Contribution of the bio-electrical impedance technique in the detection of knee mild injuries in a group of female athletes

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ABSTRACT

Quantification of liquid content of tissues has been evaluated by bio-impedance technique in many circumstances. Some attempts have been performed to use this technique to evaluate knee condition, such as in knees with mild injuries. In this study, two groups of subjects were assessed: one sedentary healthy women group (7 subjects; 14 knees) and other group of sport-women (11 subjects; 22 knees); 5 of them with healthy knees, 8 with soft tissue injuries, and 9 with crepitus of meniscus. Static and dynamic conditions were considered for comparison in each group and subgroup. Each impedance value was normalized by height and calf perimeter. Statistically significant differences were found between healthy and non-healthy knees and between subgroups. Impedance magnitude and phase are useful to discriminate knee healthy status. This fact shows the potential utility of the bio-impedance technique as a complementary technique and maybe an alternative to diagnose and monitor knee injury.

Keywords: Bioelectrical impedance, knee mild injury, sportswomen.

ABBREVIATIONS: ANOVA, Analysis of variance; BI, bioelectrical impedance; BMI, body mass index; EIT, electrical impedance tomography; MRI, magnetic resonance imaging; SD, standard deviation; STI, soft tissue injuries; Z_{NC}, impedance normalized by calf perimeters; Z_{NH}, impedance normalized by height.

INTRODUCTION

Human knee is a complex joint which is highly important to perform complex movements and carry weight. Due to its complexity and continuous use, the knee can suffer different injuries. Sports, which involves running, jumps and potential falls, may increase the probability of injuries. The Sport-related knee injuries are classified primarily by their persistence or duration as acute and chronic (Walker, 2007).

Some acute injuries can be diagnosed by an experienced physician without additional procedures, meanwhile the chronic ones require additional information such as that provided by imaging techniques. There are two main techniques to evaluate human knee: 1) conventional X-Rays (radiography) which reveals the bone damage and joint spaces between bones and 2) magnetic resonance imaging (MRI) which shows soft tissue injuries, crepitant meniscus and osteochondral injury. These contemporary medical devices allow to obtain images with high diagnostic value, but they have some disadvantages. The first one is an essential use of radiation, especially for X-Rays technique, that make the use of them almost impossible for pregnant women and children (due to the difficulty of keeping them still during the procedure). The second one is their high cost and the need of specific space and qualified personal to operate them, which makes it impossible to establish them as fast, cheap and portable devices to be used by least qualified people.

The technique proposed in this study, to evaluate the presence of knee mild injuries, is the bio-electrical impedance (BI) technique. BI is a noninvasive technique that does not involve harmful radiations and is cheap enough to be acquired by any physician and sport professional. The concept of BI is based on the injection of a known electrical current in the biological tissue under...
study and the detection of the corresponding voltage (or vice-versa). This technique is widely investigated and some applications in bio-medical areas are well established as, for example, the measurement of body fluid volume in patients with heart and kidney diseases (Piccoli, 2010); the assessment of the cardiac graft rejection degree in post-transplanted patients (Cinca et al., 2008); the cardiac volume-minute monitoring (Kubicek et al., 1970; Kaupinen et al., 1998); the cell quantification by a Coulter counter, method widely used in hospital environment (Kachel, 1990); the analysis and characterization of cells from its static and dynamic behavior (Gaever and Keese, 1993; Pething and Kell, 1987; Pething et al., 1998); and the body mass composition measurement (Lukaski et al., 1985; Lukaski et al., 1986; Lukaski, 1987; Foster and Schwan, 1989) among many others. Other BI application is the dynamic imaging obtained by a set of tetrapolar impedance measurements. This alternative is known as Electrical Impedance Tomography (EIT). EIT has been applied in clinical areas for example in the detection and quantification of liquid in lungs (Kunst et al., 1999; Arad et al., 2009); the determination of curves for pressure-volume lung air (Grychtol et al., 2009; Frerichs et al., 2013) and the monitoring and quantification of tidal volume (Balleza et al., 2015; Balleza et al., 2016).

