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Comparison of bioelectrical impedance – derived phase angle in vegan and omnivorous exercisers

Comparação do ângulo de fase da bioimpedância elétrica em praticantes de exercícios físicos veganos e onívoros

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Abstract – Phase angle (PhA) is a parameter obtained through electrical bioimpedance that can be used to indicate health, nutritional, and functional status in different populations. Vegans tend to have a higher percentage of body fat and lower muscle mass than omnivores, but it is unknown whether the PhA is different between these two groups. This study aims to compare the PhA and body composition of physically active omnivorous and vegan individuals. This cross-sectional study involved 30 exercisers (12 men and 18 women), divided into a vegan group (VG; n = 15) and an omnivore group (OG; n = 15), matched for sex (6 men and 9 women in each group), age, height, and body mass (maximum difference of 5%). Body composition was measured using a scale, a stadiometer, and octopolar bioimpedance. Right arm PhA was lower in vegans (p = 0.036; d = 0.805), omnivores consumed more protein/kg of body weight daily (p = 0.026; d = 0.856), and vegans consumed more fiber daily (p < 0.001; d = -1.610). There were no significant differences in other dietary intake and body composition parameters between vegans and omnivores. Similarities in PhA and body composition were observed between vegan and omnivorous individuals, but with lower right arm PhA in the VG.

Key words: Body composition; Electric impedance; Vegans.

Resumo – *O ângulo de fase (AF) é um parâmetro obtido por meio da bioimpedância elétrica, podendo ser usado para indicar o estado de saúde, nutricional e funcional em diferentes populações. Veganos tendem a apresentar uma porcentagem maior de gordura corporal e menor massa muscular do que onívoros, mas não se sabe se o AF é diferente entre esses dois grupos. Este estudo tem como objetivo comparar o AF e a composição corporal de indivíduos onívoros e veganos fisicamente ativos. Este estudo transversal envolveu 30 praticantes de exercícios físicos (12 homens e 18 mulheres), divididos em um grupo vegano (GV; n = 15) e um grupo onívoro (GO; n = 15), pareados por sexo (seis homens e nove mulheres em cada grupo), idade, estatura e massa corporal (diferença máxima de 5%). Uma balança, um estadiômetro e bioimpedância octopolar foram usados para medir a composição corporal. O AF do braço direito foi menor nos veganos (p = 0,036; d = 0,805), os onívoros consumiram mais proteína/kg de massa corporal diariamente (p = 0,026; d = 0,856) e os veganos consumiram mais fibras diariamente (p < 0,001; d = – 1,610). Não houve diferenças significativas em outros parâmetros de ingestão alimentar e composição corporal entre veganos e onívoros. Foram observadas semelhanças no AF e na composição corporal entre indivíduos veganos e onívoros, mas com menor AF no braço direito no GV.*

Palavras-chave: *Composição corporal; Impedância elétrica; Veganos.*

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INTRODUCTION

Phase angle (PhA) is a parameter obtained through electrical bioimpedance (BIA) that can be used as an indicator of health, nutritional, and functional status in different populations, such as patients with obesity and older adults[1-3]. Within the sports field, PhA has emerged as a useful, safe, accurate, non-invasive, easy, and inexpensive way to measure and assess body composition, water status, muscle injuries, and, consequently, the physical performance of athletes[4].

PhA is calculated as the arc tangent of the ratio of reactance (Xc) to resistance (R) and then converted to degrees. While Xc is directly related to the body's cell mass content and membrane integrity, R is inversely proportional to body water, including extra and intracellular water[1]. This means that higher Xc and lower R produce higher PhA. The level of physical activity and time spent on sedentary behavior are also linked to PhA, whose increase is mostly associated with moderate and vigorous physical activities[3]. Thus, individuals who engage in physical activity have better cellular function than sedentary individuals[3]. Meanwhile, reduced PhA emerge from water imbalances, dehydration, musculoskeletal injuries, glycogen depletion, and catabolism of lean tissues arising from a high volume of physical training[4].

The omnivorous diet is characterized by including all food groups, both animal and vegetable[5], while the vegan diet features the removal of all foods of animal origin, such as meat, eggs, honey, dairy products, and products that include animal derivatives among the ingredients, such as gelatin, albumin, milk proteins, some dyes, thickeners, and products tested on animals[5]. Veganism is becoming increasingly prevalent among the general population as well as athletes, for health, ethical, sustainability, or other reasons. In Brazil, approximately 14% of the population adopts a vegetarian diet[6], while in Germany[2] and Saudi Arabia[7], there is a prevalence of 5% and 8% of vegetarianism, respectively. It is estimated that the world population will reach 9 billion inhabitants by 2050, increasing concerns about shortages of animal products to feed the population[8]. Therefore, studies need to investigate the effects of a vegan diet on various health markers, including PhA[5].

