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Original Article

Bioimpedance Phase Angle and Muscle Strength Performance in Young Male Volleyball Athletes

Short title: Bioimpedance and Muscle Strength Performance in Volleyball Athletes

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ABSTRACT

Volleyball performance depends partially on lower limb strength. The phase angle (PhA) is a marker of functional muscle mass and a surrogate measure of athletic muscle performance. This study aimed to verify the correlation between PhA (bioimpedance) and lower limb muscle strength in young volleyball athletes. The sample included 38 young male volleyball athletes (Age: 16.7±1.3 years; Weight: 73.7±9.7 kg; Height: 179.3±6.9 cm). We performed a cross-sectional observational study and evaluated the volleyball athletes for vertical jump tests (Counter-Movement Jump: CMJ and Squat Jump: SJ) and whole-body bioimpedance. The Pearson test showed positive and moderate significant correlations between the PhA, CMJ, and SJ (r=0.550 and r=0.559, respectively). Our findings demonstrated that assessing the PhA through bioimpedance provides relevant measures of muscle strength and power in young volleyball athletes.

Keywords: Non-invasion team sports; body composition; muscle power; sports training.

INTRODUCTION

Success in volleyball depends largely on motor skills, particularly maximum strength, power, and speed in lower limbs (Pawlik et al., 2022), on an individual's ability to jump and land (Tillman et al., 2004). These motor skills are required during rallies involving explosive movements, such as spiking, blocking, and diving. Moreover, in volleyball is important to simultaneously develop overall strength, power, and speed to help support sport-specific training, performance, and injury reduction of the athletes (Hedrick, 2007).

Training the lower limbs, in particular by using plyometric methods, is essential for volleyball athletes since this methodology may develop players' performance in vertical and horizontal jumps, strength, speed, and agility (Silva et al., 2019).

Among the physical abilities necessary for success in volleyball, vertical jump height is pointed out as the most important characteristic (Crivelin et al., 2018), as it is estimated that attackers perform an average of 40 to 70 jumps per game (Tillman et al., 2004). Moreover, attacking and blocking skills characterised approximately 45% of the players' total movements and approximately 80% of the points during a match depends on performing a vertical jump (Crivelin et al., 2018). In addition, the work-rest ratio for top-level adult male volleyball players is approximately 1:6 (4.99 sec of work to 29.02 sec of rest), and it is considered a high-intensity anaerobic sport (Weldon et al., 2021).

In this sense, it is important to carry out the assessment of muscle strength in athletes, particularly through a vertical jump (lower limbs), which will make it possible to monitor athletes' strength performance (Bongiovanni et al., 2022; Cattem et al., 2021; Cirillo et al., 2023b; Crivelin et al., 2018), including young volleyball players. Several performance tests to estimate leg extensor muscles' strength and power have been used by the research community for many years (e.g., vertical jump tests). For example, Carvalho et al. (2007) assessed the lower limb strength of 10 Portuguese male volleyball athletes by using the counter-movement jump

(CMJ) and squat jump (SJ). The results obtained (CMJ: 44.0±3.7 cm; SJ: 42.6 ± 3.6 cm) exhibited the importance of assessing the lower limbs' performance.

Body composition also seems to affect athletes' performance (González-Ravé, Arija, Clemente-Suarez, 2011), as the athletes require a higher amount of lean mass, a lower amount of body fat (Zapolska, Witczak, Manczuk, Ostrowska, 2014), greater height, and longer lower and upper limbs (Gabbett & Georgieff, 2007). The practice of exercise has also been associated with the development of bone and muscle tissue, where fat-free mass (FFM) is considered a predictor of muscle strength and physical abilities (Cattem et al., 2021).