In addition to the purposes described above, BI has been already tested to evaluate different pathologies of knee. One of the most researched pathologies, using this technique, is osteoarthritis. This condition occurs when the cartilage between joints breaks down leading to pain, stiffness and swelling. For example, Neves et al. (2009) performed a study where they analyzed different levels of osteoarthritis in a sample of military people. The osteoarthritis stratification was determined by Dejour scale and volunteers were divided into a control group and a pathological group. This study evidenced that impedance parameters related to knee seem to be sensitive to physiological changes associated with osteoarthritis. These determinations were characterized by a RC circuit model, where the resistance and the capacitive-reactance increased according to the disease level. Gajreet al. (2007) analyzed osteoarthritis by BI during the walking cycle and knee swing cycle in a female sample to classify the knee condition as normal or pathological. From the comparison of impedance signals obtained in each exercise, it was evidenced a statistically significant difference of 14.82 and 11.11% between a healthy and an injury knee during walking cycle and knee swing cycle, respectively. Another BI application is the tracking of knee swelling after total knee arthroplasty surgery. Pichonnaz et al. (2015)explored the validity, the reliability and the responsiveness of biomimittance spectroscopy for measuring swelling after total knee arthroplasty. This group compared the BI determinations, the knee circumferences and the limb volume. It was reported that the correlation of BI determinations with knee circumferences and volume was of 0.75 and 0.73, respectively. These results indicated that BI can assess the knee swelling. The same research group used BI technique as a tool to evaluate the effects of manual lymphatic drainage on knee swelling and the assumed consequences of swelling after total knee arthroplasty. It was shown that BI can be used as a reference point to determine the efficacy of manual lymphatic drainage (Pichonnaz et al., 2016). Based on these results, obtained in the mentioned studies, the BI seems to be a good technique to detect levels of swelling and knee damage. However, all these investigations have been performed in patients with advanced damage knee or submitted to surgery. Therefore, these results cannot be extrapolated to other kind of subject groups or levels of knee damage without a previous validation.

As a result of what was stated in previous paragraphs, in this study, the evaluation of the usefulness of BI technique to get information about knee mild injuries is performed. The knee under static condition and its performance during movement are evaluated in a group of sportswomen as well as in a sedentary women group. Sportswomen group was chosen because of two main reasons: 1) women show higher prevalence of knee injuries due to anatomical shape of hips (Horton and Hall, 1989) and 2) as mentioned before, sport practice increases the incidences of knee injuries. The main objective of this study was to assess the capability of BI technique to discriminate between healthy and non-healthy mild injured knees, and between subgroups with different types of knee injuries.

**MATERIALS AND METHODS**

**Impedance device (BIOPAC system)**

The bioelectrical impedance device, used in this study, was an EBI100C BIOPAC® amplifier. The EBI100C® injects a very small current of 400 µA, obtaining the corresponding voltage to get impedance magnitude and phase simultaneously. Impedance determinations can be recorded at four different measurement frequencies, 12.5, 25, 50 and 100 kHz with a sensitivity of 1.5 milli-Ohm in magnitude, and 2.5 milli-degrees in phase, at 10 Hz bandwidth. The device was calibrated by a resistance of 100 ohms, setting the phase to 0 degrees. The impedance determinations obtained by EBI100C® were recorded by the BIOPAC software: AcqKnowledge®.

**Volunteers**

A total of 36 knees from women between 18 and 25 years old were analyzed. 14 knees correspond to a group of 7 sedentary women. The inclusion criteria for that group was: 1) They did not practice any kind of sport in the past 2 years, 2) They did not present any sign of knee damage.
This group was established as the sedentary female group or control group. 22 knees corresponded to a group of 11 volleyball female athletes. The inclusion criteria for that group was: 1) To practice volleyball continuously during of the past 4 years, 2) To feel any discomfort in knee and 3) Do not have any medical history of knee damage. This group was called volleyball female group or subject group.

