Bioimpedance patterns and bioelectrical impedance vector analysis (BIVA) of road cyclists

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--Manuscript Draft--

Full Title:	Bioimpedance patterns and bioelectrical impedance vector analysis (BIVA) of road cyclists
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Abstract:	Bioelectrical impedance vector-analysis (BIVA) describes cell-mass, cell function and hydration status of an individual or a group. The goal of the present investigation was to provide bioelectrical impedance data for 525 male road cyclists (155 professionals, 79 elite, 59 elite-youth, and 232 amateurs) at the time of their optimal performance level. Data were plotted on the resistance-reactance (R-Xc) graph to characterize cyclists group vectors using BIVA. Compared to the general male population, the mean vector position of the road cyclists indicates a higher body cell mass (BCM) and phase angle ($p<0.001$). The vector position of the high-performance, compared to the amateur, cyclists showed similar patterns with higher BCM and phase angles and higher reactance values for the high-performance athletes ($p<0.001$). The bio-impedance data were used to calculate the 50%, 75%, and 95% tolerance ellipses of each group of cyclists. The characteristic vector positions of the road cyclists indicate normal hydration and greater muscle mass and function of the high-performance cyclists compared to amateur cyclists and the normal population. The cyclists specific tolerance ellipses, particularly the high-performance cyclists might be used for classifying a cyclist according to the individual vector position and to define target vector regions for lower level cyclists.
Order of Authors:	Andrea Giorgi
	Maurizio Vicini
	Luca Pollastri
	Erica Lombardi
	Emilio Magni
	Andrea Andreazzoli
	Marco Orsini
	Marco Bonifazi
	Henry Lukaski
	Hannes Gatterer, PhD
Response to Reviewers:	Dear editor, dear reviewers, Thank you very much for the valuable comments. You raised very important points and we addressed all of them in our revised version. We are confident that the manuscript improved due to your support. In the following, you will find answers to all your queries. Best Comments: Reviewer #1: The paper brings a new method of evaluation, which is of great interest of readers of the submitted journal. BIVA and phase angle bring new methods of analysis, through a different perspective, that can bring additional and more precise data in comparison to the usual BIA analysis and equations. However, although authors are familiarized, they should take into account that most of the readers, even the sports-related health professionals, may not be familiarized with the method, that contains several new concepts. The large

amount of new concepts challenges the interpretation of the results if the rationale and the bases for the analysis are not thoroughly described. Once the readers of the submitted journal do not need to be familiarized with this emerging and great method, I strongly recommend that phase angle and BIVA should be explained in deeper details. If the journal was specialized in body analysis methods, I would perhaps not recommend it. But we should consider who the readers will be. Finally, I recommend an explanation of what BIVA may additionally bring that the current methods are not able to show.

Response: Thank you for this suggestion. We added information on BIVA and phase angle within the introduction and the method section and additionally amended Figure 1. Moreover, we changed the abstract to make it more comprehensible for readers not specifically familiar with BIVA. Please refer to the manuscript for details.

1. "Bioimpedance vector analysis (BIVA) is an innovative method with increasing acceptance particularly for assessment of body composition of athletes"
I am not sure if this statement is true. Actually, BIVA has been mostly studied for evaluation of criticallhy ill patients, or undergoing dialysis, or with liver cirrhosis. Only recently some studies started evaluation BIVA for athletes, but it is still not the main use of this body assessment.

Response: We agree and changed as follows: Bioimpedance vector analysis (BIVA) derived from bioimpedance (BI) measurements is a method regularly used in the clinical setting to diagnose malnutrition and monitor hydration (Lukaski, Kyle, & Kondrup, 2017; Norman, Stobäus, Pirlich, & Bosy-Westphal, 2012)”
Additionally, we later on write the following: “…Thus, BIVA allows for various applications in healthy populations and among clinical groups (Lukaski et al., 2017; Norman et al., 2012) and its value is recognized in different sports (Gatterer et al., 2011; Pollastri, Lanfranconi, Tredici, Burtscher, & Gatterer, 2016; Pollastri et al., 2016)

2. "Thus, this study aimed to establish reference BIA and BIVA data..."
You have not established the abbreviation for BIA before. This is the first time "BIA" appears in the manuscript. Please specify it.

Response: Thank you for this hint. The abbreviation for bioimpedance (i.e. BI) was established when first mentioned in the introduction section.

3. There are some overlapping characteristics between amateur cyclists, elite youth and elite cyclists, particularly regarding distance covered per year. Also, you use the expression "in general", which allows exceptions. How did you precisely define each subject into a certain category, giving the lack of precise classifications, at least through your methodology perspective?

Response: The reviewer is right, there is some overlapping and we cannot exclude some exceptions concerning distance covered and races performed. Exceptions could have happened due to illness, injury, training periodization, tactical reasons etc. Nevertheless, in this study all measurements were performed in a period where the athletes should have achieved their optimal performance level and were they actually competed in races. This was mentioned in the manuscript. Additionally, all cyclists except the amateurs are part of cycling teams and have been classified accordingly. We now included this information in the manuscript.

4. "Bioelectrical impedance was measured with a phase-sensitive impedance plethysmograph (BIA-101, Akern-RJL Systems, Florence, Italy)." -
Do you mean plethysmograph? A plethysmograph usually measures changes in volume, which is different from a bioelectrical impedance.
Also, is it there any scientific validation and standardization of the model of the bioelectrical impedance used by the study? Please show it.

Response: We agree that the term plethysmograph could be misleading, thus we changed “phase-sensitive impedance plethysmograph“ to “phase-sensitive impedance device” as was also suggested by reviewer 2. Furthermore, we added informations on the accuracy of the device. We included the following “The accuracy of the device was 1% for resistance (R) and 1% for reactance (Xc) similar as indicated elsewhere (Gatterer et al., 2014; Nescolarde et al., 2013).”

5. When you say "soft tissue"? In the manuscript, you say that "Such vector shifts indicate increased soft tissue mass and less body fluids and, together with the higher phase angle, these findings could be interpreted to mean that with increasing performance level, muscle volume and function increase.", but further in the same manuscript you also say "Climbers are characterized by less soft tissue mass and somewhat lower body fluid content. As climbers need to develop an optimal balance between body weight - which must be lifted during climbing and thus if in excess might induce a weight penalty during mountainous stages (Noakes, 2007) - and muscle volume and function, the lower soft tissue mass and fluid content might represent specific adaptations to the climbers requirements." - you give different interpretations for the "soft tissue" - or it seems different, by a strict reading of the manuscript. I recommend that you described more thoroughly what you mean with "soft tissue", and also do not generalize the first sentence, once this first sentence does not seem to be entirely applicable for the climbers.

Response: We agree that the discussion might have been misleading in some parts. Thus, we amended the discussion section hoping that we have been able to clarify these issues. Please find the highlighted changes in the manuscript.

6. "The young elite cyclists in contrast are characterized by equal soft tissue mass but to some extent lower body fluid volumes (downshifted vector on the major axis of the tolerance ellipses)."
What does this mean, in practice? Less hydration? I mean, as a reviewer I know to how to interpret this, but this should be made explicit within the manuscript.

Response: We agree that this needs some more consideration. We changed as follows “The BIVA of the young elite cyclists indicates equal soft tissue mass but to some extent higher body fluid volumes (downshifted vector on the major axis of the tolerance ellipses). Yet, the vector distribution of these young cyclists could have also been influenced by maturation level and body structure”

7. I would consider a new table or figure pointing the practical implications of each of the findings. One column with the type of cyclists (eg. Professional cyclists), the second column with the analyzed (eg. "shift of the vector to the left on the minor axis of the tolerance elipses"), the third column with the practical interpretation of the finding (eg. higher soft tissue mass and phase angles"), and the forth column with the likely explanation "higher training load and competitive level"). This would importantly improve the clarity of the findings for this great analysis.

Response: We agree that this could be very informative and we prepared a table (Table 2) with the practical implications. Thank you for this suggestion.

Reviewer 2:
1.-The TITLE could be “Bioelectrical Impedance Vector Analysis (BIVA) in road cyclists”

Response: We agree that the title could be more precise. As we describe bioimpedance patterns next to BIVA we would suggest changing it to “Bioimpedance patterns and bioelectrical impedance vector analysis (BIVA) of road cyclists”. We hope the reviewer agrees, otherwise we can change it as suggested.

2.- The vector patterns obtained from road cyclist could be help to improve the training and diet. The authors could be comment it in the OBJECTIVES of the article.

Response: We agree that this is missing. We included this information in the introduction section. We wrote the following: “and to define target values for the training process and for nutritional interventions.” Unfortunately, the abstract has a word limit of 200, thus we were not able to include this information in the abstract.

