Raw Bioelectrical Impedance Analysis Variables (Impedance Ratio and Phase Angle) and Physical Fitness in Cross-Fit® Athletes

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Abstract: Few data are available on body composition and its relationships with physical fitness in Cross-Fit® athletes. Our study aimed to evaluate changes in raw bioelectrical impedance analysis (BIA) variables and their relationships with physical fitness in male Cross-Fit® athletes. Fifteen male Cross-Fit® athletes (age 19-35 years, weight 83.8±5.6 kg, body mass index-BMI 26.0±1.9 kg/m²) and fifty-one control men, (age 20-30 years, weight 76.5±10.8 kg, BMI 24.6±3.2 kg/m²) participated in the study. Body composition was evaluated by using BIA and physical fitness was assessed by measuring handgrip strength (HGS), long jump (L-J), squat jump (SQ-J) and counter-movement jump (CM-J). Phase angles were higher and impedance ratios were lower in Cross-Fit® athletes for the whole body and limbs (both these directly-measured raw BIA variables are promising markers of muscle quality). HGS was only slightly higher in the Cross-Fit® group, whereas a clear difference emerged between groups in L-J (+16.2% in Cross-Fit® athletes), SQ-J (+21.5%) and CM-J (+21.5%). HGS, L-J, SQ-J and CM-J significantly correlated with both impedance ratios and phase angles (for whole body and limbs). In conclusion, raw BIA variables such as impedance ratio and phase angle significantly change in Cross-Fit® athletes compared to controls and also exhibit significant relationships with physical fitness.

1 INTRODUCTION

Cross-Fit® is a type of high intensity functional training (HIFT) that emphasizes functional, multi-joint movements to improve physical fitness (PhysFit) in terms of strength, power, flexibility and cardiovascular endurance. It results in greater muscle recruitment than other exercise programmes and can be adjusted to any fitness level (Feito et al. 2018).

Cross-Fit® exercises are based on elements of gymnastics, weightlifting and cardiovascular fitness, and are included in combinations known as workouts of the day (WODs) (Fisker et al. 2017), which are executed quickly, repetitively, and with little or no recovery time between sets.

The strength and power indexes of squat test (Martínez-Gómez et al. 2019) and the sum of different one-repetition maximum loads (Butcher et al. 2015) have been used as indicators of Cross-Fit® performance, while counter-movement jump test was applied to assess muscular fatigue before, during and after different WODs (Maté-Muñoz et al. 2017). CrossFit training may be useful for enhancing health-related physical fitness parameters in physically inactive adults (Brisebois et al. 2018) and for improving VO_2max (Feito et al. 2019), standing long jump and shuttle run (Eather et al. 2016). More generally, an eight-week HIFT resulted in significant enhancements of muscular strength for back squat and deadlift (Banaszek et al. 2019).

As far as handgrip strength (HGS) is concerned, no specifical data are available in Cross-Fit® athletes (Claudino et al. 2018); indeed prevoius researches have shown that physically active individuals had higher HGS when compared to those inactive (de Lima et al 2016).

To the best of our knowledge, the effect of Cross-Fit® training on body composition have been evaluated in few studies only. Cross-Fit® did not significantly affect body mass index (BMI) or body composition in sedentary men and women (Heinrich et al. 2014) whereas in both boys and girls there were

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improvements of body composition parameters such as BMI and waist circumference (Eather et al. 2016) and lean body mass further increased in already previously active young adults (Murawska-Cialowicz et al. 2015). Among obese adults the only effect was a rise in lower-limb lean body mass (Feito et al. 2019). Positive effects on body composition have been also reported in cancer survivors (Heinrich et al. 2015).

Bioelectrical impedance analysis (BIA) is a widely used, non-invasive field method for assessing body composition, which measures the electrical characteristics of human body (i.e impedance-Z and phase angle-PhA) either at 50 kHz (single-frequency BIA) or at several frequencies in the range 1-1000 kHz (multifrequency BIA or spectroscopy).

Our interest was motivated by the fact that to the best of our knowledge, there were no data available on raw BIA variables in Cross-Fit® athletes. Impedance ratio (IR=the ratio between Z at higher frequencies and Z at lower frequencies) and PhA may be considered as promising markers of muscle quality and therefore of value in athletes. Actually, these variables have been associated with muscle structure in terms of body cell mass (BCM) and the ratio between extracellular water-ECW and intracellular water-ICW (Lukaski et al. 2017). In addition, IR ans PhA have also been specifically related to muscle strength and physical activity (de Blasio et al. 2019; Mundstock et al. 2019).

