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Differences in body composition measured using the bioelectrical impedance analysis with steel and gel electrodes – on an example of professional fencers

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Abstract

Introduction: Regular assessment of body composition in athletes is a key element of their nutritional status and general condition monitoring.

Purpose: Analysis of differences in the impedance (I) and body composition measurements performed by the use of analyzers with a constant current frequency of 50 kHz with steel and gel electrodes.

Material and methods: Analysis were performed in experienced fencers by the use of analyzers: Tanita BC418MA (aT) with steel electrodes (eT) and Akern BIA101ASE (aA) with gel electrodes (eA, eL, eT). During the first stage of the study in 48 athletes I, fat mass (FM) and fat free mass (FFM) were measured using aA with eB in a supine position and after 3 min using aT with eT in a standing position. Then 10 fencers were randomly selected. For them measurements were performed after 10, 13 and 16 min in a supine position using eA, eL, eB and then after 3 min in a standing one using eT. Intrinsic impedance of the 3 types of gel electrodes (eA, eL, eB) were measured using aA.

Results: The first stage. Differences in I, FM and FFM between eT and aA were observed (women: 101.4±52.2Ω, 1.2±2.1kg, -1.2±2.1kg, men: 98.8±27.5Ω, 1.1±1.5kg, -1.1±1.5kg, respectively). The second stage. In the subsequent measurements, differences in I were observed (women: eL-eA 3.8±1.8Ω, eB-eA 26.1±8.0Ω, eT-eA 154.4±40.6Ω;, men: of -0.7±9.4Ω, 11.1±9.2Ω, 107±36.3Ω, respectively). In both subgroups along with the increase in I, FM also increased, while FFM decreased. Intrinsic impedance of the applied gel electrodes was measured and the differences between the results were reported (eL-eA 41.1±22.0Ω, eB-eL 138.4±20.7Ω, eB-eA 179.5Ω). As the intrinsic impedance of gel electrodes increased, an increase in the whole body I was observed.

Conclusion: It seems that the observed differences in the whole body impedance were not only a simple effect of changes in a body position but they might have also been related to the intrinsic impedance of electrodes.

Key words: intrinsic impedance, fat mass, fat free mass, athletes

Introduction

Regular assessment of body composition in athletes is a key element of their nutritional status and general condition monitoring as well as is helpful in appropriate adjustment of an optimal, individual training plan [1, 2, 3]. Therefore the International Olympic Committee recommends regular monitoring of body composition and strongly underlines the need for assessment procedures standardization [4].

One of the most popular methods for assessment of body composition is the bioelectrical impedance analysis (BIA), [5, 6]. In this method, many measurement conditions and factors are very important as they affect the obtained results [7]. One of them may be electrodes. In the available literature we have not found publications that analyzed the effect of the type of electrodes on the results of body composition.

The aim of the current investigation was to analyze differences in the impedance and body composition measurements performed by means of analyzers with constant current frequency of 50 kHz and common types of electrodes, i.e. steel and pre-gelled electrodes in a group of highly trained fencers.

Methods

1.1. Subjects

Experienced fencers who train fencing at least ten hours a week and at least for three years took part in the study. To the first stage of the study 48 fencers (women: n = 27; age 23.2 ± 4.9 years and men: n = 21; age 27.3 ± 6.3 years) were qualified. Subsequently, 10 fencers (women n = 5; age 23.6 ± 2.1 years and men n = 5; age 30.8 ± 6.0 years) were randomly selected from the first group and qualified for the second stage. The study was approved by the Ethics Committee of the Nofer Institute of Occupational Medicine. All the subjects gave their written informed consent to participate in the study.

1.2. Design

Body composition of the fencers was measured using two types of bioimpedance analyzers with a constant current frequency of 50 kHz. During the first stage of the study body composition of 48 fencers was measured using an analyzer Akern BIA 101 ASE, Florence, Italy (aA) with a system of eight gel electrodes Bio - Protech INC, Gangwondo, Korea (eB) and then, the measurement was performed using an analyzer Tanita BC418MA, Tokyo, Japan (aT) with a system of eight still, stainless-steel electrodes (eT) mounted on a platform. The measurement using aT was performed in a standing position, while that using aA - in a lying position.

