Effects of Intense Physical Activity with Free Water Replacement on Bioimpedance Parameters and Body Fluid Estimates

E B Neves¹, L Ulbricht¹, E Krueger², E F R Romanelli³, M N Souza⁴
¹ Biomedical Engineering Master Program/PPGEB, Federal Technological University of Paraná, Av. Sete de Setembro, 3165, 80230-901, Curitiba/PR, Brazil
² Rehabilitation Engineering Laboratory, Federal Technological University of Paraná, Av. Sete de Setembro 3165, 80230-901, Brazil
³ Automation and Control Engineering, Academic Department of Electrotechnics, Federal Technological University of Paraná, Av. Sete de Setembro 3165, 80230-901, Brazil
⁴ Biomedical Engineering Program – COPPE/UFRJ, Centro de Tecnologia, Bloco H, sala 327, 21949-900, Brazil

E-mail: borbaneves@hotmail.com

Abstract. Authors have emphasized the need for previous care in order to perform reliable bioimpedance acquisition. Despite of this need some authors have reported that intense physical training has little effect on Bioimpedance Analysis (BIA), while other ones have observed significant effects on bioimpedance parameters in the same condition, leading to body composition estimates considered incompatible with human physiology. The aim of this work was to quantify the changes in bioimpedance parameters, as well as in body fluids estimates by BIA, after four hours of intense physical activity with free water replacement in young males. Xitron Hydra 4200 equipment was used to acquire bioimpedance data before and immediately after the physical training. After data acquisition body fluids were estimates from bioimpedance parameters. Height and weight of all subjects were also acquired to the nearest 0.1 cm and 0.1 kg, respectively. Results point that among the bioimpedance parameter, extracellular resistance presented the most coherent behavior, leading to reliable estimates of the extracellular fluid and part of the total body water. Results also show decreases in height and weight of the participants, which were associated to the decrease in body hydration and in intervertebral discs.

Introduction
Bioelectrical impedance or simply bioimpedance can be defined as the frequency-dependent phenomenon associated to the electrical opposition (both real and imaginary components) a biological specimen presents to the flow of an alternating current. Bioimpedance measurement is influenced by the frequency of the electrical signal, electrochemical processes, temperature, potential of hydrogen (pH), hydration and viscosity of the fluid or biological tissue in question [1]. Among bioimpedance applications, noninvasive estimate of body fluids (extracellular fluid - ECF, intracellular fluid – ICF, and total body water - TBW) has been used in monitoring patients and athletes. Particularly, the ratio between ECF and ICF has been suggested as an effective index for
controlling health status [2]. These estimates are used independently and associated with others variables to follow-up patients with HIV [3], in the assessment of hydration status in patients undergoing hemodialysis [4], controlling the health status of patients affected by hyperthyroidism [5], dengue fever [6], in studies of hydration during cellular aging [7], and for monitoring levels of obesity and nutrition [8], among others.

Although some authors emphasize the need for previous care in order to perform reliable bioimpedance acquisition, quite different experimental protocols have been observed in the literature. Some studies control bladder emptying and type of clothing [9], while other ones advise to avoid performing intense physical exercise and to control dietary patterns, as well as alcohol intake for 24 hours before the test [10] [11]. Still others contraindicate the use of diuretic substances for 48 hours before the test [12]. One study extends for 7 days some of the recommendations listed above [13].

Regarding the influence of physical activity on the results concerning bioimpedance data, Perrella et al. [14] reported that two hours of rugby training had little effect on the Bioimpedance Analysis (BIA). On the other hand, Neves et al. [15] used several methods to assess changes in body composition of subjects after four hours of intense physical activity and observed a decrease in the mean fat percentage assessed by bioimpedance, which was considered incompatible with human physiology, indicating a strong influence of the physical activity on the results. This result reinforces the need of care protocols in assessment of body composition by BIA, as indicated by other studies [16, 17], specially under unstable conditions of hydration.

