Electromyographic assessment on transfemoral amputees to possibly control artificial lower limbs

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Abstract: This study aimed to assess the electromyographic feasibility of different hip muscles on transfemoral unilateral lower limb amputees to a possible control of artificial limbs. The volunteers were split into two groups: eight males, physically active amputees and a control group composed of eight males, healthy, non-amputees individuals. The hip muscles were assessed in accordance to the general consensus by SENIAM project, and some adaptations were made in the amputees when the anatomical references were absent, such as the knee articulation. Thus, agonists and antagonists skeleton muscles were evaluated during the isometric contraction of hips movements of extension and flexion, which were controlled by an isokinect chair. The median frequency (Fmed) values did not represent significant differences and the RMS is the best muscle activity of amputees.

Keywords: amputees; electromyographic; muscles; leg; median frequency; root mean square; exercise; articulation; artificial lower limbs; males; technology.

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1 Introduction

Surface Electromyography (sEMG) is a non-invasive method to evaluate the muscular activity, which uses silver or silver chloride electrodes attached on the skin. This technique is applied in several areas, such as neurology, rehabilitation and sports. Because of the wide possibilities of application, it is necessary a standardisation of the technique, so the Surface Electromyography for the Non-invasive Assessment of Muscles (SENIAM) was developed by Freriks and Hermens (2000).

The sEMG does not provide muscular strength information. In this way, it is fundamental the use of a dynamometer to give a feedback about the muscle contraction. The muscular strength is an important component in sports and in health areas, because it refers the ability of the contractile tissue to produce tension and resultant strength based on the muscular demand (Zabka et al., 2011).

The term amputation is defined as withdrawal, usually surgical, of a limb (Oliveira and Vilagra, 2009). The transfemoral amputation is located between the hip and the knee. This procedure leads to several dysfunctions on the body biomechanics, which generate posture and gait standards in order to compensate the limb loss (Bhaskar et al., 2014).

The residual limb after the surgery is denominated stub. When the amputation is transfemoral and the stub is proximal, some special cares to improve the gait on the amputees are demanded to avoid eschars and deformations, such as do not bearing the body’s weight on the stub and the maintenance of the pelvis rotation in order to keep good movement amplitude (Carvalho, 2003).

Prostheses are used to replace some lost body part. The conventional prostheses are the exoskeletons. They are produced with wood and plastic components. Nowadays there are lighter and more flexible materials to produce artificial limbs (Carvalho, 2003).
Europeans are pioneers on technologies applied to rehabilitation. In 1946, Haber and Schneider developed the suction socket, it works in order to stabilise the stub, providing an interface between the device and the subject body. Today, the socket is recommended to be used in all sort of prosthesis, as shown in Figure 1 (Radcliffe, 1997).

**Figure 1** Pelvis stabilisation by the use of the suction socket

![Figure 1](image_url)

*Source:* Adapted from Radcliffe (1977)

Microprocessed artificial limbs are different from the conventional ones because they got an input sensor, processing, an output and a feedback entrance. These kinds of prosthesis are distinguished by how they operate their entrance data: Computational Intrinsic Control (CIC) and Interactive Extrinsic Control (IEC) (Radcliffe, 1997).

The first one, CIC, uses intrinsic sensors which detect the gait cadence and the environment, so it undergoes some adjustments as the gait phases require. The IEC system is already being used in upper limb designs; they incorporate myoelectric signals to the device’s functional movement (Martin et al., 2010).

Balance is an inherent condition of the human being. Normally, it is acquired during the initial phases of life and this is a complex process which covers the coordinated action of biomechanical, sensory and motor central nervous system (Sharma et al., 2001).

The static balance in unilateral lower limb amputees (transtibial or transfemoral level) during standing is compromised due to the lack of active ankle and knee control in prosthetic limb. Some studies aiming to solve the contribution of the sound and the prosthetic limbs on the balance maintenance and to provide the best choice of approach in rehabilitation tasks (Jayakaran et al., 2012; Curtze et al., 2012).

Several studies (Ferreira et al., 2005; Delis et al., 2009; Huang and Ferris, 2012) evidence that sEMG provides signal patterns, which could be enough to achieve the goal of supply an artificial limb. The muscular evaluation by means of sEMG furnish
quantitative values which can be replicates when gathered during the Maximum Voluntary Contraction (MVC), aided by the use of a dynamometer so the muscular strength information can be acquires as well (Agostini et al., 2010).

This study aims assessing the electromyographic feasibility of different hip muscles on transfemoral unilateral lower limb amputees to a possible control of artificial limbs.

