Technical Note

The Time-dependent Changes in EMG Recorded from the Medial Gastrocnemius of Young and Elderly Amputees

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Abstract. [Purpose] Dysfunction of lower extremity muscles is one risk factor of falls for amputee patients. However, the change in muscle activity pattern and balance ability of amputees who have no experience in standing with prosthesis during the period from prosthesis fitting to regaining the ability to walk has never been studied. Therefore, the objectives of the present study were to elucidate changes over time in the muscle activity pattern and walking speed from first prosthesis fitting to hospital discharge. We also investigated the differences of muscle activity during standing between younger and elderly amputee patients. [Methods] Electromyography measurements were performed on the gastrocnemius of the intact leg during standing. The test subjects were asked to shift their center of gravity forward. [Results] Two unique patterns of gastrocnemius activities were observed over time. In a younger patient, the amount of muscular activity of the gastrocnemius gradually increased over time. In an elderly patient, however, the amount of muscular activity of gastrocnemius gradually decreased over time. [Conclusion] The time-dependent changes in gastrocnemius muscle activities are indicative of postural control ability. Therefore, understanding the time-dependent changes in muscle activities during rehabilitation and the differences of postural control between younger and elderly patients would contribute to the development of effective rehabilitation programs for each patient.

Key words: Prosthesis, Postural control, EMG

INTRODUCTION

The most important goal of rehabilitation for a lower limb amputee is the independent performance of daily activities through restoration of functional walking ability. Amputees, however, must have the ability to stand independently with prosthesis. Miller et al. reported that 52% of prosthesis users experienced falls and 49% of amputees have a fear of falling. It also said that the fear of falling limits the daily movement of amputees and causes further deterioration of the balance ability required for walking1). Therefore, physical therapy for lower limb amputees should be focused on the prevention of falls during movement/walking for the improvement of everyday activities. For this purpose, it is necessary to properly evaluate the balance ability of amputees and to perform training to improve the balance ability based on the results of that evaluation. The objectives of the present study were to elucidate what type of compensatory movement and postural strategy are used by lower limb amputees for posture control during the period from prosthesis fitting to hospital discharge by analyzing the muscle activity patterns of the lower limb muscles and to elucidate the changes over time in the muscle activity pattern during the course of physical therapy. Elderly patients also have a higher risk of falling than younger patients because of biomechanical, physiological, and psychological differences. However, no study has yet focused on comparing time-dependent changes in muscle activity patterns between younger and elderly patients. Therefore, the other purpose of this study was to reveal the differences in muscle activity patterns during standing between younger and elderly patients.

SUBJECTS AND METHODS

A young male, 34 years old, and an elderly female, 84 years old, who had a lower limb amputated were the subjects. Neither of the patients had a history of orthopedic or neurological disease in the unaffected lower limb or the trunk. A patient who undergoes below-knee amputation...
due to diabetes has a normal deep sensation in the unaffected ankle joint. In both of our cases, the fitting between the socket and the stump on wearing was well adjusted with no pain in the stump. The time from amputation to prosthesis fitting varied between the subjects. The prosthesis used by the lower limb amputees was a Total Surface Bearing liner type and a SACH foot (Table 1). Surface electromyography (EMG) measurements were performed of the gastrocnemius medial head (GA) of the unaffected lower limb. The electrodes were placed on the most prominent bulge of the GA muscle following SENIAM guidelines. After sufficient treatment with Skinpure to reduce the inter-electrode resistance to no more than 10 KΩ on the skin, disposable electrodes (Blue Sensor, NF-50-K/W, Ambu) were attached at an inter-electrode distance of 2 cm. The EMG signals were amplified (to 1.0 mV) and band-pass filtered between 20–1,000 Hz using a Synact MT-11 (NEC Corp., Tokyo, Japan). The EMG signals were digitized using a waveform analysis system, Power Lab 16s (AD Instruments Ltd, Hastings, UK), at a sampling frequency of 1,000 Hz, and stored on a personal computer for off-line analysis. After data input, waveform processing was performed using waveform analysis software, Chart36.8, AD Instruments. Two different tasks of maintaining the static standing position were performed on the floor. The test subjects were asked to stand on the floor with their feet shoulder-width apart and look at a point set at 1 m distance to the front at the height of the eye for 10 seconds. The first task, reference task, was to maintain upright standing position on the prosthesis while holding parallel bars. The second task, experimental task, was forward weight shift while maintaining the standing position without grasping the parallel bars. The recorded data were smoothed using the Root Mean Square (RMS) value of every 100 msec using waveform analysis software. The reference contraction is judged to be reliable by being reproducible, giving approximately equal results within subjects over trial. Therefore, we used the EMG of another task as a reference contraction for EMG normalization. The normalized level of %RMSEMG was determined using the following formula.

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\text{%RMSEMG} = \frac{\text{Experimental task RMSEMG (second task)}}{\text{Reference task RMSEMG (first task)}} \times 100\%
\]

Maximum walking speed was measured in 10 m walking. No restrictions were imposed on the use of a cane for walking. Depending on the condition at the time of the measurements, subjects were allowed to use a crutch, or a single cane on the unaffected side while walking. The surface muscle activity and the walking speed were measured once a week, a total of four occasions, starting on the day of prosthesis fitting (first week). This study was conducted after approval was obtained from the Ethics Committee of Tohoku University Graduate School of Medicine. The study patients were sufficiently informed about the purpose and methods of the study, and their consent to participation was obtained.