All tests were performed between 9 a.m. and noon in the Laboratory of Bioelectrical Impedance of the Department of Physical Engineering of the University of Guanajuato. All volunteers have signed an informed consent letter to participate in the study. This protocol was approved by the bioethics committee of the University of Guanajuato (approval code: CIBIUG-P-11-2015).

Procedure

All impedance (Z) and phase (θ) determinations were performed using a frequency of 50 kHz. This device was connected to each knee through 4 electrodes (pediatric AMBIDERM® T-718 Ag/AgCl). Two electrodes were placed at the medial level and other two at lateral level of patellar ligament of knee, as shown in Figure 1. This configuration is used to get electrical field lines along the meniscus, increasing the sensitivity of the technique to the soft and aqueous tissue. Two conditions were implied: 1) For static condition, each volunteer was asked to sit still with the knees and hips bent at 90° (Figure 2a). In this position, there were less presence of hard tissue between the areas of knee patellar ligament, so it was possible to access soft tissue easily through electrodes. 2) For dynamic condition, each volunteer was asked to perform a set of full cycle of leg flexion - extension and return to starting position (Figure 2b), alternating the leg each time. In this case, during the extension, the presence of hard tissue increases, decreasing the contribution of soft tissue. During flexion, the opposite occurred. The variations of impedance (Z) and phase (θ) determinations were simultaneously recorded during 30 s by the BIOPAC software AcqKnowledge®.

Previously to acquisition of the impedance and phase determinations, the following anthropometric parameters were measured for each volunteer: age (years), height (m), weight (kg), body mass index (BMI: kg/m²), mass of the lower extremities (kg), the diameter of femurs and the perimeters of both thighs and calves were also measured. The height was measured using a SECA® stadiometer (1mm accuracy), the height and the lower extremities were measured using an OMROM scale (100 g accuracy), the perimeters and diameters of thighs and calves were measured using a SECA measuring tape (1mm accuracy) and a short anthropometer, respectively. The clinical diagnose of knees was determined by a physician through a clinical evaluation.

Signal processing

The characteristic signal recorded and processed for each condition is shown in Figure 3. In the case of static
Figure 3: Processing of impedance ($Z$) and phases ($\theta$) signals determined by static condition and dynamic condition: a) for the signals determined by static condition an IIR low pass filter (cut frequency 0.1 Hz, $Q = 0.707$) was applied; and b) for the signals determined by dynamic condition an IIR low pass filter (cut frequency 0.8 Hz, $Q = 0.707$) was applied.

conditions, an IIR low pass filter (cut frequency 0.1 Hz, $Q = 0.707$) was applied (Figure 3a), and the average of the impedance magnitude and phase was taken to be used in the statistical analysis.

In case of moving condition, an IIR low pass filter (cut frequency 0.8 Hz, $Q = 0.707$) was applied (Figure 3b). The changes in the amplitude and phase of the impedance were considered in the analysis.

Statistical analysis

All data were expressed in terms of means ($\pm$ standard deviations). The normality behavior was confirmed by a Kolmogorov-Smirnov test. The statistical comparison of anthropometric parameters between control and subject was performed by a t-test for independent data. From this test, the most significant anthropometric parameters between groups were evidenced. Subsequently, these parameters were used to normalize the impedance determinations.

The differences of parameters obtained in both knees corresponding to each group was performed by a t-test for paired data. Subsequently, the comparison of parameters obtained in the control and subject group was performed by a t-test for independent data. Finally, an ANOVA with Bonferroni correction test was used to compare controls and subjects with different types of diagnoses 1) the mean impedance values, 2) the mean of normalized impedances determinations, and 3) the phase values. The significance p-value was set at 0.05.

RESULTS

Impedance signal interpretation

The impedance and phase data obtained from static condition and moving condition evidenced a noisy high frequency component which was eliminated by IIR digital filter. The impedance observed in static condition characterize the whole knee region mainly the knee soft tissue. This fact was because the electric field lines pass through that tissue easier than through the bone. In moving condition, the positive impedance semi-cycle corresponds to extension movement of knee. In this position, the impedance determinations are larger due to an increment of hard tissue component. On the other hand, the negative impedance semi-cycle corresponds to flexion movement when the knee returns to 90° position, so, the impedance determinations are lower because of the soft tissue exposed in this position.

