Body composition analysis using bioelectrical parameters in the Cuban sporting population

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Summary

Objectives: The purpose of this study is to provide data on bioelectrical parameters in Cuban sport population, particularly: resistance (R), reactance (Xc), impedance (Z), impedance vector component according to bioelectrical impedance vector analysis (BIVA) and phase angle (PhA), establishing references values on athletes of high performance level.
Material and method: We performed bioelectrical impedance analysis (BIA) in 943 Cuban athletes (620 male, 323 female) of 26 sports modalities. Bioelectric parameters R, Xc, Z and PhA were obtained at 50-kHz frequency and multi-frequency from 1 to 1000 kHz using a multi-frequency measuring device. From these parameters, five bioimpedance ratios were calculated (R/Height, Xc/ Height, Z/ Height, the reactance paralate, and resistence paralate) at 50 kHz. Bioelectrical impedance vectors analysis (BIVA) and Cole-Cole modeled were performed. Once R/Height and Xc/Height were estimated, the BIVA was performed. Mean and standard deviations were calculated for all variables. Unpaired t-test was used to detect differences between sexes. BIVA vectors were compared using Hotelling's T^2 test. To eliminate a null hypothesis about the equality of the examined parameters, we used the level of probability of $p < 0.05$.
Results: Compared to male population, female population had higher R, R/ Height, Xc, Xc/ Height, Z, Z/ Height and lower PhA. The accuracy of specific BIVA was different in the two sexes ($p<0.05$) and according to the Body Mass Index (≤25 and >25). Differences between sports were found in order to Z and PhA.
Conclusions: The study showed that variability of R, Xc, Z and PhA measures depends on gender, body mass characteristics of the study population, and sport.

Key words:
Bioelectrical parameters.
Bioelectrical impedance vector analysis.
Phase angle.
Cole-Cole model.

Análisis de la composición corporal empleando parámetros bioeléctricos en la población deportiva cubana

Resumen

Objetivos: La propuesta de este estudio es proveer datos de parámetros bioeléctricos de la población deportiva cubana, particularmente: resistencia (R), reactancia (Xc), impedancia (Z), ángulo de fase (AF), y los componentes del vector impedancia de acuerdo al análisis del vector bioeléctrico (BIVA), estableciendo valores de referencia en atletas de alto rendimiento.
Material y método: Se les realizó el análisis de bioimpedancia eléctrica (BIA) a 943 deportistas cubanos (620 masculinos, 323 femeninos) de 26 deportes diferentes. Los parámetros bioeléctricos R, Xc, Z y PA fueron obtenidos a una frecuencia de 50-kHz y en la gama de 1 a 1.000 kHz usando un analizador multifrecuencia. De estos parámetros, fueron calculados cinco índices (R/Estatura, Xc/ Estatura, Z/Estatura, reactancia en paralelo, y resistencia en paralelo) a 50 kHz. Se obtuvo el análisis del vector de bioimpedancia eléctrica (BIVA) y se realizó un modelado Cole-Cole. Una vez estimado R/Estatura y Xc/Estatura, fue realizado el análisis de BIVA. La media y la desviación estándar fueron calculadas para todas las variables. *La prueba t fue usada para detectar las diferencias entre ambos sexos.* Los BIVA fueron comparados usando la T^2 de Hotelling. Para contrastar la hipótesis nula de igualdad entre los parámetros examinados, se empleó el nivel de significación de $p < 0{,}05$.
Resultados: En comparación a la población masculina, la población femenina tuvo mayor R, R/*Estatura*, Xc, Xc/*Estatura*, Z, Z/*Estatura* y menor PA ($p<0{,}05$). La precisión de BIVA fue diferente entre los sexos ($p <0{,}05$) y de acuerdo al índice de masa corporal (≤25 y >25). Las diferencias entre deportes estuvieron relacionadas al valor de Z y AF.
Conclusiones: El estudio mostró que la variabilidad de R, Xc, Z y AF dependió del género, de las características de la masa corporal de la población estudiada, y del deporte.

Palabras clave:
Parámetros bioeléctricos.
Análisis del vector impedancia bioeléctrica.
Ángulo de fase.
Modelo Cole-Cole.

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Introduction

The Bioelectrical Impedance Analysis (BIA) is an indirect method of estimating body composition (BC) based on a simple, quick and non-invasive diagnosis procedure that has been used from a clinical perspective as well as for research into molecular, cellular and tissue exploration in humans[1].

Body impedance (Z) is a 2-component function: resistance (R) and reactance (Xc). R represents the resistance of the tissues as an electrical current passes through, and depends on the hydration of the tissues, whilst Xc is the additional opposition due to the capacitance of those tissues and the cell membranes; it is a fundamental parameter for differentiating extra and intracellular liquid as well as the state of cell membranes[1]. The phase angle (PA) is a quality of life indicator; it is the tangent arc (Xc/R) x 180º/π. High PA values are interpreted as cell membranes in a good state, with correct osmotic pressure and ion concentration and a high cell mass[2].

The result of the graphic representation of Xc *vs.* R in the entire range of frequencies (1kHz-1MHz) is a semi-circle with its centre under the real axis corresponding to the model called Cole-Cole[3]. The semi-circle characterises the tissue bioimpedance in 4 parameters known as: resistance to frequency 0 (R_0), resistance in the infinite (R_∞), constant characteristic of time (τ) and measurement of the depression of the semi-circular arc below the real axis (α). Based on the experimental model used, R_0 corresponds to extracellular resistance and R_∞ to intracellular resistance[3,4].

On the other hand, the graphic analysis of the R, Xc relationship, standardised by the height, enables an assessment of the body composition of a subject to be carried out, classifying the state of hydration and variation of the soft tissue. This is known as the bioimpedance vector analysis (BIVA)[5,6].

Based on a number of demographic research studies carried out, there is a growing international acceptance of the use of PA and of BIVA for the tissue and molecular analysis of the BC. Many of these studies have proven the relationship between certain values and different pathological states in the general population[5-9]. However, Llames *et al*[2] suggested that the lack of reference values for the PA have limited its use in clinical and epidemiological situations, whilst Peine *et al*[10] suggested the need to establish the BIVA and PA characteristics for the different demographics, as their use may be limited by age, sex, ethnic origin, body mass index level, among other factors.

