for group VI ($r = 0.81$). The application of the equation presented in this figure for data from group VE did not generate results significantly different between loads measured (84.2 ± 18.3 kg) and predicted (78.8 ± 14.2 kg). These measured and predicted values (1-RM) were well correlated ($r = 0.80$). The arm muscular area estimated with the inclusion of the biceps skinfold (A_{MBBT}) was significantly smaller (52.7 ± 9.4 cm²). The data derived by both methods (A_{MB} and A_{MBBT}) presented strong correlation ($r = 0,97$). The predicting capacity of 1-RM from the application of A_{MBBT} was not improved ($r = 0.78$, *EPE* = 10.0 kg, 1-RM = 13.488 + 1.293 A_{MBBT}).

DISCUSSION

The several methods proposed for the estimation of the body adiposity through anthropometric variables generally use diameters, circumferences, height of limbs and skinfold thickness. Despite the large number of anthropometric techniques for the study of the body composition, studies correlating specifically fat area of a segment with body adiposity for the Brazilian population were not found. It seems possible to expect a satisfactory predicting power of body adiposity from technique for the segment study, once the incidence of the gynoid fat distribution is prevalent in women and android in men. This hypothesis may be confirmed through results of the present study, which suggest with good external validity that the A_{GB} combined with weight may be employed in the estimation of the body adiposity. The modification of this technique through the inclusion of the biceps skinfold thickness did not improve the relation mentioned above. The arm muscular area may also be employed for the estimation of the maximal voluntary strength. In the present work, a good external validity for the relation between the load of 1-RM in the free bench press exercise and the A_{MB} was observed. The parameters of the arm fat and muscular areas may be estimated with satisfactory error between evaluators.

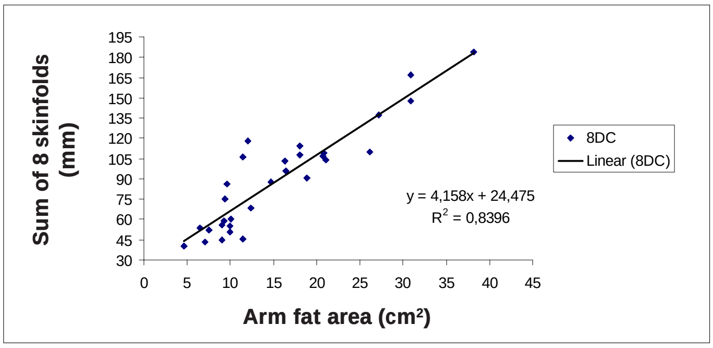

Fig. 1 *– Dispersion diagram between body adiposity (Σ8DC) and arm fat area (group VI)*

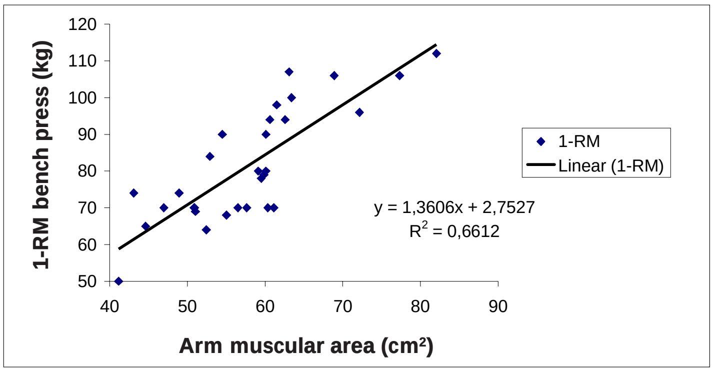

Fig. 2 *– Dispersion diagram between arm muscular area and load in 1-RM test (group VI)*

The proportion between body tissues is changed with the age(8,9,11). The subcutaneous fat tissue increases with the aging(12,14). Based on this phenomenon, in the second half of the 70th decade, Pollock *et al.*(15,16) suggested different equations for the prediction of the body density of women and men from different age ranges. In this procedure, the overestimation of the body density values of older individuals was corrected, including the age in years in the regression equation. Jackson *et al.*(17) and Guedes(18) performed the same correction in their methods and achieved excellent results for the estimation of the body density. More recently(19), a high accuracy on the estimation of the body adiposity was reported from the use of skinfold thickness compared to the method of neutron activation analysis and tritium dilution, when individuals were divided by age ranges. Therefore, it is expected that age plays a relevant role as independent variable. However, in the present study, age has not contributed to improve the relation between A_{GB} and the sum of skinfold thickness. It is observed that the age distribution of subjects from this study was not gaussian, being a positive asymmetry distribution curve (figure 3). Such asymmetry may have reduced the importance of this criterion as predictor.

