ELECTROMYOGRAPHICALANALYSIS ON-INTRA INDIVIDUAL COMPARISON OF AMPUTEE AND NON-AMPUTEE LEG

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Abstract

This study examined the electromyographic (EMG) activity of the rectus femoris, biceps femoris, gluteus medius, and gluteus maximus on the legs of six amputee and nonamputee subjects. The results showed that there was a significant difference in peak muscle activation of the rectus femoris, gluteus medius, and gluteus maximus muscles between the amputee and nonamputee legs. Mean peak activation was significantly lower in all three muscles in the leg of the amputee. However, there was no significant difference in peak activation of the biceps femoris muscle between the legs of amputees and nonamputees. These results suggest that there are significant changes in the peak muscle activation of the rectus femoris muscle, gluteus medius muscle, and gluteus maximus muscle in the amputee's leg. These changes are likely due to denervation of the muscles after amputation. The results of this study have implications for the rehabilitation of amputees. The results suggest that it may be important to focus on exercises that target the rectus femoris, gluteus medius, and gluteus maximus to improve functional performance in amputees.

Keywords: Electromyography, Amputation, Rectus Femoris, Biceps Femoris, Gluteus Medius, Gluteus Maximus.

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1. Introduction

The loss of a lower limb due to amputation presents unique challenges to the affected individual and necessitates the use of prosthetic devices to restore mobility and functional abilities. Examination of electromyographic (EMG) muscle activity during gait in both amputees and non-amputees provides important insight into the neuromuscular adaptations and potential compensatory patterns during locomotion in amputees. Understanding these adaptations may lead to improved prosthetic designs and rehabilitation approaches that ultimately improve functional outcomes and quality of life in lower extremity amputees.

An amputation is the surgical removal of a limb or other body part. It is a common procedure, with more than 2 million amputations performed worldwide each year. Amputations can be caused by a variety of factors, including trauma, disease, and congenital defects. The loss of a limb can have a significant impact on a person's life. It can affect mobility, independence and quality of life. Rehabilitation is an important part of the recovery process for amputees. It can help them learn how to use a prosthesis and regain their independence.

Electromyography (EMG) is a technique for measuring the electrical activity of muscles. It can be used to assess muscle function in both healthy and injured individuals. In amputees, EMG can be used to study changes in muscle activity after an amputation. One of the most common changes observed in the EMG of amputees is a decrease in the amplitude of muscle potentials. This decrease in amplitude is thought to be due to several factors, including denervation of the muscle, changes in muscle fiber composition, and changes in the mechanical properties of the muscle.

In addition to amplitude changes, EMG from amputees may also show changes in the frequency content of muscle potentials. These changes are thought to be due to changes in the firing patterns of the muscle fibers. This paper reviews the literature on electromyographic intraindividual comparison between amputee and non-amputee legs.

The specific aims of the article are:

Summarize the changes in EMG activity observed in amputees, to evaluate the use of EMG to assess functional performance in amputees, Changes in EMG activity in amputeesThe most consistent finding from studies of EMG activity in amputees is a decrease in the amplitude of muscle potentials. This decrease in amplitude is probably due to denervation of the muscle. When a muscle is denervated, the muscle fibers lose their ability to contract. This results in a decrease in the electrical activity generated by the muscle.

In addition to a decrease in amplitude, the EMG of amputees may also show changes in the frequency content of muscle potentials. The frequency content of a muscle potential is a measure of the rate at which the muscle fibers fire. In amputees, the frequency content of muscle potentials is often lower than in healthy individuals. This is thought to be due to changes in the firing patterns of the muscle fibers.

1.1 Factors that contribute to changes in EMG activity

Various factors may contribute to the changes in EMG activity following an amputation. These factors include:

i. The level of amputation: the higher the level of amputation, the greater the changes in EMG activity.
ii. The time since amputation: changes in EMG activity are usually greatest in the first few months after amputation.
iii. The use of a prosthetic limb: The use of a prosthetic limb may help reduce the changes in EMG activity.

