Behaviour of the electrical impedance myography in isometric contraction of biceps brachii at different elbow joint angles

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Abstract. Electrical impedance myography (EIM) can be understood as an experimental technique applied to evaluate bioelectrical impedance associated to the muscular activity. With the development of technique, some studies are trying to associate the EIM parameters with the morphological and physiological changes that occur in the muscle during contraction. In this context this work sought to associate EIM parameters observed during isometric contractions of the biceps brachii muscle at different elbow joint angles with the correspondent muscular force. Differently from previous works that did not observe significant correlation between those data, our findings point to high correlations between the some EIM resistive parameters and the muscle force. Despite the need of further investigation, our results indicated that EIM technique can be used to estimate muscle force in a noninvasive way.

1. Introduction
Electrical impedance myography (EIM) can be understood as an experimental technique applied to evaluate bioelectrical impedance associated to the muscular activity [1].

EIM has been used in the assessment of neuromuscular diseases [2] and also to investigate some aspects of muscle contraction [3,4,5]. In the last context, changes in EIM have been attributed to morphological and biochemical changes observed in the muscle during contraction. Despite those works, a better understanding of EIM behavior under isometric or dynamic muscle contractions is still a challenge.

Some studies have reported low correlation between EIM data and muscular contraction associated to joint angles. For example, Zagar [5] compared EIM parameters during rest and isometric contraction of biceps brachii muscle in order to investigate if it is possible to distinguish bioimpedance components related to biochemical and structural changes of the muscle. Although the results indicated the possibility of distinguishing these two components from EIM data, the observed low correlation might be associated to a poor estimate of the muscle strength associated to the studied joint angles.

Some authors [2,3] have also reported a low sensitivity of EIM technique in detecting changes associated to the muscular contraction using the classical tetrapolar bioimpedance electrodes arrangement (with sinusoidal constant current of 800μA, and frequency of 50 kHz) to measure segmental bioimpedance on a muscle. However, alternative methods have been reported to perform bioimpedance spectroscopy (BIS). For example, Neves and Souza [6] proposed a bioimpedance spectroscopy protocol to estimate muscle force in a noninvasive way.

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spectroscopy method based on the current response to a voltage step excitation (BIS-STEP) that has been applied in many bioimpedance applications [7,8,9]. Aiming to contribute to a better understanding of EIM, this study investigated the relationship between the force produced by the biceps brachii muscle in isometric contraction in different elbow joints and EIM parameter achieved by BIS-STEP technique.

2. Methods

2.1. Sample
Twelve subjects (9 males and 3 females), aging 27.3 ± 4.9 years, height 1.73 ± 0.07 m, and weight 80.3 ± 23.1 kg, participated in the study. All subjects were right-handed without previous registration of neuromuscular injuries of upper and lower limbs. Six of them were physically active and six sedentary.

2.2. Instrumentation
As mentioned before, EIM data were achieved using a BIS-STEP prototype developed in the Biomedical Instrumentation Laboratory at Federal University of Rio de Janeiro - Brazil. Such equipment supplies data somehow equivalent to a multifrequency bioimpedance analyzer ranging 1-500 kHz [3].

Because the BIS-STEP is a bipolar technique that considers the effect of electrode impedances, two 12cm² metallic plate electrodes with electrolyte gel were used to minimize the electrode-tissue impedance during the data acquisition of the muscle segmental bioimpedance. Each electrode was placed 2 cm apart the line defining the belly of the biceps brachii muscle. Removal of the stratum corneum layer by rubbing with cotton and saline solution was accomplished before electrodes placement.

2.3. Experimental protocol
The experimental protocol consisted of measuring EIM in volunteers’ biceps brachii muscle at different elbow joint angles, while the subjects were holding a 2.2 kg load in their hands. The studied angles were 45, 60, 90, 120 and 135 degrees, and all of them were quantified by a metallic universal goniometer. EIM measurements for each elbow joint angle were performed in a random order, adopting a rest interval of two minutes between successive measurements.