After a few days, during the second stage of the study we randomly selected 10 fencers from the first stage. In this subgroup of fencers we measured body composition using aA with 3 types of the rectangular tab electrodes with solid adhesive gel and silver/silver chloride (Ag/AgCl) sensing system: BIATRODES/0ELB100 (Akern - SRL, Pontassieve, Italy - eA), SKINTACT RT34 (Leonhard Lang GmbH, Innsbruck, Austria - eL), PROTAB PT2334 (Bio - Protech INC, Gangwondo, Korea - eB), and using aT with eT (**Figure 1**).

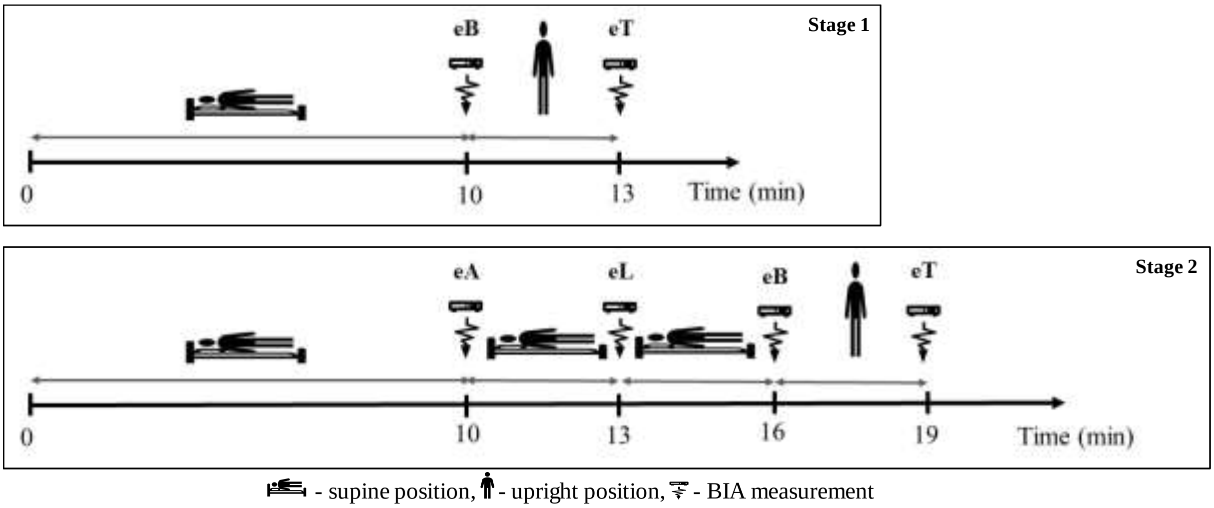

Figure 1 - The study design involving 2 stages (Stage 1 n = 48 fencers; Stage 2 n = 10 fencers). eA - gel electrodes Akern SRL, eL - gel electrodes Leonhard Lang GmbH, eB - gel electrodes Bio Protech INC, eT - stainless-steel electrodes Tanita

1.3. Methodology

Measurements of body composition were performed according to the standard procedures.[7] Measurement procedures in brief were as follows. The subjects visited the laboratory after fasting all night. They were also asked to refrain from participating in a strenuous exercise, consuming alcohol and coffee for 12 hours before testing. Each subject emptied his/her bladder immediately before the commencement of the measurements. In aA total body resistance (Rz) and reactance (Xc) were measured and for impedance (I) calculations the formula was used: I = sqrt ($Xc^2 + Rz^2$), [8, 9]. Body composition (fat free mass – FFM, body water – BW, fat mass – FM) was determined using software: Akern BodyGram Pro 3.0. In aT total body composition and I were automatically displayed.

1.4. Measurement of intrinsic impedance of gel electrodes

Intrinsic impedance variables (Rz, Xc, and I) of the three types of gel electrodes (eA, eL, eB) were measured using aA and a calibration plate with strictly defined values of Rz = 383 Ω and Xc = 45 Ω. The analyzer was calibrated before being used. After placing the electrodes on the calibration plate, crocodiles clips were attached to the electrodes (**Figure 2**).