Clinical exploration

From the clinical evaluation performed by the physician, it was evidenced that all knees of sedentary female group
Table 1: Anthropometric parameters for control (sedentary) and subject (sport women) groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Controls $\bar{X} \pm SD$</th>
<th>Subjects $\bar{X} \pm SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20 ± 2</td>
<td>19 ± 1</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>52.3 ± 7.7</td>
<td>57.9 ± 6.6</td>
</tr>
<tr>
<td>Height (m) *</td>
<td>1.56 ± 0.04</td>
<td>1.63 ± 0.04</td>
</tr>
<tr>
<td>BMI (Kg/m²)</td>
<td>21.4 ± 2.8</td>
<td>21.7 ± 2.8</td>
</tr>
<tr>
<td>Mass of lower extremities (Kg)</td>
<td>27.8 ± 8.9</td>
<td>30.0 ± 5.1</td>
</tr>
</tbody>
</table>

Diameter of femur (cm)  
Thigh perimeter (cm)  
Calf perimeter (cm)*  
Knee perimeter (cm)  

* Statistical differences between groups

Table 2: Knee impedance (total and normalized) for both groups in static and dynamic condition.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Controls</th>
<th>Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Both knees</td>
<td>Right knees</td>
</tr>
<tr>
<td>Static condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Z$ ($\Omega$) ¹</td>
<td>19.3 ± 2.7</td>
<td>19.2 ± 2.5</td>
</tr>
<tr>
<td>$ZHN$ ($\Omega$/m)²</td>
<td>12.4 ± 1.6</td>
<td>12.3 ± 1.4</td>
</tr>
<tr>
<td>$ZCN$ ($\Omega$/m)³</td>
<td>62.8 ± 10.2</td>
<td>62.6 ± 10.8</td>
</tr>
<tr>
<td>$\theta$ (Phase) ⁴</td>
<td>1.5 ± 0.3</td>
<td>1.6 ± 0.3</td>
</tr>
<tr>
<td>Dynamic condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta Z$ ($\Omega$)⁵</td>
<td>4.1 ± 1.2</td>
<td>4.1 ± 1.2</td>
</tr>
<tr>
<td>$\Delta ZHN$ ($\Omega$/m)⁶</td>
<td>2.6 ± 0.7</td>
<td>2.6 ± 0.7</td>
</tr>
<tr>
<td>$\Delta ZCN$ ($\Omega$/m)⁷</td>
<td>13.4 ± 3.8</td>
<td>13.2 ± 3.9</td>
</tr>
<tr>
<td>$\Delta \theta$ (Phase) ⁸</td>
<td>0.21 ± 0.05</td>
<td>0.20 ± 0.07</td>
</tr>
</tbody>
</table>

1. Impedance in static condition.  
2. Impedance normalized by height.  
3. Impedance normalized by calf perimeters.  
4. Phase in static condition.  
5. Impedance changes in dynamic condition.  
6. Impedance changes normalized by height.  
7. Impedance changes normalized by calf perimeters.  
8. Phase changes in dynamic condition.

The mean values ($\pm SD$) of anthropometric parameters corresponding to the control and subject groups are showed in Table 1. The assessments of data by Kolmogorov-Smirnov statistical test, for all the parameters considered, have shown p-values greater than 0.05 ($p>0.05$). Therefore, it was possible to use parametric statistical tests to analyze all results. The statistical comparison of anthropometric parameters corresponding to both groups indicated that height and calf were the parameters that showed statistically significant differences. So, the impedance determinations ($Z$ and $\Delta Z$) were normalized by the height ($Z_{NH}$ and $\Delta Z_{NH}$) and the mean of calf perimeters ($Z_{NC}$ and $\Delta Z_{NC}$).