Facing this background, the general aim of our study was to evaluate the usefulness of raw BIA variables in assessing muscle structure/quality in athletes. Specific aims were to study were to study raw BIA variables, such as IR and PhA and selected variables of physical fitness in Cross-Fit® athletes compared to control subjects.

2 METHODS

2.1 Participants

This cross-sectional study included fifteen male Cross-Fit® athletes, age 19-35 years, and fifty-one control men, age 20-30. Cross-Fit® athletes were recruited from a gym located in Naples. They trained at least five hours a week in three different sessions and had practiced at least 18 months of specific training. Other inclusion criteria were being healthy and having a body mass index (BMI) below 28 kg/m². Eighty-three per cent of the potential participants agreed to be included in the study. Controls were students attending the Federico II University of Naples who did not practice sport and did less than 100 minutes of moderate-vigorous activity per week.

Subjects were studied in the morning, after an overnight fasting, by the same operator and following standard procedures. Body weight was measured to the nearest 0.1 kg using a platform beam scale and stature to the nearest 0.5 cm using a stadiometer (Seca, Hamburg, Germany). BMI was then calculated as body weight (kg)/stature² (m²).

2.2 BIA

Z and PhA were measured at frequencies between 5 and 300 kHz (HUMAN IM TOUCH analyser, DS MEDICA, Milano), in standardized conditions: ambient temperature between 23-25 °C, fast >3 h, empty bladder, and supine position for 10 min. Subjects were asked to lie down with their upper limbs and lower limbs slightly abducted to avoid any contact between body segments. The measuring electrodes were placed on the anterior surface of the wrist and ankle, and the injecting electrodes placed on the dorsal surface of the hand and the foot, respectively. Whole body and segmental BIA have been performed using a six-electrode technique according to Organ et al. (1994). We considered data for the whole body and separately for upper and lower limbs with respect to the following BIA raw variables: 1) bioimpedance (BI) indexes at 5 or at 50-100-300 kHz (stature²/Z), as markers of ECW and fat-free mass (FFM) respectively; 2) IR between Z at high frequency (300 kHz) and Z at low frequency (5 kHz); 3) PhA measured at 50 kHz. The means of measures for right and left sides of body were considered.

FFM was estimated using the Sun equation (Sun et al. 2003). Fat mass (FM) was calculated as the difference between body weight and FFM.

2.3 Fitness Tests

The selected physical fitness tests were performed according to standardized procedures. Handgrip strength (HGS) was measured with a Dynex dynamometer (MD systems, Ohio USA) to assess isometric strength of upper limbs as described by Beaudart et al. (2019). Maximum values on three attempts on the dominant and three attempts on the non-dominant body side was used for analysis; long jump (L-J) was used to assess lower body muscle power. Participants performed a two foot take-off and landing. The swinging of the arms and flexing of the knees are permitted to provide forward drive. The subject attempts to jump as far as possible, landing on both feet without falling backwards. Length was measured to the nearest point of contact on the landing. Two attempts were performed and the best value was used for analysis. Squat jump (SQ-J) and countermovement jump (CM-J) were measured with the OptoJump® device (MicroGate, Italy) to assess the explosive power of lower limbs (Markovic et al. 2004). In both cases, the highest of three jumps was used for analysis.

2.4 Statistical Analysis

Results are reported as mean±standard deviation. Statistical significance was pre-determined as $p<0.05$. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS Inc, Chicago, IL, USA) version 24.

Shapiro-Wilk test was applied to assess the normality of data. The general linear model was used to assess differences after controlling for body weight.

Differences between groups were assessed using one-way ANOVA or general linear model (when data were adjusted for weight). Association between variables was evaluated using partial correlations to control for group and age, while multiple regression was employed to identify the predictors of physical fitness.

3 RESULTS

The general characteristics of the study groups are reported in Table 1. Cross-Fit® athletes were slightly heavier than controls, with no statistical difference for stature and BMI.

Table 1: General characteristics and body composition in Cross-Fit® athletes and controls.