	3.- In INTRODUCTION, when the BIVA methods is fist named; the reference to the authors who develop must be described. Please include this sentence. The BIVA method proposed by Piccoli, et al., 1994,.... Response: We changed as suggested, thank you. 4.- In METHOD, change the sentence "…Bioelectrical impedance was measured with a phase-sensitive impedance plethysmograph (BIA-101, Akern-RJL Systems, Florence, Italy). The device emits an alternating sinusoidal electric current of 800 µA at an operating single frequency of 50 kHz…" The term "emitted" are not correct for AC; the correct term is "inject AC" Bioelectrical impedance was measured with a phase-sensitive impedance device (BIA-101, Akern-RJL Systems, Florence, Italy). The device inject an alternating sinusoidal electric current of 240 µARMS at 50 kHz… Response: We changed as suggested, thank you. 5.- In METHOD the reference of the Ag/AgCl electrode used in the measurements must be named. Response: We included the type of electrodes and the company, thank you. 6.- Please, include this reference: Hotelling H. The generalization of Student's ratio. Annals of Mathematical Statistics 1931; 2: 360-78. Response: Done, thank you very much.

Bioimpedance patterns and bioelectrical impedance vector analysis (BIVA) of road cyclists

Abstract

Bioelectrical impedance vector-analysis (BIVA) ~~evaluates~~ describes cell-mass, cell function and hydration status of an individual or a group. The goal of the present investigation was to provide bioelectrical impedance data for 525 male road cyclists~~. 525 cyclists~~ (155 professionals, 79 elite, 59 elite-youth, and 232 amateurs) ~~performed whole-body impedance measurements~~ at the time of their optimal performance level. Data were plotted on the ~~R~~resistance-reactance (R-Xc) graph to characterize cyclists group vectors using BIVA. Compared to the general male population, the mean vector position of the road cyclists ~~was shifted to the left on the minor axis of the tolerance ellipse~~indicates a higher body cell mass (BCM) and phase angle~~s~~ (p<0.001). The vector position of~~for~~ the high-performance, compared to the amateur, cyclists showed similar patterns with higher BCM and phase angles and higher reactance values for the high-performance athletes~~both a shift to the left on the minor axis and an upward shift on the major axis of the tolerance ellipses~~ (p<0.001). The bio-impedance data were used to calculate the 50%, 75%, and 95% tolerance ellipses of each group of cyclists. The characteristic vector positions ~~BIVA indicates that~~of the road cyclists indicate normal hydration and~~have an increased body cell mass and greater phase-angle, indicative for~~ greater muscle mass and function of the high-performance cyclists compared to amateur cyclists and the normal population. ~~, than the normal population and these differences are greater in higher performance level cyclists.~~ The cyclists specific tolerance ellipses, particularly the high-performance cyclists might be used for classifying a cyclist according to the individual vector position and to define target vector regions for lower level cyclists.

Key words: road cyclists, anthropometry, body composition, phase angle, reference values, performance level

Introduction

A variety of methods exists for the determination of body composition~~ of athletes~~, each characterized by advantages and disadvantages (Ackland et al., 2012; Gatterer, Schenk, & Burtscher, 2017). Bioimpedance vector analysis (BIVA) derived from bioimpedance (BI) measurements is a~~n innovative~~ method regularly used in the clinical setting to diagnose malnutrition and monitor hydration (Lukaski, Kyle, & Kondrup, 2017; Norman, Stobäus, Pirlich, & Bosy-Westphal, 2012).~~with increasing acceptance particularly for assessment of body composition of athletes of athletes.~~ The originality of BIVA is the change from quantitative estimates of body composition components (fat mass, fat free mass and percent body fat) that depend on sample-specific regression prediction equations and questionable assumptions regarding the chemical composition of the fat-free body to equation independent outcomes (Lukaski, 2013). The BIVA method first proposed by Piccoli, Rossi, Pillon, & Bucciante (1994) uses~~ raw~~ raw BI measurements (resistance, R and reactance, Xc) ~~measurements~~ to characterize body cell mass (BCM) and hydration. Resistance ~~(R)~~ indicates the conduction of a safe, low-level alternating current by water and electrolytes in fluids and tissues. ~~and reactance (Xc) is~~ Reactance specifies the capacitative component of tissues (cells and tissue interfaces) and is associated with cell size and integrity of the cell membranes (Gatterer et al., 2014; Lukaski, 2013; Lukaski & Piccoli, 2012; Lukaski et al., 2017; Norman et al., 2012; Piccoli et al., 1994). Additionally, the phase angle (PA), which is a composite of Xc and R, is characterized physiologically as an index of cell membrane integrity and vitality and expresses the quantity and quality of soft tissue (Lukaski et al., 2017), as such~~suggested to be~~ it can be considered an indicator of cell function including muscular strength and endurance (Norman et al., 2012). BIVA illustrates these bioelectrical parameters as a vector, either for an individual or a group, on the R-Xc graph to classify hydration status and differences in cell mass relative to a healthy, gender-matched control group or among different groups (Piccoli et al., 1994). Thus, BIVA~~is capability~~ allows for various applications in healthy populations and among clinical groups (Lukaski et al., 2017; Norman et al., 2012) and~~.~~ its value is recognized ~~Concurrently, these applications extend~~ in~~to~~ different sports (Gatterer et al., 2011; Pollastri, Lanfranconi, Tredici, Burtscher, & Gatterer, 2016; Pollastri et al., 2016). ~~with BIVA standards established for specific athletes groups such as the soccer population (Micheli et al., 2014).~~

Impedance measurements depend on age, sex, fluid distribution, and body mass index (BMI) (Lukaski et al., 2017). Thus, i~~I~~nterpretation of the impedance ~~measures~~ data of a specific population or athlete ~~or population group~~group ~~-~~requires population- or sport-specific impedance measures and reference distributions of vectors. ~~with BIVA s~~Standards exist for the normal healthy population (Piccoli et al., 1995) and have been established for specific athletes groups (e.g., ~~such as the~~ soccer population) (Micheli et al., 2014). For the ~~general road cyclist~~broad performance range of road cyclist, ~~population or elite road cyclists~~ such standards are not available. Thus, this study aimed to establish reference BI~~A~~ and BIVA data for the road cycling population and to compare these vector patterns ~~with those of the high- performance cyclists~~of various performance levels of cyclists. Such standards offer a unique opportunity to interpret individual bioelectrical ~~compositional~~ measurement data and associated performance characteristics of an individual cyclist and to define target values for the training process and for nutritional interventions. We hypothesized that high-performance road cyclists, compared to the healthy road cycling population, have a different vector position on the R-Xc graph ~~compared to the healthy road~~

~~cycling population and differences in vector position parallel~~indicative of adaptations of body composition due to differences in training and performance.

Methods

Participants

Five hundred and twenty-five male cyclists volunteered to participate in the study (Table 1). ~~Baseline characteristics of the participants are shown in Table 1.~~ The sample included 155 professional, 79 elite, 59 elite youth and 232 amateur road cyclists. The professional riders were further classified as sprinter, all-rounder and climber, according to their roles in competition (Table 1). The professional cyclists were members of professional road cycling teams (World Tour Team, Professional Team, Continental Team). ~~In general, t~~They cover between 30000 and 35000 km/~~ per~~ y~~ea~~r and complete 65 ~~and~~ to 90 d~~ays~~ of competition per season (ranging from 1-d races to stage races of 3 wk) (Faria, Parker, & Faria, 2005; Lucía, Hoyos, Pérez, Santalla, & Chicharro, 2002; Pinot & Grappe, 2014). The elite cyclists are members of cycling teams, which are not considered ~~members of~~ professionals, yet ~~teams but~~they mostly earn their livelihood with the cycling sport. They cover distances ranging from 18000 to 26000 km/~~ per~~ y~~ea~~r and have between 50 and 70 d~~ays~~ of competition per season (ranging from 1-day races to stage races of 1 week) (Antón et al., 2007; Pinot & Grappe, 2014). The elite youth cyclists are members of adolescent teams and train and compete to become professionals. ~~In general t~~They cover distances of about 15,000-20,000 km/~~per~~ y~~ea~~r. The amateur cyclists compete for pleasure and they are not necessarily part of a cycling team. Nonetheless, their training effort can be essential covering up to 25,000 km/~~ per~~ y~~ea~~r (Lucía et al., 2002). Yet, in general they cover distances between 3,000 and 10,000 km/~~ per~~ y~~ea~~r.

The study was carried out in conformity with the ethical standards laid down in the 1975 declaration of Helsinki and was approved by the local ethical committee.