Vegans tend to have less muscle mass but smaller waist circumferences than omnivores[9]. In addition, vegetarians seem more likely to consume alcoholic drinks[10] and consume less protein[9]. These factors could negatively impact PhA.

We believe that the intake of any protein sources (animal and vegetable) can guarantee an adequate PhA, as long as the amount of dietary protein is sufficient to meet the exercisers' needs. However, we hypothesized that vegans have lower PhA than omnivores due to the lower amount of muscle mass and daily protein intake. Therefore, our study aims to compare the PhA and body composition of physically active omnivorous and vegan individuals.

METHODS

Study design

This cross-sectional observational study uses a non-probabilistic sample composed of 30 physical exercise practitioners (12 men and 18 women).

Participants were recruited via telephone, email, social networks, or direct invitation. The surveys and evaluations were carried out at the Federal University of Mato Grosso do Sul (UFMS) or at the participants' homes, from October 2022 to August 2023. This study was approved by the Human Subjects Research Ethics Committee of the Federal University of Mato Grosso do Sul (no. 79957217.6.0000.0021). Participants were fully informed of the risks and benefits of taking part in the study by signing an informed consent form on the Multiprofessional Evaluation: Determinants of Athletes' Longevity and Performance (MEDALHA Project).

Participants

All vegan participants were matched with the omnivores for purposes of controlling confounding effects based on sex, age, height, and body mass, with a maximum variation of 5% between the groups.

The included participants were physically active adults, with a minimum weekly physical activity of three days and a total workload of six hours per week. Participants in the vegan group (VG) were required not to have consumed protein of animal origin, including its derivatives, for at least one year. Participants in the omnivorous group (OG) were required to consume foods of animal origin. All participants aged between 19 and 48 years of age since there are no significant differences in PhA in this age range[11]. The following exclusion criteria were applied: pregnant women, disabled participants, users of pacemakers, body pins, plates, or other types of metal objects in their bodies, catabolic patients, or users of pharmacological ergogenic aids such as anabolic steroids.

Body composition

Body mass was measured using a digital scale to the nearest 0.01 kg, with the participants barefoot and wearing light clothing. Height was measured to the nearest 0.1 cm using a stadiometer (Sanny, São Bernardo do Campo, Brazil). The body mass index (BMI) was calculated based on the weight in kilograms (kg) divided by the square of height in meters (m^2).

PhA, skeletal muscle mass, and percentage of body fat were obtained using an octapolar (8-Point Tactile Electrode) impedance analyzer (Inbody® S10, Cerritos, USA), at an operating frequency of 50 kHz. The equipment provides bioelectrical impedance (Z), reactance (Xc), and PhA of the whole body and each of five segments (right arm, left arm, trunk, right leg, and left leg) using no empirical estimations based on age, sex, or other variables to calculate body composition. The principle of the InBodyS10 analyzer is that the volume of body water is calculated first with a measured impedance value. The fat-free mass (which includes minerals and skeletal muscle mass) is then obtained based on the volume of body water. Body fat mass is subsequently determined by deducting the fat-free mass from the measured weight.

The assessment followed the procedures described in the MEDALHA Project Assessment Manual[12]. Before the tests, the participants were instructed not to exercise for at least eight hours, not to eat food for two hours, to empty the urinary bladder, and not to drink alcoholic or caffeinated beverages for 48 hours.

On the day of the test, the participants lay on a stretcher in light clothing, without any metallic objects on the body, about 10 to 15 minutes before the test started, with their arms not touching their bodies at a 15° angle, and legs shoulder-width apart without touching between the thighs. The electrodes were attached to the backs of the hands and feet in a standard external and internal position and sanitized with alcohol before and after the tests[12].

Food consumption

Participants' food intake was assessed on two random days using a 24-hour recall (R24h)[13] applied by a trained nutrition student. Participants were asked to declare all food items, dietary supplements, and beverages consumed in the previous 24 hours, reporting the amount in grams or a homemade measure. In addition, they were asked to detail preparation methods, ingredients used in mixed dishes, and the brand of commercial products and ready-to-eat foods[13].

All food and drinks that the participant could not report in grams were estimated and recorded in standardized household measures (e.g., glasses, cups, spoons)[13]. Dietary supplements were recorded according to the manufacturer's suggested serving size (e.g., scoops, capsules, pills). Food records were obtained from WhatsApp messages, containing meals with their respective times, foods, drinks ingested, ingredients, and quantities in grams or homemade measures. The nutritional composition of the food or the manufacturer's declaration of the nutritional composition of supplement items were calculated according to the Brazilian food database (Web Diet® software, Rio de Janeiro, RJ, Brazil).

