韓國精密工學會 2002年度 秋季學術大會論文集 pp.1070 ~ 1073 KSPE 02F102

Relationships Between the Transfemoral Socket Interface Pressure and Myoelectric Signal of Residual Limb During Gait

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ABSTRACT

The biomechanical interaction between the stump and the prosthetic socket is critically important to achieve close-to-normal ambulation. Many investigators suggested that the pressure changes during gait of transfemoral amputees are closely related to the prosthetic alignment, the socket shape, the stump size, and the residual muscle activity. The effects of the prosthetic alignment, the socket shape, and the stump size on the interface pressure were investigated previously. However, there is no report how the residual muscle activities in the transfemoral stump affect the socket interface pressure characteristics during gait. Since designs of socket for lower limb amputees need to consider the socket interface pressure characteristics, the interface pressure patterns by the residual muscle activities during gait should be investigated. In this study, myoelectric signals (MES) and socket interface pressure in residual limb of transfemoral amputees were measured during the stance and swing phases of gait. For the purpose, specially designed quadrilateral sockets that MES electrodes could be instrumented were fabricated. A total of two transfemoral amputees were participated in the experiments. The measured temporal MES amplitude and interface pressure in knee flexor (biceps femoris) and extensor (rectus femoris) had significant correlations ($P < 0.05$). Based on the test results, it was suggested that the residual muscle activity of transfemoral amputees stump is an important factor affecting socket pressure changes during walk.

Key Words : Transfemoral Amputee, Gait Analysis, Socket Interface Pressure, Myoelectric Signal, Socket Design Residual Muscle Activity

1. Introduction

For transfemoral amputees, the biomechanical interaction between the stump and the prosthetic socket during the stance and swing phases of gait is critically important to achieve normal-like ambulation. It is widely accepted that an abnormal socket interface pressure distribution and behavior cause pathology in the stump, which directly affects gait of amputees. Therefore, many investigators have studied static and dynamic socket pressure behaviors. The results of the investigations suggested that the pressure changes during gait of transfemoral amputees are closely related to the prosthetic alignment, the socket shape, and the stump size[1]. It is suggested that the temporal changes of hip moment during ambulation also affect the socket pressure distributions of transfemoral amputees[2]. Since knee flexor and extensor muscle activities are essential for normal gait, in addition, it can be postulated that the residual muscles in the stump of transfemoral amputees are still active. As a result, the residual muscle activities could affect to the socket interface pressure characteristics. However, relationships between the residual muscle activities and the socket pressure have not been well understood. Also, the behavior of knee flexor and extensor during gait of transfemoral amputees is not studied. The purpose of this study is to investigate the relationships between the residual muscle activities and the socket pressure characteristics during amputee gait with transfemoral prostheses.

2. Materials And Methods

In this study, an intelligent swing phase controlled 4-bar pneumatic knee transfemoral prosthetic system (BK Meditech, Korea). In addition, a quadrilateral suction socket based on brims (Otto bock, Germany) was utilized. To measure MES of residual muscles in the stump, specially designed sockets that the MES electrodes could be instrumented between the skin and inner wall of the socket were fabricated based on the individual muscle anatomy of subjects. Two unilateral transfemoral amputees fitted with the knee prosthesis, a fixed ankle, an energy storing foot, and the quadrilateral suction socket, participated in gait experiments (VICON 370, UK) with measuring socket interface pressures near at the MES electrodes (Novel, Germany). Figure 1 is a photo of the socket pressure measurement system with the MES electrodes. The prosthetic knee, foot, ankle, and socket were developed by Korea Orthopedic and Rehabilitation Engineering Center (KOREC).

