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Estimation of Arm Fat Percentage: from Segmental Bioimpedance to Anthropometry

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Resumen

Introducción: Actualmente no existen fórmulas para estimar el porcentaje de grasa por segmentos del cuerpo a partir de medidas antropométricas. El objetivo de este trabajo fue correlacionar el porcentaje de masa grasa del brazo (obtenido mediante bioimpedancia segmentaria) con medidas antropométricas, para generar una fórmula de predicción válida para ambos sexos. **Métodos:** En este estudio observacional se analizó una muestra de 100 individuos (50 mujeres y 50 hombres) de 18 a 70 años. Se realizó un análisis de bioimpedancia y determinaciones antropométricas según estándares ISAK. **Resultados:** El porcentaje de masa grasa del brazo estimado por bioimpedancia se correlacionó fuerte y positivamente con los pliegues cutáneos del tríceps y bíceps, el área grasa del brazo y su porcentaje de área grasa, en ambos sexos. En las mujeres, el porcentaje de masa grasa del brazo también se correlacionó con el índice de masa corporal, la circunferencia del brazo y el área de los músculos del brazo. **Conclusión:** Mediante una fórmula de regresión lineal aplicable a ambos sexos se puede estimar el porcentaje de grasa del brazo a partir de tres medidas antropométricas.

Palabras Clave: Antropometría, Bioimpedancia, Composición Corporal, Masa Grasa, Bioimpedancia Segmentaria.

Abstract

Introduction: Currently, there are no formulas to estimate the percentage of fat by segments of the body from anthropometric measurements. The objective of this work was to correlate the percentage of arm fat mass (obtained through segmental bioimpedance) with anthropometric measurements, to generate a prediction formula valid for both genders. **Methods:** A sample of 100 individuals (50 women and 50 men) from 18 to 70 years old was analyzed in this observational study. A bioimpedance analysis was performed along with anthropometric determinations according to ISAK standards. **Results:** The percentage of arm fat mass estimated by bioimpedance strongly and positively correlated with the triceps and biceps skin folds, the arm fat area, and its percentage of fat area, in both sexes. In women, the percentage of arm fat mass also correlated with body mass index, arm circumference, and arm muscle area. **Conclusion:** Through a linear regression formula applicable to both sexes, the percentage of arm fat can be estimated from three anthropometric measurements.

Keywords: Anthropometry, Bioimpedance, Body Composition, Fat Mass, Segmental Bioimpedance

Introduction

Bioimpedance analysis (BIA) is a popular and non-invasive method utilized for estimating body composition, particularly in determining body fat percentage. This technique operates on the principle that different tissues within the body conduct electrical currents at varying rates. Developed in the 1960s (Thomasset, 1962) and introduced in the 1980s (Lukaski et al., 1985), BIA has evolved into a widely utilized tool in both clinical and research settings due to its simplicity, portability, and relatively low cost compared to other methods.

More recently, the incorporation of segmental bioimpedance analysis has enabled targeted evaluation of specific body segments, such as the arms and the legs (Cornish et al. ,1999; Lorenzo & Andreoli ,2003). This technique involves the use of multiple electrodes strategically placed on the body to measure impedance at various points along the body (Esco et al., 2015; Campa et al., 2021). By analyzing impedance data from different segments of the arm (or any other segment), segmental BIA can delineate the distribution of fat mass within these regions with greater precision. Moreover, this approach allows for the identification of asymmetries or imbalances in fat distribution between the left and right arms, which may have implications for overall health and fitness (Ward, 2012).

Besides, triceps and biceps skinfold thickness measurements constitute a fundamental component of anthropometric assessments for estimating body fat mass (Durnin & Womersley 1974; Martin et al., 1985; Meyer et al., 2013). These measurements involve the use of calipers to grasp and measure the subcutaneous fat layer at specific sites on the upper arm. The triceps skinfold, typically measured halfway between the acromion process and the olecranon process on the posterior aspect of the arm, reflects fat accumulation in the posterior upper arm region. Conversely, the biceps skinfold, measured at the same level but on the anterior aspect of the arm, provides insight into fat deposition in the anterior upper arm (Lohman, Roche & Martorell, 1988).

Both methodologies are deemed “doubly indirect”, and their precision may be subject to various influencing factors including temperature, hydration status, skin elasticity, and operator technique. However, when employed concurrently or integrated within a multifaceted assessment framework, both BIA and skinfold thickness measurements serve as significant contributors to the comprehensive evaluation of body composition and nutritional status.