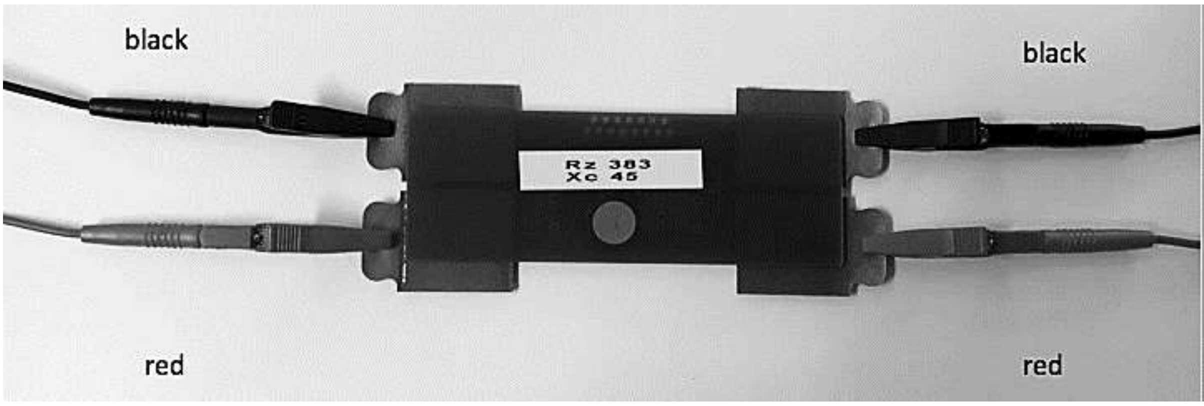

Figure 2 - A method for measuring intrinsic impedance of the gel electrodes (black/red – colors of clips)

Values of the intrinsic impedance of each type of gel electrodes were obtained by deduction of the measurement values from the values of the calibration plate. Measurements of the intrinsic impedance were performed on five pairs of each type of electrodes from the same batch. The measured electrodes were used before their expiry date.

1.5. Statistical analysis

Normality was assessed by visual inspection of histograms and the Shapiro–Wilk test. Basic statistics included mean, standard deviation (SD) as well as minimum and maximum of the observed values. In the statistical analysis, also absolute difference (AD = parameter measured with electrode 1 – parameter measured with electrode 2), relative difference (RD = [parameter measured with electrode 1 – parameter measured with electrode 2] × 100 / parameter measured with electrode 2) and a coefficient of variation (CV = SD / mean × 100) were calculated. Results obtained in the same group of fencers but using different analyzers or electrodes were compared for statistical significance using the Paired t-test. Statistical significance was set at $P < 0.05$. All the statistical procedures were completed using Statistica (StatSoft Inc., Tulsa, USA) version 13.1 software for Windows.

Results

Physical characteristics of the female fencers (n = 27) were as follows: height – 173.3 ± 8.6 cm, body weight – 64.7 ± 9.5 kg, BMI – 21.5 ± 1.8 kg/m^2 and male fencers (n = 21) height – 182.2 ± 6.5 cm, 80.9 ± 9.0 kg, and 24.4 ± 2.1 kg/m^2, respectively. In both groups there were significant differences between the values of impedance, measured by the aA and aT. Values of AD and RD referring to I in the women and men were at a similar level. In both groups significant differences were observed in all the analyzed parameters of total body composition. Both in the women and in the men differences between FFM, BW and FM oscillated at about 0.9 – 1.2 kg (**Table 1**).

Table 1 Values of total body impedance and body composition measured by analyzer Akern BIA 101 ASE (aA) with Bio Protech INC gel electrodes (eB) and analyzer Tanita BC418MA (aT) with Tanita stainless-steel electrodes (eT) in women (n=27) and men (n=21) fencers, (mean ± SD)

		I (Ω)	FFM (kg)	BW (kg)	FM (kg)
Women					
	eB	590.8 ± 71.1	48.6 ± 5.6	35.6 ± 4.1	16.2 ± 5.6
	eT	692.3 ± 66.0	47.3 ± 5.5	34.7 ± 4.1	17.4 ± 4.8
*P**	eT - eB	0.0000	0.0051	0.0048	0.0046
AD (Ω)	eT - eB	101.4 ± 52.1	-1.2 ± 2.1	-0.9 ± 1.5	1.2 ± 2.1
RD (%)	eT - eB	14.6 ± 6.9	-2.7 ± 4.6	-2.8 ± 4.7	8.1 ± 12.8
Men					
	eB	464.7 ± 33.9	67.4 ± 6.7	49.4 ± 4.7	13.5 ± 4.4
	eT	563.5 ± 38.9	66.3 ± 6.8	48.6 ± 5.0	14.6 ± 4.0
*P**	eT - eB	0.0000	0.0026	0.0024	0.0025
AD (Ω)	eT - eB	98.8 ± 27.5	-1.1 ± 1.5	-0.9 ± 1.2	1.1 ± 1.5
RD (%)	eT - eB	17.4 ± 4.3	-1.7 ± 2.2	-1.9 ± 2.6	9.3 ± 13.7