Statistical analysis

Statistical analyses were carried out using JASP® statistical software (version 0.19.03). Values are presented as mean and standard deviation upon showing normal distribution, and median and first and third quartiles upon showing non-normal distribution. Categorical variables are presented as absolute (numbers) and/or relative values (%). Data normality was verified by the Shapiro-Wilk test. Comparisons of body composition (body mass, muscle mass, fat mass, fat percentage, height, BMI), macronutrients (carbohydrates, lipids, fiber, and water), and BIA markers (PhA, impedance, reactance, resistance, intracellular water, extracellular water, and total body water) between the VG and OG were carried out by the Student's t-test for independent samples (for parametric data) or Mann-Whitney U-test (for non-parametric data). The effect sizes of the differences between the groups were analyzed using Cohen's d or rank biserial correlation. The effect size was interpreted as small (0.20), medium (0.50), or large (0.80)[14] when by the Student's t-test, and the magnitude of the correlation was classified as 0 - 0.3 small, 0.31 - 0.49 moderate, 0.5 - 0.69 strong, 0.7 - 0.89 very strong, and 0.9 - 1 almost perfect[15] using the Mann-Whitney U-test. Statistical significance was set at $p < 0.05$.

RESULTS

The VG included nine women and six men, with an average age of 27 years, who practiced weight training, running, calisthenics, volleyball, wrestling, functional training, and walking, with an average weekly practice of seven hours and 12 minutes. The OG included nine women and six men, with an average age of 23 years, who practiced bodybuilding, dancing, running, and walking, with an average weekly practice of six hours and 30 minutes.

Both groups showed similar sociodemographic characteristics (Table 1). There was no significant difference for body mass, height, BMI, skeletal muscle mass, fat mass, body fat, cellular mass, total body water, intracellular water, and extracellular water between the VG and OG.

Table 1. Body composition characteristics and respective comparisons between the vegan and omnivorous groups.

	Vegan group (n = 15)			Omnivorous group (n = 15)			Effect size†	p†
	All (n = 15)	Men (n = 6)	Women (n = 9)	All (n = 15)	Men (n = 6)	Women (n = 9)		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
Body mass (kg)	63.7 ± 9.6	72.4 ± 7.4	57.9 ± 5.7	63.2 ± 9.8	72.4 ± 8.0	57.1 ± 5.0	-0.049	0.894
Height (cm)	169.0 ± 10.2	176.8 ± 9.7	164.2 ± 7.2	168.0 ± 10.3	178.8 ± 4.8	161.2 ± 5.7	-0.097	0.791
BMI (kg/m2)	22.2 ± 2.3	23.2 ± 2.6	21.5 ± 2.1	22.2 ± 1.3	22.6 ± 1.6	22.0 ± 1.7	0.011	0.975
Skeletal muscle mass (kg)	27.5 ± 6.5	33.7 ± 4.6	23.4 ± 3.7	27.9 ± 8.6	37.4 ± 5.0	21.7 ± 2.2	0.057	0.877
Fat mass (kg)	14.1 ± 5.6	12.7 ± 6.1	15.1 ± 5.5	13.2 ± 6.3	7.2 ± 4.0	17.3 ± 3.6	-0.146	0.693
Body fat (%)	22.5 ± 9.2	17.4 ± 7.9	26.0 ± 8.8	22.1 ± 11.3	9.9 ± 5.0	30.2 ± 5.0	-0.045	0.903
Cellular mass (kg)	32.4 ± 7.2	39.2 ± 5.1	27.9 ± 4.1	32.9 ± 9.5	43.2 ± 5.5	26.0 ± 2.4	0.054	0.884
Total body water (L)	36.3 ± 7.9	43.8 ± 5.8	31.3 ± 4.4	36.6 ± 10.2	47.7 ± 5.6	29.1 ± 2.6	0.028	0.938
Intracellular water (L)	22.6 ± 5.0	27.4 ± 3.6	19.5 ± 2.9	23.0 ± 6.6	30.2 ± 3.8	18.1 ± 1.6	0.052	0.888
Extracellular water (L)*	13.4 (11.6 – 15.7)	16.4 ± 2.3	11.8 ± 1.6	12.1 (11.0 – 16.5)	17.5 ± 1.8	11.0 ± 1.0	-0.062	0.787

Note. BMI, body mass index; SD, standard deviation; kg, kilogram; cm, centimeters; kg/m², kilograms per square meter; L, liters; *Non-parametric data are presented as median (interquartile range), and comparisons were performed using the Mann-Whitney U-test; †effect size of the difference between the means and p-value for comparisons between all participants in the vegan group and the omnivorous group.

There were significant differences in food consumption between the groups (Table 2). Compared to omnivores, vegans consumed significantly more fiber ($p < 0.001$; $d = -1.610$) and less protein g/kg/day ($p = 0.026$; $d = 0.856$), both with a large effect size, and carbohydrate/kg/day ($p = 0.036$; $r = -0.200$), with a small effect size. However, there were no significant differences in the intake of total protein and total carbohydrates, or total and relative daily intake of lipids and water.