2 Methods

2.1 Sampling

The sample was intentional, represented by 16 male physically active volunteers. First of all from this sampling, eight of them were transfemoral amputated, the aim group and the other eight volunteers were non-amputated, and the second one was the control group.

Some inclusion criteria were taken under consideration to constitute the aim group, such as the amputation must have been unilateral and occasioned by trauma or neoplasia and the subjects should be adapted to the use of their own prosthesis.

2.2 Instrumentation

The equipment used was a wireless digital electromyograph (16 channels) to collect the sEMG signals and an isokinect chair to control the MVC. The sampling frequency was adjusted to 1000 Hz. The high-pass filter 20 Hz with Bessel third-order filter and Butterworth first-order filter. Low-pass filter 460 Hz and cut-off 60 Hz. Data processing was made using the Matlab software R2012. Surface electrodes used were from AMBU with 25 mm, as well the ground electrodes.

2.3 Procedure

Measurements were preceded in a quiet environment and the temperature was kept in 24°C. The hip muscles selected are strategic to the gait and to the balance. Also, they are potentially nice natural sensors because they are large and superficial muscles (Yang et al., 2007). The selection was made for hip flexion and extension movements and they were agonist and antagonist as well, depending on the movement. The picked up muscle were the same for both limbs (stub and healthy limb): Retus femoralis (RF), Biceps Femoralis (BF), Semitendineous (ST) and Paravertebralis (PV).

First, the volunteers rested for 5 min and then the identification for the best muscle site and cleaning (70% alcohol) of the area was done. Following, to start the muscle sites identification: RF the electrodes were placed at 50% on the line from the anterior spina iliaca superior to the superior part of the patella; BF were placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia; ST were placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia; the PV muscle (fifth lumbar vertebra) does not have a standardisation by SENIAM, in this case the muscle position was anatomically inferred, an example of placing electrodes can be observed in Figure 2. The identification of ideal muscular sites on the stub of the amputees subjects was proceed by observing the symmetry to the healthy contralateral limb, because of the lack of anatomical reference owing to the level of amputation the knee articulation was absent.
2.4 SENIAM project

The surface electromyography for the non-invasive assessment of muscle (SENIAM) is a project developed by Freriks and Hermens (2000) to standardise the protocol and method of sEMG signals capture. The project is basically an anatomical guide to locate the best muscular site to capture the highest amplitudes and frequencies of the sEMG signal. Based on this standardisation, an experimental protocol was developed to the current study (Alves et al., 2012).

2.5 Static protocol

The static protocol was performed on the isokinect chair. First, the volunteer performed the hip flexion during the MVC, after that the same volunteer performed the hip extension also during MVC. These movements were performed three times and each trial (hip flexion or hip extension) lasted 10 s. The isokinect chair was positioned in two different angles (30° and 60°), so intervals of 2 min for the different movements and angles were fulfilled. During the exercise was held vocal motivation to encourage the volunteer and they could also watch their effort on the computer’s screen when the strength bars went up and down while they were proceeding the muscular contraction, this action helped as a visual feedback to the volunteers.

2.6 Statistic method

For this kind of sampling, the statistical method chosen to apply is the one-way ANOVA, because it provides the comparison of two or more random groups, which follow a normal distribution. The choice of significance level is random, in this research was used a significance level of 5%, thus it was possible to raise the level of reliability (Rosner, 2010).
3 Results

The measurements were accomplished in a three-month period. The group A was composed of the amputees and the group B is the control volunteers.

3.1 Analysis intra-group A (30°)

In Table 1, for extension, the intact muscles showed greater RMS and F_med compared to the stub muscles. Also, the hip extension in 30° for the RF, ST and BF muscles has shown difference between the intact limb and stub in both parameters, RMS and F_med. The PV muscle has shown similar values for each sample.

During the movement of hip’s flexion, Table 1 indicates that the intact muscles (RF, BF and ST) have shown greater RMS values than the stub muscles. The same occurred for the F_med values, in exception to the ST muscle, but that can be attributed to the frequency’s outliers. The PV, both intact, has shown similar values for both, RMS and F_med parameters.

Table 1

<table>
<thead>
<tr>
<th>p-value RMS</th>
<th>p-value F_med</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muscle</strong></td>
<td><strong>Ext.</strong></td>
</tr>
<tr>
<td>RF</td>
<td>0.0263*</td>
</tr>
<tr>
<td>ST</td>
<td>0.0011*</td>
</tr>
<tr>
<td>BF</td>
<td>0.0019*</td>
</tr>
<tr>
<td>PV</td>
<td>0.4342</td>
</tr>
</tbody>
</table>

Note: * p < 0.05.