Procedures and Measurements

During 2015-2017 professional road cycling teams were ~~asked~~ invited to participate in the study and 155 cyclists agreed to participate. The elite (n=79), the elite youth (n=59) and the amateur (n=232) cyclists were recruited by convenient sampling. Cyclists were tested at the time of their optimal performance level. Body weight and height was measured to the nearest 0.1 kg and 0.5 cm, respectively. Body surface area was calculated according to ~~(~~Du Bois & Du Bois~~,~~ (1916): BSA = 0.007184 x body mass$^{0.425}$ x height$^{0.725}$. Bioelectrical impedance was measured with a phase-sensitive impedance ~~plethysmograph~~ device (BIA-101, Akern-RJL Systems, Florence, Italy). The device ~~emits~~ injects an alternating sinusoidal electric current of ~~800~~ 240 μARMS at ~~an operating single frequency of~~ 50 kHz. The accuracy of the BI instrument was determined~~, and was calibrated~~ every morning by~~,~~ using a calibration circuit ~~procedure~~ of known impedance (R= 380 Ohm, Xc = 47 Ohms) supplied by the manufacturer. The accuracy of the device was 1% for R and 1% for Xc similar as indicated elsewhere (Gatterer et al., 2014; Nescolarde et al., 2013). The Ag/AgCl electrodes (SMT medical, Würzburg, Germany) used during all measurements had low intrinsic impedance ~~and were provided by the manufacturer of the BIA device as recommended by~~ (Nescolarde et al., 2016). Standard whole-body tetrapolar measurements were performed according to the manufacturer guidelines. All BI~~A~~ measurements were made under resting conditions at least 24~~-~~h~~ours~~r after the last exercise session and either in a fasting state, yet well hydrated or within 2 hours from the last meal. As fluid and food within the abdominal cavity is "electrically silent" (Kushner, Gudivaka, & Schoeller, 1996) these procedure should only have had minor influence on the outcome parameters. The measurements were performed on the dominant side with the participants in a supine position with their arms and legs abducted. It was ensured that their thighs were not in contact with each other and their arms were not touching the sides of their bodies.

~~The~~ BIVA ~~was performed as previously~~ described in detail elsewhere (Kyle et al., 2004; Lukaski, 2013; Piccoli et al., 1994)~~.~~ enables classification (under-, normal and overhydration) and ranking of hydration (more or less than before intervention), as well as BCM, for an individual by examining the position of an individual vector relative to a reference population (Lukaski, 2013). The reference population is represented by the bivariate normal distribution with elliptical probability areas (50, 75 and 95%) in the tolerance ellipses (Figure 1, left panel) (Lukaski, 2013). ~~Shortly,~~For the analysis ~~the~~ impedance measurement ~~was~~ are standardized by the height (H) of the participants, expressing both, R/H and Xc/H in Ohm/m. ~~(Lukaski, 2013)~~Vector position on the R-Xc graph can be interpreted following two directions on the R-Xc graph (Figure 1, left panel). ~~(Lukaski, 2013)~~Vector displacements parallel to the major axis of tolerance ellipses indicate progressive changes in tissue hydration. Long vectors out of the upper pole of the 50% and 75% ellipses point out mild and severe dehydration, respectively. Short vectors out of the lower pole of the 50% and 75% ellipses reflect mild and severe fluid overload with apparent oedema (Lukaski & Piccoli, 2012). Additionally, peripheral vectors lying in the left or right side of the major axis of the tolerance ellipses indicate more or less cell mass, respectively (Lukaski, 2013; Lukaski & Piccoli, 2012). The phase angle further helps to interpret the R-Xc graph. It is the angle of the impedance vector and can be directly calculated from Xc and R as the arc-tangent [(Xc/R)(180°/π)]. The phase angle has been suggested to be an indicator of cell function (Kyle, Genton,

& Pichard, 2013; Norman et al., 2012) and was shown to be associated with performance in elite road cyclists (Pollastri et al., 2016).

Statistical analysis

A univariate analysis of variance and Dunnett-T3 (variance homogeneity not accepted) or Bonferroni (variance homogeneity accepted) post hoc tests for multiple comparisons were performed with SPSS software (Chicago, IL, USA, ver. 18).

The 50%, 75%, and 95% tolerance ellipses of individual vectors and the 95% confidence ellipses of mean vectors were determined for each group according to the BIVA method (Piccoli et al., 1995; Piccoli et al., 1994). Separate confidence ellipses indicate a significant vector displacement ($p < 0.05$). Exact probabilities were calculated with the Hotelling's T2 test (Hotelling, 1931). Results are presented as means ± SD and CI. Significance level was set at $p \leq 0.05$.

Results

The bioelectrical impedance characteristics of the road cyclist population differed~~and divided~~ by performance levels ~~are shown in~~(Table 1). The reactance values divided by height were significantly greater among the professional road cyclists compared to the youth elite and the amateur cyclists ($p<0.05$). The phase angle of the elite and amateur cyclists was lower compared to the professionals ($p<0.05$). Among the professional cyclists, resistance values were significantly greater but phase angle was less for climbers compared to sprinters and all-rounder ($p<0.05$). Figure 1 shows the mean vectors with the 95% confidence ellipses of the different performance levels in addition to the 50%, 75%, and 95% tolerance ellipses of the healthy male Italian reference population (Piccoli et al., 1995). All vectors lay within the 50^{th} percentile of the tolerance ellipse.

Hotelling's T2 test showed different vector distributions between all groups (p<0.05). Figure 2 shows the mean vectors with the 95% confidence ellipses of the different professional specialists (climbers, sprinters, all-rounder) together with the 50%, 75%, and 95% tolerance ellipses calculated for the professional cyclists. Hotelling's T2 test showed different vector distributions between climbers and sprinters as well as climbers and all-rounders (p<0.05).

Figure 3 shows the 50%, 75%, and 95% tolerance ellipses calculated for the overall cyclist population, for the combined values of the elite and the professional and for the professional road cyclists alone.

Discussion

The present study, for the first time, reports bioelectrical impedance data of male road cyclists of varying performance levels. Data show that compared to the healthy Italian male population, road cyclists in general show an impedance vector shift to the left on the minor (Xc) axis of the tolerance ellipses, indicating higher ~~soft tissue mass~~BCM. Additionally, among road cyclists, the vector of the high-performance level cyclists (i.e. elite youth, elite and professionals) compared to the amateurs showed both a shift to the left on the minor axis and an upward shift on the major axis (R or fluid) of the tolerance ellipses with a concomitant increased phase angle (p<0.001). ~~Such vector shifts indicate increased soft tissue mass and less body fluids and, together with the higher phase angle,~~ T~~t~~hese findings ~~could be interpreted to mean~~indicate that even within the road cyclist population different vector positions occur that may reflect increased muscle volume and function with increasing performance level. Additionally, vector position indicates normal hydration of road cyclists as all vectors lay within the 50th percentile of the tolerance ellipse (Table 2 summarizes these outcomes and its interpretation). In addition, the present study identified the

50%, 75% and 95% tolerance ellipses for the road cyclist population as well as for the high-performance road cyclists (Figure 3).

In recent years BIVA has ~~gained~~ received ~~popularity~~ consideration within the sport medicine and sport science field as a method to classify different sport populations ~~with respect to bioimpedance characteristics~~ as related to function and performance. Such population specific standards are essential when comparing and interpreting individual results of an athlete in regard to sport-specific colleagues. Additionally, the phase angle, the BCM and Xc attained from BIVA have been shown to be related to power output during cycling and muscle function (Norman et al., 2012; Pollastri et al., 2016) indicating the importance of these measures for the sport performance.

One important finding of the present investigation was that male road cyclists exhibited specific BIVA distributions which distinguish them from the normal healthy population (Figure 1). Compared to the healthy Italian male reference population (Piccoli et al., 1995), the vectors are shifted to the left on the minor axis of the tolerance ellipses ($p<0.001$). This indicates an increased ~~soft tissue mass~~BCM compared to the normal population that might reflect the sport and training specific adaptation of body masses and composition (Andreoli et al., 2003). A further important finding was that BIVA distributions differ according to the performance levels of the cycling population as well as for specialisations (Figure 1 and 2). In comparison to the amateur cyclists, the vector of the professionals, the elite and the youth elite cyclists showed both a shift to the left on the minor axis and a upward shift on the major axis of the tolerance ellipses ($p<0.001$) and additionally a higher phase angle. This could either be interpreted to mean that high level cyclists represent a distinct group or that muscle mass and function increases with increasing performance level. Interestingly, also within the high-level groups (i.e. youth elite, elite and professionals), vectors showed some differences, even though the magnitude was less. For instance, the professionals compared to the elite show a shift of the vector to the left on the minor axis of the tolerance ellipses, again indicating higher ~~soft tissue mass~~BCM and phase angles. This might be attributed to the higher training load and competitive level of the professional road cyclist leading to these specific adaptations. The BIVA of the young elite cyclists ~~in contrast are characterized by~~indicates equal soft tissue mass but to some extent ~~lower~~ higher body fluid volumes (downshifted vector on the major axis of the tolerance ellipses). Yet, the vector distribution of these young cyclists could have also been influenced by maturation level and body structure. Of further importance was the finding that within the professional cyclists, characteristic BIVA distributions exist (Figure 2). Data indicate that sprinters and all-rounders show comparable vectors, whereas climbers clearly differ from their counterparts. Climbers from a BIVA point of view are characterized by less soft tissue mass and somewhat lower body fluid content and additionally show a lower BMI. As climbers need to develop an optimal balance between body weight - which must be lifted during climbing and thus if in excess might induce a weight penalty during mountainous stages (Noakes, 2007) - and muscle volume and function, the lower soft tissue mass and BMI ~~and fluid content~~ might represent specific adaptations to the climbers requirements and/or natural selection. The somewhat prolonged vector (upward shifted on the major axis of the tolerance ellipses) of the climbers compared to sprinters and all-rounder might indicate lower body fluid content and/or body structure differences.