In addition, knowledge of body composition variables, bioelectrical impedance (BIA) parameters, and strength tests can help verify the effects of physical activity and sports practice over time (Cattem et al., 2021). Through the BIA test, we obtained the Phase Angle (PhA), which is considered an important parameter that is calculated directly from the primary values of resistance (R) and reactance (Xc). In clinical use, the PhA seems to reflect the cellular health, body cell mass, and cell wall integrity (Norman et al., 2012). The PhA is calculated using the equation $PhA = \arctan Xc / R \times 180o\pi$ (Baumgartner et al., 1988).

Therefore, the PhA corresponds to a direct measure of stability at the cellular level (Souza et al., 2017) and can be influenced by factors such as sex, age, and body mass index (Bosy-Westphal et al., 2006; Gonzalez et al., 2016). In healthy individuals, values can reach between 5º and 7.5º (Barbosa-Silva et al., 2005; Bosy-Westphal et al., 2006; Kyle et al., 2001), while in trained athletes (including young athletes), it can reach 8.5º (Cirillo et al., 2023b; Marra et al., 2016). In volleyball athletes, PhA values have been reported of 6.8º ± 0.43 (Di Vincenzo et al., 2020), 7.5º ± 0.6 (Campa et al., 2020), and 6.91º ± 0.48 (Mala et al., 2015). Moreover, the PhA values are also proposed to strongly predict the total participation of skeletal muscle and limb muscle mass (Hetherington-Rauth et al., 2021; Kołodziej et al., 2020).

Scientific evidence elucidated the existence of a relationship between PhA lower limb strength tests (CMJ and SJ) (Bongiovanni et al., 2021; Cirillo et al., 2023a). Although some studies report that there is a vast field to better understand the state of the art considering these variables, in which several studies demonstrated a consensus that PhA can also be used to monitor physical condition and sports performance in adolescent athletes and may be crucial to assess the body composition of athletes, providing useful data on the percentage of body cell mass and fat-free mass (Cirillo et al., 2023b; Di Vincenzo et al., 2019).

To the best of our knowledge, no studies verified the relationship between PhA and muscle strength of lower limbs in young volleyball athletes. In this sense, the present study aimed to verify the correlation between PhA (whole body) and the muscle strength of lower limbs in young male volleyball athletes. It is expected that we observed a positive correlation between PhA lower limb strength of young male volleyball players.

METHODS

Study design

We performed a cross-sectional observational study. The evaluations were carried out during the final phase of the Paraná Youth Games, ensuring that the best athletes from Paraná participated in the research. The sample underwent whole-body BIA analysis (in a fasted state for 4 hours) for PhA verification, in addition to vertical jump tests (CMJ and SJ).

Sample

We performed the sample calculation using G*Power, version 3.1.9.7 (Dusseldorf, Germany), which resulted in the appropriate sample size for carrying (suggesting a sample size of 38) out this study ($\alpha = 0.05$; $\beta = 0.95$) (Verma & Verma, 2020). Study participants included thirty-eight young sub-elite Brazilian male volleyball athletes (Age: 16.7 ± 1.3 years; Weight: 73.7 ±

9.7 kg; Height: 179.3 ± 6.9 cm). The athletes had been training for at least 4.7 ± 2.1 years, with a weekly workload of 9.6 hours/week, at the sub-elite level. The inclusion criterion was: (i) being an active and semi-professional participant in the included competition in volleyball sport. The exclusion criteria were: (i) lack of authorisation from those responsible; (ii) lack of interest in performing the tests; and (iii) any physical problem that prevented the athlete from performing any of the tests proposed in the research. The sample characteristics are presented in Table 1.

Table 1: Mean values and standard deviation of anthropometric characteristics of volleyball athletes.

Variables	m ± SD
Age (year)	16.7 ± 1.3
Height (cm)	179.3 ± 6.9
Weight (kg)	73.7 ± 9.7
BMI (kg/m^2)	22.9 ± 2.5
Fat Mass (%)	10.1 ± 3.7

Procedures

Athletes and guardians were fully informed about the procedures of this research, as well as the aims and potential risks, and all participants and their parents/guardians provided written consent prior to their participation. As the sample included athletes under 18 years of age, this term was signed by the team's coach. This study was performed according to the Declaration of Helsinki and was approved by the Ethics Committee of the lead university (protocol number S2121). Also, we were authorised by the Secretary of State for Sport and Tourism of the State of Paraná (Brazil) to collect data from the athletes through a consent form.