		Cross-Fit® (n=15)	Controls (n=51)
Age	yrs	27.6±6.3	25.4±3.7
Weight	kg	83.8±5.6	76.5±10.8[a]
Stature	cm	179.4±4.1	176.4±6.8
Body mass index	kg/m^2	26.0±1.9	24.6±3.2
Fat-free mass	kg	66.9±3.3	61.7±7.2[a]
Fat mass	kg	16.9±4.6	15.0±5.6
Fat mass	%	20.0±4.3	19.2±5.2

mean±standard deviation. a=$p<0.05$ between groups.

According to BIA, FFM was significantly higher in the Cross-Fit® athletes ($p<0.05$), with no difference after controlling for body weight. Similarly, as far as raw BIA variables were concerned (Table 2), BI indexes at 5 and 300 kHz were higher in the Cross-Fit® group compared to control group (+7.5% and +9.8%, respectively). Indeed those differences di not persist after controlling for body weight.

Table 2: Bioimpedance indexes of the whole body in Cross-Fit® athletes and controls.

Bioimpedance index (cm^2/kHz) at the frequency:	Cross-Fit® (n=15)	Controls (n=51)
5 kHz	60.3±4.3	56.1±7.1[a]
50 kHz	72.1±5.0	65.9±8.9[a]
100 kHz	77.3±5.5	70.4±9.7[a]
300 kHz	85.3±6.2	77.7±10.8[a]

mean±standard deviation.
a=$p<0.05$ between groups.

On the other hand, as reported in Table 3, PhAs were clearly higher in Cross-Fit® athletes by 6.6% for the whole body, 5.8% for upper limbs and 5.6% for lower limbs. In the opposite direction, significant lower IRs were observed in the Cross-Fit® group compared to the control group. Selected physical fitness tests were performed, focusing on the domain of strength.

As summarized in Table 4, HGS was only slightly higher in the Cross-Fit® group, the difference being further reduced after adjusting for body weight. On the contrary, higher values emerged in Cross-Fit® athletes regarding L-J (+16.2%), SQ-J (+21.5%) and CM-J (+21.5%).

Table 3: Impedance ratio (IR=Z 300 kHz/Z 5 kHz) and phase angle (at 50 kHz) measured on the whole body and limbs in Cross-Fit® athletes and controls.

	Cross-Fit® (n=15)	Controls (n=51)
Impedance ratio		
Whole body	0.707±0.023	0.724±0.022[a]
Upper-limbs	0.701±0.026	0.722±0.022[a]
Lower-limbs	0.719±0.026	0.734±0.026[a]
Phase angle (degrees)		
Whole body	7.46±0.70	7.00±0.66[a]
Upper-limbs	6.72±0.71	6.26±0.71[a]
Lower-limbs	8.26±0.82	7.82±0.72[a]

mean±standard deviation. PhA= phase angle
a=$p<0.05$ between Cross-Fit® athletes and controls

Then, the association of PhysFit with selected variables of interest was evaluated by partial correlation (Table 5). HGS, L-J, SQ-J and CM-J showed a significant association with whole body IR and PhA.

Table 4: Physical fitness in Cross-Fit® athletes and controls as assessed by different tests.

Performance Tests		Cross-Fit® (n=15)	Controls (n=51)
Handgrip strength	kg	52.0±6.2	47.7±8.3
Long jump	cm	193.6±25.7	166.7±36.7[a]
Squat jump	cm	29.9±10.2	24.6±6.0[a]
Countermovement jump	cm	28.9±10.6	23.8±5.3[a]

mean±standard deviation.
a=p<0.05 between groups.

Similar results were also obtained in most cases for the association with upper-limb and lower-limb IRs and PhA (results not shown). Multiple regression analysis (data on the whole body) showed that BI index at 300 kHz was the most important predictor of HGS, whereas IR or PhA were the most significant predictors of L-J, SQ-J and CM-J.

4 DISCUSSION

This study shows that raw BIA variables such as IR and PhA significantly differed (suggesting improved muscle structure) in Cross-Fit® athletes compared to controls and also exhibit significant relationships with PhysFit.

We performed BIA in Cross-Fit® athletes and controls. First, FFM was estimated by means of predictive equations that include BIA variables, age, stature and body weight (Sun et al. 2003).

Table 5: Partial correlation of physical fitness with impedance ratio (IR=Z 300 kHz/Z 5 kHz) and phase angle.