A further outcome of the present investigation was the identification of the road cyclist population specific 50%, 75% and 95% tolerance ellipses (Figure 3). These ellipses, especially the ellipses plotted from data of the elite and professional cyclists, could be used for the classification of an individual vector and might represent target zones of impedance vectors for lower level cyclists.

However, if dehydration and/or catabolism thresholds, established for the normal or specific patient population (e.g., vectors out of the upper pole of the 75% ellipse indicates dehydration (Lukaski & Piccoli, 2012)) can be applied for the cyclist population, has still to be investigated. The latter would be of importance since adverse states might limit performance or training adaptations.

Conclusions

The~~is~~ ~~study showed different~~ BIVA distributions within the road cyclist population ~~and also compared to~~differ from data of the healthy Italian population and among themselves. BIVA distributions, the phase angle and the reactance value ~~may~~ reflect specific body composition, which might be a consequence of sports specific training and performance and/or natural selection (Table 2). Furthermore, present study identified the specific 50%, 75% and 95% tolerance ellipses of the entire road cyclist population, as well as for the high-level cyclists. These ellipses might be useful for interpreting individual vectors and to define target regions of impedance vectors for lower level athletes who seek to achieve a higher performance level based on body structure. A practical use of a BIVA vector position is to characterize the physiological profile of a cyclist, similar to body fatness that could be used to compare with elite cyclists to individualize training and dietary recommendations (Wilmore, 1983). Further studies should establish the usefulness of the tolerance ellipses for monitoring hydration status as well as performance changes.

Conflict of interest

The authors report no conflicts of interest

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None

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Table legend

Table 1. Characteristics of the male road cyclist population and divided by performance level and within the professional group by specialization

Table 2.

Practical implications of the bioimpedance vector analysis of the road cycling population

Figure legends

Figure 1 – Mean impedance vectors with their 95% confidence ellipses for the professional, elite, youth elite and amateur road cyclists compared to the 50%, 75%, and 95% tolerance ellipses of the healthy male Italian reference population (Piccoli et al., 1995). The right panel is an enlarged view of the area framed in the left panel.

Figure 2 - Mean impedance vectors with their 95% confidence ellipses of the different specialists within the professional road cyclist population compared to the 50%, 75%, and 95% tolerance ellipses of the professional road cyclists. The right panel is an enlarged view of the area framed in the left panel.

Figure 3 – 50%, 75%, and 95% tolerance ellipses of a) the male road cyclist population (including all the cyclists investigated) b) the combined professional and elite cyclist population and c) the professional cyclist population. Beside the R/H and Xc/H values the correlation coefficient r between R/H and Xc/H is needed to draw the ellipses. The correlation coefficient r for the entire road cyclist population, the combined professional and elite cyclist population and the professional cyclist population were r=0.473, r=0.568, r=0.547, respectively.

Table 1
Characteristics of the male road cyclist population and divided by performance level and within the professional group by specialization

	all	elite	youth elite	amateurs	professionals			
	n=525	n=79	n=59	n=232	all n=155	sprinter n=28	all-rounder n=81	climber n=46
Age (yr)	30.1±11.3	21.1±2.9*#	16.8±1.1*#§	39.0±10.5*	26.3±4.7	26.1±4.1	26.5±4.3	26.2±5.6
Height (cm)	177.2±6.2	178.1±5.8	176.6±6.3	176.1±6.4*	178.6±5.9	179.4±5.5	178.8±6.0	177.9±6.3
Weight (kg)	69.7±8.3	69.2±7.5	65.4±7.2*#§	71.1±9.5 kg	69.5±6.2	73.5±4.3	71.0±5.8	64.3±4.6*#
BMI (kg/m²)	22.2±2.3	21.8±1.6#	20.9±1.7*#§	22.9±2.8*	21.8±1.6	22.9±1.3	22.2±1.3	20.3±1.2*#
BSA (m²)	1.86±0.12	1.86±0.12	1.81±0.12	1.87±1.35	1.87±0.10	1.92±0.08	1.89±0.10	1.80±0.09
R/H (Ω/m)	278.6±37.2	284.5±31.4	264.1±40.7§	279.1±36.8	280.3±38.2	268.4±37.9	272.8±34.8	300.8±36.8*#
	(275.4-281.8)	(277.5-291.5)	(253.5-274.7)	(274.3-283.9)	(274.2-286.4)	(253.7-283.1)	(265.1-280.5)	(289.9-311.7)
Xc/H (Ω/m)	33.6±4.4	34.9±4.1#	33.7±3.7*#	31.6±4.2*	35.8±3.8	36.4±3.3	35.3±4.1	36.3±3.4
	(33.2-34.0)	(34.0-35.8)	(32.7-34.7)	(31.1-32.1)	(35.2-36.4)	(35.1-37.7)	(34.4-36.2)	(35.3-37.3)
R/BSA (Ω/m²)	267.0±43.5	273.5±37.6	259.7±46.6	265.3±45.3	269.0±42.0	251.2±38.9	259.1±37.0	297.2±39.0*#
	(263.3-270.7)	(265.1-281.9)	(247.6-271.8)	(259.4-271.2)	(262.3-275.7)	(236.1-266.3)	(250.9-267.3)	(285.6-308.8)
Xc/BSA (Ω/m²)	32.2±4.9	33.6±4.7#	33.1±4.4#	30.0±4.7*	34.3±4.1	34.1±3.4	33.6±4.3	35.9±3.9#
	(31.9-32.7)	(32.5-34.7)	(32.0-34.2)	(29.4-30.6)	(33.6-35.0)	(32.8-35.4)	(32.6-34.6)	(34.7-37.1)
PA (°)	6.9±0.9	7.0±0.7*#	7.4±1.2#	6.5±0.8*	7.4±0.8	7.8±0.9	7.4±0.8	7.0±0.8*#
	(6.8-7.0)	(6.8-7.2)	(7.1-7.7)	(6.4-6.6)	(7.3-7.5)	(7.5-8.1)	(7.2-7.6)	(6.8-7.2)

BMI, body mass index; PA, phase angle; R/H, resistance divided by body height; Xc/H, reactance divided by body height
*indicates differences to the professionals (comparison between performance levels) or sprinters (comparison within professional)
#indicates differences to the amateurs (comparison between performance levels) or all-rounders (comparison within professional)
§indicates differences to the elite (comparison between performance levels)
Data are presented as mean±SD. Additionally, for the bioimpedance values the 95% confidence interval (CI) is presented.