We carried out the sequence of tests so that the effort of one test would not influence the result of the subsequent test: i) Questionnaire (sample characterisation only); ii) Weight and height; iii) Bioimpedance; iv) Vertical Jump.

Instruments (testers were blind)

Assessment of body composition and BIA

A questionnaire was used to verify the number of years that athletes practised volleyball and the weekly training hours. Also, we measured height and body mass, which were recorded using a stadiometer, with a precision of 0.01 cm (Cardiomed Model Avanutri, Ref. 5130332, Rio de Janeiro, Brazil) and a digital scale, with a precision of 0.1 kg (Cristal Seven Plenna /Model, Ref. SIM00530, São Paulo, Brazil), respectively.

The body composition variables (fat mass, lean mass, intra and extracellular mass, total body water, intra and extracellular water and basal energy metabolism) and whole body BIA parameters (R, Xc, PhA) were obtained by using a BIA (biodynamics model 450, version 5.1, BiodynamicsR, Corp. Seattle, WA, USA) and Resting Tab ECG electrodes (Conmed R Corporation, Utica, NY, USA). The equipment provides body parameters through the flow of an alternating current of low frequency and high voltage (800 mA and 50 kHz), with accuracy values of 0.1% in R, 0.2% in Xc, and 0.2% in PhA (Biodynamics Corporation, 2007).

The athletes were positioned in a comfortable dorsal decubitus position, without using metallic objects (e.g., watches, bracelets, and earrings), barefoot, with their legs apart at 45º in relation to the midline of the body and with the upper limbs positioned 30º from the trunk. The skin was initially cleaned with pads soaked in alcohol. Then four adhesive electrodes were positioned as recommended: one electrode on the dorsal surface of the right wrist, another on the third metacarpal, one on the anterior surface of the right ankle between the prominent portions of the bones, and the last electrode on the dorsal surface of the third metatarsal. To minimise possible interference in the results, we previously advised the athletes not to ingest alcoholic drinks, take diuretics, and fast for at least four hours before the test.

To obtain a greater precision of the results, this equipment enables the addition of information on age, sex, height, weight of the individual, and weekly hours of training and provides results in a short time.

Muscle strength of lower limbs

Vertical jump tests

The vertical jump tests carried out were the SJ and CMJ (Bosco et al., 1987), using a system for measuring and analysing vertical jumps through optoelectronic sensors from the Sys Jump brand (Sys Jump, Systware, Miami, Florida, USA). From the half-flexion of the knees, in the SJ, the athlete remained in the jump area in a half-squat position for 5 seconds, with hands on the waist and knees at 90º. The evaluator gave a verbal signal for the athlete to perform the jump as high as possible without removing the hands from the waist and without retracting the feet or throwing them forward. In the CMJ, the athlete was positioned in the standing jump area, with hands resting on the waist and legs extended. After the evaluator's verbal command, the athlete performed a quick squat and then jumped as high as possible without removing the hands from the waist and without retracting the feet or throwing them forward. The athletes performed three attempts in both tests, with an interval of 30 seconds between executions. We recorded the best result in cm (Rodrigues & Marins, 2011).

Statistical Analysis

To verify the normality of the data, the Shapiro-Wilk test was applied, demonstrating normal distribution. Descriptive statistics (mean ± standard deviation) were calculated for all measurements. A Pearson correlation test (r) was used to assess the correlation between PhA, CMJ and SJ, which was considered a very weak correlation between 0.00 and 0.19, weak between 0.20 and 0.39, moderate between 0.40 and 0.69, strong between 0.70 and 0.89, and very strong between 0.90 and 1.00 (Maroco, 2007). Data were analysed with IBM SPSS Statistics, version 23.0 (IBM Corp., Armonk, NY, USA). The alpha level for significance was set at $p < 0.05$.