Currently, there are no formulas to estimate percentage of fat by segments from anthropometric measurements. Analogous to the estimation of total body fat through the assessment of skinfold thickness, it would be possible and useful to estimate the percentage of fat in body segments such as arms and legs through easily accessible anthropometric measurements. The aim of this study was to establish a correlation between the percentage of fat mass in the arms (derived from segmental BIA) and anthropometric measurements, thereby devising a prediction formula applicable to both sexes.

Material and Methods

An observational study was conducted involving 100 participants (50 men and 50 women) aged between 18 and 70 years, who were opportunistically recruited during routine nutritional consultations. On the day of their consultation, participants underwent anthropometric measurements and BIA, following the provision of written consent to partake in the research. Measurements were conducted in the morning, between 8 and 9 a.m., with participants arriving after a two-hour interval post a light breakfast, and were instructed to refrain from engaging in physical activity within the preceding 12 hours. Notably, the sample encompassed individuals across a spectrum of physical activity levels, ranging from sedentary individuals to highly active athletes.

Anthropometric measurements

ISAK guidelines were followed (Lohman, Roche and Martorell 1988; Esparza-Ros, Vaquero-Cristóbal and Marfell-Jones 2019). The height of the volunteers was recorded with the individuals without shoes, using a stadiometer attached to the wall, with a precision of 0.5 cm. Next, the mid-upper arm circumference was measured, using a flexible inextensible steel tape (Mednib), with a resolution of 1 mm, and the tricipital and bicipital subcutaneous skinfold thickness, using a plastic caliper (SlimGuide), with a precision of 0.5 mm.

Bioimpedance Analysis

It was performed with the Tanita RD-545 HR segmental bioimpedance scale, with the individual wearing underwear, following the manufacturer's instructions. The optimal conditions for foot-to-hand measurements were standardized: body position, previous diet and exercise (Kyle et al. 2004a; Kyle et al. 2004b; Campa et al. 2021). The percentage of fat mass of the right arm was recorded. The body mass index (BMI) calculated with the previously measured height was also recorded, as an approximation of the average body size of each individual, and taking into account that it is not currently considered a tool to assess distribution or quantity of fat (Bray et al. 2023). The Bioimpedance scale used in this study has been used successfully in other investigations (although they focused on estimating muscle tissue in comparison with the dual-energy X-ray absorptiometry analysis (DXA) (Anusitviwat et al., 2023).

Derived measures

Additionally, other derived measures were calculated in order to find better estimators:

- Arithmetic mean of both skinfolds and sum of both skinfolds.

- Arm area: (arm circumference)2 / 4π
- Arm muscular area (using the revised equations of Heymsfield et al. 1982):
- For men: { [Arm circumference – (π × Triceps skinfold thickness /10)] 2 – 10} / 4π
- For women: { [Arm circumference – (π × Triceps skinfold thickness /10)] 2 – 10} / 4π
- Arm fat area: Arm area – Arm muscular area
- Percentage of fat area (“arm fat index”): Arm fat area / Arm area × 100

Statistical Analyses

The GraphPad Prism 8 program (GraphPad Software, Inc.) was used. For descriptive statistics, the minimum and maximum values, the arithmetic mean and the standard deviation are reported. To analyze the normality of the variables, the D'Agostino-Pearson test was used. To compare means of the variables between women and men (Table 1), the Student's t test for independent samples was used (for arm fat and percentage of fat area, which passed the normality test), while for the other variables the Mann – Whitney U test was used (since they failed to pass the normality test). Finally, the Spearman correlation coefficient was analyzed (Figures 1-3) and simple and multiple linear regression analysis was performed (Table 2). The minimum value of statistical significance for rejection of the null hypothesis used in all tests was 0.05.