I – impedance of total body; FFM – fat free mass; BW – body water; FM – fat mass;
*P** - level of significance; AD - absolute difference = parameter measured with electrode 1 – parameter measured with electrode 2; RD - relative difference = (parameter measured with electrode 1 – parameter measured with electrode 2) × 100 / parameter measured with electrode 2

Bearing in mind the differences occurring in the values of I as well as in body composition in the first stage of the study, in the second stage of the study measurements using the aT with stainless-steel electrodes and aA with three types of gel electrodes (eA, eL and eB) were performed in the subgroup of women (n = 5, height – 166.2 ± 7.9 cm, body weight – 58.2 ± 6.1 kg, BMI – 21.1 ± 1.7 kg/m^2) and men (n = 5, height – 182.8 ± 9.9 cm, body weight – 81.0 ± 6.3 kg, BMI – 24.3 ± 1.0 kg/m^2) who were randomly selected from the previously studied group of fencers (n = 48).

Gel electrodes used for measurements were manufactured by three various manufacturers and varied in their overall dimensions (eA – 2.7 x 2.9 cm, eL – 2.2 x 3.4 cm, eB – 2.3 x 3.4 cm) as well as conductive area (eA – 7.29 cm^2, eL – 5.06 cm^2, eB – 5.75 cm^2). eA had the largest dimensions and surface adhesion, while eL had the smallest. They also significantly differed in terms of the intrinsic Rz and I – the largest values were in eB and the smallest in eA. In the case of eA there was the highest coefficient of variation at a level of 50% both for Rz as well as for

I. This coefficient, in the case of eL and eB was much lower. The smallest absolute difference, and thus, also relative differences in the analysed Rz and I were reported between eL and eA and the biggest – in the case of eB and eA (**Table 2**).

Table 2 Comparison of intrinsic values of resistance, reactance and impedance of three commercial silver/silver chloride (Ag/AgCl) tab electrodes determined with Akern BIA 101 ASE analyzer (mean ± SD, min – max, CV)

Manufacturer of electrodes		R	XC	I
eA	mean ± SD (Ω)	44.7 ± 22.8	1.7 ± 0.7	44.7 ± 22.8
	min-max (Ω)	(28.1 - 84.3)	(1.1 - 3.0)	(28.1 - 84.4)
	CV (%)	51.0	41.3	51.0
eL	mean ± SD (Ω)	85.8 ± 3.6	1.9 ± 1.1	85.8 ± 3.6
	min-max (Ω)	(81.5 - 91.0)	(0.3 - 3.4)	(81.5 - 91.1)
	CV (%)	4.2	57.9	4.2
eB	mean ± SD (Ω)	224.0 ± 18.8	8.1 ± 8.2	224.0 ± 18.7
	min-max (Ω)	(197.8 - 246.4)	(0.7 - 19.0)	(197.8 - 246.4)
	CV (%)	8.4	101.2	8.3
Comparison of intrinsic values of tested electrodes				
*P**	eL - eA	0.0040	0.7706	0.0040
	eB - eL	0.0001	0.1734	0.0001
	eB - eA	0.0000	0.1212	0.0000
AD (Ω)	eL - eA	41.1 ± 21.9	0.2 ± 1.5	41.1 ± 22.0
	eB - eL	138.2 ± 20.7	6.2 ± 8.4	138.4 ± 20.7
	eB - eA	179.3 ± 23.7	6.4 ± 7.8	179.5 ± 23.6
RD (%)	eL - eA	121.3 ± 73.9	31.0 ± 111.7	121.1 ± 73.8
	eB - eL	161.7 ± 27.7	417.8 ± 421.1	161.9 ± 27.8
	eB - eA	473.6 ± 184.1	331.6 ± 455.5	473.8 ± 184.4

R - resistance; XC - reactance; I - impedance; eA - electrodes Akern SRL; eL - electrodes Leonhard Lang GmbH; eB - electrodes Bio Protech INC; *P** - level of significance; CV - coefficient of variation (SD / mean × 100); AD - absolute difference (parameter measured with electrode 1 – parameter measured with electrode 2); RD - relative difference [(parameter measured with electrode 1 – parameter measured with electrode 2) × 100 / parameter measured with electrode 2]

During the second stage conducted in selected subgroups of women and men, the values of AD and RD referring to I obtained using eT i eB were at a similar level as those at the first stage of the study in the group of 48 fencers. The values of I obtained by the use of stainless-steel electrodes eT were much higher that the values obtained by the use of all the three types of gel electrodes. Both in the subgroup of women and men differences were also observed in the values of I measured by means of the three types of gel electrodes: the values of AD were most similar in the case of eA and eL, while the largest differences were observed between eB and eL, eA. In both subgroups as I increased, FM also increased but FFM and BW decreased (**Table 3**).