It has been demonstrated that the sporting population constitutes a wide segment of physiological variability that can reveal similar PA and BIVA values to people with abnormal pathological states, but in their case these are considered normal adaptations to the sport[11,12]. In turn, in literature specialising in athletes, the demographic characteristics of the BC bioelectrical parameters are not well documented, which could contribute to the study of the limits reached by these indicators and their more rational use in the field of nutritional assessment and of the biomedical control of training.

Based on the previous approaches, the authors proposed: 1) establishing the general characteristics of the bioelectrical parameters in elite Cuban athletes of both sexes at the frequency of 50Hz and the characteristic frequency, 2) establishing the characteristics of the BIVA vector in relation to the sex and body mass index, 3) establishing the demographic differences for the phase angle between the demographic studied and a reference one, and 4) comparing the sports assessed using the body Impedance and the Phase Angle parameters.

Material and method

Type of study and universe

A descriptive and prospective research study was carried out between 14th March and 20th October 2013. The population studied comprised 936 people, which made up the Cuban adult national selection in 26 sports. 620 male subjects and 323 females subjects were assessed, the distribution of which can be seen in Table 1. The average age of participants was 22.75±4.11 and 22.38±3,53 years for males and females respectively.

Methods and procedures

Before starting the study, all the subjects were informed and gave their consent to participate. The study was approved by the Cuban Sports Medicine Institute ethics committee.

Table 1. Sample composition according to sex and sport.

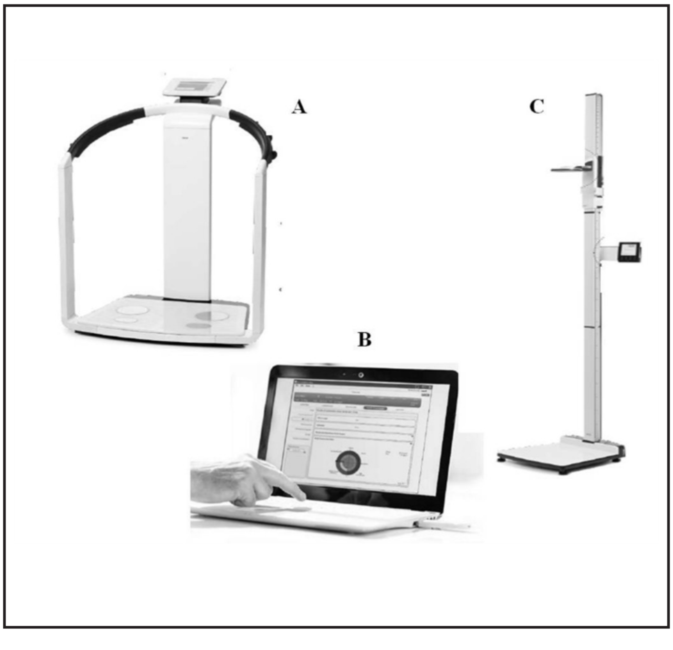
	Male	Female	Total
Basketball	27	54	81
Handball	36	15	51
Baseball	47	0	47
Boxing	25	0	25
Boating	38	11	49
Fencing	37	32	69
Football	63	13	76
Artistic gymnastics	13	1	14
Rhythmic gymnastics	0	12	12
Weight lifting	31	13	44
Grass hockey	22	17	39
Judo	18	25	37
Greek-Roman wrestling	36	0	36
Free-style wrestling	46	27	73
Figure skating	2	2	4
Speed skating	10	2	12
Basque pelota	5	5	10
Modern pentathlon	7	4	11
Water polo	13	0	13
Rowing	53	18	71
Table tennis	3	5	8
Sport shooting	8	8	8
Triathlon	7	4	11
Sailing	15	6	21
Volleyball	47	41	88
Beach volleyball	11	8	19
Total	620	323	943

The study was carried out in the morning by trained personnel, in an air-conditioned premises at 23ºC. To ensure validity and reliability, a protocol was designed which considered the following: 1) not to use diuretics within the previous week, 2) not to drink alcohol in the 48 hours prior to the exam, 3) not to carry out intense exercise at least 12 hours before, 4) not to consume food or drink 4 hours prior to the start of the tests, 5) to urinate/defecate for the last time 30 minutes before starting the programmed tests, 6) in the case of women, the phase of the menstrual cycle was taken into account, only performing the assessment during the oestrogenic phase.

To establish the Bioimpedance, the multifrequency analyser mBCA 514/515 was used *(medical Body Composition Analyser)* made in Germany (Seca 514/515 GmbH & co. kg, Hamburg) (Figure 1A), which was coupled to two units with wireless communication comprising a PC with a Seca Analytics mBCA 115 software (Figure 1B) and a wireless transmission stadiometer 360° Wireless Seca 284 (Seca GmbH & co. kg, Hamburg) (Figure 1C). The units had a precision of 50 g and 1 mm for the weight and height measurements, respectively.

Once the general data was entered into the PC (ID number, age ethnic origin, sport) the height was measured (H) in the wireless transmission stadiometer 360º Wireless Seca 284 (Seca GmbH & co. kg. Hamburg) and was transferred to the analyser using a switch. The height was assessed according to the requirements of the International Society for the Advancement of Kinanthropometry[13]: the subject stood barefoot on the stadiometer base with heels together, the medial borders of the feet at a 60º angle, the back side of the gluteus and the back part of the back touching the stadiometer. The head was positioned in the Frankfurt plane angle, with a slight tilt upwards as the subject breathed in.

Figure 1. Wireless units used to undertake the research.



Next, the individuals stood in an upright position on the analyser with a scapular-humeral joint flex of 30º. The analyser is composed of a pair of electrodes that make contact with the feet (metatarsal-calcaneus) and three pairs on the railings that are at different heights and are adjusted to the height of each subject. In this position the body weight and the body mass were analysed, a 100 µA current was introduced via the stimulating electrodes, whilst the voltage drop (V) was detected by the sensor electrodes, in accordance with Ohm's law (Z=Voltage/ Intensity of the current).