RESULTS

The PhA, CMJ and SJ variables, expressed in mean and standard deviation, are presented in Table 2.

Table 2: Mean and standard deviation values of the PhA, CMJ and SJ.

Variables	m ± SD
PhA (º)	8.1 ± 0.56
CMJ (cm)	50.9 ± 8.3
SJ (cm)	42.2 ± 5.9

The correlation values obtained between the PhA, CMJ and SJ evidenced a moderate significant correlation (r = 0.550 and r = 0.559, respectively) (Table 3).

Table 3: Pearson correlation values (r) between the PhA, CMJ and SJ.

		CMJ (cm)	SJ (cm)
PhA	Pearson correlation	.550**	.559**
	p	.000	.001

** The correlation is significant at 0.01 level (bilateral).

Moreover, both vertical jump tests: CMJ (r = 0.587, p = 0.000) and SJ (r = 0.526, p = 0.001), evidenced a positive correlation with PhA.

DISCUSSION

The present study aimed to verify the relationship between the PhA (whole body) and the performance variables for lower limb strength in young volleyball athletes. Our hypothesis was confirmed since the PhA were positive and moderately correlated with strength values for all applied tests.

According to the existing literature, and to the best of our knowledge, we observed that any study analysed the correlation between PhA and muscle strength in young male volleyball players.

Hetherington-Rauth et al. (2021) evaluated 117 adult athletes from different sports, including volleyball (21.0 ± 3.8 years), and found that PhA measurements (whole-body) were also highly correlated with the lower limbs (CMJ) ($r = 0.86$, $p < 0.05$). Referring to their results, the authors suggested that PhA may also be a relevant marker of athletes' muscle performance, particularly in strength. Albeit in our study we found a moderate correlation, we strongly believed that these results were due to the age of our athletes (16.7 ± 1.3 years) because the athletes are still in the maturation phase with consequent muscle formation. In support of our results, an investigation found significant and positive correlations, when controlling chronological age, between maturity and handgrip strength and various medicine ball throw tasks in young tennis players aged between 8 and 16 years old (Myburgh, Cumming, Silva, Cooke, Malina, 2016).

Based on the positive and moderate correlation between PhA and lower limb strength, we confirm our hypothesis, whether for SJ or CMJ. Incidentally, we did not find studies that aimed to verify the correlation between PhA and SJ in young volleyball players. The PhA can also be used to analyse only the concentric phase of the vertical jump movement.

Moreover, some studies have suggested the use of PhA and CMJ to monitor the strength performance of athletes (Bongiovanni et al., 2021; Cirillo et al., 2023b); this premise was also confirmed in our study by using young volleyball players, which now should be included in the sample categories.

Finally, according to Di Vincenzo et al. (2020), PhA has the potential to be applied by athletic trainers to facilitate and rapidly assess muscle performance, which can help in the determination of competition readiness, training progress, and tracking the return of muscle performance during the rehabilitation phase. Therefore, for training monitoring, we reinforce the use of the PhA due to its practicality, which was mentioned in the present study, together with CMJ and the SJ, considering that sports teams need evaluation and monitoring procedures to be quick, agile and easy to interpret throughout a sports season, including volleyball.

As a limitation, we emphasised the need to carry out these same tests during different moments of a season to verify how the correlation between PhA and strength tests of lower limbs behave in this sample.

CONCLUSION

The present study confirmed the relationship between PhA and lower limb strength (CMJ and SJ) in young volleyball athletes. In addition, the results underlined that evaluations based on the BIA test can be useful in an assessment focused on monitoring training programs. Furthermore, the findings add information about the clear relationship between PhA and muscle strength in young volleyball athletes.

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