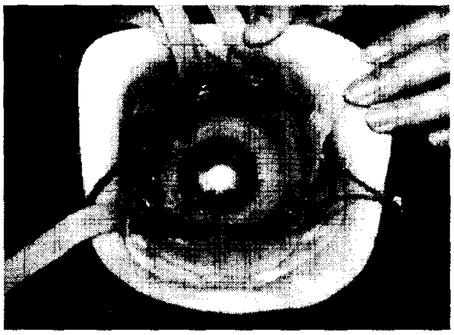


Figure 1. Configuration of the specially designed quadrilateral socket to place MES electrodes and interface pressure sensors

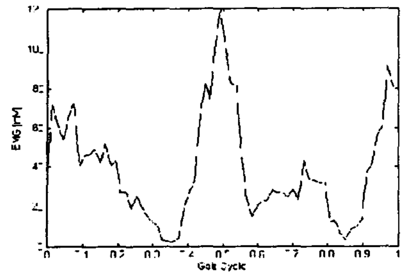
The subjects had no prior stump pain and disorder. Before the tests, the subjects were instructed and trained for close-to-normal ambulation for 4 weeks with the prostheses. The prosthetic system including the socket was carefully aligned based on individuality of each subject to make sure for close-to-normal walking before experiments. Data acquisition was performed in a manner that captured one complete, gait cycle with a gait speed of 1.14 m/s. Minimums of five gait trials for each subject for the statistical analysis were performed as a rate of 60 frame per second. The pressure measurements were synchronized to the gait experiments. Also, the MES electrodes were placed on the rectus femoris and biceps femoris that are the knee extensor and flexor, respectively. The MES was measured as a sampling rate of 1200 Hz and processed using the adaptive filter algorithm[3]. Figure 2 shows the completed experimental setup. Pearson correlation method (Minitab, USA) was applied to understand the relationship between the MES amplitude of residual muscles, and the measured socket interface pressure changes.

Figure 2. Experimental setup for the gait analysis with instrumentations of MES electrodes and interface pressure sensors

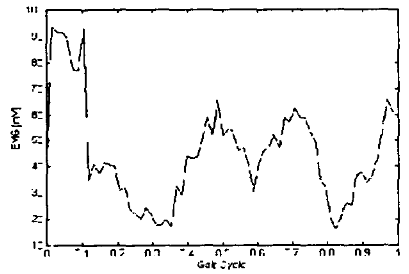
3. Results

Figure 3 shows the temporal changes of MES of residual muscles in stump for the subjects during gait. Figure 4 shows the MES of the rectus femoris and biceps femoris from normal person's gait [4]. As seen in Figures 3 and 4, the activities of residual muscles in transfemoral stump are different from those of normal person. For the biceps femoris, MES behavior of subject 1 and 2 shows an abnormal second burst near 50% of gait cycle, which cannot be observed in the normal gait. However, the residual muscle activity at the beginning period of gait is still existed. This means that the biceps femoris in the transfemoral stump is still working as the assistant for the hip extensor. However, it can be known that the function as decelerator for the swing leg at the terminal swing phase is lost. For the rectus femoris of transfemoral amputees, the activity still can be observed as seen in the normal gait. Particularly, the activities just after toe-off (about 50 to 60% of gait cycle), which is assisting the hip flexion to pull swing limb forward, is existed. Therefore, it can be understood that the residual muscles in the transfemoral stump are active to assist the gait of transfemoral amputee's gait. In this study, the stump length of transfemoral amputees is moderate. Thus, more study is required to know the effect of stump length variation on the residual muscle activities.

Table 1 shows the measured socket interface pressure and MES of the rectus femoris and biceps femoris (subjects 1 and 2) in transfemoral residual limb for all gait events.



(a)



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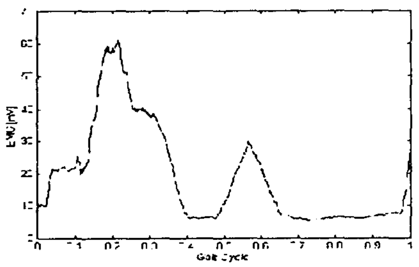

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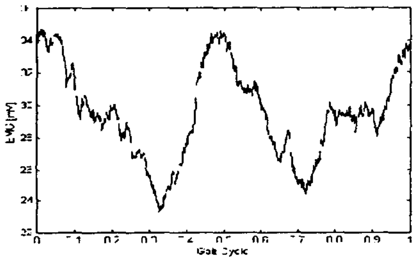