The BIA measurements were assessed at the frequencies 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 30, 50, 75, 100, 150, 200, 300, 500, 750 and 1,000 kHz. The 19 frequencies were used for the Cole-Cole arc model to establish resistance when the frequency tends towards infinity (R∞), resistance when the frequency tends towards zero (R_0), the characteristic frequency (Cf) and the depression angle, so that based on the values obtained the following were estimated: the membrane capacity (Mc), the extracellular (R_0) and intracellular resistances (R∞) and the arc radius (r), the area below the curve. To obtain the average values of R/H, Xc/H, Z/H, Rp/H, Xcp/H and PA, the 50 kHz frequency was used, while for R0/H, R∞/H, Mc/H, and PA, the Cf of the Cole-Cole model was used. The resistance and reactance in parallel (Rp and Xcp) and the membrane capacity (Mc) were estimated using the following formulas:

$$Rp = R + \frac{Xc^2}{R}$$

$$Xcp = Xc + \frac{R^2}{Xc}$$

$$Cm = Xc + \frac{1}{2\,\pi\, Fc\ x\ \ X\,Cp}$$

The graphs for the BIVA analysis were obtained using the software designed by Picolli and Patori (2002) and to process the BIVA analysis (Piccoli A, Pastori G: BIVA software. Department of Medical and Surgical Sciences, University of Padova, Padova, Italy, 2002 (available from: E-mail: apiccoli@unipd.it).

Statistical analysis

The demographic data obtained from the analysis was first exported to an Excel sheet then to the statistics package IBM-SPSS 20.0 for Windows, where the descriptive statistics were carried out.

After performing an exploratory analysis, the absolute and height-related average values (X) and the standard deviation (SD) of R, Xc, Z, Rp, Xcp and PA were obtained at the frequency of 50 kHz, whilst for R0, R∞, Mc, Z and PA, they were obtained at the Cf frequency.

The Student t test for independent samples was used to check the hypothesis of equality of averages between sexes for each of the bioelectrical indicators studied, following verification of the statistical assumptions of normality and homogeneity of variance.

The comparison between the BIVA vectors of different Body Mass categories (BM I≤25Kg/m^2 *vs* BMI >25Kg/m^2) and between sexes was established using the Hotelling T^2 test, following verification of the statistical assumptions of normality and homogeneity of variance.

The level of significance used to rule out the zero-equality hypothesis of averages or of vectors for the checks was $p < 0.05$.

The normal distribution of the PA was verified using the plotting of the quantiles on the Q-Q graph and through the visual inspection based on the exploratory analysis carried out. The overlap of normal distributions of the demographic studied and that of the German reference study[10] were compared, and the overlap area was determined to establish the demographic similarities, adapting the Bivariate Overlap Zone by Norton & Olds[14].

For the description of the results by sports, the percentile distribution was established for Z and the PA, in the percentiles (p) 5, 10, 25, 50, 75, 90 and 95. From these, the following channels emerged: C1 (<5p), C2 (5-10p), C3 (10-25p), C4 (25-50p), C5 (50-75p), C6 (75-90p), C7 (90-95p), C8 (>95p).

To establish the central trend of the Phase Angle, the Body Impedance and the BMI for each sport, the average (X) was used, and the variability index used was the coefficient of variation (CV).

Results

Anthropometric characteristics and bioelectrical parameters (50Hz)

Table 2 displays the descriptive statistics of the anthropometric characteristics and bioelectrical parameters subdivided by sex.

Male athletes had a significantly higher average height and weight than female athletes (p = 0.00), proving that weight-height dimorphism does exist in both parameters. The body mass index revealed similar average values, but significantly different between both sexes (p = 0.00).

Table 2. Estimated values of bio-electric parameters at 50KHz (X±SD).

	Male	Female
Weight (kg)	81.0±14.0**	68.0±11.0
Height (cm)	180.0±10.0**	171.0±10.0
BMI (Kg/m^2)	24.0±3.0**	23.0±2.0
R (Ω)	506.2±60.7	628.0±69.1**
Xc (Ω)	58.9±6.7	63.7±7.2**
Z	509.6±60.8	632.2±69.0**
R/Height (Ω/m)	280.6±34.7	367.7±41.9**
Xc/Height (Ω/m)	32.7±4.6	37.3±4.8**
Z/Height (Ω/m)	282.6±34.9	369.0±42.0**
PA (º)	6.7±0.6**	5.8±0.6
Rp (Ω)	513.0±61.0	635.0±69.3**
Xcp (Ω)	4444.4±782.0	6334.7±1133.0**
Rp/Height (Ω/m)	284.5±85.1	3716.0±42.2**
Xcp/Height (Ω/m)	2457.7±400.0	3699.7±655.0**

*Significant (p < 0.05); **Very significant (p<0.01)

The bioelectrical parameters of the sporting demographic studied, at the frequency of 50Hz, were represented by a significantly lower resistance upon passing the current for males (506.2Ω <628.0 Ω) compared to females (p = 0.00). The Xc revealed higher opposition upon passing the current, due to the capacitance of these tissues and the cell membranes in females (63.7Ω >58.9Ω) (p = 0.00). These differences had a repercussion on the R/H, Xc/H, Z/H, Rp, Xcp, Rp/H, Xcp/E values, which revealed significantly higher average values of resistance, reactance and impedance for females (p = 0.00). The male PA (6.7º) was significantly greater to that found for females (5.8º), revealing greater relative cell mass (p = 0.00).

Results of the parameters based on the Cole-Cole model

These same parameters were also established on the base of the characteristic frequency (Table 3), in order to better characterise the population, and in this case the results were similar to those of 50 kHz.

In the data obtained following the Cole-Cole model (Table 3), it was established that resistance when the frequency tends towards infinite (R∞), resistance when the frequency tends towards zero (R_0) and intracellular resistance (intraR) had significantly lower averages in males (p = 0.00). Also the difference in resistances between both extremes of Cole's arc (ΔR), the radius (r) and the area below the curve were significantly lower for males at the characteristic frequency (p =

Table 3. Values estimated according to the Cole-Cole model in the Cuban athletic demographic of both sexes, established at the characteristic frequency (X±SD).