Results

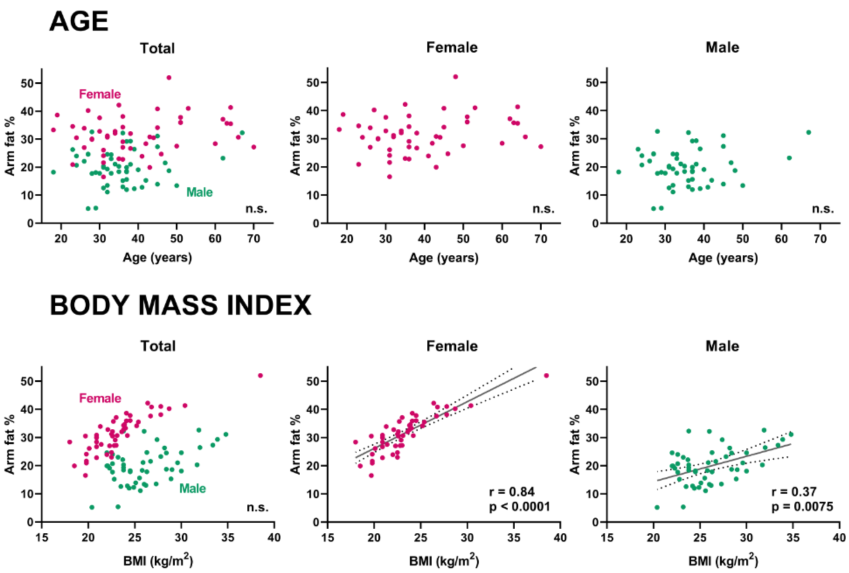

Figure 1. Association between age and body mass index with arm fat

Table 1. Descriptive statistics

	Female				Male				P
	Min	Max	Mean	SD	Min	Max	Mean	SD	
Age (years)	18	70	39.72	13.11	18	67	35.6	9.04	0.2033
BMI (kg/m^2)	18	38.5	23.29	3.42	20.4	34.8	26.18	3.44	<0.0001
Arm fat (%)	16.5	52	31.58	6.75	5.2	32.6	19.91	6.43	<0.0001
Arm circumference (cm)	22.3	39	27.64	2.78	27.4	42.2	33.36	3.06	<0.0001
Triceps skinfold thickness (mm)	6	38	17.02	6.27	2.5	22.5	9.16	4.90	<0.0001
Biceps skinfold thickness (mm)	1.5	18	6.65	3.01	1.5	11	4.22	2.33	<0.0001
Arm area (cm^2)	39.57	121	61.38	13.07	59.74	141.7	89.29	16.69	<0.0001

Arm muscular area (cm^2)	23.54	51.78	33.27	6.29	32.1	124.5	64.78	16.32	<0.0001
Arm fat area (cm^2)	7.07	62.76	21.61	9.68	4.94	42.62	14.51	8.13	<0.0001
Percentage of fat area (%)	12.83	52.67	34.13	8.99	3.71	35.51	16.38	7.93	<0.0001
P: significance of Student's t test (for arm fat and percentage of fat area) or Mann – Whitney U test.									