Table 2

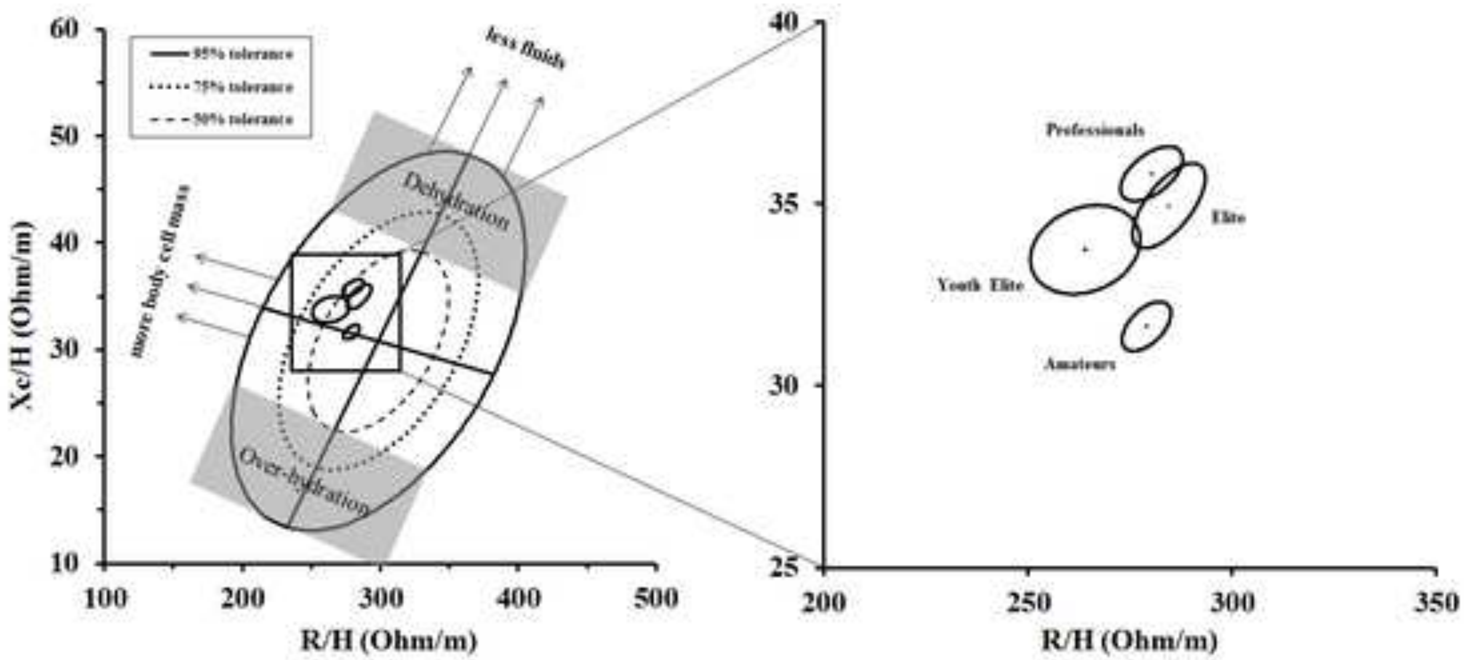
Practical implications of the bioimpedance vector analysis of the road cycling population

Performance level	Vector position	Interpretation of the vector position	Likely explanation	Vector position	Interpretation of the vector position	Likely explanation
	Compared to the Italian male population			Compared to the professional cyclists		
Professionals	Shift to the left on the minor axis and an upward shift on the major axis of the tolerance ellipses	Higher BCM and PA, lower body fluid volume, normal hydration*	Very high training load and/or natural selection			
Elite	Shift to the left on the minor axis and an upward shift on the major axis of the tolerance ellipses	Higher BCM and PA, lower body fluid volume, normal hydration*	High training load and/or natural selection	Shift to the right on the minor axis of the tolerance ellipses	Lower BCM and PA	Lower training load and/or natural selection issue
Youth elite	Shift to the left on the minor axis of the tolerance ellipses	Higher BCM and PA, normal hydration*	High training load and maturation level	Downward shift on the major axis of the tolerance ellipses	Higher body fluid volume	Lower training load and maturation level
Amateurs	Shift to the left on the minor axis of the tolerance ellipses	Higher BCM and PA, normal hydration*	Training load	Shift to the right on the minor axis and an downward shift on the major axis of the tolerance ellipses	Lower BCM and PA, higher body fluid volume	Lower training load and/or natural selection issue

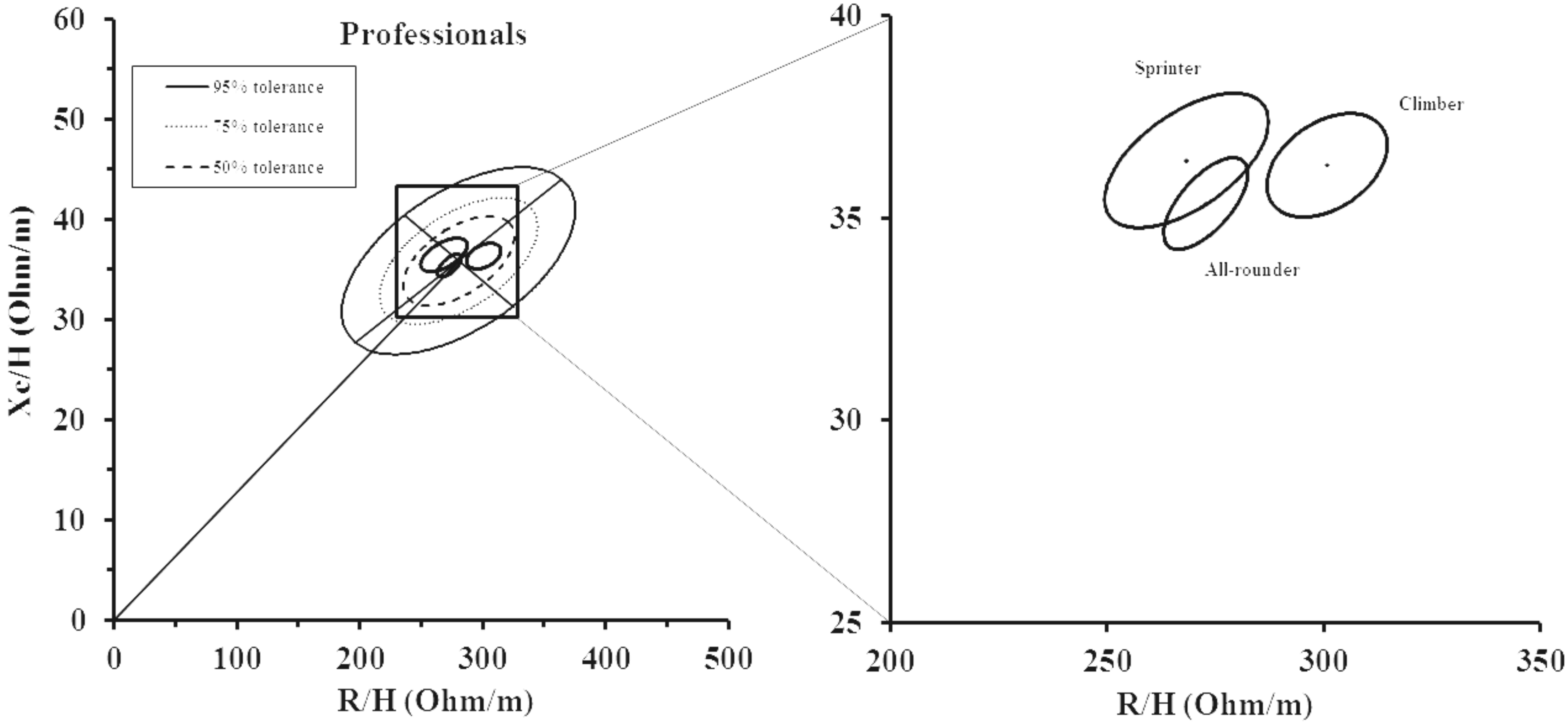
Body cell mass, BCM; phase angle, PA

*No vector lays out of the upper and lower pole of the 50% ellipse (for detailed information please refer to the text and Figure 1), which indicates normal hydration

