33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Assessment and follow-up of muscle injuries in athletes by bioimpedance: Preliminary results

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Abstract—**Mono-frequency (50 kHz) whole-body and segmental bioimpedance is measured before sport training in 14 high performance athletes. The athletes are classified in two groups according to the team sport: football and basketball. Bioelectrical impedance vector analysis (BIVA) method is used to obtain the individual whole-body impedance and 6 segmental impedance vectors in the main muscular groups in the lower-limbs. The whole-body vector is analyzed in the tolerance ellipses of the reference population. Individual impedance vector components are standardized by the height H of the subject, (R/H and Xc/H) to obtain the impedance vector (Z/H) of each segment. The hypotheses of the study are: 1) Not all the sports have the same pattern of bioimpedance vector by muscle group. 2) In elite well trained athletes their muscle groups are symmetrical (right and left sides), thus each athlete is its own reference for future comparisons. 3) We expect a change in the two components of bioimpedance vector (R/H and Xc/H) in front of a muscle injury. In order to compare the differences between the complex Z/H vector (R/H, Xc/H) we use Hotelling's T2 test. Preliminary results show a significant difference ($P < 0.05$) in bioimpedance vectors between groups according to the team sport, and also between normal muscle condition and after muscle injury producing hyper-hydration.**

I. INTRODUCTION

Clinical diagnosis of muscle lesions is based mainly on the symptoms, especially in the history of the mechanism of injury and physical examination. Imaging studies using musculoskeletal ultrasound and magnetic resonance imaging are complementary to confirm a diagnosis [1-4]. Also, the determination of serum muscle contractile proteins [5, 6] and mechanical properties [7] has been used in the monitoring of muscle injury.

Although there are very few references to the application of bioimpedance in sport, whole-body has been used to assess the sports training and evaluate the nutrition and hydration state [8]. Also, a similar method to the one proposed in this paper based on measuring local electrical impedance of muscle groups, has been used for the evaluation of neuromuscular damage [9]. Segmental measurements have also been used in healthy volunteers with similar anthropometry to evaluate body fluid shift, showing that the use of segmental impedances improves the accuracy of whole-body measurements to estimate hydration state and fluid changes [10, 11].

Bioelectrical impedance vector analysis (BIVA) is accepted as a non-invasive, innocuous and repetitive method of body composition analysis, specific for the assessment of soft tissue hydration [12]. This method is unaffected by regression adjustments to estimate body composition, body geometry or hydration state.

The objectives of this work is to establish the mean impedance vectors in whole-body and in each lower-limb before sports training in two different team sports and to evaluate this technique for monitoring the muscle state, which may be of interest as a predictive marker to assess and follow-up muscle injuries until complete resolution, in professional sports.

II. MATERIAL AND METHODS

A. Sample

Measurements were done, in the morning, before sport training in 14 high performance Caucasian athletes (football: N=10, BMI 23.15 ± 1.45 kg/m^2, H 1.78 ± 0.05 m; basketball: N=4, BMI 24.31 ± 1.14 kg/m^2, H 2.09 ± 0.06 m) at the medical services of Football Club Barcelona (FCB). At least 2 hours before the measurement session the subjects have not taken any drink or food. Also, at the beginning of each measurement session, the weight and the height of the athletes were taken.

The inclusion criteria were: 1) to be professional male team athlete; 2) to be aged over 18 years. The exclusion criteria included: 1) not accepting to participate in the study; 2) presence of any medical condition, either acute or chronic. All of them showed their agreement to participate in the study.

The subjects will be lying prone and placed in a comfortably slightly reclined position on a stretcher 15 minutes before the bioimpedance measurement started. All the required electrodes are placed on specific locations during this time.

B. Electrode placement description

Athletes are measured in the supine decubitus position during 10 minutes. Single-frequency at 50 kHz, tetrapolar (connecting four leads, with two electrodes for injecting current I, and two for sensing voltage V), in whole-body and

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Manuscript received March 24, 2011.

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six segmental-longitudinal biompedance measurements are obtained.

1- RS: Standard whole-body configuration

Segmental:

2-ARIGHT-leg1 and ALEFT-leg1: Right-femoral quadriceps and left-femoral quadriceps respectively: 5 and 10 cm distally from anterior inferior iliac spine and proximally from the superior pole of patella.