Analysis of anthropometric data

The mean values ($\pm SD$) of anthropometric parameters corresponding to the control and subject groups are showed in Table 1. The assessments of data by Kolmogorov-Smirnov statistical test, for all the parameters considered, have shown p-values greater than 0.05 ($p>0.05$). Therefore, it was possible to use parametric statistical tests to analyze all results. The statistical comparison of anthropometric parameters corresponding to both groups indicated that height and calf were the parameters that showed statistically significant differences. So, the impedance determinations ($Z$ and $\Delta Z$) were normalized by the height ($Z_{NH}$ and $\Delta Z_{NH}$) and the mean of calf perimeters ($Z_{NC}$ and $\Delta Z_{NC}$).

Static condition

Impedance data

The impedance results for the control and subject groups are showed in Table 2. The differences of mean values of $Z$, $Z_{NH}$, $Z_{NC}$ and $\theta$ between right and left knees in the control...
Table 3: Knee impedance values according to health condition and kind of injury in sportswomen (subjects).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Healthy</th>
<th>Soft tissue injury</th>
<th>Crepitus of meniscus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static condition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z (Ω)¹</td>
<td>14.7 ± 1.6</td>
<td>17.4 ± 1.3</td>
<td>17.9 ± 3.3</td>
</tr>
<tr>
<td>ZHN (Ω/m)²</td>
<td>8.9 ± 1.0</td>
<td>10.8 ± 1.0</td>
<td>10.8 ± 2.1</td>
</tr>
<tr>
<td>ZCN (Ω/m)³</td>
<td>43.5 ± 6.7</td>
<td>51.2 ± 4.8</td>
<td>50.8 ± 9.4</td>
</tr>
<tr>
<td>θ(Phase)⁴</td>
<td>2.1 ± 0.9</td>
<td>2.0 ± 0.5</td>
<td>1.9 ± 0.5</td>
</tr>
<tr>
<td><strong>Dynamic condition</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔZ (Ω)⁵</td>
<td>2.0 ± 0.6</td>
<td>2.7 ± 1.0</td>
<td>2.3 ± 1.1</td>
</tr>
<tr>
<td>ΔZHN (Ω/m)⁶</td>
<td>1.2 ± 0.4</td>
<td>1.6 ± 0.6</td>
<td>1.4 ± 0.7</td>
</tr>
<tr>
<td>ΔZCN (Ω/m)⁷</td>
<td>6.0 ± 1.9</td>
<td>7.6 ± 2.7</td>
<td>6.8 ± 2.9</td>
</tr>
<tr>
<td>Δθ (Phase)⁸</td>
<td>0.28 ± 0.13</td>
<td>0.26 ± 0.08</td>
<td>0.22 ± 0.05</td>
</tr>
</tbody>
</table>

1. Impedance in static condition.
2. Impedance normalized by height.
3. Impedance normalized by calf perimeters.
4. Phase in static condition.
5. Impedance changes in dynamic condition.
6. Impedance changes normalized by height.
7. Impedance changes normalized by calf perimeters.
8. Phase changes in dynamic condition.

Table 4: p-values obtained from t-test statistical comparisons of impedance and phase data for both groups.

<table>
<thead>
<tr>
<th>Comparisons</th>
<th>Groups</th>
<th>Static condition</th>
<th>Dynamic condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Z¹ (Ω)</td>
<td>ZHN² (Ω/m)</td>
</tr>
<tr>
<td>Right knees vs Left knees*</td>
<td>Controls</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Subjects</td>
<td>0.017</td>
<td>0.014</td>
</tr>
<tr>
<td>Controls vs Subjects**</td>
<td>All knees</td>
<td>0.017</td>
<td>0.001</td>
</tr>
</tbody>
</table>

1. Impedance in static condition.
2. Impedance normalized by height.
3. Impedance normalized by calf perimeters.
4. Phase in static condition.
5. Impedance changes in dynamic condition.
6. Impedance changes normalized by height.
7. Impedance changes normalized by calf perimeters.
8. Phase changes in dynamic condition.
*All p-values were obtained by a t-test of paired data.
**All p-values were obtained by a t-test of independent data.

In the case of the subjects group, the differences of mean values of Z, Z⁻¹ᴷ, Zᴺ, and θ obtained in the right and left knees were statistically significant (p-value < 0.05), being higher in the left knees under static conditions (Table 4).