Figure

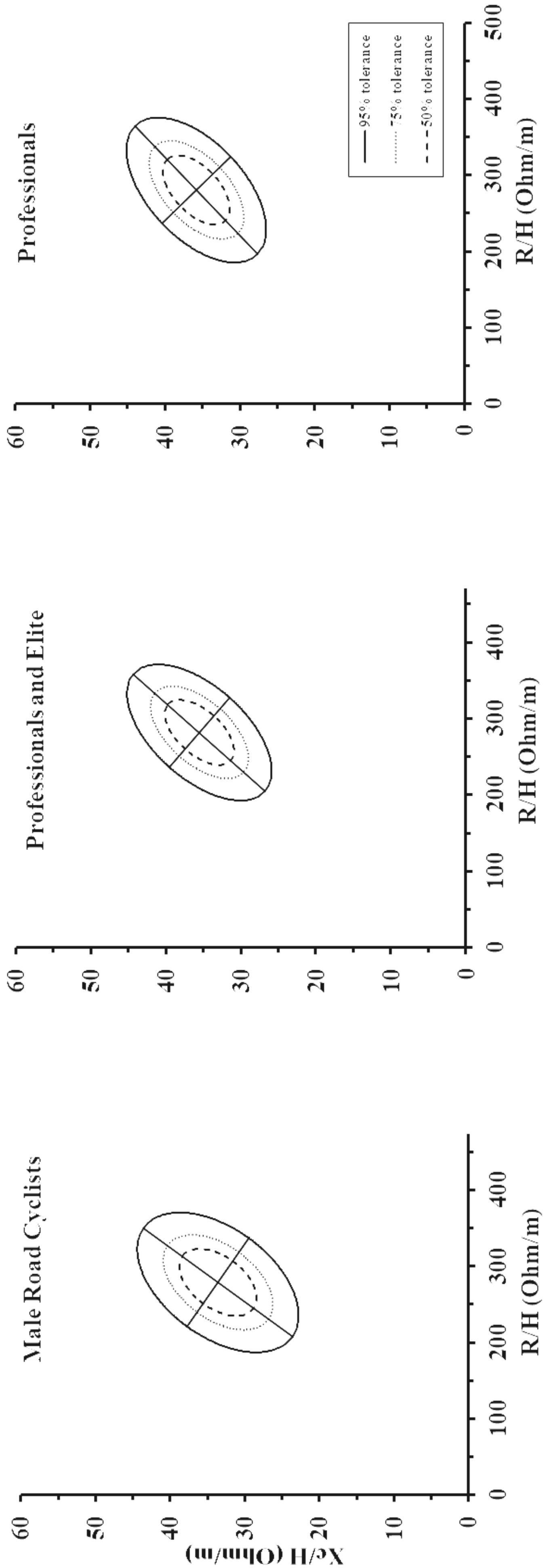

95% tolerance
75% tolerance
50% tolerance
less fluids
more body cell mass
Dehydration
Over-hydration
Xc/H (Ohm/m)
R/H (Ohm/m)
60
50
40
30
20
10
100
200
300
400
500
Professionals
Elite
Youth Elite
Amateurs
40
35
30
25
200
250
300
350
R/H (Ohm/m)

Figure



Professionals
95% tolerance
75% tolerance
50% tolerance
Xc/H (Ohm/m)
R/H (Ohm/m)
0
10
20
30
40
50
60
0
100
200
300
400
500
Sprinter
Climber
All-rounder
25
30
35
40
200
250
300
350
R/H (Ohm/m)

Figure



Male Road Cyclists
Professionals and Elite
Professionals
95% tolerance
75% tolerance
50% tolerance
Xc/H (Ohm/m)
R/H (Ohm/m)
0
10
20
30
40
50
60
100
200
300
400
500

Bioimpedance patterns and bioelectrical impedance vector analysis (BIVA) of road cyclists

Andrea Giorgi[a,b], Maurizio Vicini[b], Luca Pollastri[c], Erica Lombardi[d], Emilio Magni[e], Andrea Andreazzoli[f], Marco Orsini[g], Marco Bonifazi[a], Henry Lukaski[h], Hannes Gatterer[i,j*]

[a] *Department of Medicine, Surgery and Neuroscience, University of Siena, Siena, Italy*

[b] *Androni Giocattoli-Sidermec, Professional Cycling Team, Vignola, Italy*

[c] *Sports Medicine Laboratory, PENTAVIS, Lecco, Italy*

[d] *RusVelo – Gazprom Professional Cycling Team, Abbadia San Salvatore, Italy*

[e] *Bahrain-Merida Pro Cycling Team, Prato, Italy*

[f] *Pro Team Astana – Kazakhstan, Massa, Italy*

[g] *Area Zero Pro Team, Terni, Italy*

[h] *Department of Kinesiology and Public Health Education, University of North Dakota, Grand Forks, North Dakota, United States of America*

[i] *Department of Sport Science, University of Innsbruck, Innsbruck, Austria*

[j] *Institute of Mountain Emergency Medicine, EURAC Research, Bolzano, Italy*

*corresponding author
Hannes Gatterer
Institute of Mountain Emergency Medicine, EURAC Research
Viale Druso 1
I-39100 Bolzano
Tel.: +39 0471 055 578
e-mail: hannes.gatterer@eurac.edu

Running head
Impedance values of the road cyclists

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Abstract

Bioelectrical impedance vector-analysis (BIVA) describes cell-mass, cell function and hydration status of an individual or a group. The goal of the present investigation was to provide bioelectrical impedance data for 525 male road cyclists (155 professionals, 79 elite, 59 elite-youth, and 232 amateurs) at the time of their optimal performance level. Data were plotted on the resistance-reactance (R-Xc) graph to characterize cyclists group vectors using BIVA. Compared to the general male population, the mean vector position of the road cyclists indicates a higher body cell mass (BCM) and phase angle ($p<0.001$). The vector position of the high-performance, compared to the amateur, cyclists showed similar patterns with higher BCM and phase angles and higher reactance values for the high-performance athletes ($p<0.001$). The bio-impedance data were used to calculate the 50%, 75%, and 95% tolerance ellipses of each group of cyclists. The characteristic vector positions of the road cyclists indicate normal hydration and greater muscle mass and function of the high-performance cyclists compared to amateur cyclists and the normal population. The cyclists specific tolerance ellipses, particularly the high-performance cyclists might be used for classifying a cyclist according to the individual vector position and to define target vector regions for lower level cyclists.

Key words: road cyclists, anthropometry, body composition, phase angle, reference values, performance level

Introduction

A variety of methods exists for the determination of body composition, each characterized by advantages and disadvantages (Ackland et al., 2012; Gatterer, Schenk, & Burtscher, 2017). Bioimpedance vector analysis (BIVA) derived from bioimpedance (BI) measurements is a method regularly used in the clinical setting to diagnose malnutrition and monitor hydration (Lukaski, Kyle, & Kondrup, 2017; Norman, Stobäus, Pirlich, & Bosy-Westphal, 2012). The originality of BIVA is the change from quantitative estimates of body composition components (fat mass, fat free mass and percent body fat) that depend on sample-specific regression prediction equations and questionable assumptions regarding the chemical composition of the fat-free body to equation independent outcomes (Lukaski, 2013). The BIVA method first proposed by Piccoli, Rossi, Pillon, & Bucciante (1994) uses raw BI measurements (resistance, R and reactance, Xc) to characterize body cell mass (BCM) and hydration. Resistance indicates the conduction of a safe, low-level alternating current by water and electrolytes in fluids and tissues. Reactance specifies the capacitative component of tissues (cells and tissue interfaces) and is associated with cell size and integrity of the cell membranes (Gatterer et al., 2014; Lukaski, 2013; Lukaski & Piccoli, 2012; Lukaski et al., 2017; Norman et al., 2012; Piccoli et al., 1994). Additionally, the phase angle (PA), which is a composite of Xc and R, is characterized physiologically as an index of cell membrane integrity and vitality and expresses the quantity and quality of soft tissue (Lukaski et al., 2017), as such it can be considered an indicator of cell function including muscular strength and endurance (Norman et al., 2012). BIVA illustrates these bioelectrical parameters as a vector, either for an individual or a group, on the R-Xc graph to classify hydration status and differences in cell mass relative to a healthy, gender-matched control group or among different groups (Piccoli et al., 1994). Thus, BIVA allows for various applications in healthy populations and among clinical groups (Lukaski et al., 2017; Norman et al., 2012) and its value is recognized in different sports (Gatterer et al., 2011; Pollastri, Lanfranconi, Tredici, Burtscher, & Gatterer, 2016; Pollastri et al., 2016).

Impedance measurements depend on age, sex, fluid distribution, and body mass index (BMI) (Lukaski et al., 2017). Thus, interpretation of the impedance data of a specific population or athlete group requires population- or sport-specific impedance measures and reference distributions of vectors. Standards exist for the normal healthy population (Piccoli et al., 1995) and have been established for specific athletes groups (e.g., soccer population) (Micheli et al., 2014). For the broad performance range of road cyclist, such standards are not available. Thus, this study aimed to establish reference BI and BIVA data for the road cycling population and to compare these vector patterns of various performance levels of cyclists. Such standards offer a unique opportunity to interpret individual bioelectrical measurement data and associated performance characteristics of an individual cyclist and to define target values for the training process and for nutritional interventions. We hypothesized that high-performance road cyclists, compared to the healthy road cycling population, have a different vector position on the R-Xc graph indicative of adaptations of body composition due to differences in training and performance.

Methods

Participants

Five hundred and twenty-five male cyclists volunteered to participate in the study (Table 1). The sample included 155 professional, 79 elite, 59 elite youth and 232 amateur road cyclists. The professional riders were further classified as sprinter, all-rounder and climber, according to their roles in competition (Table 1). The professional cyclists were members of professional road cycling teams (World Tour Team, Professional Team, Continental Team). They cover between 30000 and 35000 km/yr and complete 65 to 90 d of competition per season (ranging from 1-d races to stage races of 3 wk) (Faria, Parker, & Faria, 2005; Lucía, Hoyos, Pérez, Santalla, & Chicharro, 2002; Pinot & Grappe, 2014). The elite cyclists are members of cycling teams, which are not considered professionals, yet they mostly earn their livelihood with the cycling sport. They cover distances ranging from 18000 to 26000 km/yr and have between 50 and 70 d of competition per season (ranging from 1-day races to stage races of 1 week) (Antón et al., 2007; Pinot & Grappe, 2014). The elite youth cyclists are members of adolescent teams and train and compete to become professionals. They cover distances of about 15,000-20,000 km/yr. The amateur cyclists compete for pleasure and they are not necessarily part of a cycling team. Nonetheless, their training effort can be essential covering up to 25,000 km/yr (Lucía et al., 2002). Yet, in general they cover distances between 3,000 and 10,000 km/yr.