Table 3 Values of total body impedance and body composition measured by analyzer Akern BIA 101 ASE with gel electrodes: Akern SRL (eA), Leonhard Lang GmbH (eL), Bio Protech INC (eB) and by analyzer Tanita BC418MA with Tanita stainless-steel electrodes (eT) in women (n = 5) and men fencers (n = 5), (mean ± SD)

	I (Ω)	FFM (kg)	BW (kg)	FM (kg)
Women				
eA	529.6 ± 38.4	47.8 ± 4.8	35.0 ± 3.5	10.3 ± 3.1
eL	533.4 ± 38.1	47.6 ± 4.7	34.9 ± 3.5	10.4 ± 3.0
eB	555.7 ± 44.5	46.6 ± 4.8	34.1 ± 3.5	11.5 ± 2.9
eT	684.1 ± 75.0	45.8 ± 5.5	33.0 ± 3.9	12.3 ± 2.3
Men				
eA	423.9 ± 17.5	71.1 ± 7.6	52.0 ± 5.6	10.1 ± 2.9
eL	423.3 ± 9.6	71.0 ± 6.7	52.0 ± 4.9	10.2 ± 2.4
eB	435.1 ± 20.4	70.0 ± 7.8	51.2 ± 5.7	11.2 ± 2.4
eT	531.0 ± 19.6	67.8 ± 5.2	48.4 ± 3.1	13.2 ± 1.6

I – impedance of total body; FFM – fat free mass; BW – body water; FM – fat mass

Absolute differences in I and the total body composition compartments such as FFM, BW, FM are shown in **Figure 3**. The greatest differences in those parameters occurred in the measurements taken by the use of eT and eA, while the smallest in the case of measurement taken using eA and eL.

