Segmental bioimpedance analysis in professional cyclists during a three week stage race

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Abstract

Bioelectrical impedance analysis has been widely used in the clinical and sport areas because it is a safe, non-invasive, rapid and inexpensive technique that evaluates some electrical properties of the body, such as resistance ($R$), reactance ($X_c$) and phase angle (PhA).

The aim of this study is to evaluate body composition changes in professional cyclists, participating at the Giro D’Italia 2012, a three week stage race, and in particular PhA modifications as an expression of fat free mass nutritional status.

Data were collected at the beginning, in the middle and at the end of the competition. Body weight, circumferences, skinfold thickness and BIA variables (total and segmental body) were measured.

Body composition, measured by skinfold thickness, changed during the competition: fat free mass increased, but not significantly, in the middle and at the end of the competition, whereas fat mass significantly decreased versus the baseline in the middle and at the end of the competition. The total PhA did not significantly change in the middle of the competition but was significantly reduced at the end. The arm PhA did not change significantly at both times of the competition, whereas a significant reduction was reported for leg PhA in the middle and at the end of the competition.
These results suggest the use of bioimpedance analysis, in particular PhA measurement, to monitor athletes’ fat-free mass characteristics during medium- and long-term competitions.

Keywords: segmental bioimpedance analysis, elite athletes, phase angle, athletic performance

(Some figures may appear in colour only in the online journal)

Introduction

Bioelectrical impedance analysis (BIA) has been widely used in the clinical and research areas because it is a safe, non-invasive, rapid and inexpensive technique that evaluates some electrical properties of the body such as resistance (R), reactance (Xc) and phase angle (PhA) (Kyle et al. 2004a, 2004b). Whole-body R is inversely related to total body water while the reactance and PhA are expected to be related to cell membranes and tissue interfaces (Kushner et al. 1992, Lukaski 1996, Schwenk et al. 2000). R corrected by height (bioimpedance index = height/R cm$^2$ Ω$^{-1}$) is used to estimate the body composition through regression equations, which are based on age, gender, height and weight (Kushner et al. 1992). The PhA is obtained from the relationship between resistance and reactance using the following equation:

$$\text{phase angle (degrees)} = \text{arctan(reactance/resistance)} \times (180/\pi).$$

Previous research has proved that a PhA of 50 kHz carries both intra- and extracellular water (ECW) information. Moreover, the PhA is more appropriate than impedance for the assessment of nutritional status, because the PhA contributes to identifying the degree of cellular health (Gupta et al. 2008, Santarpia et al. 2009, Lee et al. 2015). In healthy people, the PhA ranges from 5° to 7° (Barbosa-Silva 2005), and in athletes it may reach 8.5° (Marra et al. 2014). Low PhA (<5°) indicates pathological membrane state and function (Scalfi et al. 1999, Selberg and Selberg 2002, Marra et al. 2005).

Several researchers have proved the close relation between PhA and nutritional state. The PhA exhibits a negative correlation with the subjective global assessment (SGA) score (Gupta et al. 2008). The PhA indeed correlates with various indices of functional (grip strength in liver cirrhosis, knee extension strength and Barthel index in elderly institutionalized subjects) and nutritional (albumin, SGA) status (Castillo Martinez et al. 2007, Gupta et al. 2008, Kyle et al. 2012, Norman et al. 2015). An improvement in nutritional status is also accompanied by a rise in PhA. Studies have shown that in patients with anorexia nervosa, the PhA increased by 0.6° after 15 weeks of successful nutritional therapy, and 1.1° in the stable refeed state (Scalfi et al. 1999, Mika et al. 2004, Marra et al. 2005). Also, lasting and intensive physical activity could modify body composition (in particular body water distribution). In the literature there are few studies on the application of PhA in sport to evaluate physical performance (Marra et al. 2009, Silva et al. 2010, 2011); Silva has described a positive correlation between handgrip strength and PhA in elite judo athletes during a competition (Silva et al. 2011). Recently, Marra et al. (2014) showed a significant and progressive reduction of PhA in a team of cyclists participating in the Giro d’Italia 2011. In athletes, a progressive reduction in the PhA may be due to vigorous exercise during a competition, such as the Giro d’Italia. Therefore, it may be of interest to evaluate the PhA of the different body compartments (total body, arms and legs) to verify changes after intense physical activity.
The aim of this study is to evaluate changes in body composition in professional cyclists participating in the Giro D’Italia 2012, a three week stage race, and in particular PhA modifications as an expression of fat free mass nutritional state in total body and segments (arm and leg).