The study was carried out in conformity with the ethical standards laid down in the 1975 declaration of Helsinki and was approved by the local ethical committee.

Procedures and Measurements

During 2015-2017 professional road cycling teams were invited to participate in the study and 155 cyclists agreed to participate. The elite (n=79), the elite youth (n=59) and the amateur (n=232) cyclists were recruited by convenient sampling. Cyclists were tested at the time of their optimal performance level. Body weight and height was measured to the nearest 0.1 kg and 0.5 cm, respectively. Body surface area was calculated according to Du Bois and Du Bois (1916): BSA = 0.007184 x body mass$^{0.425}$ x height$^{0.725}$. Bioelectrical impedance was measured with a phase-sensitive impedance device (BIA-101, Akern-RJL Systems, Florence, Italy). The device injects an alternating sinusoidal electric current of 240 µARMS at 50 kHz. The accuracy of the BI instrument was determined every morning by using a calibration circuit of known impedance (R= 380 Ohm, Xc = 47 Ohms) supplied by the manufacturer. The accuracy of the device was 1% for R and 1% for Xc similar as indicated elsewhere (Gatterer et al., 2014; Nescolarde et al., 2013). The Ag/AgCl electrodes (SMT medical, Würzburg, Germany) used during all measurements had low intrinsic impedance (Nescolarde et al., 2016). Standard whole-body tetrapolar measurements were performed according to the manufacturer guidelines. All BI measurements were made under resting conditions at least 24-hr after the last exercise session and either in a fasting state, yet well hydrated or within 2 hours from the last meal. As fluid and food within the abdominal cavity is "electrically silent" (Kushner, Gudivaka, & Schoeller, 1996) these procedure should only have had minor influence on the outcome parameters. The measurements were performed on the dominant side with the participants in a supine position with their arms and legs abducted. It was ensured that their thighs were not in contact with each other and their arms were not touching the sides of their bodies.

BIVA described in detail elsewhere (Kyle et al., 2004; Lukaski, 2013; Piccoli et al., 1994) enables classification (under-, normal and overhydration) and ranking of hydration (more or less than before intervention), as well as BCM, for an individual by examining the position of an individual vector relative to a reference population (Lukaski, 2013). The reference population is represented by the bivariate normal distribution with elliptical probability areas (50, 75 and 95%) in the tolerance ellipses (Figure 1, left panel) (Lukaski, 2013). For the analysis impedance measurement are standardized by the height (H) of the participants, expressing both, R/H and Xc/H in Ohm/m. Vector position on the R-Xc graph can be interpreted following two directions on the R-Xc graph

(Figure 1, left panel). Vector displacements parallel to the major axis of tolerance ellipses indicate progressive changes in tissue hydration. Long vectors out of the upper pole of the 50% and 75% ellipses point out mild and severe dehydration, respectively. Short vectors out of the lower pole of the 50% and 75% ellipses reflect mild and severe fluid overload with apparent oedema (Lukaski & Piccoli, 2012). Additionally, peripheral vectors lying in the left or right side of the major axis of the tolerance ellipses indicate more or less cell mass, respectively (Lukaski, 2013; Lukaski & Piccoli, 2012). The phase angle further helps to interpret the R-Xc graph. It is the angle of the impedance vector and can be directly calculated from Xc and R as the arc-tangent [(Xc/R) (180°/π)]. The phase angle has been suggested to be an indicator of cell function (Kyle, Genton, & Pichard, 2013; Norman et al., 2012) and was shown to be associated with performance in elite road cyclists (Pollastri et al., 2016).

Statistical analysis

A univariate analysis of variance and Dunnett-T3 (variance homogeneity not accepted) or Bonferroni (variance homogeneity accepted) post hoc tests for multiple comparisons were performed with SPSS software (Chicago, IL, USA, ver. 18).

The 50%, 75%, and 95% tolerance ellipses of individual vectors and the 95% confidence ellipses of mean vectors were determined for each group according to the BIVA method (Piccoli et al., 1995; Piccoli et al., 1994). Separate confidence ellipses indicate a significant vector displacement ($p < 0.05$). Exact probabilities were calculated with the Hotelling's T2 test (Hotelling, 1931). Results are presented as means ± SD and CI. Significance level was set at $p \leq 0.05$.

Results

The bioelectrical impedance characteristics of the road cyclist population differed by performance levels (Table 1). The reactance values divided by height were significantly greater among the professional road cyclists compared to the youth elite and the amateur cyclists ($p<0.05$). The phase angle of the elite and amateur cyclists was lower compared to the professionals ($p<0.05$). Among the professional cyclists, resistance values were significantly greater but phase angle was less for climbers compared to sprinters and all-rounder ($p<0.05$). Figure 1 shows the mean vectors with the 95% confidence ellipses of the different performance levels in addition to the 50%, 75%, and 95% tolerance ellipses of the healthy male Italian reference population (Piccoli et al., 1995). All vectors lay within the 50^{th} percentile of the tolerance ellipse. Hotelling's T2 test showed different vector distributions between all groups ($p<0.05$). Figure 2 shows the mean vectors with the 95% confidence ellipses of the different professional specialists (climbers, sprinters, all-rounder) together with the 50%, 75%, and 95% tolerance ellipses calculated for the professional cyclists. Hotelling's T2 test showed different vector distributions between climbers and sprinters as well as climbers and all-rounders ($p<0.05$).

Figure 3 shows the 50%, 75%, and 95% tolerance ellipses calculated for the overall cyclist population, for the combined values of the elite and the professional and for the professional road cyclists alone.

Discussion

The present study, for the first time, reports bioelectrical impedance data of male road cyclists of varying performance levels. Data show that compared to the healthy Italian male population, road cyclists in general show an impedance vector shift to the left on the minor (Xc) axis of the tolerance ellipses, indicating higher BCM. Additionally, among road cyclists, the vector of the high-performance level cyclists (i.e. elite youth, elite and professionals) compared to the amateurs showed both a shift to the left on the minor axis and an upward shift on the major axis (R or fluid) of the tolerance ellipses with a concomitant increased phase angle ($p<0.001$). These findings indicate that even within the road cyclist population different vector positions occur that may reflect increased muscle volume and function with increasing performance level. Additionally, vector position indicates normal hydration of road cyclists as all vectors lay within the 50^{th} percentile of the tolerance ellipse (Table 2 summarizes these outcomes and its interpretation). In addition, the present study identified the 50%, 75% and 95% tolerance ellipses for the road cyclist population as well as for the high-performance road cyclists (Figure 3).

In recent years BIVA has received consideration within the sport medicine and sport science field as a method to classify different sport populations as related to function and performance. Such population specific standards are essential when comparing and interpreting individual results of an athlete in regard to sport-specific colleagues. Additionally, the phase angle, the BCM and Xc attained from BIVA have been shown to be related to power output during cycling and muscle function (Norman et al., 2012; Pollastri et al., 2016) indicating the importance of these measures for the sport performance.

One important finding of the present investigation was that male road cyclists exhibited specific BIVA distributions which distinguish them from the normal healthy population (Figure 1). Compared to the healthy Italian male reference population (Piccoli et al., 1995), the vectors are shifted to the left on the minor axis of the tolerance ellipses ($p<0.001$). This indicates an increased BCM compared to the normal population that might reflect the sport and training specific adaptation of body masses and composition (Andreoli et al., 2003). A further important finding was that BIVA distributions differ according to the performance levels of the cycling population as well as for specialisations (Figure 1 and 2). In comparison to the amateur cyclists, the vector of the professionals, the elite and the youth elite cyclists showed both a shift to the left on the minor axis and a upward shift on the major axis of the tolerance ellipses ($p<0.001$) and additionally a higher phase angle. This could either be interpreted to mean that high level cyclists represent a distinct group or that muscle mass and function increases with increasing performance level. Interestingly, also within the high-level groups (i.e. youth elite, elite and professionals), vectors showed some differences, even though the magnitude was less. For instance, the professionals compared to the elite show a shift of the vector to the left on the minor axis of the tolerance ellipses, again indicating higher BCM and phase angles. This might be attributed to the higher training load and competitive level of the professional road cyclist leading to these specific adaptations. The BIVA of the young elite cyclists indicates equal soft tissue mass but to some extent higher body fluid volumes (downshifted vector on the major axis of the tolerance ellipses). Yet, the vector distribution of these young cyclists could have also been influenced by maturation level and body structure. Of further importance was the finding that within the professional cyclists, characteristic BIVA distributions exist (Figure 2). Data indicate that sprinters and all-rounders show comparable vectors, whereas climbers clearly differ from their counterparts. Climbers from a BIVA point of view are characterized by less soft tissue mass and somewhat lower body fluid content and additionally show a lower BMI. As climbers need to develop an optimal balance between body weight - which must be lifted during climbing and thus if in excess might induce a weight penalty during mountainous stages (Noakes, 2007) - and muscle volume and function, the lower soft tissue mass and BMI might represent specific adaptations to the climbers requirements and/or natural selection. The somewhat prolonged vector (upward shifted on the major axis of the tolerance ellipses) of the climbers compared to sprinters and all-rounder might indicate lower body fluid content and/or body structure differences.