**RESULTS**

When the time-dependent changes in muscular activity of GA, which is the most active muscle in the standing position, were investigated in the forward weight shift task, two unique patterns were observed. For the younger subject, no muscle activity of GA was observed in the standing position tasks in the first week, but the amount of muscular activity of GA gradually increased over time. On the other hand, for the elderly subject, increased activity of GA was observed in the forward weight shift task in the first week, when the prosthesis was worn for the first time, followed by a gradual decrease in activity over time (Table 2). The maximum walking speed gradually increased over the period from

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### Table 1. Characteristics of the subjects

| Subjects | Sex | Age (year) | Height (cm) | Weight (kg) | Amputation Site | Socket | Ankle Joint | Cause | Week to start PT after amputation | Week to wear prosthesis after amputation | Week to discharge after wearing prosthesis for the first time |
|----------|-----|------------|-------------|-------------|----------------|--------|-------------|-------|-------------------------------|---------------------------------|-----------------------------------|
| Young    | M   | 33         | 175         | 72          | Right BKA     | TSB    | SACH        | Tumor | 1                             | 7                               | 4                                  |
| Elder    | F   | 85         | 150         | 45          | Left BKA      | TSB    | SACH        | Diabetes | 1                             | 5                               | 14                                 |

M: Male, F: Female, BKA: Below knee amputee, TSB: Total surface bearing, SACH: Solid ankle cushion heel; J-foot M1170, PT: Physical therapy

### Table 2. Time shift of activity in GA (%RMSEMG) and walking speed (m/min)

| Week    | %RMSEMG (%) | MWS (m/min) |
|---------|-------------|-------------|
|         | Younger     | Elderly     | Younger     | Elderly     |
| First   | 0.66        | 18.43       | 48.58       | 15.12       |
| Second  | 4.71        | 16.48       | 73.89       | 24.57       |
| Third   | 5.98        | 12.65       | 80.32       | 24.33       |
| Fourth  | 8.85        | 5.41        | 100         | 43.17       |

%RMSEMG: % Root mean square electromyography, MWS: Maximum walking speed
when the prosthesis was worn for the first time to when the subjects were discharged from the hospital (Table 2).

**DISCUSSION**

The basic elements for the smoothest and most energy efficient walk are proper balance ability and posture control function\(^2\). In lower limb amputation, the contralateral lower limb function influences subsequent ability to perform daily living and transfer activities, and standing balance on the unaffected side is an important determinant of whether walking with a prosthesis is possible or not\(^3\). Isakov et al. reported that the muscle of the unaffected lower limb of prosthesis wearers tended to adopt a balancing strategy to compensate for the loss of the ankle joint and muscles due to amputation\(^4\). Therefore, lower limb amputees need to adapt to asymmetrical body weight and muscular strength when they exert effort to maintain static standing while wearing a prosthesis. In the present study, we evaluated the changes in surface EMG activity of the gastrocnemius during standing, and the walking speed with a prosthesis. The muscular activity of GA is most conspicuous when the amputee is standing with the prosthesis for the first time. When the static standing position is maintained, the GA is activated in preparation for the forward movement of the center of pressure\(^5, 6\). We found two unique muscle activity patterns were exhibited by the two below-knee amputees. When the prosthesis was first worn, the younger subject was so careful about maintaining the standing posture that adequate forward movement of the center of gravity could not be achieved. For the elderly subject, however, marked activity of the GA was found, and GA activity at the final assessment was lower than that of the initial measurement, especially during the forward weight shift task. These time-dependent changes in the muscular activity of GA indicate how younger and elderly amputees adapt muscular force to maintain standing posture, and it might also be as a cause of falls by elderly patients in the early stage of standing or gait training. Excessive movement of the center of gravity affects postural control. The subjects learned the method for shifting the center of gravity forward in a stable manner, resulting in the gradual reduction or increase of GA muscle activity. These activities of GA, therefore, are indicative of postural control ability. There are many factors known to contribute to the improvement of the walking speed of amputees. As far as the results of this study are concerned, it can be concluded that one important factor is regaining the ability to be able to shift the center of gravity in the static standing position through the efficient muscle activity of the unaffected lower limb. In conclusion, the trend of muscle activities over time should contribute to the development of effective rehabilitation programs.

Due to the limited number of subjects included in this study, a statistical analysis of sufficient power could not be performed. Furthermore, there were obvious differences in biomechanical, physiological, and psychological attributes because of age differences. Biomechanical or physiological perspective approaches are very important. In this study, however, there was no history of disorders of the trunk, such as lordosis or kyphosis, so we only focused on the differences in EMG. Further studies with larger numbers of subjects stratified by the causes and types of amputation are needed to clarify the specific factors associated with the acquisition of the ability to walk by amputees, and the development of efficient methods for physical therapy and programs.

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