Table 2. Food intake among vegans and omnivores and respective comparisons between the groups.

	Vegan group (n = 15)			Omnivorous group (n = 15)			Effect size †	*p* †
	All (n = 15)	Men (n = 6)	Women (n = 9)	All (n = 15)	Men (n = 6)	Women (n = 9)		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
Carbohydrates (g/day) *	245.3 (197.2 – 425.7)	444.9 ± 186.9	234.6 ± 86.1	221.0 (164.7 – 331.0)	344.9 ± 95.9	182.8 ± 79.6	-0.253	0.250
Carbohydrates (g/kg/day) *	3.8 (3.1 – 7.0)	6.2 ± 2.6	3.6 (2.9 – 4.7)	3.9 (2.9 – 4.7)	4.9 ± 1.6	3.2 ± 1.4	-0.200	**0.036**
Lipids (g/day) *	43.0 (37.2 – 56.3)	65.8 ± 40.0	40.7 ± 12.9	48.5 (41.1 – 86.5)	78.8 ± 29.0	44.2 (40.3 – 48.5)	0.211	0.285
Lipids (g/kg/day) *	0.8 (0.5 – 0.9)	0.9 ± 0.5	0.7 ± 0.2	0.9 (0.7 – 1.3)	1.1 ± 0.4	0.9 ± 0.3	0.360	0.098
Protein (g/day)	88.7 ± 39.7	118.6 ± 41.0	68.7 ± 24.3 [a]	118.0 ± 44.5	146.5 ± 44.6	99.2 ± 34.8	0.699	0.066
Protein (g/kg/day)	1.3 ± 0.5	1.7 ± 0.6	1.2 ± 0.4 [a]	1.8 ± 0.5	2.0 ± 0.5	1.7 ± 0.5	0.856	**0.026**
Water (L/day) *	2.5 (2.0 – 3.3)	3.0 (2.2 – 3.5)	2.4 ± 0.6	2.5 (2.5 – 3.0)	3.0 (2.6 – 3.8)	2.5 ± 0.7	0.173	0.422
Fiber (g/day)	49.9 ± 22.0	58.9 ± 26.4 [b]	43.9 ± 17.7 [a]	21.4 ± 11.8	30.5 ± 10.9	15.4 ± 8.1	-1.610	**<0.001**

Note. SD, standard deviation; kg, kilogram; cm, centimeters; g/kg, gram per kilogram; L, liters; [a]significant differences between the women in the vegan group compared to the women in the omnivorous group using the Student's t-test (p<0.05); [b]significant differences between the men in the vegan group compared to the men in the omnivorous group using the Student's t-test (p<0.05); *Non-parametric data are presented as median (interquartile range), and comparisons were performed using the Mann-Whitney U-test; †effect size of the difference between the means and p-value for comparisons between all participants in the vegan group and the omnivorous group. Numbers in bold denote significance.

Significant differences were found in the sex-based comparisons (Table 2). Women in the OG consumed more protein/kg/day (p = 0.027; d = 1.146) and protein/day compared to the VG (p = 0.047; d = 1.016). As expected, both men and women from the OG consumed less fiber than those from the VG (p <0.001; d = - 2.071), both with a large effect size.

Table 3 presents the body composition analysis by body segment. Considering all participants or by sex, neither the content of intra- and extracellular water nor the skeletal muscle mass and fat mass differed between the VG and OG.

Table 3. Comparison of total, intracellular, and extracellular water, skeletal muscle mass, and body fat per body segment between vegan and omnivorous groups.