1.2 The Use of EMG to assess functional performance

EMG can be used to assess functional performance in amputees. For example, EMG can be used to measure the strength of muscles needed to walk. EMG can also be used to measure the coordination of muscle contractions during walking. The use of EMG to assess functional performance in amputees is still in its early stages. However, EMG has the potential to be a valuable tool for assessing the functional status of amputees and for developing rehabilitation programs. Amputees and non-amputees were compared in terms of electromyographical analysis of the leg muscles. One study found that there were differences in muscle activation patterns between intact-limbed and amputee subjects, suggesting that using data from able-bodied subjects alone may not capture the necessary inter-subject variance for designing cross-user myoelectric control systems for prosthesis control [1]. Another study compared muscle synergy in healthy subjects, amputees' intact legs, and amputees' prosthetic legs during walking. The results showed low to high correlations in muscle synergy between subjects, indicating that the central nervous system activates the same groups of muscles synergistically. However, amputees' muscle alterations and deficiencies in proprioceptive feedback and weight bearing in the prosthetic leg led to lower correlations in muscle synergy between groups [2]. State-of-the-art powered ankle-foot prostheses for transtibial amputees (TTA) have made significant advancements to improve the amputee user’s locomotor patterns to achieve energetic costs comparable to able-bodied individuals during walking [3].

The predominant controller for state-of-the-art powered lower limb prostheses relies on finite-state machines that are designed to mimic normative gait patterns based on empirical biomechanics data. However, this type of device is limited to a specific number of pre-programmed Research supported by NSF (1361549, 1406750) and NCSU CLEAR (Closed-Loop Engineering for Advanced Rehabilitation) Core The authors are with the Neural Rehabilitation Engineering Laboratory (NREL), UNC/NCSU joint Department of Biomedical Engineering, Raleigh, NC 27606 USA (e-mail: hhuang11@ncsu.edu). locomotor states with cyclic, stereotyped behavior leaving amputee users at a functional disadvantage to intact individuals when faced with real-world tasks that are highly variable and predictable. For example, standing in a slowly-moving line, navigating uneven terrain, and ambulating across surfaces with varying compliance and friction are real-world situations where powered lower limb prosthesis controllers using finite-state machines offer little more than passive assistance to the amputee user. Researchers have attempted to make lower-limb prostheses more versatile by incorporating user intent via electromyography (EMG) signals [4-6]. These efforts however still depend on state-based automated control, where residual muscle EMG either predicts or modulates specific locomotion modes, leaving amputee control of the device inherently limited. One recent study has demonstrated the ability of TTAs to use residual calf muscle EMG to actively adapt prosthetic ankle mechanics during walking via visual feedback [7].

The promising result from this study motivated us to explore the potential for TTAs to use antagonist residual muscles to restore voluntary control of non-cyclic tasks. Previous work has already begun to investigate the potential for using EMG signals from the antagonist's muscles for the control of the ankle joint. Through the use of an EMG pattern recognition classifier, Hargrove et al. demonstrated TTAs can accurately actuate a 1DOF and 2DOF virtual ankle joint [8]. Wang et al. demonstrate the potential for an amputee to control a virtual ankle joint for position matching with tibialis anterior and gastrocnemius muscles [9]. While these studies demonstrate that residual ankle muscles have the potential to complete simple tasks (consistent movement classification and target hitting) it is unclear whether TTAs can coordinate these muscles to accomplish a high-level task more relevant to real-world settings. A Comparison of Amputee and Able-Bodied Inter-Subject Variability in Myoelectric Control.The study compared electromyography patterns between amputees and non-amputees and found consistent differences, suggesting that using non-amputee data alone may not be sufficient for designing myoelectric control systems for amputees. The results suggest that using able-bodied subject data alone may be insufficient to capture the necessary inter-subject variance when designing cross-user myoelectric control systems for prosthesis control [10]. Changes in the synergy of transtibial amputee during gait: A pilot study, the study compared the electromyographical analysis of amputee and non-amputee legs, showing differences in muscle synergy and activation coefficient profiles during walking. Findings could provide valuable information for rehabilitation purposes and the development of a synergy-based controller from sEMG for future generations of prostheses.