Variables	Male	Female
R∞(Ω)	446,9±43,0	567,9±46,7**
Rº(Ω)	665,1±43,0	810,1±46,7**
intraR(Ω)	1429,1±272,1	1980,6±402,0**
Mc(nF)	6,9±1,50**	5,3±2,50
Cf (KHz)	44,89±3,9*	43,02±4,6
Z(Ω)559,3±60,0	692,4±73,0**	
PA(º)	6,26±0,61**	5,7±0,70
Depression angle α(º)	0,51±0,17	0,52±0,18*
ΔR(Ω)	209,1±21,7	232,8±24,2**
r(Ω)	84,7±53,1	93,8±57,8**
Area(Ω^2)	9857,2±2155,0	11205,9±2305,8**
R∞/H(Ω/m)	369,5±23,9	473,7±27,3**
Rº/H(Ω/m)	247,5±23,9	332,1±27,3**
intraR/H(Ω/m)	793,9±151,2	1158,2±235,1**
Mc/H(nF/m)	3,8±7,0**	3,1±6,5
Z/H(Ω/m)	310,7±40,8	404,9±47,0**

*Significant (p < 0.05); **Very significant (p<0.01)

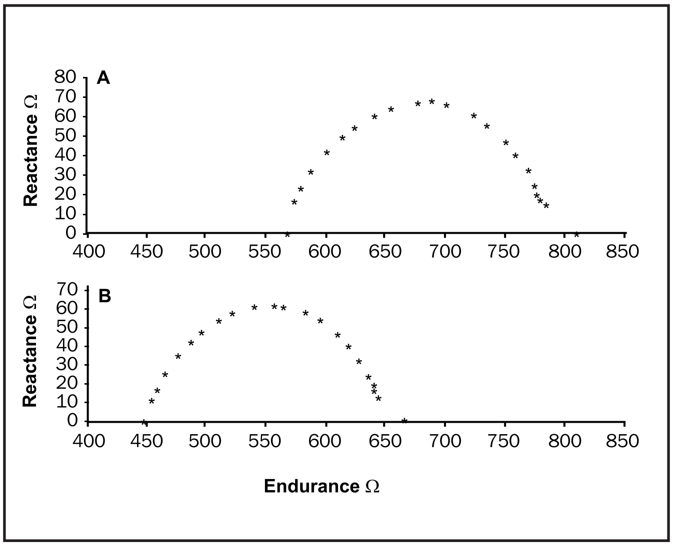


Figure 2. Differences in the arc of the Cole-Cole model for females (a) and males (b) through the experimental dependence Xc-R.

0.00). These characteristics increased at the relative indicators R∞/H, R^o/H, intraR/H, Z/H (Ω/m), which revealed significant differences (p = 0.00). Both the PA as well as the membrane capacity in its absolute (Mc) and relative value (Mc/H) revealed significant and higher average values in males (p = 0.00).

The graphic analysis of the Cole-Cole model (Figure 2) revealed differences between male and female resistances: The R∞ value was lower for males, whilst the Xc was maximal, coinciding with the R∞ value for females. On the other hand, the R^o values proved to be considerably greater in females, whilst the maximum Xc value, at the critical frequency, reached much higher ohmic resistance values.

Characteristics of the BIVA vector on a demographic population and in relation to the BMI

The result of the graphic analysis of the BIVA is displayed in Figure 3. This displays the graphs that form the R/H *vs* Ex/H pairs for each sex, in which the average length of the vectors and the confidence ellipse reflect the characteristics of the body composition in the demographic assessed.

Upon analysing the figure, the BIVA vector was longer and had a smaller angle regarding the abscissas for females. The separation of the confidence ellipses between both sexes confirmed the significant differences between then upon establishing the Hotelling T^2 contrast (p = 0.00). The female athletes, in comparison to the male athletes, revealed a larger ellipse, which reflected great heterogeneity in the BIVA characteristics.

The average BMI values for the BMI>25 Kg/m^2 categories were 27.0±2.0 and 28.0±5.08 kg/m^2 for males and females respectively. For the BMI≤25 kg/m^2 category they were 22.0±1.8 and 21.6±2.1 kg/m^2 for the same order of sexes.

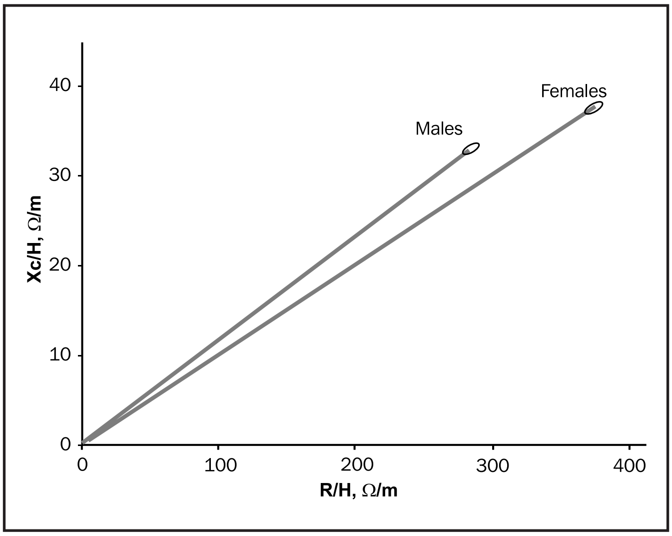


Figure 3. Impedance vector and reliability ellipse at 95% of the Cuban sporting population of both sexes.

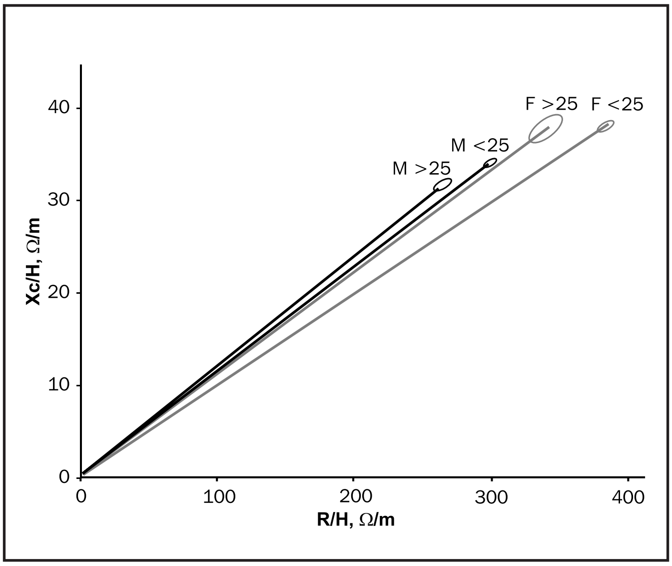


Figure 4. Impedance vector and reliability ellipse at 95% of the Cuban sporting population of both sexes, by body mass index groups.