	Vegan group (n = 15)			Omnivorous group (n = 15)			Effect size †	*p* †
	All (n = 15)	Men (n = 6)	Women (n = 9)	All (n = 15)	Men (n = 6)	Women (n = 9)		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
Right arm								
Total water (L) *	2.0 (1.5 – 2.5)	2.6 ± 0.4	1.6 ± 0.3	1.7 (1.5 – 2.6)	2.8 ± 0.4	1.5 ± 0.2	0.022	0.934
Intracellular water (L) *	1.3 (0.9 – 1.6)	1.6 ± 0.2	1.0 ±0.2	1.1 (0.9 – 1.7)	1.8 ± 0.2	0.9 ± 0.1	0.027	0.917
Extracellular water (L) *	0.7 (0.6 – 0.9)	1.0 ± 0.1	0.6 ± 0.1	0.6 (0.6 – 1.0)	1.0 ± 0.1	0.6 ± 0.1	-0.013	0.967
Skeletal muscle mass (kg) *	2.5 (1.9 – 3.2)	3.3 ± 0.5	2.0 ± 0.4	2.2 (1.9 – 3.4)	3.7 ± 0.5	1.9 ± 0.3	0.027	0.917
Body fat (kg)	0.8 ± 0.4	0.7 ± 0.4	1.0 ± 0.4	0.7 ± 0.5	0.3 ± 0.2	1.1 ± 0.3	-0.138	0.709
Left arm								
Total water (L)	1.9 ± 0.5	2.6 ± 0.4	1.6 ± 0.3	2.0 ± 0.7	2.8 ± 0.4	1.5 ± 0.2	0.051	0.890
Intracellular water (L)	1.2 ± 0.3	1.6 ± 0.2	1.0 ± 0.2	1.2 ± 0.4	1.8 ± 0.2	0.9 ± 0.1	0.068	0.853
Extracellular water (L) *	0.7 (0.6 – 0.9)	1.0 ± 01	0.6 ± 0.1	0.6 (0.6 – 1.0)	1.0 ± 0.1	0.6 ± 0.1	-0.036	0.885
Skeletal muscle mass (kg)	2.5 ± 0.7	3.3 ± 0.5	2.0 ± 1.9	2.6 ± 0.9	3.6 ± 0.5	1.9 ± 0.3	0.061	0.870
Body fat (kg)	0.8 ± 0.4	0.7 ± 0.4	1.0 ± 0.4	0.7 ± 0.5	0.3 ± 0.2	1.1 ± 0.3	-0.158	0.669
Trunk								
Total water (L)	16.9 ± 3.5	20.4 ± 2.1	14.6. ± 2.0	17.1 ± 40.3	21.9 ± 1	14.0 ± 1.4	0.067	0.855
Intracellular water (L)	10.5 ± 2.2	12.8 ± 1.3	9.0 ± 1.3	10.7 ± 2.8	13.9 ± 1.4	8.7 ± 0.8	0.094	0.799
Extracellular water (L) *	6.2 (5.3 – 7.5)	7.7 ± 0.9	5.5 ± 0.7	5.8 (5.3 – 7.8)	8.1 ± 0.7	5.3 ± 0.5	0.004	1.000
Skeletal muscle mass (kg)	21.7 ± 4.6	26.3 ± 2.7	18.7 ± 2.6	22.1 ± 5.6	28.3 ± 2.7	18.0 ± 1.7	0.069	0.852
Body fat (kg)	6.9 ± 3.1	6.6 ± 3.8	7.2 ± 2.8	6.4 ± 3.4	3.2 ± 2.4	8.6 ± 2.1	-0.154	0.676
Right leg								
Total water (L) *	6.1 (5.1 – 6.6)	6.9 (6.3 – 7.3)	5.2 ± 0.8	5.2 (4.8 – 7.3)	8.1 ± 1.2	4.8 ± 0.5	-0.071	0.756
Intracellular water (L) *	3.8 (3.2 – 4.2)	4.3 (4.0 – 4.6)	3.3 ± 0.5	3.2 (3.0 – 4.6)	5.2 ± 0.8	3.0 ± 0.3	-0.076	0.744
Extracellular water (L) *	2.3 (2.0 – 2.4)	2.6 (2.4 – 2.7)	2.0 ± 0.3	2.0 (1.8 – 2.7)	2.9 ± 0.4	1.8 ± 0.2	-0.102	0.648
Skeletal muscle mass (kg) *	7.9 (6.5 – 8.5)	8.7 (8.1 – 9.4)	6.7 ± 1.1	6.6 (6.1 – 9.4)	10.4 ± 1.5	6.1 ± 0.6	-0.076	0.744
Body fat (kg)	2.2 ± 0.8	1.9 ± 0.7	2.5 ± 0.9	2.1 ± 0.9	1.2 ± 0.6	2.7 ± 0.5	-0.114	0.758
Left leg								
Total water (L) *	6.1 (5.1 – 6.6)	6.9 (6.4 – 7.4)	5.2 ± 0.8	5.2 (4.8 – 7.3)	8.0 ± 1.1	4.8 ± 0.5	-0.044	0.852
Intracellular water (L) *	3.9 (3.2 – 4.2)	4.3 (4.0 – 4.6)	3.2 ± 0.5	3.2 (3.0 – 4.6)	5.1 ± 0.8	3.0 ± 0.3	-0.022	0.934
Extracellular water (L) *	2.2 (2.0 – 2.5)	2.6 (2.4 – 2.8)	2.0 ± 0.3	2.0 (1.8 – 2.7)	3.0 ± 0.4	1.8 ± 0.2	-0.093	0.683
Skeletal muscle mass (kg) *	7.9 (6.5 – 8.5)	8.9 (8.2 – 9.5)	6.7 ± 1.1	6.6 (6.2 – 9.4)	10.4 ± 1.5	6.2 ± 0.6	-0.036	0.885
Body fat (kg)	2.2 ± 0.8	1.9 ± 0.7	2.4 ± 0.9	2.1 ± 0.9	1.2 ± 0.6	2.7 ± 0.5	-0.098	0.790

Note. SD, standard deviation; *Non-parametric data are presented as median (interquartile range), and comparisons were performed using the Mann-Whitney U-test; †effect size of the difference between the means and p-value for comparisons between all participants in the vegan group and the omnivorous group.