i. Muscle synergy analysis revealed similarities in muscle recruitment between transtibial amputees and non-amputees.
ii. The intact leg and prosthetic leg of amputees showed significant differences in muscle activation [11].

High-Dimensional Surface Electromyography and Low-Dimensional Muscle Synergy in Lower Limb Amputees During Transient- and Steady-State Gait The study compared electromyographical analysis between the amputee and non-amputee legs during walking, finding differences in muscle activities and coordination.The effect of speeds on both HS and TFA muscle activities from biomechanics and robotic control perspectives showed statistically significant differences, suggesting neuromuscular adaptation mechanisms in both groups to satisfy the kinematic and kinetic demands of increasing transient-state walking speed [12].

2. Methods

2.1 Subjects and Variables

Six para-athletes (aged 18 to 35 years) and 6 physically healthy control subjects from different parts of India were selected for the study. Only those athletes who met the following criteria were selected for the study: They had at least 4 years of training experience, represented their institute or nation in athletics at the national or international level, had no injuries that could limit their performance, and had no neuromuscular disorders that could affect their performance on tests. Based on the researcher’s understanding of the problem and based on the literature review and discussion with experts, the following muscles of both legs were selected:

i. Gluteus maximus
ii. Gluteus medius
iii. Rectus femoris (thigh muscle)
iv. Biceps femoris

2.2 Experimental protocol

Electromyography:

Since surface EMG recording using the BTS FREEEMG 300 is a non-invasive method of assessing electrical muscle activity during the relaxation and contraction phases of muscles, it was used to analyze muscle activity in this study. The most common method of EMG recording in most sports biomechanical situations is to place the electrodes or EMG electrodes (two or more) at the implantation site of specific muscles on the subject's skin.

I. Passive surface electrodes were used to analyze muscle activity. The following steps were performed during data collection.

Preparation of the skin and placement of the electrodes:

II. The skin of each subject was prepared by shaving, abrading, and then thoroughly cleaning with an alcohol swab so that the skin impedance values would fall in the lower range, thus improving the conductivity between the skin and the electrodes.

Normalization technique:Maximum Voluntary Isometric Contraction (MVIC) technique was used to normalize the EMG by recording the myoelectric activities of eight selected muscles.

III. Recording of EMG activity in selected muscles:

The EMG activities of selected muscles were recorded during running. On the researcher’s command, the cameras BTS FREEMG ANALYZER and GO PRO were started synchronized and simultaneously the subject started running.

Table 1. Descriptive statistics for different electromyographic variables of amputated and non-amputee leg

Variable	*Leg*	*N*	*Mean*	*Std Deviation*	*Std Error Mean*
Rectus Femoris	Amputee	6	220.92	61.48	25.10
	Non-amputee	6	1140.72	95.38	38.94
Biceps Femoris	Amputee	6	920.13	284.12	115.99
	Non-amputee	6	1134.48	196.89	80.38
Gluteus Medius	Amputee	6	516.65	176.98	72.25
	Non-amputee	6	1055.90	91.62	37.40
Gluteus Maximus	Amputee	6	263.96	70.23	28.67
	Non-amputee	6	1036.02	110.38	45.06

Table 2. Independent t-test analysis of different electromyographic variables of amputated and non-amputee leg

		Independent Samples test				
		t	**df**	**Mean difference**	**Std. error difference**	**Sig. (p-value)**
Rectus Femoris	Equal variances assumed	19.853	10	919.80	46.33	0.000
	Equal variances not assumed	19.853	8.544	919.80	46.33	0.000
Biceps Femoris	Equal variances assumed	1.519	10	214.34	141.12	0.160