3.2 Analysis intra-group A (60°)

In Table 2, for extension movement, the BF muscle has shown difference in RMS values and the ST muscle has shown difference for the F_med values. Although the RF and PV have similar values for both parameters.

As Table 2, in flexion movement, shows that there is difference only in RMS value for ST and BF muscles.

Table 2

<table>
<thead>
<tr>
<th>p-value RMS</th>
<th>p-value F_med</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muscle</strong></td>
<td><strong>Ext.</strong></td>
</tr>
<tr>
<td>RF</td>
<td>0.5242</td>
</tr>
<tr>
<td>ST</td>
<td>0.3126</td>
</tr>
<tr>
<td>BF</td>
<td>0.0043*</td>
</tr>
<tr>
<td>PV</td>
<td>0.5872</td>
</tr>
</tbody>
</table>

Note: * p < 0.05.
The comparison intra-groups during the hip extension movement have shown different values for the RF, ST and BF muscles. This can be explained by the literature, it says that sectioned muscles lose their insertion and sufferer a severe denervation, causing a structural loss on the muscle anatomy and physiology (Carvalho, 2003). This can be also found in the study of Huang and Ferris (2012), they observed statistical difference between the intact limb and the stub during the MVC.

### 3.3 Analysis inter-groups A and B (30°)

In Table 3, during the hip extension, it is possible to observe that there is no significant difference in RMS and $F_{med}$ values between group A and B.

However, also in Table 3 it is clear that the RF muscle has shown, only in the RMS, greater values comparing to the group B.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Ext.</th>
<th>Flex.</th>
<th>Ext.</th>
<th>Flex.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>0.7978</td>
<td>0.0221*</td>
<td>0.6808</td>
<td>0.1316</td>
</tr>
<tr>
<td>ST</td>
<td>0.6474</td>
<td>0.4149</td>
<td>0.1516</td>
<td>0.7718</td>
</tr>
<tr>
<td>BF</td>
<td>0.9924</td>
<td>0.0661</td>
<td>0.9612</td>
<td>0.1311</td>
</tr>
<tr>
<td>PV</td>
<td>0.2648</td>
<td>0.1133</td>
<td>0.6622</td>
<td>0.7628</td>
</tr>
</tbody>
</table>

Note: * $p < 0.05$.

### 3.4 Analysis inter-groups A and B (60°)

Tables 4 shows the $p$-values for RMS and $F_{med}$ and there is no significant difference between the groups A and B.

Analysing the inter-group results of RMS and $F_{med}$ parameters during hip’s extension and flexion on the four different muscles, it is possible to say that there are no statistical differences in the evaluated muscles, a processed signal sample of the rectus femoralis (RF) muscle of the eight amputee volunteers can be seen in Figure 3. This improves the thesis that the intact limb does not suffer changes on their electrophysiological parameters, as described by Huang and Ferris (2012) and Seyedali et al. (2012).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Ext.</th>
<th>Flex.</th>
<th>Ext.</th>
<th>Flex.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>0.5354</td>
<td>0.5364</td>
<td>0.2925</td>
<td>0.5636</td>
</tr>
<tr>
<td>ST</td>
<td>0.5097</td>
<td>0.8463</td>
<td>0.3596</td>
<td>0.5464</td>
</tr>
<tr>
<td>BF</td>
<td>0.5052</td>
<td>0.5285</td>
<td>0.2832</td>
<td>0.2076</td>
</tr>
<tr>
<td>PV</td>
<td>0.2725</td>
<td>0.1250</td>
<td>0.942</td>
<td>0.4838</td>
</tr>
</tbody>
</table>

Note: * $p < 0.05$. 

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4 Discussion and conclusion

Recently, advances in prostheses for lower limb controlled by microcomputer have proved promising for improving mobility and quality of life of individuals with lower limb amputation. However, the dynamics aspect of these prostheses still represents some challenges depending on some factors such as the locomotion intention of the user, type of task and the different ground levels (Zhang et al., 2011a; Zhang et al., 2011b; Huang et al., 2011). The static analysis performed in this study showed that the RMS value best represents the electrical activity of residual muscles, information relevant to the control of prostheses in static positions, such as standing. Faced with the need to control neural prosthetic leg, Huang et al. (2009) conducted a study aiming to investigate how accurately sEMG combined with pattern recognition (PR) could identify the transportation modes of users and concluded that the system phase-dependent sEMG PR was able to accurately recognise seven tasks modes. However, in order to improve the reliability of pattern recognition (PR), an additional module called the module fault detection sensor (SFD) was developed. This module not only accompanied individual sEMG electrode recordings, but also regained the classification performance of the system when one or more signals were altered (Huang et al., 2010).