When the effect of the BMI on the BIVA vector characteristics was examined visually (Figure 4), males revealed a shorter length, regardless of the BMI category (M >25, M ≤25) upon comparison with females (F ≤25 and F >25). In males, the vector length was lower for those with a BMI higher than 25 kg/m^2 (M >25), whilst it was slightly higher in females in the same category (F >25).

When the confidence ellipses that form the R/H *vs* Xc/H pairs for each sex were compared, significant differences were found between the BIVA using for the T^2 Hotelling test (p = 0,00). Male athletes revealed

Figure 5. Plotting of the normal phase angle comparing the phase angle values to the normal standard distribution for male subjects (to the left) and female subjects (to the right).

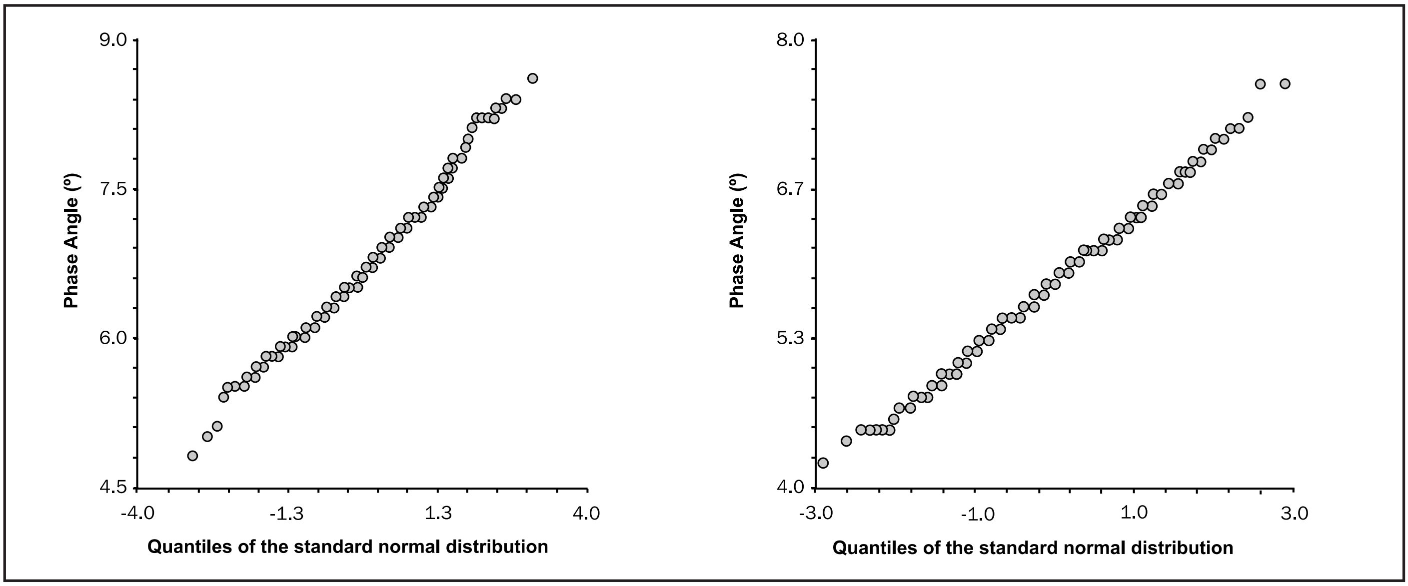
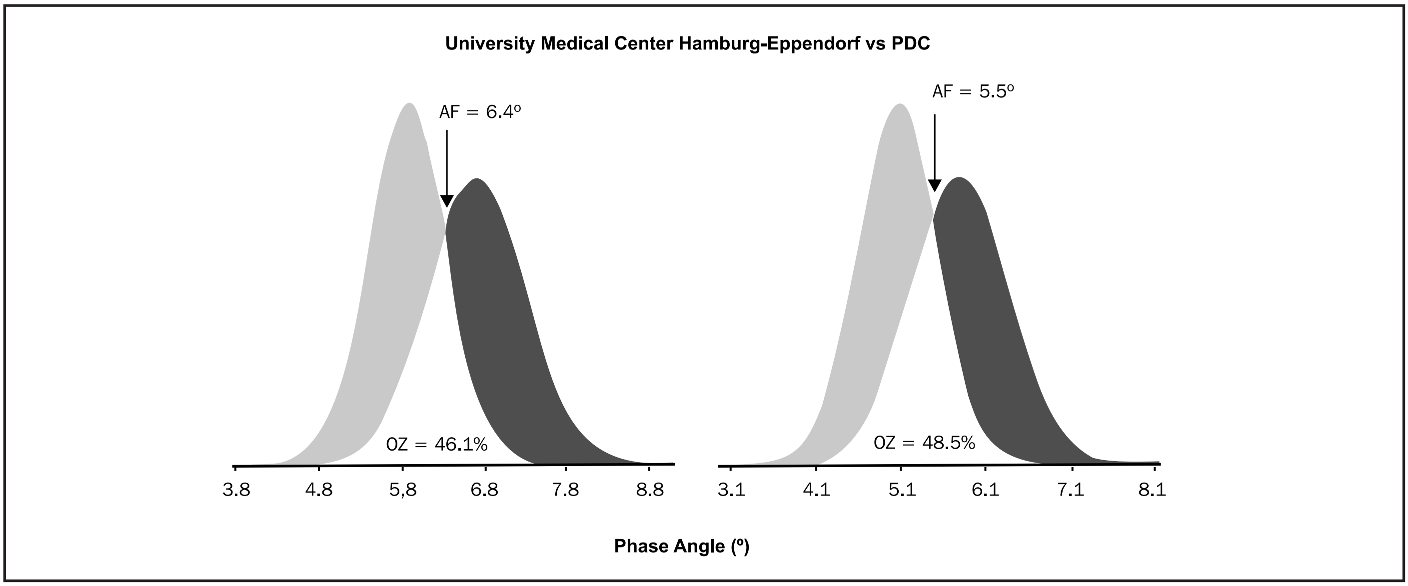


Figure 6. Overlap Zone (OZ) between the sample from the study by the University Medical Center Hamburg-Eppendorf and the PDC. The graph on the left shows the male demographic and the one on the right, the female demographic for both studies.



significant differences between the BMI categories (p = 0.00), whilst differences were found between females athletes from one BMI category to another (p = 0.00).