A further outcome of the present investigation was the identification of the road cyclist population specific 50%, 75% and 95% tolerance ellipses (Figure 3). These ellipses, especially the ellipses plotted from data of the elite and professional cyclists, could be used for the classification of an individual vector and might represent target zones of impedance vectors for lower level cyclists. However, if dehydration and/or catabolism thresholds, established for the normal or specific patient population (e.g., vectors out of the upper pole of the 75% ellipse indicates dehydration (Lukaski & Piccoli, 2012)) can be applied for the cyclist population, has still to be investigated. The latter would be of importance since adverse states might limit performance or training adaptations.

Conclusions

The BIVA distributions within the road cyclist population differ from data of the healthy Italian population and among themselves. BIVA distributions, the phase angle and the reactance value reflect specific body composition, which might be a consequence of sports specific training and performance and/or natural selection (Table 2). Furthermore, present study identified the specific 50%, 75% and 95% tolerance ellipses of the entire road cyclist population, as well as for the high-level cyclists. These ellipses might be useful for interpreting individual vectors and to define target regions of impedance vectors for lower level athletes who seek to achieve a higher performance level based on body structure. A practical use of a BIVA vector position is to characterize the physiological profile of a cyclist, similar to body fatness that could be used to compare with elite cyclists to individualize training and dietary recommendations (Wilmore, 1983). Further studies should establish the usefulness of the tolerance ellipses for monitoring hydration status as well as performance changes.

Conflict of interest

The authors report no conflicts of interest

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Table legend

Table 1. Characteristics of the male road cyclist population and divided by performance level and within the professional group by specialization

Table 2.

Practical implications of the bioimpedance vector analysis of the road cycling population

Figure legends

Figure 1 – Mean impedance vectors with their 95% confidence ellipses for the professional, elite, youth elite and amateur road cyclists compared to the 50%, 75%, and 95% tolerance ellipses of the healthy male Italian reference population (Piccoli et al., 1995). The right panel is an enlarged view of the area framed in the left panel.

Figure 2 - Mean impedance vectors with their 95% confidence ellipses of the different specialists within the professional road cyclist population compared to the 50%, 75%, and 95% tolerance ellipses of the professional road cyclists. The right panel is an enlarged view of the area framed in the left panel.

Figure 3 – 50%, 75%, and 95% tolerance ellipses of a) the male road cyclist population (including all the cyclists investigated) b) the combined professional and elite cyclist population and c) the professional cyclist population. Beside the R/H and Xc/H values the correlation coefficient r between R/H and Xc/H is needed to draw the ellipses. The correlation coefficient r for the entire road cyclist population, the combined professional and elite cyclist population and the professional cyclist population were r=0.473, r=0.568, r=0.547, respectively.

Table 1
Characteristics of the male road cyclist population and divided by performance level and within the professional group by specialization

	all	elite	youth elite	amateurs	professionals			
	n=525	n=79	n=59	n=232	all n=155	sprinter n=28	all-rounder n=81	climber n=46
Age (yr)	30.1±11.3	21.1±2.9*#	16.8±1.1*#§	39.0±10.5*	26.3±4.7	26.1±4.1	26.5±4.3	26.2±5.6
Height (cm)	177.2±6.2	178.1±5.8	176.6±6.3	176.1±6.4*	178.6±5.9	179.4±5.5	178.8±6.0	177.9±6.3
Weight (kg)	69.7±8.3	69.2±7.5	65.4±7.2*#§	71.1±9.5 kg	69.5±6.2	73.5±4.3	71.0±5.8	64.3±4.6*#
BMI (kg/m²)	22.2±2.3	21.8±1.6#	20.9±1.7*#§	22.9±2.8*	21.8±1.6	22.9±1.3	22.2±1.3	20.3±1.2*#
BSA (m²)	1.86±0.12	1.86±0.12	1.81±0.12	1.87±1.35	1.87±0.10	1.92±0.08	1.89±0.10	1.80±0.09
R/H (Ω/m)	278.6±37.2	284.5±31.4	264.1±40.7§	279.1±36.8	280.3±38.2	268.4±37.9	272.8±34.8	300.8±36.8*#
	(275.4-281.8)	(277.5-291.5)	(253.5-274.7)	(274.3-283.9)	(274.2-286.4)	(253.7-283.1)	(265.1-280.5)	(289.9-311.7)
Xc/H (Ω/m)	33.6±4.4	34.9±4.1#	33.7±3.7*#	31.6±4.2*	35.8±3.8	36.4±3.3	35.3±4.1	36.3±3.4
	(33.2-34.0)	(34.0-35.8)	(32.7-34.7)	(31.1-32.1)	(35.2-36.4)	(35.1-37.7)	(34.4-36.2)	(35.3-37.3)
R/BSA (Ω/m²)	267.0±43.5	273.5±37.6	259.7±46.6	265.3±45.3	269.0±42.0	251.2±38.9	259.1±37.0	297.2±39.0*#
	(263.3-270.7)	(265.1-281.9)	(247.6-271.8)	(259.4-271.2)	(262.3-275.7)	(236.1-266.3)	(250.9-267.3)	(285.6-308.8)
Xc/BSA (Ω/m²)	32.2±4.9	33.6±4.7#	33.1±4.4#	30.0±4.7*	34.3±4.1	34.1±3.4	33.6±4.3	35.9±3.9#
	(31.9-32.7)	(32.5-34.7)	(32.0-34.2)	(29.4-30.6)	(33.6-35.0)	(32.8-35.4)	(32.6-34.6)	(34.7-37.1)
PA (°)	6.9±0.9	7.0±0.7*#	7.4±1.2#	6.5±0.8*	7.4±0.8	7.8±0.9	7.4±0.8	7.0±0.8*#
	(6.8-7.0)	(6.8-7.2)	(7.1-7.7)	(6.4-6.6)	(7.3-7.5)	(7.5-8.1)	(7.2-7.6)	(6.8-7.2)

BMI, body mass index; PA, phase angle; R/H, resistance divided by body height; Xc/H, reactance divided by body height
*indicates differences to the professionals (comparison between performance levels) or sprinters (comparison within professional)
#indicates differences to the amateurs (comparison between performance levels) or all-rounders (comparison within professional)
§indicates differences to the elite (comparison between performance levels)
Data are presented as mean±SD. Additionally, for the bioimpedance values the 95% confidence interval (CI) is presented.

Table 2

Practical implications of the bioimpedance vector analysis of the road cycling population

Performance level	Vector position	Interpretation of the vector position	Likely explanation	Vector position	Interpretation of the vector position	Likely explanation
	Compared to the Italian male population			**Compared to the professional cyclists**		
Professionals	Shift to the left on the minor axis and an upward shift on the major axis of the tolerance ellipses	Higher BCM and PA, lower body fluid volume, normal hydration*	Very high training load and/or natural selection			
Elite	Shift to the left on the minor axis and an upward shift on the major axis of the tolerance ellipses	Higher BCM and PA, lower body fluid volume, normal hydration*	High training load and/or natural selection	Shift to the right on the minor axis of the tolerance ellipses	Lower BCM and PA	Lower training load and/or natural selection issue
Youth elite	Shift to the left on the minor axis of the tolerance ellipses	Higher BCM and PA, normal hydration*	High training load and maturation level	Downward shift on the major axis of the tolerance ellipses	Higher body fluid volume	Lower training load and maturation level
Amateurs	Shift to the left on the minor axis of the tolerance ellipses	Higher BCM and PA, normal hydration*	Training load	Shift to the right on the minor axis and an downward shift on the major axis of the tolerance ellipses	Lower BCM and PA, higher body fluid volume	Lower training load and/or natural selection issue

Body cell mass, BCM; phase angle, PA

*No vector lays out of the upper and lower pole of the 50% ellipse (for detailed information please refer to the text and Figure 1), which indicates normal hydration