The aim of this study was to quantify the changes observed in bioimpedance parameters, as well as in bioimpedance estimates of body fluids, after four hours of intense physical activity with free water replacement in young males.

**Materials and Methods**

1.1. Bioimpedance data acquisition and estimates of body fluids

A Xitron Hydra 4200 equipment was used to acquire bioimpedance parameters in a tetrapolar arrangement of electrodes that considered the whole body, i.e., wrist to ankle protocol [4]. Figure 1 depicts the electrode placement, where I symbols indicate the sites where the current electrodes were placed, and V symbols indicate the sites associated to the voltage electrodes. Such electrodes placement and subject position during the measurement follow the indication established in the Xitron Hydra 4200 user’s manual [4] for a whole body assessment. Stainless steel electrodes of 12 cm² area and electrolyte gel were used instead of the Xitron original electrodes.

The device uses 50 fixed frequencies between 5 kHz and 1 MHz, and a sinusoidal current excitation in a range from 50 to 700 µA. Based on 50 data acquisitions of impedance, the firmware of the equipment estimates values associated to a Cole model [18], composed, among other parameters, by the extracellular resistance (Re), the intracellular resistance (Ri) and the membrane capacitance (Cm).

![Figure 1. Electrodes placement according Xitron Hydra 4200 user’s manual.](image-url)
After bioimpedance parameters are determined, Re is firstly used to estimate ECF. Then, Re and Ri are used to estimate ICF and finally the total body water (TBW) is derived by adding ECF and ICF. References [19] and [20] can be seen for more details concerning the equations used to perform such estimates. Briefly, ECF and ICF can be calculated by equations (1) and (2) based on bioimpedance resistive parameters. Thus, total body water can be calculated by equation (3).

$$ECF = \frac{1}{1000} \cdot \left( \frac{K_b \rho_{ECF}}{D_b} \right)^{\frac{2}{3}} \cdot \left( \frac{H^2 \sqrt{W}}{R_e} \right)^{\frac{2}{3}}$$  \hspace{1cm} (1)$$

$$ICF = ECF \cdot \left\{ \left[ \frac{\rho_{TBW}(R_e + R_i)}{\rho_{ECF} R_i} \right]^{\frac{1}{3}} - 1 \right\}$$  \hspace{1cm} (2)$$

$$TBW = ECF + ICF$$  \hspace{1cm} (3)$$

Where, $K_b$ is a correction factor for a whole body measurement, relating the relative proportions of the leg, arm, trunk and height; $\rho_{TBW}$ is the resistivity of the overall fluid in [$\Omega \cdot m$]; $\rho_{ECF}$ is the resistivity of the extracellular fluid in [$\Omega \cdot m$]; $H$ is the body height in [cm]; $D_b$ is the body density in [Kg/l] and $W$ is the body weight in [Kg].

According Xitron Operational Manual [4], the FFM can be calculated by equation 4, the hydration by equation 5, the Fat by equation 6 and the Fat % by the equation 7.

$$FFM = (d_{ECW} \cdot V_{ECW}) + (d_{ICW} \cdot V_{ICW})$$  \hspace{1cm} (4)$$

$$Hydration = \frac{TBW}{FFM}$$  \hspace{1cm} (5)$$

Where, $d_{ECW}$ (1.106) is the mean density of extracellular water and $d_{ICW}$ (1.521) is the mean density of the intracellular water and its associated materials.

$$Fat = W_t - FFM$$  \hspace{1cm} (6)$$

$$Fat\% = \frac{Fat}{W_t \cdot 100}$$  \hspace{1cm} (7)$$

Where, $W_t$ is the total weight value.
1.2. Subjects
The study sample universe was initially composed by 422 students from a military parachuting course in Brazilian Army. From such sample 92 male students were randomly selected to be evaluated during the three weeks that composed the first phase of the parachuting course, which occurred in the period from January 6th to 24th, 2009. The study was performed according to principles expressed in Declaration of Helsinki and was approved by the Ethical Committee of the Airborne Instruction Center in charge of the parachuting unit.