2.4. Analysis and data processing
The current response associated to the BIS-STEP method was interpreted using the electric model depicted in Figure 1. A gradient descent method was used to optimize the electric model parameters that best fit experimental data, in particular the bioimpedance ones (extracellular resistance – \( R_e \), intracellular resistance – \( R_i \), membrane capacitance – \( C_m \)). The parameter \( C_e \) models the electrode capacitance and was also estimated by the gradient descent method. The resistive part of electrode impedance was fixed and calculated from geometric and dimensional features.

![Electric model used to analyze the BIS-STEP current response. The extracellular resistance – \( R_e \), intracellular resistance – \( R_i \), and membrane capacitance – \( C_m \), stand for the segmental bioimpedance model. The capacitances \( C_e \) and resistances \( R_b \) are associated to the impedances of the electrode-tissue interfaces.](image)
The behavior of EIM parameters at different elbow joint angles was compared to the behavior of an estimate of the biceps brachii force obtained using a biomechanical model (Figure 2) proposed by Tozeren [10].

**Figure 2.** Biomechanical model used to estimate the force of the biceps brachii muscle. $a$ – length of the arm, $b$ – length of the forearm + half length of the hand, $c$ – length of the biceps brachii, $d$ – distance between the muscle biceps and the elbow, $L$ – load mass $M$.

Anthropometric variables used in the biomechanical model were estimated from percentages of subjects’ heights according [11], as shown in Table 1. Mean values for the length of the arm, forearm and hand were used to estimate the general behavior of the biceps brachii force at the studied elbow joint angles.

**Table 1.** Anthropometric variables of the studied sample

| Height | Length of humerus | Length of forearm | Length of hand | Half length of hand | Hand and forearm |
|--------|-------------------|-------------------|----------------|---------------------|------------------|
| 163,0  | 28,19             | 26,08             | 09,64          | 4,82                | 30,90            |
| 174,5  | 30,18             | 27,92             | 10,33          | 5,16                | 33,08            |
| 172,0  | 29,75             | 27,52             | 10,18          | 5,09                | 32,61            |
| 165,0  | 28,54             | 26,40             | 09,76          | 4,88                | 31,28            |
| 173,5  | 30,01             | 27,76             | 10,27          | 5,13                | 32,89            |
| 185,0  | 32,00             | 29,60             | 10,95          | 5,47                | 35,07            |
| 174,0  | 30,10             | 27,84             | 10,30          | 5,15                | 32,99            |
| 174,0  | 30,10             | 27,84             | 10,30          | 5,15                | 32,99            |
| 180,0  | 31,14             | 28,80             | 10,65          | 5,32                | 34,12            |
| 185,0  | 32,00             | 29,60             | 10,95          | 5,47                | 35,07            |
| 179,0  | 30,96             | 28,64             | 10,59          | 5,29                | 33,93            |
| 163,5  | 28,28             | 26,16             | 09,67          | 4,83                | 30,99            |
| Mean   | 30,10             | 27,84             | 10,30          | 5,15                | 32,99            |
Considering isometric contraction, and that the elbow flexion is produced just the biceps brachii muscle, equation (1) holds.

\[ M_b = m \, g \, \frac{b}{2} \sin \theta + M \, g \, b \, \sin \theta \]  

(1)

Here \( M_b \) is the torque produced by the biceps brachii muscle, \( m \) is the estimate mass for the forearm, \( b \) is the length of the forearm, \( \theta \) is the elbow joint angle, and \( M \) is load mass.

The biceps torque must the equal to the product of the muscle force by the distance \( d \) (Figure 2) from the force direction (direction of the muscle) to the rotation point of the elbow, i.e.:

\[ M_b = F_m \, d \]  

(2)

where it can be demonstrated that

\[ d = \frac{\sqrt{4 \, a^2 \, c^2 - (-b^2 + a^2 + c^2)^2}}{2 \, c} \]  

(3)

where \( a \) is length of the arm, \( b \) is length of the forearm + half length of the hand, \( c \) is length of the biceps brachii.