The estimation error of adiposity through the arm tissue areas method was close to error observed in studies of the body composition. For such comparison, due to the difference on the units adopted (g/mm³, %, kg or cm²), the *EPE* of the method was divided by the average of the group studied; this allowed announcing the *EPE* as average percentage. The *EPE* announced so was similar to *EPE* found in literature(16,20,21) for estimations of the body composition. Durnin and Womersley(22) and Baumgartner *et al.*(23) found indexes (*EPE*) of 22% and 25-30% of the average for the

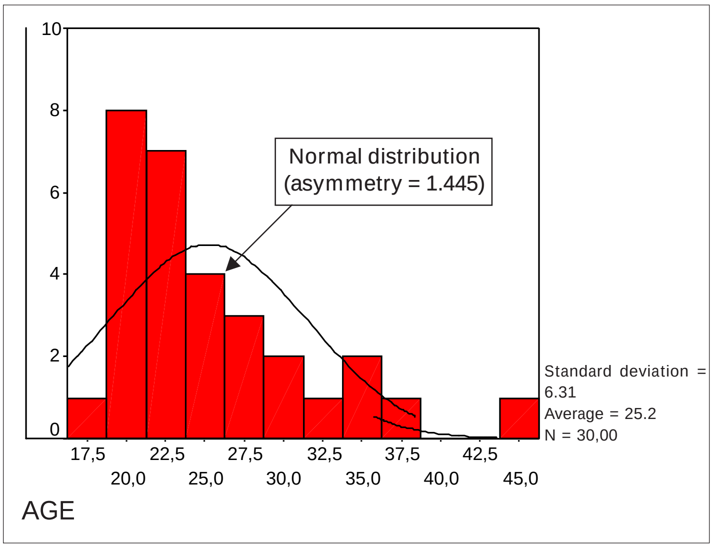

Fig. 3 *– Distribution of age frequencies of group VE*

prediction of fat in men, employing the hydrostatic weighting and the bioelectrical impedance techniques, respectively.

Heymsfield *et al.*(24) studied the possibility of improving the inference technique of A_{GB}, suggested by Frisancho(10,11) and Katch and Hortobagyi(25). Those authors demonstrated that half of the triceps skinfold underestimates the subcutaneous fat tissue radius when determined through computerized tomography. De Koning *et al.*(26) used the sum of the biceps and triceps skinfolds thickness to infer A_{MB} and A_{GB} determined by anthropometry and computerized tomography and found results similar to results from the first study(24). The last study(26) demonstrated that the area calculated through the anthropometric technique underestimated the measure through tomography. In face of such considerations, and considering the present results, the inclusion of the biceps skinfold measure seems not to improve the method.

The variance of the maximal voluntary strength of trunk and upper limbs was explained in 66% through A_{MB}. Other studies also observed correlation between cross-section muscular area with 1-RM in men(27,28). In a study(25), a correlation of A_{MB} for men and women was proposed, comparing values obtained through computerized tomography to values estimated through anthropometry. Such results are based on the hypothesis that the strength of a given muscle is proportional to its cross-sectional area(5,29,30). Thus, besides the technique error(31), it is likely that the involvement of other muscles in the exercise may have affected the FVM prediction. The specific tension values (T_{ESP}) observed in the present study (14.2 ± 1.7 N/cm^2) were close to the variation proposed by Enoka(32) (16 – 30 N/cm^2) for *in situ* experiments. The *t-test* applied between values measured and values predicted of group VE for both the body adiposity and the 1-RM indicates a good external validity. We may, therefore, use the equations expecting acceptable error ranges when individuals similar to those from this study are analyzed. The consideration of the humerus bone area may improve the relations found in the present study. However, the subtraction of 10.0 cm^2 as bone area index, as proposed in the study adopted as reference(9,10), will increase the number of calculations with no alterations of regressions here observed.

Objectivity studies include the intra-evaluator error and the validity of the method. In the case of the present technique the intra-evaluator error seems to be similar to those observed in other investigations. Heymsfield *et al.*(24) obtained variation coefficients of 7.1% for A_{MB} and 1.0% for the arm total area between two evaluators. Other authors also observed satisfactory results for intra-evaluator measures for arm circumference and triceps skinfold separately(30-33). However, a higher objectivity of A_{GB} in relation to A_{MB} is expected due to the smaller area occupied by the fat tissue. Thus, small differences observed in values of circumference and triceps skinfolds will be less evident in A_{GB} than in A_{MB}. The A_{TB} may be determined with lower variation between evaluators, possibly due to the small sum of errors for the attainment of variables A_{TB}, once the skinfold thickness is not employed in this calculation.

Finally, it has been concluded that the inference anthropometric technique of muscular and arm fat areas may be employed with reasonable agreement between evaluators for the estimation of the body adiposity and maximal voluntary strength of trunk and upper limbs.

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