1.3. Assessment Protocol
During data collection each subject was evaluated twice in a single day. The first evaluation took place immediately before the four-hours training and considering that the subjects were advised to perform bladder emptying with 30 minutes early and do not drink alcohol within 72 hours before the test. The second evaluation was performed immediately after 4 hours of intense physical activity. In addition to bioimpedance data acquisition, height and weight of all subjects were acquired to the nearest 0.1 cm and 0.1 kg, respectively. The subjects were using light clothing during data collection.

1.4. Data Analysis
Statistical Package for Social Sciences for Windows, version 17.0 (SPSS Inc., Chicago, IL, EUA), was used to perform statistical analysis. Descriptive statistics were reported as mean and standard deviation (Std). Paired t-test was used to verify the difference between the studied variables before and after the period of physical activity. Inferential tests considered significant P-value < 0.05.

Results
Ninety two male military paratroopers were assessed before (index 1) and immediately after (index 2) four hours of physical training. Results concerning bioimpedance parameters are shown in Table 1. Table 2 shows the results of ten variables that were assessed before and immediately after the physical training. Some of them were directly measured, as weight and height, while other ones were estimates by BIA. In this table one can observe that there were decreases in the mean-values of weight, height, body fat percentage (Fat %) and body mass index (BMI) after the intense physical activity period, which was expected due to a reduction in the level of hydration despite the free water replacement.

As mentioned before, despite the total body water (TBW) has remained stable; there was a reduction in the level of hydration and the ratio between the intracellular and extracellular fluid (ECF / ICF) due to a decrease in extracellular fluid (ECF) and an increase in fluid intracellular (ICF).

| Table 1. Changes in bioimpedance parameters after four hours of intense physical activity. Indexes 1 and 2 stand for parameters before and immediately after the physical training, respectively. |
|---------------------------------|--------------|----------------|-----------------|-----------------|
|                                | Mean         | N  | Std. Deviation | Std. Error Mean |
| Pair 1                         |              |    |                |                 |
| Re 1[Ω]                        | 528.98       | 92 | 44.37          | 4.63            |
| Re 2[Ω]                        | 533.63       | 92 | 43.15          | 4.50            |
| Pair 2                         |              |    |                |                 |
| Ri 1[Ω]                        | 1021.06      | 92 | 132.64         | 13.82           |
| Ri 2[Ω]                        | 977.65       | 92 | 127.18         | 13.26           |
| Pair 3                         |              |    |                |                 |
| Cm 1[nF]                       | 2.52         | 92 | 0.37           | 0.04            |
| Cm 2[nF]                       | 2.68         | 92 | 0.39           | 0.04            |
Table 2. Results of assessment for the ten studied body characteristics after four hours of intense physical activity. Indexes 1 and 2 stand for parameters before and immediately after the physical training, respectively.

| Pair     | Parameter 1 | Parameter 2 | N  | Std. Deviation | Std. Error Mean |
|----------|-------------|-------------|----|----------------|-----------------|
| Pair 1   | Weight 1 [kg] | 76.35       | 92 | 7.45           | 0.78            |
|          | Weight 2 [kg] | 74.08       | 92 | 7.13           | 0.74            |
| Pair 2   | Height 1 [cm] | 174.61      | 92 | 5.90           | 0.62            |
|          | Height 2 [cm] | 173.24      | 92 | 5.73           | 0.60            |
| Pair 3   | BMI 1 [kg/m²] | 25.04       | 92 | 2.10           | 0.21            |
|          | BMI 2 [kg/m²] | 24.69       | 92 | 2.07           | 0.22            |
| Pair 4   | ECF 1 [L]    | 19.50       | 92 | 1.84           | 0.19            |
|          | ECF 2 [L]    | 18.98       | 92 | 1.66           | 0.17            |
| Pair 5   | ICF 1 [L]    | 26.82       | 92 | 3.01           | 0.31            |
|          | ICF 2 [L]    | 27.38       | 92 | 3.04           | 0.32            |
| Pair 6   | TBW 1[L]     | 46.33       | 92 | 4.59           | 0.48            |
|          | TBW 2 [L]    | 46.36       | 92 | 4.40           | 0.46            |
| Pair 7   | FFM 1[kg]    | 62.37       | 92 | 6.30           | 0.66            |
|          | FFM 2 [kg]   | 62.68       | 92 | 6.14           | 0.64            |
| Pair 8   | Fat % 1 [%]  | 18.18       | 92 | 4.99           | 0.52            |
|          | Fat % 2 [%]  | 15.19       | 92 | 6.19           | 0.65            |
| Pair 9   | Hydration 1 [%] | 74.29 | 92 | 0.41           | 0.04            |
|          | Hydration 2 [%] | 73.99 | 92 | 0.92           | 0.10            |
| Pair 10  | ECF/ICF 1    | 0.73        | 92 | 0.05           | 0.01            |
|          | ECF/ICF 2    | 0.70        | 92 | 0.05           | 0.01            |