All parameters (Z, Z⁻¹ᴷ, Zᴺ and θ) obtained in controls (sedentary) and subjects (sport-women) were compared between them by t-test for independent data. From the analysis, statistically significant differences (p<0.05) for all parameters were evidenced (Table 4).

**Impedance data stratified by injuries**

The stratified impedance and phase data for static condition of subjects (sportwomen) is shown in Table 3. The comparison of the parameters (Z, Z⁻¹ᴷ, Zᴺ and θ) obtained in control (sedentary) and subjects stratified by
Injuries was performed by an ANOVA with Bonferroni correction.

The statistical comparison between the healthy knees for control and subject with healthy knees showed statistically significant differences in the parameters $Z$, $Z_{NH}$ and $Z_{NC}$. From the comparison between the healthy knees for control group and knees with crepitant meniscus and those with soft tissue injuries, statistically significant differences in the parameter $Z_{NC}$ were evidenced. All these results are shown in Table 5. Subsequently, all parameters of the healthy knees for subjects group were compared with the parameters obtained for knees with soft tissue injury and knees with crepitus in meniscus. Statistically significant differences in all parameters were not demonstrated in the first and in the second case. Finally, from the comparison of knees with soft tissue injuries and those with crepitant meniscus, no significant differences were evidenced (Table 5).

### Dynamic condition

#### Impedance data

The amplitude of impedance and phase changes for control and subjects group are shown in Table 2. The differences of mean values of $\Delta Z$, $\Delta Z_{NH}$, $\Delta Z_{NC}$ and $\Delta \theta$ between right and left knees obtained in each group were compared by a t-test for paired data. For the case of control group (sedentary), non-statistically significant differences were evidenced for all parameters. For the case of subjects group (sportwomen), statistically significant differences in the parameters $\Delta Z$ and $\Delta Z_{NH}$ were evidenced (Table 4).

All parameters ($\Delta Z$, $\Delta Z_{NH}$, $\Delta Z_{NC}$ and $\Delta \theta$) obtained in Controls (sedentary) and subjects (sport women) were compared between them by t-test for independent data. From the analysis, statistically significant differences in the parameter $\Delta Z$, $\Delta Z_{NH}$ and $\Delta Z_{NC}$ were evidenced (Table 4).

### Impedance data stratified by injuries

The impedance and phase data for moving condition of subjects stratified by kind of injury is shown in Table 3. The parameters ($\Delta Z$, $\Delta Z_{NH}$, $\Delta Z_{NC}$ and $\Delta \theta$) obtained in control (sedentary) and subjects (sportwomen) stratified by injuries were compared by an ANOVA with Bonferroni correction.

The statistical comparison between the healthy knees for control and those knees with crepitant meniscus for subjects, statistically significant differences in all parameters ($\Delta Z$, $\Delta Z_{NH}$, $\Delta Z_{NC}$ and $\Delta \theta$) were observed. From the comparison of healthy knees for control and those knees with soft tissue injuries for subjects, statistically significant differences in $\Delta Z$, $\Delta Z_{NH}$ and $\Delta Z_{NC}$ were shown (Table 5).

Subsequently, all parameters of healthy knees for subjects were compared with those obtained in knees with crepitant meniscus and soft tissue injuries. From the comparison between healthy knees and those with crepitant meniscus, statistically significant differences in $\Delta \theta$ were evidenced. However, from the comparison between healthy knees and soft tissue injuries, non-statistically significant differences were shown for any parameter. Finally, from the comparison between the knees with crepitant meniscus and those with soft tissue injuries, statistically significant differences in $\Delta \theta$ were evidenced.

### Table 5:
P-values obtained from an ANOVA with Bonferroni correction of impedance and phase data obtained in control and subjects stratified by injuries.