3- PRIGHT-leg1 and PLEFT-leg1: Right-hamstrings and left-hamstrings: 5 and 10 cm distally from the ischiatic tuberosity and proximal from the popliteal line.

4-PRIGHT-leg2 and PLEFT-leg2: Right-gastrocnemius muscles and left-gastrocnemius muscles: 5 and 10 cm distally from the popliteal line and 15 and 10 cm from the posterior intermaleolar line (see Figure 1).

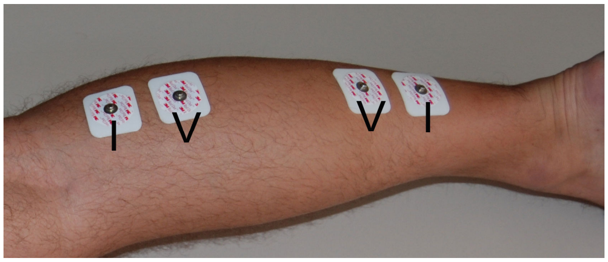

Fig. 1. Gastrocnemius electrode placement for segmental bioimpedance configurations. The configurations for right-leg are the same configurations to left-leg.

C. *Bioimpedance Analyzer*

Bioimpedance measurements are taken using the BIA-101 analyzer (AKERN-RJL system, Italy). Measurement errors of the system are lower than 1 Ω and 1º at 50 kHz tested using electrical models. The injected current is 800 µA peak. The multi-purpose monitoring electrodes Ag/AgCl, with sticky gel (3M Red Dot 2560, Canada) are used.

D. *Statistical Analysis*

The hypotheses of the study are: 1) Not all the sports have the same pattern of bioimpedance vector by muscle group. 2) In elite well trained athletes their muscle groups are symmetrical (right and left sides), thus each athlete is its own reference for future comparisons. 3) We expect a change in the two components of bioimpedance vector (R/H and Xc/H) in front of a muscle injury.

BIVA method [12] is used to obtain the individual whole-body impedance and 6 segmental impedance vectors in the main muscular groups in the lower-limbs. In order to compare the differences between the complex Z/H vector (R/H, Xc/H) we use Hotelling's T2 test. Statistical significance was set at $P < 0.05$.

III. RESULTS

Table 1 and 2 show athlete's mean values for all segments before sport training. Figure 2 shows mean vectors in whole-body (Z/H) for football and basketball samples in comparison with the tolerance ellipses of the European reference population of the same race, gender, body mass index (BMI), and age class [13].

Figure 3 shows the mean bioimpedance vectors for football and basketball players for all measured segments for the muscular groups measured in both legs.

Figure 4 shows the segmental bioimpedance vector in two football players with right-gastrocnemius strain: grade one in Player 1, and grade two in Player 2, diagnosed by magnetic resonance.

TABLE I

BIOIMPEDANCE VECTOR COMPONENTS IN FOOTBALL PLAYERS

Football N=10	R/H, Ω/m Mean ± SD	Xc/H, Ω/m Mean ± SD	PA, ° Mean ± SD
RS	268.86±22.39	37.39±3.82	7.93±0.68
ARIGHT-leg1	19.78±1.06	6.26±0.38	17.55±0.69
ALEFT-leg1	20.22±1.15	6.37±0.64	17.47±1.40
PLEFT-Leg1	18.28±2.06	5.40±0.64	16.51±1.64
PRIGHT-leg1	17.88±1.97	5.46±0.45	17.10±1.71
PLEFT-Leg2	36.45±4.60	9.08±0.61	14.19±2.27
PRIGHT-leg2	36.43±6.07	9.58±1.03	14.98±2.27

TABLE II

BIOIMPEDANCE VECTOR COMPONENTS IN BASKETBALL PLAYERS

Basketball N=4	R/H, Ω/m Mean ± SD	Xc/H, Ω/m Mean ± SD	PA, ° Mean ± SD
RS	221.80±22.93	28.75±4.87	7.35±0.61
ARIGHT-leg1	20.98±2.31	4.90±0.63	13.26±2.25
ALEFT-leg1	20.75±2.14	5.02±0.86	13.72±2.88
PLEFT-Leg1	22.97±4.23	3.95±1.22	9.99±3.47
PRIGHT-leg1	21.68±3.88	5.15±1.20	13.94±5.29
PLEFT-Leg2	27.53±4.82	6.32±1.13	13.05±2.15
PRIGHT-leg2	26.94±3.20	6.92±0.72	14.51±1.85