Table 3 shows the results of the paired t-test for all variables depicted in Tables 1 and 2. There were statistically significant differences for most of variables, but TBW and fat-free mass (%).

Table 3. Results of paired t-test for all studied variables.

| Pair     | Parameter 1 | Parameter 2 | N  | Pearson Correlation | P       | t value | P       |
|----------|-------------|-------------|----|---------------------|---------|---------|---------|
| Pair 1   | Weight 1 & Weight 2 | 92 | 0.992 | 0.000               | 21.945  | 0.000   |
| Pair 2   | Height 1 & Height 2 | 92 | 0.995 | 0.000               | 21.238  | 0.000   |
| Pair 3   | IMC 1 & IMC 2    | 92 | 0.987 | 0.000               | 10.249  | 0.000   |
| Pair 4   | ECF 1 & ECF 2    | 92 | 0.884 | 0.000               | 5.856   | 0.000   |
| Pair 5   | ICF 1 & ICF 2    | 92 | 0.735 | 0.000               | -2.426  | 0.017   |
| Pair 6   | TBW 1 & TBW 2    | 92 | 0.799 | 0.000               | -0.101  | 0.920   |
| Pair 7   | FFM 1 & FFM 2    | 92 | 0.787 | 0.000               | -0.718  | 0.474   |
| Pair 8   | Fat % 1 & Fat % 2| 92 | 0.472 | 0.000               | 4.904   | 0.000   |
| Pair 9   | Hydration 1 & Hydration 2 | 92 | 0.305 | 0.003 | 3.249   | 0.002   |
| Pair 10  | ECF/ICF 1 & ECF/ICF 2 | 92 | 0.647 | 0.000 | 7.182   | 0.000   |
| Pair 11  | Re 1 & Re 2      | 92 | 0.911 | 0.000               | -2.411  | 0.018   |
| Pair 12  | Ri 1 & Ri 2      | 92 | 0.883 | 0.000               | 6.592   | 0.000   |
| Pair 13  | Cm 1 & Cm 2      | 92 | 0.823 | 0.000               | -6.891  | 0.000   |
Discussion
Four hours of intense physical activity with free water replacement induced changes in body fluids in the studied population but not exactly as one could expected, because the estimates of TBW remained almost constant.

Considering the bioimpedance parameters, it was verified that Re increased continuously with the increasing of muscle activity (due to water loss from the body). However, the behavior of Ri was not clear. This fact may be related to the type of dehydration suffered by subject, where depending on the amount of water and electrolytes lost through sweat, osmotic effect within the body leads to intra and extracellular compensation, resulting in positive or negative changes in ICF that affect Ri parameter. Change in muscle pH after exercise can also have affected BIA accuracy. There is a significant correlation between pH change and percentage change in ICF, with a significant increase in ICF during exercise [19]. At the beginning of the exercise sympathetic over activity occurs by stimuli from the motor cortex and maintained by stimuli from the central and peripheral receptors that capture the changes in pH and PCO2. Furthermore, it is known that the increase in lactic acid levels modifies the pH and blood CO2 [20].