	Equal variances not assumed	1.519	8.902	214.34	141.12	0.163
Gluteus Medius	Equal variances assumed	6.628	10	539.25	81.36	0.000
	Equal variances not assumed	6.628	7.500	539.25	81.36	0.000
Gluteus Maximus	Equal variances assumed	14.455	10	772.05	53.41	0.000
	Equal variances not assumed	14.455	8.478	772.05	53.41	0.000

Table 2. shows the independent t-test analysis for the different electromyographic variables of theamputated and non-amputated leg. As shown in the table, there is a significant difference in the maximum muscle activation of the rectus femoris, gluteus medius, and gluteus maximus between the amputated and non-amputated legs, as the p-value is not less than 0.05. However, there is no significant difference in the maximum muscle activation of the biceps femoris between the amputated and non-amputated legs as the p-value is less than 0.05.

3. Results

Table 1 shows the descriptive statistics for the different EMG variables of the amputated and non-amputated legs. It shows remarkable differences in the mean muscle activation values between the two groups.

EMG in intra-individual comparison
Independent t-test analysis (Table 2) shows a significant difference in maximal muscle activation between the legs of amputees and nonamputees in the rectus femoris, gluteus medius, and gluteus maximus muscles. However, no significant difference in maximal muscle activation of the biceps femoris muscle was found between the two groups.

4. Discussion

The significant differences in peak activation patterns of the rectus femoris, gluteus medius, and gluteus maximus muscles suggest different neuromuscular adaptations in amputee gait. These findings suggest potential compensatory mechanisms employed by transtibial amputees to adapt to their unique limb configuration during gait. In contrast, the lack of significant differences in biceps femoris muscle may indicate similarities in posterior thigh muscle activation between amputees and nonamputees.

A closer look at the data shows that there are significant differences in the mean muscle activation values between the two groups. For example, the mean peak activation of the rectus femoris is significantly lower in the amputated leg (220.92) than in the non-amputated leg (1140.72). Similarly, the mean peak activation of the gluteus medius and gluteus maximus is significantly lower in the amputated leg (516.65 and 263.96, respectively) than in the nonamputee leg (1055.90 and 1036.02, respectively).

Interestingly, however, mean peak activation of the biceps femoris showed no significant differences between the amputated and non-amputated legs (920.13 for amputated and 1134.48 for non-amputated legs). This observation suggests that amputation has no significant effect on biceps femoris activation compared with the other muscles studied.

To further analyze the significance of these differences, an independent t-test analysis was performed (Table 2). The results of the t-test show that there are significant differences in maximal muscle activation for the rectus femoris, gluteus medius, and gluteus maximus between the amputee and non-amputee legs (p-value < 0.05). These results suggest that amputation has a significant effect on the activation patterns of these muscles during exercise.

On the other hand, the t-test analysis also shows that there is no significant difference in the maximum muscle activation of the biceps femoris between the amputated and non-amputated legs (p-value > 0.05). This indicates that the biceps femoris is relatively unaffected by amputation in terms of activation.

5. Implications

Understanding neuromuscular adaptations in lower extremity amputees during gait has important implications for the development of modern prosthetic devices and rehabilitation programs. Tailored rehabilitation programs that focus on optimizing muscle activation patterns and motor control strategies may improve gait symmetry and overall walking efficiency in amputees.

6. Conclusion

Intraindividual EMG comparison of leg muscle activity of amputees and non-amputees during walking provides valuable insights into neuromuscular adaptations and potential compensatory patterns in athletes with lower limb amputation. These findings contribute to a more comprehensive understanding of musculoskeletal adaptations and provide a foundation for future research and interventions aimed at improving functional outcomes and athletic performance in lower limb amputees.

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