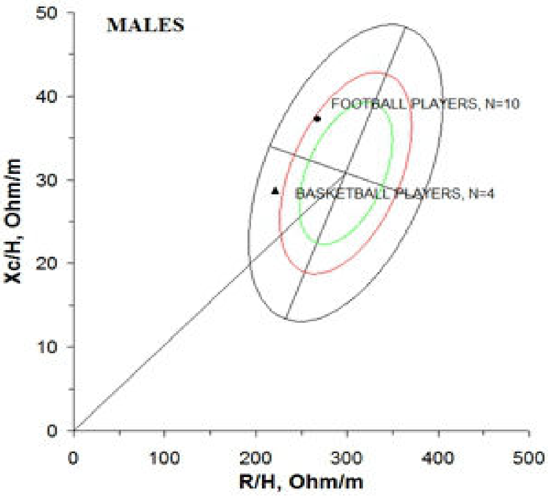

Fig. 2. Mean whole-body bioimpedance vector in football and basketball players compared with 50%, 75% and 95% tolerance ellipses of an equivalent healthy European population.

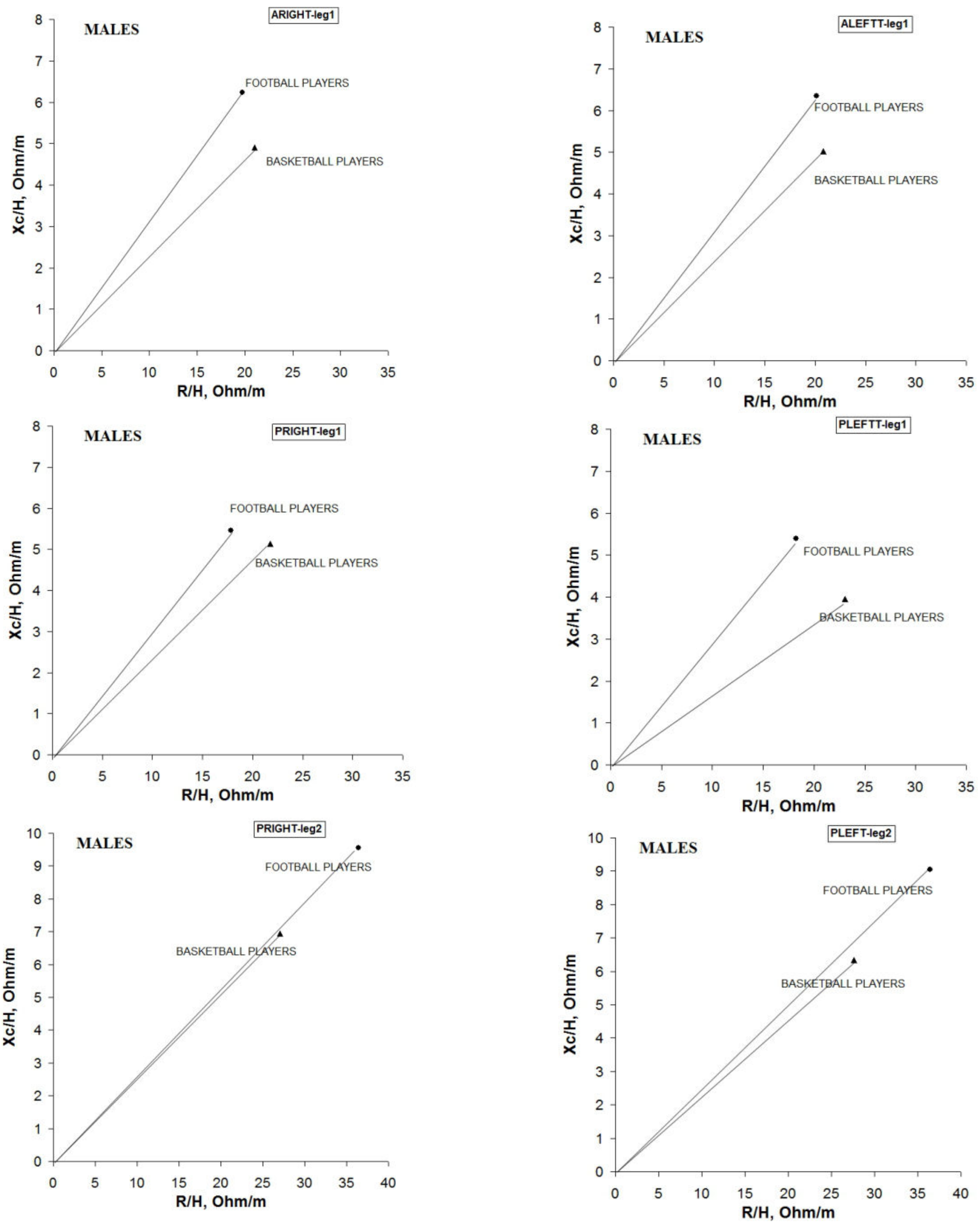

Fig. 3. Mean segmental bioimpedance vectors in football and basketball players for all measured muscular groups in left and right legs.

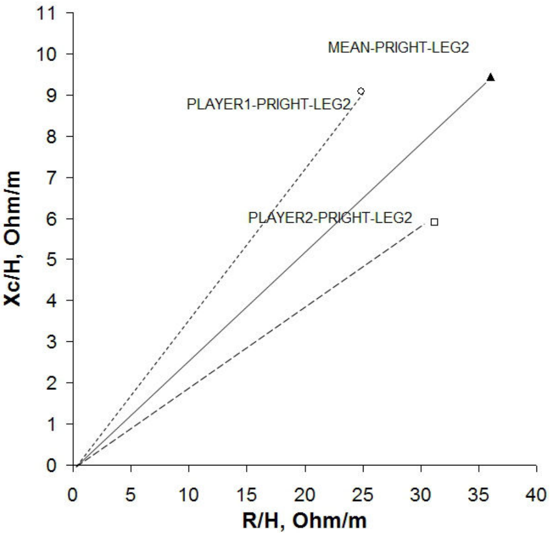

Fig. 4. Segmental bioimpedance vectors in two football players compared with the mean value for the same segment: Player1 Right-gastrocnemius strain grade one, Player 2 Right-gastrocnemius strain grade two.

IV. DISCUSSION

As shown in Figure 2 and Figure 3, we can observe a significant difference ($P < 0.05$) in whole-body and in the 6 segmental impedance Z/H vectors of the main muscular groups in the lower-limbs of football and basketball players. This could be due to a different anthropometry and muscular structure between athletes of both sports. These results confirm that it is necessary to establish different normal bioimpedance vectors in different sports. In Table 1 and 2 we can observe the symmetry between right and left sides of muscular groups in football and basketball players; most remarkable in football players. This confirms that in elite well trained athletes their muscle groups are symmetrical.

Analysis of the Z/H vector in the RXc-graph is interesting since it provides information on the hydration state (R/H) and on the structure of soft tissues (Xc/H) [12]. For these reasons, we can expect a change in the two components of the bioimpedance vector (R/H and Xc/H) due to a muscle strain grade two and three; and only a change in R/H in strain grade one. As we can see in Figure 4, the injured muscular group (segment PRIGHT-leg2) in player 1 shows a decrease only in R/H with respect to the mean value in the equivalent muscular group. However, player 2 shows a decrease in both components R/H and Xc/H. Players 1 and 2 are part of the same football team of the reference sample, but because they were injured, where not included in the reference sample.

V. CONCLUSIONS

Segmental bioelectrical impedance vector analysis could contribute in the assessment of muscle injury. The symmetry of segmental bioimpedance vectors in muscular groups in lower-limbs could be used to detect changes in muscular structure and/or hydration. This method is promising for the follow-up of recovery after muscle injuries, which could be helpful to determine the return-to-play.

ACKNOWLEDGMENT

L. Nescolarde and J. Rosell-Ferrer would like to thank the medical services of FCB for their support in this paper and Professor Antonio Piccoli for his scientific advice in BIVA methods.

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