Jürimäe et al. [21] investigated the influence of long-term exercise on body fluids of professional athletes (N = 12) of rowing. Each player paddled for two hours and seventeen minutes. The BIA tests were applied (I) before exercise, (II) immediately after exercise, (III) 30 min, (IV) 60 min and (V) 120 min after the end of exercise. The results showed that the weight of the participants was significantly reduced from 82.0 ± 10.8 kg to 80.6 ± 2.11 kg. However, there was no reduction in TBW immediately after exercise, but just 30 min after the end of the activity (48.7 ± 4.4 to 47.9 ± 4.1, p <0.05). The amount of ECF also decreased significantly after 30 min of the end of exercise (23.3 ± 2.0 to 22.7 ± 1.91, p <0.05). In the present study, the decrease in extracellular fluid (ECF) (Tables 2 and 3) was immediately observed at the end of exercise.

The decrease in height, weight, and consequently in BMI, of the participants in this study may be explained by the decrease in body hydration and in the intervertebral discs (assessed by height variation). Similar results were found by Neves et al. [15] to paratroopers and Jürimäe et al. [21] to rowing athletes.

A limitation of this study was the lack of control over temperature of the skin surface that is increased by physical activity. Beckmann [22] and Röthlingshöfer [23] reported that even after a recovery time of 15 minutes the temperature of skin remained high.

In this study, the reduction in fat percentage immediately after the exercise is a result of changes in body fluids, because, according Saunders et al. [24] a small change in balance of body fluids can be incorrectly interpreted by BIA, in form of changes in adipose tissue of athletes. Moreover, ionic losses resulting from the physical activity [23] can infer an erroneous reading of an increase in fat free mass, resulting from increased ICF.

Conclusions
We investigated changes observed in bioimpedance parameters and in estimates of body fluids by BIA after four hours of intense physical activity with free water replacement. Among the bioimpedance parameters Re exhibited the most coherent behavior, leading to reliable estimates of ECF and part of TBW. The intracellular resistance Ri seems to be more affected by changes in metabolic products of the exercise. Results also show decreases in height, weight and BMI of the participants, which can be associated to the decrease in body hydration and in intervertebral discs. Overall, our findings reinforce the need of care protocols in assessment of body composition by BIA.
References

[1] Neves EB, Pino AV, De Almeida RMVR and Souza MN 2010 Knee bioelectric impedance assessment in healthy/with osteoarthritis subjects, *Physiological Measurement*, vol. 31, pp. 207-219.

[2] Jaffrin MY, Kieffer R and Moreno MV 2005 Evaluation of a foot-to-foot impedance meter measuring extracellular fluid volume in addition to fat-free mass and fat tissue mass, *Nutrition*, vol. 21, pp. 815-824.

[3] Morrow JR, Jackson A, Disch JG and Mood D 2010 *Measurement and evaluation in human performance*: Human Kinetics Publishers.

[4] Matthie J 1997 Hydra ECF/ICF Bioimpedance Analyzer (Model 4200) Operational Manual Revision 1.01, *San Diego, CA: Xitron Technologies Inc.*, pp. 44-8.

[5] Earthman CP, Matthie JR, Reid PM, Harper IT, Ravussin E and Howell WH 2000 A comparison of bioimpedance methods for detection of body cell mass change in HIV infection, *Journal of Applied Physiology*, vol. 88, pp. 944-956.

[6] Zhu F, Schneditz D and Levin NW 1999 Sum of segmental bioimpedance analysis during ultrafiltration and hemodialysis reduces sensitivity to changes in body position, *Kidney international*, vol. 56, pp. 692-699.

[7] Hu H and Kato Y 1995 Body composition assessed by bioelectrical impedance analysis (BIA) in patients with Graves’ disease before and after treatment, *Endocrine journal*, vol. 42, p. 545.