Demographic characteristics of the phase angle

The average PA value for the male demographic studied (6.7±0.6°) was significantly higher than that of the females (5.8±0.6°)($p <0.05$), whilst the quantiles 25, 50 and 75 for males (6.2°-6.70°-7.1°) revealed a wider range than the range for females (5.5°-5.8°-6.2°).

Upon contrasting the average PA values for males with that of the reference male German population (n= 528, PA =5.9±0.5º) significant differences were found (p = 0.00), whilst females revealed the same qualitative result when the Cuban and German populations were compared (n = 518, PA = 5.0±0.5º) (P = 0.00).

Once the normal PA distribution had been verified, in accordance with the Q-Q plotting displayed in Figure 5, the analysis of the demographic overlap between the compared demographics was reflected (Figure 6).

Table 4. Percentiles for the impedance vector and the phase angle in the Cuban sporting population of both sexes.

			X±SD	5	10	25	50	75	90	95
Z	Male	Ω	509.6±60.8	416.7	434.9	476.2	512.3	558.2	602.6	625.3
	Female	Ω	632.2±69.0	512.4	549.1	596.3	634.3	684.1	724.6	768.1
PA	Male	°	6.70±0.6	5.7	5.9	6.2	6.70	7.1	7.3	7.6
	Female	°	5.80±0.6	4.8	5.0	5.5	5.80	6.2	6.6	6.9

Table 5. Descriptive statistic of the impedance vector and the phase angle by sport (X [CV]).

Sport	Male				Female			
	BMI (Kg/m²)	Z (Ω)	PA (º)	EVA	BMI (Kg/m²)	Z (Ω)	PA (º)	EVA
Basketball	24.7 (10.6)	520.3 (7.9)	6.5 (7.4)	C5>C4	24.1 (10.7)	640.6 (7.9)	5.8 (8.2)	C5>C4
Handball	25.6 (11.4)	496.8 (12.7)	6.4 (7.2)	C3<C4	23.2 (9.6)	634.0 (10.7)	5.8 (8.8)	C4=C4
Baseball	27.1 (13.5)	528.6 (14.1)	6.6 (11.0)	C5>C4	-	-	-	-
Boxing	23.5 (12.0)	542.7 (10.9)	6.7 (7.4)	C5>C4	-	-	-	.
Boating	25.1 (6.2)	490.4 (7.8)	7.0 (5.7)	C4<C5	23.8 (7.8)	574.6 (10.3)	6.5 (4.8)	C3<C7
Fencing	23.2 (9.2)	546.7 (9.5)	6.4 (8.5)	C5>C4	22.5 (9.7)	678.9 (7.5)	5.7 (8.5)	C5>C4
Football	23.1 (7.1)	547.0 (8.6)	6.4 (7.3)	C5>C4	22.6 (8.4)	648.7 (11.5)	5.3 (10.4)	C5>C3
Artistic gymnastics	22.8 (5.5)	494.2 (11.4)	7.0 (7.8)	C4<C5	21.2 (0.3)	668.6 (5.1)	7.0 (1.3)	C5<C8
Rhythmic gymnastics	-	-	-	-	18.7 (5.1)	738.6 (8.5)	5.1 (6.8)	C7>C3
Weight lifting	29.5 (15.2)	423.8 (10.6)	7.7 (7.6)	C2<C8	27.0 (16.4)	554.7 (10.0)	6.8 (7.1)	C3<C7
Hockey	23.4 (8.3)	538.6 (8.0)	6.6 (8.5)	C5>C4	22.3 (7.7)	639.4 (7.3)	5.6 (8.9)	C5>C4
Judo	27.6 (23.2)	471.5 (9.9)	6.8 (8.5)	C3<C5	25.3 (19.1)	550.2 (9.6)	6.2 (8.8)	C3<C5
Wresting	26.6 (8.2)	464.1 (8.9)	7.0 (6.9)	C3<C5	24.9 (8.7)	565.1 (9.5)	6.2 (8.0)	C3<C5
Synchronised swimming	-	-	-	-	19.1 (8,5)	703.3 (6.6)	5.6 (6.2)	C6>C4
Figure skating	23.3 (2.4)	483.5 (5.2)	6.8 (2.6)	C3<C5	23.0 (5.0)	628.3 (6.0)	5.0 (5.7)	C4>C2
Speed skating	22.4 (8.2)	542.0 (6.9)	6.7 (6.5)	C5>C4	22.6 (0.3)	670.0 (4.3)	6.1 (9.1)	C5=C5
Basque pelota	25.0 (9.8)	512.8 (7.0)	6.6 (9.3)	C5>C4	23.8 (10.2)	645.2 (8.9)	5.7 (6.8)	C5>C4
Pentathlon	22.7 (10.6)	543.5 (9.9)	6.5 (9.9)	C5>C4	22.4 (4.4)	663.2 (8.6)	6.0 (9.9)	C5=C5
Water polo	25.6 (7.7)	498.7 (9.4)	6.5 (7.0)	C4=C4	-	-	-	
Rowing	24.7 (8.0)	504.9 (7.3)	6.6 (7.8)	C4=C4	22.1 (7.1)	625.3 (6.7)	5.8 (7.0)	C4=C4
Table tennis	24.4 (11.6)	554.2 (14.8)	6.6 (8.0)	C5>C4	22.8 (4.8)	650.4 (7.0)	5.7 (9.5)	C5>C4
Sport shooting	25.6 (13.4)	554.6 (12.4)	6.2 (8.7)	C5>C3	23.8 (13.9)	707.4 (7.9)	5.0 (11.4)	C6>C2
Triathlon	23.9 (7.0)	482.6 (7.0)	7.8 (4.2)	C4<C8	21.4 (6.6)	625.3 (3.2)	5.9 (2.6)	C4<C5
Sailing	22.3 (8.3)	558.4 (11.0)	6.5 (6.1)	C6>C4	22.8 (7.0)	596.0 (9.0)	5.7 (11.2)	C3<C4
Volleyball	22.7 (8.0)	550.3 (8.3)	6.3 (6.3)	C5>C4	20.6 (6.6)	667.8 (8.0)	5.6 (5.3)	C5>C4
Beach volleyball	22.8 (10.8)	550.5 (9.1)	6.3 (7.5)	C5>C4	22.2 (6.9)	642.7 (4.9)	6.0 (8.0)	C5=C5