(d)

Figure 3. Transfemoral amputees' residual muscle activities (the vertical axis is MES in microvolts, mV) of the biceps femoris and rectus femoris plotted as a function of the gait cycle (a) MES of the biceps femoris: subject 1, (b) MES of the rectus femoris: subject 1, (c) MES of the biceps femoris: subject 2, and (d) MES of the rectus femoris: subject 2

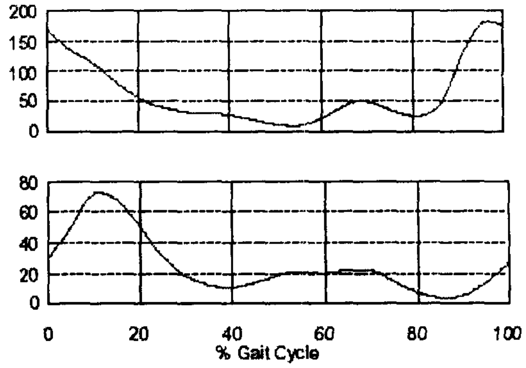

Figure 4. Normal person's muscle activity (the vertical axis is MES in microvolts, mV) of the biceps femoris and rectus femoris plotted as a function of the gait cycle[4]

For all events in gait cycle such as IC (initial contact), FF (foot flat), MS (mid-stance), PS (push-off), TO (toe-off), and TS (terminal swing), the interface pressure values of the rectus and biceps femoris were significantly correlated with the MES behavior for both subjects ($P < 0.05$). For the rectus femoris, Pearson correlation coefficients were 0.92, and 0.86 for subjects 1 and 2, respectively. For the biceps femoris, the coefficients for each subject, were 0.72, and 0.61, respectively. Based on the test results, it was suggested that the residual muscle activities, the rectus and biceps femoris, of amputee's stump is an important factor affecting socket interface pressure changes during walk. To understand changes of MES pattern in the transfemoral stump, more extensive research is required for all residual muscles.

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Table 1. Measured socket interface pressure and MES of the rectus femoris and biceps femoris (subjects 1 and 2) in transfemoral residual limb for all gait events.

Subject 1

Event		Rectus femoris	Biceps femoris
IC	MES	41.5	62.9
	(±SD)	±5.9	±20.9
	PRESSURE	91.3	26.6
	(±SD)	±26.5	±23.4
FF	MES	114.1	75.1
	(±SD)	±19.7	±26.2
	PRESSURE	254.3	209.0
	(±SD)	±21.0	±167.1
PO	MES	65.5	61.5
	(±SD)	±3.1	±52.2
	PRESSURE	179.6	68.6
	(±SD)	±16.6	±35.1
TO	MES	42.4	25.5
	(±SD)	±9.5	±12.3
	PRESSURE	52.6	4.0
	(±SD)	±32.6	±6.9
TS	MES	57.6	81.1
	(±SD)	±13.9	±16.1
	PRESSURE	94.0	44.3
	(±SD)	±12.7	±27.1

Subject 2

Event		Rectus femoris	Biceps femoris
IC	MES	32.7	11.1
	(±SD)	±2.16	±0.44
	PRESSURE	181.0	22.6
	(±SD)	±76.0	±33.2
FF	MES	32.2	28.0
	(±SD)	±6.6	±6.8
	PRESSURE	296.6	90.6
	(±SD)	±18.17	±14.15
PO	MES	36.0	9.5
	(±SD)	±4.4	±1.6
	PRESSURE	377.6	64.0
	(±SD)	±41.7	±11.7
TO	MES	29.6	13.0
	(±SD)	±5.2	±6.6
	PRESSURE	18.6	0
	(±SD)	±4.7	±0
TS	MES	33.4	30.1
	(±SD)	±2.3	±8.8
	PRESSURE	274.3	81.6
	(±SD)	±16.9	±6.0

※ IC: Initial Contact, FF: Foot Flat, PO: Push-Off, TO: Toe-Off, and TS: Terminal Swing

§ Unit: MES [μV] and Pressure [N/cm^2]