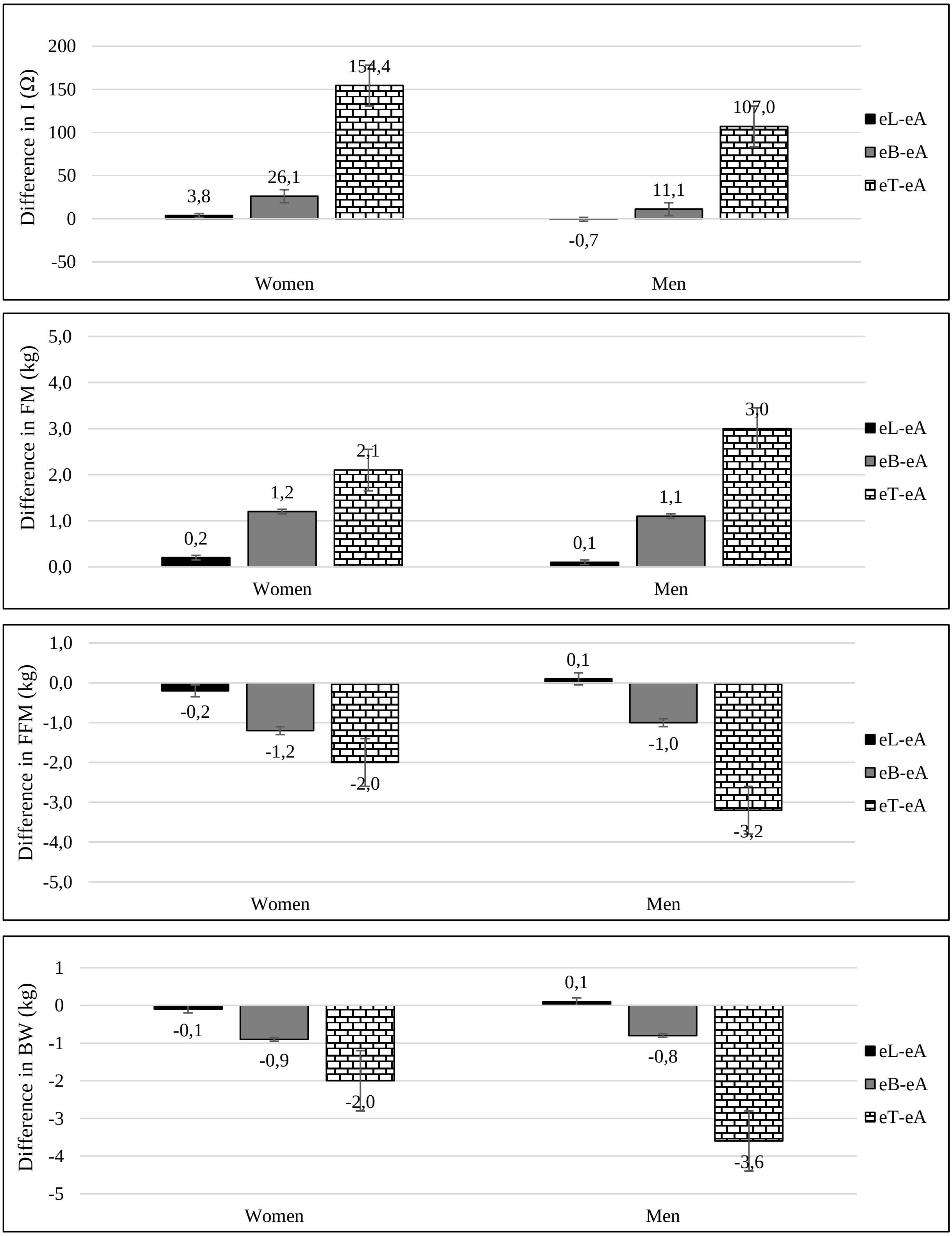

Figure 3 - Absolute difference (mean ± SEM) in total body impedance (I), fat mass (FM), fat free mass (FFM) and total body water (BW) in women (n=5) and men (n=5) assessed by analyzer Akern BIA 101 ASE with gel electrodes: Akern SRL (eA), Leonhard Lang GmbH (eL), Bio Protech INC (eB) and by analyzer Tanita BC418MA with Tanita stainless-steel electrodes (eT)

Discussion

In our studies using two analyzers with a constant current frequency of 50 kHz, there were significant differences in the body composition. They might have resulted from different formulas used for calculations and from a change in I associated with a change of a body position. After 10 min in a supine position an increase in I of 2 (-9 to 4) Ω, and after 20 min of 5 (-4 to 9) Ω was reported. Between 10 and 20 min in a supine position the impedance values were more stable and then started to increase [10]. Also other studies have shown that changes in a body position are connected with the whole body I [11, 12]. In our study, differences in the supine I between 10 and 16 min, i.e. during the period in which stabilization should occur, the differences were much higher than those reported by Shirreffs & Maughan [10] after 20 min in a supine position. In the measurements using aT after 3 min in a standing position the impedance values were ≥ 100 Ω compared to those obtained using eB in a supine position. In the people who changed from a standing to a supine body position, the whole body resistance increased, which is connected with changes in a regional distribution of extracellular volume [13]. Bearing that in mind, in our research during changes from a supine to a standing body position I should decrease rather than increase. Our results that were obtained using the analyzers with the same current frequency suggest that the observed changes in I were not only a result of changes in a body position but that they might have been also affected by the type of the electrodes applied.

Taking into consideration the observed differences between I values we decided to verify what influence on the obtained I values and body composition the type of the applied gel electrodes have. The electrodes used in our study had surface size > 4 cm^2, which is recommended for bioelectrical impedance analysis [7]. In the study three types of electrodes, which are very popular in our country, were used. Considerable, statistically significant differences in intrinsic impedance of those electrodes were reported. Aa that had the biggest surface and thicker layer of loose gel had the lowest intrinsic impedance. However, in the case of these electrodes high diversity of intrinsic impedance was observed. The difference in the intrinsic impedance between the minimal and maximal values in the case of these electrodes amounted even up to 56 Ω. In the studies that were performed by Nescolarde et al. [14] standard deviation of intrinsic R, Xc and I was at a very low level when compared to the results obtained in our study. Those differences may have resulted from, e.g. conditions during electrodes transportation and related to it a very low or very high temperature, depending on the season of the year. After being purchased, the electrodes were stored in a fridge, but we do not know anything about the conditions in which they were stored after being produced and conditions during their transportation. When compared to Aa, eL had higher intrinsic impedance on average by more than 40 Ω, while eB had the highest – values of their intrinsic impedance were higher than that of eA by nearly180 Ω. eB electrodes had the driest and the most consistent gel structure.