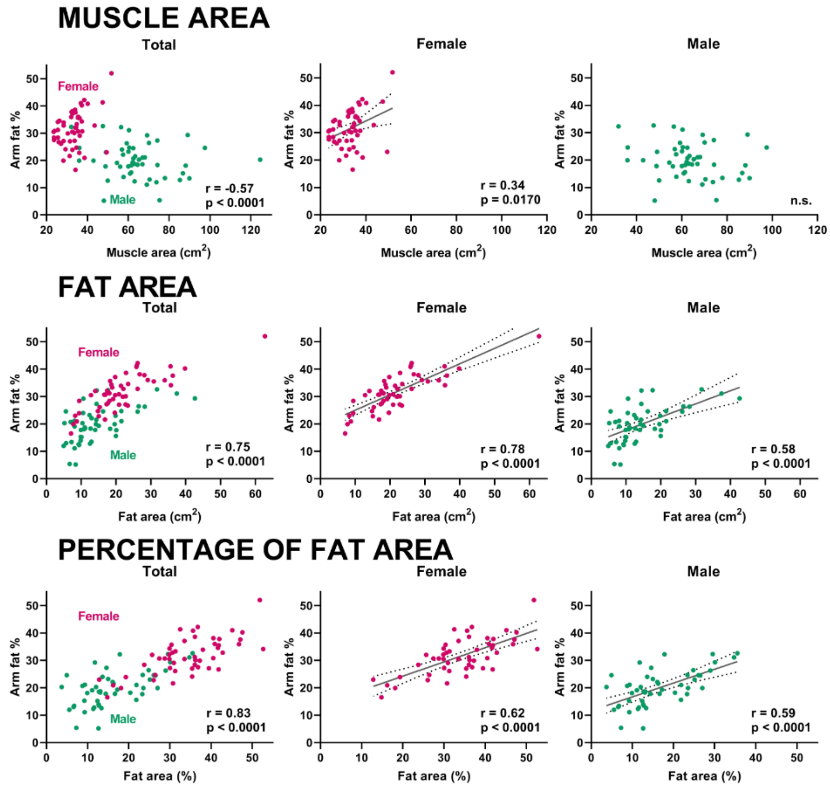

Figure 2. Assoc ith arm fat

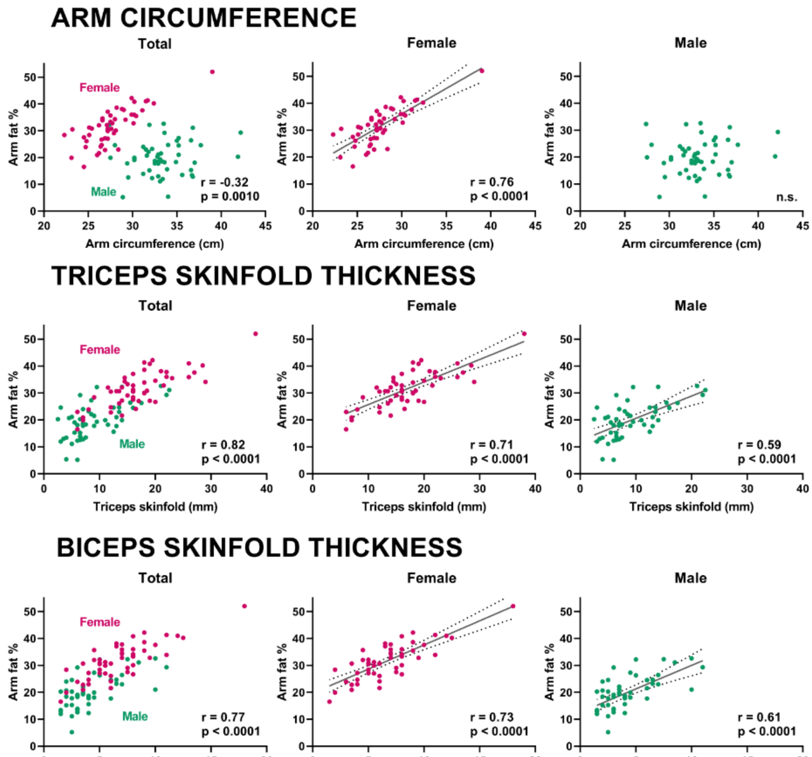

Figure 3. Association between muscle area, fat area, and percentage of fat area with arm fat

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Table 2. Regression formulas to estimate arm fat mass percentage

Model	Formula	r^2	p
1	Arm fat = 23.6 – AC × 0.386 + TS × 0.634 + BS × 1.030	0.711	<0.0001
2	Arm fat = 11.61 + TS × 0.785 + BS × 0.709	0.682	<0.0001
3	Arm fat = 12.004 + TS × 1.05	0.668	<0.0001
AC: Arm circumference; TS: Triceps skinfold thickness; BS: Biceps skinfold thickness			

Discussion

This work is the first report of the relationship between a segmental bioimpedance value and anthropometric measurements obtained according to ISAK guidelines. It also represents the first proposal to estimate the percentage of fat in a segment of the human body through anthropometric measurements, with an acceptable level of precision.

Firstly, as detailed in Table 1, differences were detected between women and men in all measurements carried out. Of special interest is the percentage of arm fat measured by BIA and the thickness of subcutaneous fat folds, which all turned out to be higher in female participants. These findings are in line with previous reports that assume sexual dimorphism in the distribution of body fat, although they have focused more on abdominal fat, trunk fat, and upper half of the legs (Blaak 2001; Veilleux and Tchernof 2012; Bredella 2017).

Second, as detailed in Figure 1, the percentage of arm fat mass was not related to age in either sex. Regarding its association with BMI, it was noted that in the whole sample there is no association, but when analyzed separately in women and men, a high correlation was observed in females. It is striking how the distribution of arm fat mass analyzed according to BMI seems to correspond to two different populations according to sex, since the points form two separate groups in the scatter plot. Again, the relationship between BMI and the amount and distribution of body fat has been the subject of intense study in recent decades, and although positive associations and differences between sexes and ethnicities have been found (Gallagher et al. 1996; Deurenberg, Weststrate and Seidell 1991), currently it does not represent a good indicator of adiposity (Bray et al. 2023).