<table>
<thead>
<tr>
<th>Group</th>
<th>Compared with</th>
<th>$Z_1$ ($\Omega$)</th>
<th>$Z_{NH1}$ ($\Omega/m$)</th>
<th>$Z_{NC1}$ ($\Omega/m$)</th>
<th>$\Delta Z_{1}$ ($\Omega$)</th>
<th>$\Delta Z_{NH1}$ ($\Omega/m$)</th>
<th>$\Delta Z_{NC1}$ ($\Omega/m$)</th>
<th>$\Delta \theta_{1}$ (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>Healthy knees in subjects</td>
<td>0.008</td>
<td>0.001</td>
<td>0.001</td>
<td>0.004</td>
<td>0.001</td>
<td>0.001</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Crepitant meniscus in subjects</td>
<td>NS</td>
<td>NS</td>
<td>0.16</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Soft tissue injury in subjects</td>
<td>NS</td>
<td>NS</td>
<td>0.029</td>
<td>0.044</td>
<td>0.015</td>
<td>0.003</td>
<td>NS</td>
</tr>
<tr>
<td>Healthy knees in subjects</td>
<td>Crepitant meniscus in subjects</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>Soft tissue injury in subjects</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Crepitant meniscus in subjects</td>
<td>Soft tissue injury in subjects</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>p&lt;0.001</td>
</tr>
</tbody>
</table>

1. Impedance in static condition.
2. Impedance normalized by height.
3. Impedance normalized by calf perimeters.
4. Phase in static condition.
5. Impedance changes in dynamic condition.
6. Impedance changes normalized by height.
7. Impedance changes normalized by calf perimeters.
8. Phase changes in dynamic condition.
DISCUSSION

The objective of this research was to assess the feasibility to detect mild knee injuries by BI in a group of female athletes. To perform this task, two female groups were analyzed and compared. One group was composed by 7 sedentary females (14 knees) and the other by 11 sport-women (22 knees). It was evidenced that all knees from sedentary group did not show any injury. However, in sport-women, two kind of knee mild injuries were found: 1) soft tissue injuries and 2) crepitant meniscus. The anthropometric parameters corresponding to both groups were statistically compared. The obtained results showed that the height and the calf perimeters were the most significant parameters that differ between groups. This fact indicates that athletes are taller, and their calves are bigger than that of sedentary women. Both parameters were used to normalize the impedance determinations because they depend on internal features, volume and shape of tissues (Bera, 2014). For assessment of each knee, we have considered two measurement conditions: 1) static condition and 2) dynamic condition. Combining both, it is possible to determine a wide range of impedance variations due to the presence of hard and soft knee tissue.

Table 4 summarize all performed statistical comparison for better understanding. The statistical comparison of all parameters (Z, Z_{NH}, Z_{NC}) and θ or ΔZ, ΔZ_{NH}, ΔZ_{NC} and Δθ in the case of dynamic evaluation) obtained in both conditions, corresponding to right and left knees of sedentary group, did not evidence any statistically significant difference. This fact reflects the tissue similarities between knees in this group. In the case of sport-women, statistically significant differences in all parameters were obtained at static condition, while in moving condition, there were significant differences in two parameters:ΔZ and ΔZ_{NH}. In the case of static condition, the position of knee placed at 90° without movement allowed further exposure of the knee soft tissue. This fact allowed the tissue detection differences between both knees. In dynamic condition, the impedance changes and those normalized by the height detected tissue differences between the right and left knee. However, the perimeter of calves (used to normalize impedance determinations) and the parameter Δθ were not significant.

The statistical comparison between all parameters corresponding to both groups (sedentary female and athletes), submitted to both conditions, evidenced significant differences, except Δθ (dynamic condition). So, knee tissue differences between both groups could be evidenced using all impedance parameters determined by both conditions. The differences of θ (static condition) could suggest detection of changes in tissue composition (for example, lack of liquid) between knee groups.

The comparison between control and subjects stratified by injuries was performed by an ANOVA with Bonferroni correction (Table 5). From the statistical comparison of all impedance determinations obtained in sedentary group with those obtained in healthy knees from athletes, statistically significant differences in impedance parameters for static (Z, Z_{NH}, Z_{NC}) or dynamic (ΔZ, ΔZ_{NH}, ΔZ_{NC}) conditions, were evidenced except in phases (θ). Despite the small number of healthy knees in athletes, it was possible to detect changes in the structure of tissues (volume and shape) using both conditions.