Manufacturers offer a wide choice of rectangular tab electrodes that are characterized by different functionality. For example, Leonhard Lang has developed a range of conductive mediums such as: a liquid gel designed for fast pick up with easy application and removal, a solid wet gel which is less prone to drying out and can be pressed in the centre without the risk of gel spreading onto the adhesive, as well as solid adhesive hydrogel electrodes which are characterized by i.e. quick pick up even despite inadequate skin preparation and consistently high quality recordings [15]. Akern SRL recommends gel electrodes with extremely low capacitive skin coupling in conjunction with high tackiness [16]. A diverified structure of gel enables to obtain various beneficial functional features, unfortunately it is also a factor that affects intrinsic impedance of electrodes. The issue concerning considerable diversity of intrinsic impedance of various types of electrodes has been described in literature. Xu et al. [17] have analyzed impedance of five types of electrodes and stated significant differences between them. In the studies of electrical impedance tomography (EIT), which was performed for long-term continuous imaging monitoring of brain using these electrodes, the authors observed differences in contact impedance, uniformity and stability. Nescolarde et al. [14] have measured intrinsic impedance variables of snap and tab electrodes from six different manufacturers. The intrinsic R, Xc and I values of majority of the analyzed electrodes were statistically different. The bioelectrical impedance vector analysis method was performed using a 50 kHz BIA analyzer with the highest and lowest intrinsic impedance electrode. Differences of the mean bioimpedance vectors were compared and significant displacement of vector positions in healthy adults was found.

The study conducted by us indicates that diversity concerning both surface area of electrodes as well as gel structure may have a significant influence on their intrinsic resistance, which in turn translates into impedence values during body composition measurements. The lowest values of impedance in the studied subgroups of women and men occurred during measurement in which eA electrodes with the lowest intrinsic impedance were used. The highest were reported in the case of eB electrodes application with the highest intrinsic impedance. However, impedance that was obtained in the measurements taken by the use of steel electrodes was much higher than in the case of all the applied gel electrodes. This translated into the results of body composition measurements. Along with the increase in impedance, a higher content of FM and lower content of FFM and BW was observed.

In the studies, in which body composition was measured using the bioimpedance method authors usually provide information on the type of applied analyzers. However, there is no information on the type of electrodes used. This refers especially to gel electrodes 18, 19, 20]. Bearing in mind considerable differences in body composition measured by the use of various types of electrodes, it seems advisable to provide in the manuals information on the type, kind and manufacturer of the electrodes. Another challenge is also considerable diversity of intrinsic impedance in the case of the same type of electrodes, which may affect body composition measurements results.

To the best of our knowledge, this is the first study that has focused on analyzing the effects of impedance of commercial stainless-steel and gel Ag/AgCl electrodes on measurements of the total body and segmental Rz, Xc and I as well as body composition by the BIA method. Therefore, we cannot discuss the results with other authors.

Taking into account the possibility to compare changes in body composition of atheles in time as well as possibility to compare body composition in groups of individuals with a different level of training and experience it seems important that in procedures concerning body composition measurements by the use of the bioimpedance method there was information on the intrinsic impedance of electrodes, which should be used for that purpose. Another problem is diversity of intrinsic impedence of the same type of electrodes produced by the same manufacturer. In the case of high diversity of intrinsic impedance it is difficult to detect minor changes in body composition. It also seems reasonable to verify the coefficient of variation of each batch of gel electrodes.

Conclusion

To summarize in body composition measurements using the bioimpedance method an important element that can influence on the obtained results is the type of electrodes used. While monitoring body composition of an athlete and planning nutrition and training strategies on its basis, it is very important to use the same type of electrodes and to use those that have the smallest diversity in terms of intrinsic impedance. It seems, that standardization of the bioimpedance method should also take into account the type and structure of electrodes, as these factors can affect accuracy and repeatability of the obtained results.

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The results of the current study do not constitute endorsement of the product by the authors.

Authorship

The study was designed by LK and OL. Data were collected, analysed, and subsequently interpreted by LK, OM and AM. Manuscript preparation, including drafting of the article was undertaken by LK, OM and AM. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Founding and conflict of interest

This research did not receive any external funding. We have no conflicts of interest to disclose.

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