The percentage of arm fat was then analyzed with direct measurements of the same body segment (Figure 2). The apparent weak negative relationship with upper-mid arm circumference in both sexes can be better understood if women and men are analyzed separately. In this way, a positive correlation between arm circumference and its fat percentage was seen in women, so it can be assumed that much of their arm apparent size is due to the fat component. This association was not observed in males. Furthermore, triceps and biceps skinfolds were positively related to arm fat percentage, both overall and in the sexes separately. This association gains strength when analyzing the complete sample, since, as it was initially seen, men and women have differences in the measurements involved, so the integration of both shows a greater range and a stronger correlation. Among all the measurements analyzed, the triceps skinfold thickness is the one that has always been related to the adipose component of the human body, at all ages and for several decades, both in healthy individuals and in various pathologies (Yin et al. 2022; Nikolaidis, Rosemann and Knechtle 2020, Ribeiro et al. 2022; Addo, Pereira and Himes 2012). The average and the sum of both skinfolds were similarly correlated to the arm fat mass ($r=0.82$, $p<0.0001$ for both, data not shown) and they did not represent a better alternative than the previously mentioned measures.

Finally, the associations between arm fat and the muscular and fatty components of the arm can be seen in Figure 3. The total arm area was not shown in the figure, since its correlations are equivalent to those of the arm circumference. The muscle area was negatively associated with the percentage of fat in the entire sample, but when separating between both sexes it was noticed that the muscle compartment behaves differently between them, in relation to the fat compartment. Again, two separate point clouds are displayed in the scatter plot. Finally, fat area and percentage of fat area were positively correlated, in the entire sample and in the genders separately. As expected, the percentage of fat area was the derived measure that best related to the value obtained by bioimpedance, yielding a correlation coefficient of 0.83 in the entire sample. Once again, two sets of practically separate points can be seen: men towards the left of the scatter plot (with lower fat values) and women towards the right (with higher fat values). The muscle and fat areas of the arm have been extensively studied in recent decades, with special emphasis on childhood and adolescence (Frisancho 1981; Sann et al. 1988; Pereira-da-Silva et al. 1999; Oyhenart et al. 2019). Surprisingly, a 1988 study linked muscle and fat areas of arm sections with bioimpedance analysis and computerised tomography, in what could be considered a precursor to the present study (Brown et al. 1988). In any case, although this research did not evaluate fat as a percentage component as we currently understand it, it was declared that bioimpedance is a better predictor of fat and muscle areas than anthropometry.

Based on these data, and taking into account that the correlations of the complete sample are stronger than those of the sexes separately, since they cover a greater spectrum of the graph, the following formula is proposed to predict the percentage of fat mass of the arm from the three anthropometric measurements of the segment:

Arm fat (%) = 23.6 – Arm Circumference (cm) × 0.386 + Triceps Skinfold (mm) × 0.634 + Biceps Skinfold (mm)× 1.030

This formula explains 71.1% of the variations in the percentage of arm fat based on the three measurements that make it up. Two other formulas were tested and gave significant results, but with a lower r2 (Table 2).

The relevance of the present study lies in the fact that the percentage of fat mass of each arm could be estimated through the proposed regression formula, this way helping to detect potential asymmetries with the same usefulness that the segmental BIA provides. This approach could also be used to estimate percentages of leg fat mass using the corresponding reference skinfolds or other lower limb measurements. On the other hand, this model may not be completely accurate, since it sought to estimate fat from two indirect methods, and not from a more precise method such as DXA. Furthermore, the measurement sites used do not take into account the adiposity of other parts of the upper limb such as the forearm and shoulder, nor the internal fat that may exist beyond that detectable from the skinfolds that are superficial. Future research should bridge these details and help predict the fat compartment of individual limbs from detailed analysis of anthropometric values with a more powerful reference method.

Conclusions

This work is the first report of the relationship between a segmental bioimpedance value and anthropometric measurements obtained according to ISAK guidelines. It also represents the first proposal to estimate the percentage of fat in a segment of the human body through anthropometric measurements, with an acceptable level of precision

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Data availability

Full access to data on request (diego.n.messina@gmail.com).

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Conflicts of Interest

The Author have no conflict of interest to declare

Informed Consent Statement

All the athletes included in the study provided written informed consent.

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