Method

A team of nine professional cyclists of the Pro Cycling Team Liquigas Cannondale participated in the study. All data were collected at the Giro D’Italia 2012, a three week stage race. Subjects were studied at three steps: (1) the day before the competition (baseline), (2) the day of rest (after the 9th day lap), (3) the last day of the competition (21st lap).

No special advice was given for food and water intake.

All measurements were performed by the same operator following standard procedures. Height was measured to the nearest 0.1 cm using a stadiometer and body weight to the nearest 0.1 kg on a balance beam scale with the subject barefoot and wearing only light undergarments. Skinfold thickness was measured on the left side of the body, in triplicate to the nearest 0.2 mm, using a Harpenden caliper at the biceps, triceps, subscapular and suprailiac sites. Percentage of body fat was derived from the sum of four subcutaneous skinfolds (biceps, triceps, subscapular and suprailiac sites) according to Durnin and Womersley (1974). The PhA was measured by BIA (Human IM Plus II—DS Medica) at 50kHz in the post-absorptive state, at an ambient temperature of 22–24 °C, after voiding and after being in the supine position for 20min (figure 1).

For the segmental BIA exam, the length of each segment was measured and the electrodes were properly positioned to obtain resistance and reactance values for each segment: arm and leg. This evaluation was conducted according to the Organ method (Organ et al 1974).

The statistical analysis was performed using a paired t-test between different time points (software SPSS version 15). The results were expressed as mean and standard deviation.

The study was carried out according to the Declaration of Helsinki and its protocol was approved by the local ethics committee.

Results

The athletes’ general characteristics at the baseline are described in table 1. Their average body weight did not significantly differ during the competition: the mean body weight reduction was −0.8 kg and −0.6 kg in the middle and at the end of the competition, respectively.
Table 1. Subjects’ characteristics at baseline, in the middle and at the end of the three week race.

|        | N = 9 | Baseline | 9th lap | Δ 0–9th lap | 21st lap | Δ 0–21st lap |
|--------|-------|----------|---------|-------------|----------|-------------|
| Age    | years | 28.8 ± 3.5 |         |             |          |             |
| Height | cm    | 182 ± 5   |         |             |          |             |
| Weight | kg    | 70.2 ± 5.6 | 69.3 ± 5.7 | -0.8 ± 0.7 | 69.5 ± 5.7 | -0.6 ± 1.5  |
| BMI    | kg m⁻²| 21.2 ± 1.2 |         |             |          |             |

Values are mean ± SD.
BMI, body mass index.
Δ, average reduction between baseline, 9th lap and 21st lap.

Table 2. Skinfold thickness and body composition values at baseline, at the 9th and at the 21st lap of the competition.

|        | N = 9 | Baseline | 9th lap | Δ 0–9th lap | 21st lap | Δ 0–21st lap |
|--------|-------|----------|---------|-------------|----------|-------------|
| Skinfold thickness | | | | | | |
| Biceps | mm    | 3.89 ± 0.54 | 3.69 ± 0.39 | -0.20 ± 0.42 | 3.78 ± 0.66 | -0.11 ± 0.50 |
| Triceps | mm    | 6.47 ± 1.32 | 5.62 ± 0.80⁺ | -0.84 ± 0.63 | 5.60 ± 0.83ᵇ | -0.87 ± 0.73 |
| Subscapular | mm | 7.38 ± 1.37 | 6.71 ± 1.21⁺ | -0.67 ± 0.42 | 6.78 ± 1.04ᵇ | -0.60 ± 0.45 |
| Iliac | mm    | 6.82 ± 2.60 | 5.51 ± 1.75⁺ | -1.31 ± 1.20 | 5.58 ± 2.01ᵇ | -1.24 ± 1.24 |
| Body composition | | | | | | |
| Fat free mass | kg    | 63.1 ± 5.6 | 63.3 ± 5.4 | +0.24 ± 0.68 | 63.4 ± 5.7 | +0.37 ± 1.36 |
| Fat mass | kg    | 7.1 ± 1.6 | 6.0 ± 1.3⁺ | -1.09 ± 0.58 | 6.1 ± 1.2ᵇ | -1.00 ± 0.76 |

Values are mean ± SD.
Δ, average reduction between baseline and 9th lap, and between baseline and 21st lap.
⁺ p < 0.05 baseline versus after 9th lap.
b p < 0.05 baseline versus after 21st lap.