Males revealed a lower degree of overlap in terms of the reference distribution (46.1%) than females (48.5%), however, the distribution for the sporting populations was to the right of the reference values, with the coincidence values of both distributions 6.4 and 5.5º coinciding with the 25th percentile of the distributions of both males and females, respectively.

Reference values for the body impedance vector and the phase angle by sports

Table 4 reflects the percentile range of Z and the PA on a demographic level. The differences between sexes appear reflected descriptively in each percentile of the range.

Table 5 displays the descriptive statistic of the BMI, the Z vector and of the PA, as well as the assessment corresponding to its percentile distribution by sport in accordance with Table 4.

From a descriptive perspective, male athletes specialising in weightlifting, judo, baseball, wrestling, water polo, handball and boating revealed higher average BMI values, whilst female athletes revealed higher average values in weightlifting, judo, wrestling, basketball and boating.

On the other hand, athletes specialising in weightlifting, wrestling, judo, skating, triathlon, artistic gymnastics and boating revealed a more modest Z vector average value than the other sports among males. Coincidently, athletes specialising in triathlon, boating, artistic gymnastics wrestling, judo, figure skating and weightlifting had higher average PA values than athletes from other sports.

Upon establishing the individual characteristics of the Z and PA parameters, in accordance with the standards in Table 4, athletes specialising in weightlifting and triathlon were positioned in the C2 and C4 percentile channels for Z length, and C8 for the estimated phase angle average (Table 5).

For females, athletes specialising in weightlifting, wrestling, judo, triathlon and boating revealed a more modest Z vector average value than the other sports. Coincidently, athletes from boating, artistic gymnastics, wrestling, judo and weightlifting had higher average values for the PA.

The percentile distribution of the average estimated value for each sport produced more extreme Z and PA values, and weightlifting and boating were positioned in the C3 channel for Z length, and C7 for the estimated average PA value, whilst the distribution of those of rhythmic gymnastics was opposite. Athletes from artistic gymnastics revealed a C5<C8 distribution (Table 5).

Discussion

This research promotes the use of bioelectrical parameters of the body composition via BIA. This establishes the standards in a specific, previously unstudied demographic using this technology.

A clear sexual dimorphism was discovered in the parameters studied, as well as differences between subjects with different levels of Body Mass Index and belonging to different sports. This aligns with that found in specialised literature for healthy subjects[15,16].

Upon comparing the values obtained for each sex, the absolute and relative differences found in the R and the Xc reflected that there was sexual dimorphism, based on the parameters studied. Núñez *et al*.[16] considered that a lower R favours a higher blood supply, facilitating a better conduction of the current, both in the extracellular and intracellular environment.

On the other hand, these authors16 indicate that a greater membrane capacity reflects a higher volume of muscle fibres, due to the fact that this parameter is related to the area and thickness of the body's cell membranes, whilst the lower value of the area below the curve, coincidentally with the R and the radius, could be due to a greater number of mitochondria for producing energy; with the result that the muscle is provided with a more efficient oxidative metabolism, and allowing, by performing to a greater measure, the optimisation of performance in males.

Likewise, the graphic representation of the phenomenon, using the Cole-Cole diagram, facilitated the understanding of dimorphism, providing information about how a lower extracellular and intracellular resistance in males refers to a greater hydration of the extra and intracellular compartments of this sex[16].

Hyper-hydration or dehydration can be assessed based on the shortening or lengthening of the impedance vector, whilst the variation of the amount of soft tissues can be assessed via the variation of the phase angle[5,15,17]. In this respect, greater hydration was observed among males, regardless of the BMI value. This indicator also predicted the state of hydration by establishing that those with a higher BMI were more hydrated, regardless of the sex.

On the other hand, with the BIVA vector analysis, the differences in the body composition between both sexes were confirmed. The shorter vector, associated with a high BMI value, suggested less fatty mass, whilst the ellipse of the smaller size indicated greater uniformity in the body composition for males in any of the graphic representations carried out.

The average values found for the PA in this study (6.7º and 5.8º) were much lower than those reported by Barbosa-Silva *et al*[18] for the American population of males (8.02º) and females (6.98º), whilst the values found in the German population[19] for males (6.89º) and females (5.98º) were similar to the estimates obtained in this study. Kyle *et al*[20] reported values of 7.5º and 6.6º for the Swiss population of males and females, respectively. The values found in this research study coincided with those reported among the American demographic for the third age, and with those found among the German and Swiss population aged between 50 and 60 years, approximately[18].

In the sporting population, few values relating to the PA have been reported. One of the studies found reported values of 6.62º and 6.28º for volleyball players from the Czech Republic and the Russian Federation that were higher than those found for Cuban volleyball players of the same level in this research study (5.6º)[11]. Another research study reported values of 7.0º and 7.7º for pre-juvenile and juvenile Spanish athletes in synchronised swimming[21].

Although a high value for the phase angle reveals development of the cell mass and a good nutritional state, the authors consider that the differences found on a demographic level in the literature prove that this is a good discriminant between individuals of different ethnic origin and physical constitution[7,8,15-17]. Therefore, the differences discovered between the volleyball players studied - the Russians and the Czechs - are not defining in this analysis. Likewise, the same occurs for Spanish synchronised swimmers, who revealed values that were considerably higher than the majority of Cuban athletes[21].