From equations (1), (2), and (3) can estimate the biceps brachii force \( F_m \) as a function of the elbow joint \( \theta \). Those estimates were compared with the corresponding values of resistive parameters of EIM. Besides the comparison with values of \( Re \) and \( Ri \), values of \( R_{inf} \), defined as the parallel association of \( Re \) and \( Ri \), were also studied.

3. Results
The behavior of the estimated biceps brachii force \( F_m \) as a function of the elbow joint \( \theta \) is depicted in Figure 3. The \( F_m \) estimates, computed considering equations (1), (2) and (3), used mean values of the anthropometric variables for the studied sample.

![Figure 3. Behavior of the estimated force of the biceps brachii muscle at different elbow joint angles](image)
The behaviors (mean and standard deviation) of EIM resistive parameters are depicted in Figure 4.

The linear correlation between the series of the estimated force of the biceps brachii muscle and the resistive EIM parameter can be seen in Table 2.

### Table 2. Linear Person correlation ($r$) between the estimated force of the biceps brachii muscle and the resistive EIM parameter

|        | $R_i$ | $R_e$ | $R_{inf}$ |
|--------|-------|-------|-----------|
| Average Force | 0.891 | 0.984 | 0.971     |
| Angle   | 0.919 | 0.999 | 0.991     |

### 4. Discussion

Our findings agree with some previous studied that observed a high correlation between EIM parameters and both joint angle and associated muscle force [2, 12]. Some previous works, have been consider three aspects for explanation changes of bioimpedance parameters during muscle contraction in different joint angles: change in distance between electrodes, muscle contraction physiology and morphologic changes during variations of muscle joint studied [3, 12].

It has been reported that changes in inter-electrodes distance at different joint angles is a factor that can influence bioimpedance parameters [2, 3, 6]. Our estimates using the biomechanical model indicate that the length of biceps brachii muscle changes from 24.57 cm (at 45°) to 37.02 cm (at 135°), representing a change of about 33%. Thus, it is seems reasonable that this change the muscle length can lead to an associated change in the effective distance between the electrodes that explains part of the behavior observed in EIM resistive parameters.

Modifications in the transverse section of muscle at different joint angles can be another factor that can change EIM resistive parameters. However, the change in the transverse section can be considered correlated to the above-mentioned influence related to the muscle length, i.e., as the muscle contracts its length decreases and its transverse section increases. Thus, since the resistive parameters should be somehow proportional to the muscle length and inverse proportional to the transverse section, both effects would contribute to change the resistive parameters in the same direction. Kim [12] also reported high correlation between joint angles variations and bioimpedance variables and attributed such findings to morphological modifications of the muscle.
Physiological components could have also influenced our findings. Even holding a low weight load (2.2kg), especially the sedentary volunteers (6 of 12) could have experienced changes in their physiological muscle activity at the different joint angles studied. This physiological activity is basically changed in concentrations of ions in intracellular and extracellular liquids. For example, as muscle contracts potassium (K⁺) concentration decreases in intracellular medium and increases in extracellular medium. Others ions as chlorine (Cl⁻), sodium (Na⁺) and calcium (Ca²⁺) have a opposite drift comparing with potassium during muscle contraction [13]. Shiffman [3] reported an increase of EIM values even before the muscle force generation. Those results were only associated to the physiological factors. However, the way each ion concentration affects EIM parameters is still a challenge.

5. Conclusion
We conclude that the BIS-STEP technique seems to be sensitive enough to EIM application and that it capable to supply parameter that are high correlated with muscle contraction. Part of the changes observed for those parameters can be explained by morphological changes of the muscle and another part associated to physiological changes in ionic concentrations of the extracellular and intracellular mediums. Further investigation must be performed in order to better distinguish these two components.

6. References
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