Table 3. Total and segmental (arm and leg) PhA at baseline, at the 9th and at the 21st lap of the competition.

|        | N = 9 | Baseline | 9th lap | Δ 0–9th lap | 21st lap | Δ 0–21st lap |
|--------|-------|----------|---------|-------------|----------|-------------|
| PhA    |       |          |         |             |          |             |
| Total degrees | | 7.57 ± 0.53 | 7.58 ± 0.54 | +0.01 ± 0.31 | 7.27 ± 0.70ᵇ | -0.30 ± 3.4 |
| Arm degrees | | 5.79 ± 0.52 | 5.89 ± 0.74 | +0.96 ± 0.31 | 5.88 ± 0.89 | +0.91 ± 0.46 |
| Leg degrees | | 9.12 ± 0.51 | 8.80 ± 0.51⁺ | -0.32 ± 0.44 | 8.36 ± 0.58ᵇ | -0.72 ± 0.38 |

Values are mean ± SD.
Δ, average reduction between baseline and 9th lap, and between baseline and 21st lap.
⁺ p < 0.05 baseline versus after 9th lap.
b p < 0.05 baseline versus after 21st lap.

Biceps skinfold did not significantly change, whereas a significant reduction was reported for triceps, subscapular and suprailiac skinfold at both time points of the competition (p < 0.05) (table 2). Body composition, measured by skinfold thickness, significantly changed during the competition: fat free mass increased, but not significantly, in the middle (0.2 kg) and at the end of the competition (0.4 kg), whereas the mean fat mass reduction versus baseline (−1.08 kg and −1.00 kg in the middle and at the end of the competition, respectively) was significantly different (table 2).
The total PhA did not significantly change in the middle of the competition but was significantly reduced at the end of the competition ($-0.29 \Omega$, $p < 0.05$) (table 3). Arm PhA did not significantly change at both times of the competition whereas a significative reduction was reported for leg PhA ($-0.32 \Omega$ and $-0.72 \Omega$ in the middle and at the end of the competition, respectively) (table 3).

Discussion

This study confirms our dissertation results (Marra et al. 2014) (five out of the nine athletes had already participated in Giro D’Italia 2011). We found that both body weight and fat free mass did not significantly change during a three week stage race, whereas fat mass significantly decreased during the competition.

Interesting results emerged from segmental BIA exam and also the PhA, a BIA variable related to the capacitance of cell membranes and tissue interfaces and therefore related to body cell mass. The total body PhA significantly decreased during the competition, as already described in our previous study. Moreover, the results of a segmental BIA exam, the reduction in PhA and intra-cellular water (ICW), can be explained by long-term competition and continuous vigorous exercise (Silva et al. 2011, Marra et al. 2014). We only observed a reduction in leg PhA (in the cycling the leg is the most stressed body compartment), whereas arm PhA did not change during the competition.

To our knowledge, only one recent study by Silva et al. (2010, 2011) has evaluated total body, ECW and ICW changes and the relationship with forearm maximal strength loss in elite judo athletes: a significant effect of ICW changes on the risk of decreasing forearm maximal strength was reported (Silva et al. 2011). Independent of body weight changes, athletes with a decreased ICW were more prone to reduced grip strength.

Conclusion

The results of this study encourage further investigation using BIA, and in particular the evaluation of the PhA, in order to monitor the performance of athletes during medium- and long-term competition. In fact, we have demonstrated a clear modification in leg PhA following strenuous exercise (about 200 km cycling per day for twenty consecutive days) accompanied by a substantially unmodified PhA registered in both arms during the same assessment and period of time.

These results could also be relevant for future investigations in other groups of athletes of different sport specialties, involving different muscle groups, for the assessment of the relationship between fatigue and performance. This perspective deserves further investigation for potential use in sport medicine.

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