The comparison made with the matrix study by the University Medical Center Hamburg-Eppendorf proved that there are demographic differences for the assessment of the phase angle. Whilst in the German population the normal ranges were between 5.03-6.73º and 4.28-5.82º for the assessment of males and females[14], this research study produced values between 6.02-7.1º and 5.5-6.2º. This suggests that the cut-off points of the analysers like SECA mBCA are specific to the German reference population and overestimate the qualitative assessment of the sporting population.

On an individual level, it was proven that a suitable discrimination can be made with the Z-PA relationship of the state of hydration and nutritional level presented. In the analysis of extreme cases such as rhythmic gymnastics and weightlifting in females, it has been shown that for female rhythmic gymnasts a Z vector located in one of the highest channels (C7) and a PA located in the lowest channels (C3) represent low levels of hydration and cell mass, supported by the low BMI value present. For weightlifting, there was a high hydration and cell quality, based on a greater cell mass and hydrophilic interstitial structure proteins, or a better nutritional state, which suggests that the high BMI can reflect hypertrophy and not obesity. In males, weightlifting revealed the same result as for their female counterparts, whilst sailing athletes revealed an average PA (C4) with a larger Z vector, which reflects the lower quantity of body fluids in this demographic.

The results found on an individual level correspond to those described by Kim *et al*.[17], who were able to establish the relationship between the Z vector and the PA with the body type estimated using the somatotype and the BMI. For this author, low R values and high PA values are associated with artistic gymnasts, whilst low PA and high R values correspond to rhythmic gymnasts, dancers and ballet dancers.

The main limitation posed by this research study radiates in the fact that the results were not compared to those of the general public, which prevents the limits of adaptation to the practice of the sports in the researched environment from being determined. On the other hand, given the extension of the research study, the impact of the sporting factor on the BIVA vector characteristics could not be specified, which would have provided more details about the tissue, cell and molecular characteristics of the body composition under the different training regimes.

Despite that indicated, the research provides results that can be used as references in the clinical and medical-sporting practice, as well as in research studies that require greater reliability than when they use indirect equations available in analysers, as these are extent of assumptions for their determination.

Conclusions

Through the reference values provided it was possible to assess the discriminatory power of the bioelectrical parameters of Bioimpedance, as well as their usefulness in analysing the body composition of the sporting population. The study revealed that the variability of the bioelectrical parameters of Body Impedance, Resistance, Reactance, Phase Angle and the Bioimpedance Vector Analysis depended on the sex, on the body mass characteristics of the demographic studied, and on the sport.

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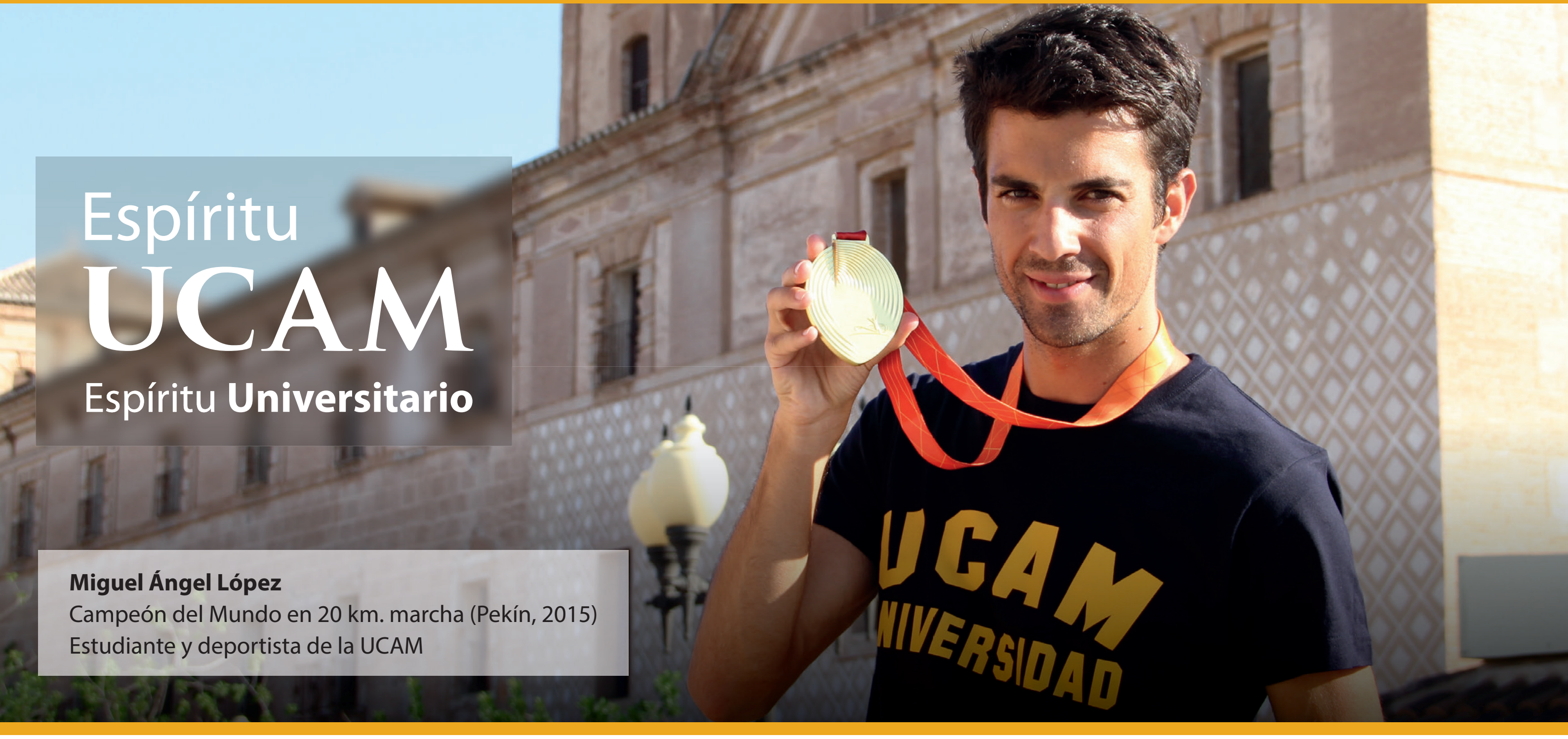

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