In terms of the BIA raw parameter, the VG and OG showed similarities across all body segments, except for PhA (p = 0.036; d = 0.805) and Xc (p = 0.023; d = 0.493) of the right arm, which were higher in the OG compared to VG, both with a large effect size (Table 4).

There were significant intra-sex differences between the groups (Table 4). OG women exhibited higher Z (p = 0.031; r = 0.605) and R values (p = 0.031; r = 0.605) of the trunk, as well as a higher Xc value of the right arm (p = 0.031; d = 1.112) than VG women, with the differences between the groups exhibiting strong effect sizes for Z and R, and a large effect size for Xc. Men in the OG had higher PhA compared to those in the VG in the right arm (p = 0.019; d = 1.606), left arm (p = 0.025; d = 1.518), and trunk (p = 0.046; d = 1.312), all with large effect sizes.

Table 4. Comparison of phase angle, impedance, reactance, and resistance by body segment between vegan and omnivorous groups.

	Vegan group (n = 15)			Omnivorous group (n = 15)			Effect size †	*p* †
	All (n = 15)	Men (n = 6)	Women (n = 9)	All (n = 15)	Men (n = 6)	Women (n = 9)		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
PhA Total (°)	6.0 ± 0.8	6.6 ± 0.6 [b]	5.7 ± 0.8	6.6 ± 1.0	7.6 ± 0.9	6.0 ± 0.5	0.615	0.103
Right arm								
PhA (°)	5.7 ± 0.8	6.2 ± 0.6 b	5.3 ± 0.8	6.4 ± 1.0	7.3 ± 0.7	5.8 ± 0.6	0.805	**0.036**
Xc (Ω) *	34.0 (30.1 – 38.6)	32.6 ± 4.8	36.6 ± 4.4 [a]	40.7 (34.6 – 42.5)	34.2 (33.8 – 34.8)	42.3 (40.7 – 42.6)	0.493	**0.023**
Z (Ω)	361.0 ± 61.5	300.1 ± 28.7	394.7 ± 38.6	351.0 ± 72.8	282.1 ± 32.1	403.8 ± 26.7	-0.045	0.365
R (Ω)	355.3 ± 61.6	298.3 ± 28.5	392.6 ± 38.78	355.8 ± 70.0	279.8 ± 32.0	401.6 ± 26.8	-0,051	0.890
Left arm								
PhA (°)	5.6 ± 0.8	6.2 ± 0.7 b	5.4 ± 0.7	6.2 ± 1.0	7.2 ± 0.7	5.6 ± 0.5	0.617	0.102
Xc (Ω) *	34.8 (30.1 – 38.1)	30.1 (29.1 – 33.7)	36.4 ± 4.2	39.2 (33.6 – 41.4)	33.8 (33.2 – 35.0)	39.9 ± 4.2	0.378	0.081
Z (Ω)	357.0 ± 60.2	298.6 ± 27.2	391.2 ± 40.2	351.5 ± 73.3	282.6 ± 30.5	408.9 ± 29.9	0.032	0.930
R (Ω)	355.3 ± 60.3	296.7 ± 27.1	389.0 ± 40.2	357.1 ± 70.9	280.4 ± 30.3	406.9 ± 29.8	0.027	0.941
Trunk								
PhA (°)	6.4 ± 1.4	7.3 ± 0.9 b	6.4 ± 1.5	6.9 ± 1.3	8.4 ± 0.7	6.3 ± 0.6	0.390	0.295
Xc (Ω) *	2.7 (2.6 – 3.3)	3.0 ± 0.6	2.7 ± 0.7	3.1 (3.0 – 3.3)	3.1 (3.0 – 3.3)	3.1 ± 0.2	0.249	0.251
Z (Ω) *	24.5 (23.7 – 2.2)	23.7 ± 2.3	24.6 (23.9 – 27.2)[a]	27.5 (22.0 – 29.5)	21.7 ± 1.4	28.8 (28.0 – 30.6)	0.129	0.561
R (Ω) *	24.3 (23.5 – 26.0)	23.5 ± 2.3	24.5 (23.9 – 27.1)[a]	27.4 (21.8 – 29.3)	21.4 ± 1.4	28.6 (27.8 – 30.5)	0.124	0.575
Right leg								
PhA (°)	6.5 ± 0.8	6.9 ± 0.7	6.2 ± 0.8	6.8 ± 1.2	7.8 ± 1.3	6.1 ± 0.7	0.292	0.431
Xc (Ω)	30.5 ± 4.1	30.1 ± 3.8	32.0 ± 4.6	32.4 ± 4.2	31.1 ± 5.4	31.2 ± 3.0	0.383	0.303
Z (Ω)	268.0 ± 29.7	250.5 ± 33.5	272.8 ± 21.5	269.1 ± 47.7	230.3 ± 31.9	293.7 ± 28.5	0.154	0.676
R (Ω)	266.3 ± 29.7	248.6 ± 33.5	270.4 ± 21.3	272.1 ± 46.9	282.2 ± 31.8	291.4 ± 28.5	0.150	0.685
Left leg								
PhA (°)	6.6 ± 0.8	7.0 ± 0.8	6.3 ± 0.8	6.6 ± 1.2	7.8 ± 1.4	6.2 ± 0.7	0.326	0.380
Xc (Ω)	30.7 ± 4.6	29.9 ± 4.8	31.8 ± 4.7	32.8 ± 4.2	31.2 ± 5.1	31.4 ± 3.3	0.399	0.284
Z (Ω)	268.4 ± 31.1	246.0 ± 35.6	284.1 ± 16.8	269.2 ± 47.6	231.2 ± 32.2	291.0 ± 28.6	0.140	0.704
R (Ω)	266.6 ± 31.0	244.1 ± 35.4	282.5 ± 16.6	271.9 ± 46.4	229.0 ± 32.2	289.3 ± 28.6	0.135	0.714