Performance Tests	IR		Phase angle	
	r	p	r	p
Handgrip strength	-0.412	<0.001	0.461	<0.001
Long jump	-0.308	0.018	0.273	0.036
Squat jump	-0.536	<0.001	0.504	<0.001
Countermovement jump	-0.361	0.004	0.337	0.008

Results for the whole body (after adjustment for age).

No major impact of Cross-Fit® training emerged from our data with respect to FFM or FM. Then, as major aim, we focused our attention on those raw BIA variables (IR and PhA) that are related to ECW/ICW ratio, body cell mass (BCM), and cellular integrity (Lukaski et al. 2017). PhA and IR have also been shown to be significantly associated with muscle strength and physical activity (de Blasio et al. 2019; Mundstock et al. 2019) and to vary between genders and with aging (Barbosa-Silva et al. 2018; Bosy-Westphal et al. 2008).

PhA describes the angular shift (phase difference) between voltage and current sinusoidal waveforms, which in humans is likely due to cell membranes and tissue interface (Lukaski et al. 2017; Norman et al. 2012). As reported in a recent systematic review of our group (Di Vincenzo et al. 2019), it is still to be defined to what extent PhA changes between different sports and with training/un-training. Only few studies have shown that mean whole-body PhA is higher in athletes vs. controls, while scarce data are available on the segmental evaluation of upper and lower limbs (Di Vincenzo et al. 2019).

We observed that PhA was significantly higher in Cross-Fit® athletes, with a relatively small difference between groups (+6.6% for the whole body, +5.8% for upper limbs and +5.6% for lower limbs). Said differently, the variation of whole-body PhA (0.46 degrees) was close to the pooled SD of 0.70 degrees. An increase of this magnitude (or slightly higher) has been already observed by us in female ballet dancers, cyclists and male marathon runners (Di Vincenzo et al. 2019).

The Z of human tissues is frequency-dependent since alternate current at low frequencies passes through the extracellular fluid, whereas at higher frequencies (i.e. ≥50 kHz) also penetrates cell membranes. Thus, the IR is similar to a phase shift (Mundstock et al. 2019), being inversely correlated with PhA when calculated with the approach used in the present study.

To the best of our knowledge, there are no data on the IR of subjects practicing sports. Actually, we found that IRs were clearly lower in the Cross-Fit® group than in the control group. A first glance, the differences in IRs appear negligible in percentage terms. Actually, they should be considered in view of the very small standard deviations observed for those variables. For instance, the difference in IR for the whole body was 0.017, which was close to the pooled SD of 0.025.

A few previous studies have shown that Cross-Fit® training may be useful for improving health-related PhysFit (Brisebois et al. 2018; Feito et al. 2019; Eather et al. 2016; Banaszek et al. 2019). As further point, we evaluated a certain number of

PhysFit tests, concentrating on the domain of strength. These tests were selected according to the fact that they can be applied to subjects practicing different sports, as well as in young controls. Interestingly, no increase in HGS was observed in Cross-Fit® athletes, in agreement with previous study on Judo (Sterkowicz et al. 2016). On the contrary, higher mean values were observed for L-J, SQ-J and CM-J, demonstrating an improvement in the explosive strength of lower limbs.

Finally, an interesting issue was to explore whether and to what extent PhysFit was related to those raw BIA variables that are promising markers of muscle structure. As far as we know, no consistent data are available in the literature on the topic (Di Vincenzo et al. 2019).

Based on our results (partial correlation), the fitness variables considered were all significantly associated, although differently, with IR and PhA. It should be noted that the associations with L-J, SQ-J and CM-J were stronger for lower limb than upper limb IR or PhAs, while the opposite was observed for HGS. While our results are pretty consistent, a small sample of Cross-Fit® athletes has been evaluated and gender differences were not analysed because only young men were measured. Moreover, further studies are needed to confirm that the concurrent use of BIA and physical fitness tests is a valuable approach for assessing muscle quality in athletes in terms of both muscle structure and strength.

In conclusion, raw BIA variables such as IR and PhA significantly change in male Cross-Fit® athletes compared to controls, suggesting higher BCM, and also exhibit significant relationships with PhysFit. More information on body composition are given by segmental BIA of upper and lower limbs, which can be useful for a better evaluation of the relationships between body composition and PhysFit.

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