All parameters obtained in healthy knees from sedentary women were compared with those with crepitant meniscus from athletes. The results showed significant differences in Z_{NC} for static condition. This parameter was capable to detect changes in the knee tissue structure between groups. In dynamic condition, statistically significant differences in all parameters (ΔZ, ΔZ_{NH}, ΔZ_{NC} and Δθ) were evidenced. In this case, the movement of knee could have allowed the detection of tissue changes evidencing not only the volume or shape (by impedance parameters) but also the tissue composition (by Δθ).

From the comparison of impedance determinations obtained in healthy knee from sedentary women and knees with soft tissue injury from subjects, statistically significant differences in Z_{NC} for static condition and impedance parameters (ΔZ, ΔZ_{NH}, ΔZ_{NC}) for dynamic condition were evidenced. For both cases, the impedances determinations were capable to detect changes in knee volume. The obtained data suggests that it could be possible to detect alterations in soft tissue by impedance determinations for both conditions. However, the parameters θ and Δθ did not show any changes between the groups of knees.

Subsequently, all parameters (Z, Z_{NH}, Z_{NC}, θ and ΔZ, ΔZ_{NH}, ΔZ_{NC}, Δθ) of both conditions obtained in healthy knees of subjects, despite the reduced number of elements, were compared with those knees with crepitant meniscus and those with soft tissue injuries. From the statistical comparison of healthy knees and those with crepitant meniscus, the most significant differences were found only in Δθ for dynamic condition. Probably, it is possible to differentiate the tissue composition between both groups of knees. However, it is necessary to increase the sample of healthy knees from athletes to confirm this result. From the statistical comparison of healthy knees and those with soft tissue injuries, non-significant parameter was evidenced. In this case, no differences in changes of impedance and phase were detected.

Finally, from the comparison of all parameters of those knees with crepitant meniscus and those with soft tissue injuries, only statistically significant differences in Δθ (dynamic condition) were demonstrated. This fact could be explained by the initial process of meniscus damage for the case of crepitant meniscus and the alterations suffered by soft tissues for the case of soft tissue injuries. Both pathologies could provoke changes in knee tissue composition. These changes are evident during the movement and could affect the transmission of electrical current, causing a possible dielectric effect in knee tissues detected by the changes of phase (Δθ). From the same
analysis, impedance parameters did not show statistical differences between groups, evidencing no changes in volume or shape of knee tissue. Probably, the detection of tissue composition is detected independently of volume changes suffered in knee tissues.

From the analysis of results, our research group propose the bioelectrical impedance as a viable complementary method to help in the detection of mild knee injuries. On the one hand, the main advantage of our method includes being sensitive to knee mild injury during the movement of joint. On the other hand, the impedance devices used to perform these evaluations are non-invasive, cheap and easy to use.

CONCLUSIONS

The vector of bioimpedance could be an option to detect changes in structure of knee tissues between sedentary females and sport-women under static and dynamic condition.

The differences in knee tissues between groups were detected using the self-normalized parameter $Z_{nc}$ for static condition and the parameters for impedance change ($\Delta Z$, height normalized $\Delta Z_{NH}$, calf normalized $\Delta Z_{NC}$) in the case of dynamic condition. So, it was possible to differentiate between the healthy knees of sedentary women and female athletes with healthy knees, with crepitant meniscus and with soft tissue injuries.

In addition to impedance, the change of phase $\Delta \theta$ (dynamic condition) was the only parameter that evidence the detection of differences between healthy knees and those knees with crepitant meniscus of subjects. It is necessary to increase the sample of healthy knees of athletes to confirm this statement. The same parameter $\Delta \theta$ was sensitive enough to detect differences between crepitant meniscus knees of subjects and those with soft tissue injuries. So, the detection of knee tissues composition could be performed by analyzing the changes in impedance and phase corresponding to dynamic condition. However, these statements must be assessed with other medical trials and in extended sample.

REFERENCES