Note. SD, standard deviation; °, degrees; Ω, ohms; [a]significant differences between the women in the vegan group compared to the women in the omnivorous group using the Student's t-test (p<0.05); [b]significant differences between the men in the vegan group compared to the men in the omnivorous group using the Student's t-test (p<0.05); *Non-parametric data are presented as median (interquartile range), and comparisons were performed using the Mann-Whitney U-test; †effect size of the difference between the means and p-value for comparisons between all participants in the vegan group and the omnivorous group. Numbers in bold denote significance.

DISCUSSION

This study indicates subtle differences in the raw parameters of the bioimpedance analysis between the vegan and omnivorous participants studied, especially related to PhA. By comparing the sexes between the groups, PhA was higher in omnivorous compared to vegan men in arms and trunk, while omnivorous women had higher Xc, R, and Z values in the trunk. After carefully reviewing the literature, we believe that this is the first study to compare vegan and omnivorous diets in terms of BIA markers in the different body segments. Dawczynski et al.[9] investigated nutritional markers of individuals following omnivorous, flexitarian, vegetarian, or vegan diets, but using whole body values. In line with our results, the authors observed that whole body PhA did not differ between the groups. However, our segmental analysis showed that right arm, left arm, and trunk PhA values were lower in vegans compared to omnivorous men, and Xc was higher in the right arm of omnivorous compared to vegan women.

Reactance is a marker of functionality demonstrated by the resistive effect of the capacitance produced by tissue interfaces and cell membranes. Factors that positively affect reactance and PhA include muscle mass, cellular mass, membrane permeability, and intracellular water[1], which, in turn, can be influenced by physical exercise[16]. Physical exercise improves the quality and integrity of the muscle cell, by calorie and protein consumption[17,18] and by the anti-inflammatory and antioxidant state of the cell, since inflammatory processes can compromise the integrity of the cell membrane[19].

The data show that total and segmental skeletal muscle mass values were similar between vegans and omnivores, corroborating the results of Hevia-Larraín et al.[18]. However, the lower Xc in vegan women and the lower PhA in vegan men may reflect lower cell integrity[16]. Such a difference could be explained by the lower amount of protein and higher amount of fiber ingested by vegans compared to omnivores.

The consumption of proteins of high biological value is related to both muscle quantity[20] and quality. In this sense, greater muscle mass has a positive impact on PhA[17,21]. Interestingly, the main sources of protein in the diet of the vegans in our study were legumes, tofu, and textured soy protein, while eggs and meat were more consumed by omnivores. Plant-based protein sources may provide lower amounts of certain essential amino acids (especially lysine, methionine, and leucine) since larger quantities of food are often required to meet protein needs. This lower availability could compromise the process of muscle protein synthesis. In contrast, foods of animal origin contain a more complete amino acid profile and are easier to access in small volumes, which generally favors anabolism[22].

An analyzing of the potential of vegetable protein for muscle protein synthesis reveals that soy protein is similar to whey protein[23]. Pinckaers et al.[8] analyzed the aminogram and anabolic response to vegetable proteins and concluded that a decrease in muscle anabolism occurs when large quantities of the vegetable protein source food are ingested to reach the recommended protein values. Consequently, anti-nutritional factors and fibers are ingested more often, which can hinder absorption, thus justifying the use of isolated protein products, such as powdered supplements that are free of dietary fibers.