[8] Klassen P, Mazariegos M, Deurenberg P, Solomons N and Fürst P 2000 Hydration status assessed by bioelectrical impedance spectroscopy and dilution methods in patients with classical dengue fever, *Annals of the New York Academy of Sciences*, vol. 904, pp. 163-170.

[9] Wittchen HU and Jacobi F 2005 Size and burden of mental disorders in Europe--a critical review and appraisal of 27 studies, *European neuropsychopharmacology*, vol. 15, pp. 357-376.

[10] Ribeiro SML, Miyamoto MV, de Melo CM and Kehayias J 2011 Análise vetorial de bioimpedância e estado nutricional de idosas de acordo com o índice de massa corporal, *Rev Bras Cineantropom Desempenho Hum*, vol. 13, pp. 415-421.

[11] Moreira MM, de Souza HPC, Schwingel PA, de Sá CKC and Zoppi CC 2008 Efeitos do Exercício Aeróbico e Anaeróbico em variáveis de risco Cardíaco em Adultos com Sobrepeso, *Arq Bras Cardiol*, vol. 91, pp. 200-206.

[12] Rossi L and Tiraegui J Avaliação antropométrica segmentar comparativa de triatletas e maratonistas.

[13] Lima LD, Moraes CMB and Kirsten VR 2010 Muscle dysmorphia and the use of ergogenic supplements in athletes, *Revista Brasileira de Medicina do Esporte*, vol. 16, pp. 427-430.

[14] Perrella MM, Noriyuki PS and Rossi L 2005 Avaliação da perda hídrica durante treino intenso de rugby, *Rev Bras Med Esporte*, vol. 11, pp. 229-32.

[15] Neves EB, Oliveira AGV, Macedo ARM, Souza MN and Almeida RMVR 2008 Avaliação da hidratação dos alunos do curso de formação de Pára-quadristas Militares do Exército Brasileiro; Assessment of hydration among Brazilian army parachuting training program rookies, *Cad. saúde colet.*, (Rio J.), vol. 16, pp. 53-66.

[16] O’Brien C, Young A and Sawka M 2002 Bioelectrical impedance to estimate changes in hydration status, *International journal of sports medicine*, vol. 23, pp. 361-366.

[17] Koulmann N, *et al.* 2000 Use of bioelectrical impedance analysis to estimate body fluid compartments after acute variations of the body hydration level, *Medicine & Science in Sports & Exercise*, vol. 32, p. 857.

[18] Cole KS 1968 *Membranes, ions, and impulses: a chapter of classical biophysics* vol. 1: Univ of California Pr.
[19] Wang Z, Deurenberg P, Wang W, Pietrobelli A, Baumgartner RN and Heymsfield SB 1999 Hydration of fat-free body mass: new physiological modeling approach, *American Journal of Physiology-Endocrinology And Metabolism*, vol. 276, pp. E995-E1003.

[20] Åstrand PO 2003 *Textbook of work physiology: physiological bases of exercise*: Human Kinetics Publishers.

[21] Jürimäe J, Jürimäe T and Pihl E 2000 Changes in body fluids during endurance rowing training, presented at the Annals of the New York Academy of Sciences, 2000.

[22] Beckmann L, Hahne S, Medrano G, Kim S, Walter M and Leonhardt S, Monitoring change of body fluids during physical exercise using Bioimpedance Spectroscopy", 2009, pp. 4465-4468.

[23] Röthlingshöfer L, Ulbrich M, Hahne S and Leonhardt S 2011 Monitoring Change of Body Fluid during Physical Exercise using Bioimpedance Spectroscopy and Finite Element Simulations, *Journal of Electrical Bioimpedance*, vol. 2, pp. 79-85.

[24] Saunders MJ, Blevins JE and Broeder CE 1998 Effects of hydration changes on bioelectrical impedance in endurance trained individuals, *Medicine & Science in Sports & Exercise*, vol. 30, pp. 885-92.