In the current study, transfemoral amputees were evaluated, so different essential gait and balance muscles were assessed. In this way, this proposal brings new data about muscular parameters in amputees, which could be used to provide feedback for an artificial active limb and consequently helping to control the knee joint and static balance maintenance of lower limb amputees.
Under the electrophysiologic point of view, as reported by Huang and Ferris (2012), the sEMG signal found in the amputees’ stubs and in their healthy limb imply that the myoelectric signals could be enough to provide feedback to myoelectric knee, working as myosensors providing information to the IEC kind of prosthetics microprocessors as mentioned in the introduction session (Radcliffe, 1997). This fact has already been verified by Paz Junior and Braga (2007), in the study they compared the upper limb stub peripheral muscular activation, using sEMG to the cortical motor activation by the means of the Functional Nuclear Resonance Magnetic (fNMR), and also by Huang and Ferris (2012), who evaluated the patterns of sEMG signals in the transtibial stub of the amputee.

Generally, the prostheses developed control the knee impedance in each phase of gait. However, as the dynamics and the kinematics of the knee often vary between different modes of locomotion, it is necessary to develop prostheses controlled by the user, capturing the intended function in preference to isolated phases (Huang et al., 2011). In this sense, the mechanical sensors respond to the movements of the patient, while the electromyographic signals precede the onset of movements and can be used to help predict tasks transitions. In this regard, Du et al. (2013) conducted a study to further improve the performance of a locomotion system through the introduction of information about the walk environment. The recognition system associated with environmental knowledge significantly outperforms the system without prior information.

Hoover et al. (2013) proposed the development and experimental demonstration of a system based on sEMG signals for the direct control of a transfemoral prosthesis system. The control interface implemented experimentally provided a direct torque control of the knee to the amputated subject, through surface electromyography of the residual thigh muscles and knee impedance adjustment switches, which were based on foot contact with the floor. Force was effectively modulated by sEMG during the stance phase by taking advantage of the swing phase. In the swing phase, the influence of sEMG to achieve the desired trajectory was considered modest. According to Wentink et al. (2013), initiation of gait in transfemoral amputees is different from not amputated due to the lack of stability and prosthesis detachment. Therefore, the authors studied the feasibility of detecting the initiation of gait in real time through sEMG muscle and inertial sensor data. The sEMG was able to anticipate the step of fingers withdrawing and heel strike before 130–160 ms, which results in a timely manner to control the prosthesis. In this study, we showed that the residual muscles show signs of significant sEMG, especially the RMS value, to help control the knee during the swing phase (contralateral leg) and double support during gait, enabling the static control knee.

Ha et al. (2011) assert that the amputee must be able to control the active prosthesis during an activity without weight bearing. To achieve this, they presented a method for providing voluntary control of an active knee prosthesis activity in non-weight bearing, such as sitting. The voluntary movement of the knee joint is controlled by the user utilising electromyographic signals captured from the quadriceps and hamstrings muscles of the residual limb. As a result, the authors report that the implementation of the integrated sEMG socket can promote an effective control of motion range in the knee without weight bearing activities. In relation to static control the prosthesis with or without weight discharge.

Thus, the present work showed that the electromyographic patterns in the stubs are viable, in other words, they could turn on an active prosthesis, and this is of main relevance to the current state of art. This study also showed that the sEMG patterns in the
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Intact limb of the amputees are similar to the patterns found on healthy subjects. Generally speaking, this data, mainly the RMS parameter, evidence that the muscles of active prosthesis users are able to provide feedback to myoelectric artificial limbs.

Hence, electromyography is effective for the control of neural prostheses, since sEMG signals can anticipate the beginning of the movement, which helps to predict tasks transitions. Moreover, when associated with mechanical sensors (neuromuscular-mechanical fusion) it can improve user performance on uneven terrain, facilitating movement and improving the quality of life of lower limb amputees. It is important to emphasise that this study highlights the need for rehabilitation and maintenance of the electrical activity of the residual muscles, which may go unnoticed to health professionals, when they offer a programme of functional rehabilitation of lower limb amputees.

References