The greater PhA of the right arm of the omnivores in our study could be explained not by greater muscle mass, since there were no differences between the groups, but by the higher quality of the muscle cells. It is worth mentioning that both the vegans and omnivores in this study are mostly right-handed (93.3%). Therefore, it is assumed that the right arm is highly stimulated in daily activities, thus impacting the uptake of dietary amino acids, as well as cellular quality and function, and, consequently, Xc and PhA. Thus, the higher protein intake of the omnivorous diet could act synergistically with physical activity, increasing the uptake of amino acids in this limb.

Both groups were eutrophic (BMI < 25 kg/m^2) and showed muscle mass[24] and PhA values[25] within the reference standards for healthy individuals. The average total PhA of the vegan group (6.0 degrees) suggests that the vegan diet is sufficient to achieve "adequate" PhA values by being close to the reference values of athletes[26]. In addition, the daily protein intake was considered adequate for both groups, considering the recommendations for exercisers (i.e., 1.4 to 2.0 g/kg)[20].

Therefore, the similarity between the groups in terms of total PhA is assumed to derive from the good nutritional status of both vegans and omnivores.

The vegan diet is usually rich in antioxidant foods, such as vitamin C, vitamin E, and β-carotene, favoring a more inflammatory profile for this group[27]. It is known that inflammation and oxidative stress can cause cell membrane dysfunction, which would harm PhA. Thus, vegan diets appears to amplify PhA and reduce the probable differences associated with protein consumption.

As expected, women in our study had higher R values compared to men. This can be explained by the lower fat mass and greater muscle mass and intra- and extracellular water content (with the dissolved electrolytes) of men compared to women. Muscles and cellular fluids facilitate the electrical current flow, offering lower resistance (R), while fat offers higher resistance to the current flow[28].

Considering the relevance to clinical practice, our results show that vegan diets can produce results similar to omnivorous diets in terms of muscle and cell quantity. It should be noted that a diet balanced in micro and macronutrients and the intake of essential amino acids in sufficient quantities to maintain muscle mass is vital[22]. In addition, the Academy of Nutrition and Dietetics highlights importance of the vegan diet for maintaining the health of various populations and reducing the environmental damage caused by excessive meat consumption[29].

Although prior studies have analyzed PhA in the general population[25], athletes[26], and in exercises[3], one of them addressed PhA in physically active vegans. Therefore, further studies must analyze not only total PhA, but also total body composition as well as by segment, such as arms, trunk, and legs, in this population.

The comparison of PhA between the groups is limited by the possibility of variation due to the different sports disciplines, the impossibility of accounting for essential amino acids ingested by the groups, and the cross-sectional observational nature of the study. Thereby, there were no nutrient adjustments for further analysis. The small number of participants is also an issue that reduced the power of the study. Finally, the self-reported record of food intake on two random days carries the risk of under-reporting foods with a higher energy content and overestimating healthy foods.

Furthermore, the fact that individuals who follow a diet without animal products or foods have lower PhA does not allow us to state that vegan diets are less effective than omnivorous diets, since the difference was generally not significant. In addition, electrical impedance is a practical, non-invasive, and low-cost tool for repeating the analysis. Finally, our research suggests similar body compositions between vegans and omnivores. Future research could encompass a larger number of participants to increase the power of the study.

We believe that our findings might help nutritionists and health professionals to understand the usefulness of practical and safe equipment for nutritional and health assessments, such as bioimpedance, and the impact of plant-based food on the human body, thus fostering greater acceptance of vegan diets and non-discrimination against this choice. It should be emphasized that a well-structured and planned diet reduces the differences between vegans and omnivores in terms of health and physical performance.

CONCLUSION

Although there was no significant difference in the amount of skeletal muscle mass between the groups, our results indicate that the non-vegan group had significantly higher right arm PhA than the vegan group. Meanwhile, the vegan group consumed less protein (g/kg) and significantly more fiber daily, which may have had an impact on the final PhA result. In the context of sports nutrition, PhA could be a practical tool for assessing the nutritional status of exercisers throughout their lives. However, more studies on PhA are needed in the field of sport.

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COMPLIANCE WITH ETHICAL STANDARDS

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical approval

Ethical approval was obtained from the local Human Research Ethics Committee of the Federal University of Mato Grosso do Sul, and the protocol (no. 79957217.6.0000.0021) was written according to the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflicts of interest to declare.

Author Contributions

Experiment planning and design: GS, PHH, FCPR, CFC-R; Experiment performance: PHH, CFC-R; Data analysis: GS, PHH, BOO, FCPR, LAG, CFC-R; Analysis tools: GS, PHH, BOO, FCPR, LAG, CFC-R; Writing: GS, PHH, BOO, FCPR, LAG, CFC-R.

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