



Original Article

The relationship between trans-femoral prosthesis alignment and the center trajectory of plantar pressure in the frontal plane

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Abstract. [Purpose] It is difficult to identify by visual observation whether alignment abnormalities in trans-femoral prostheses in the frontal plane are attributable to the adduction angle or the abnormal alignment of the positions of the medial and lateral sides of the socket in relation to the foot. Therefore, we focused on the trajectory of the center of plantar pressure during walking, and we proposed a method for differentiating these two alignment abnormalities. [Subjects and Methods] We recruited 4 trans-femoral unilateral amputees. Bench alignment was achieved initially. We compared the amplitude of the trajectory of the center of plantar pressure when walking under 2 conditions: 1) when changing the adduction angle and 2) when changing the positional relationship between the socket and the foot. [Results] It was not possible to distinguish between the 2 types of malalignment on the prosthesis side. There was a significant difference when changing the positional relationship on the contralateral side. Thereby, the plantar pressure of the contralateral side could be used to distinguish between the 2 types of malalignment. [Conclusion] The results of this study suggested that trans-femoral prosthesis malalignment could be evaluated through the plantar pressure of the contralateral side in amputees.

Key words: Trans-femoral prosthesis, Prosthesis alignment, Center of trajectory of plantar pressure

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INTRODUCTION

A trans-femoral prosthesis is used by individuals with above-knee amputation. Alignment is one of the features of a prosthesis that needs to be adjusted. Prosthesis alignment represents the relative positional relationship among the prosthesis socket (hereinafter referred to as the socket), knee joint, and foot, and it is adjusted by changing the angle and distance. The adjustment is usually performed by a prosthetist, but it is also desirable that physical therapists have a thorough understanding of alignment for gait training.

To perform adjustments, it is necessary to examine gait abnormalities. Currently, visual observation is the main assessment method, but this requires experience. As amputees may be rarely seen in clinical practice, it can take many years to acquire this skill. A method of evaluating prosthesis alignment abnormalities using objective data would enable alignment abnormalities to be detected with greater certainty. Such a method would fill the gap in outcomes between skilled and non-skilled physiotherapists. The effects of malaligned prostheses were previously studied in the field of physical therapy¹⁻³. This is therefore an important topic for physical therapists.

A system for evaluating alignment abnormalities in trans-tibial prostheses has been developed⁴⁻⁷. This method involves

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inserting the sensor immediately below the socket and estimating various alignment abnormalities using the measured moment.

Rather than using the moment measured on the prosthesis, some studies have examined the plantar pressure. When a healthy person is in a standing position, the left and right plantar pressures are almost equal. Thus, Smith et al. announced that it may be possible to identify prosthesis alignment abnormalities by measuring the left and right sole pressures while wearing the prosthesis⁸⁾. Perkins et al. revealed the characteristics of a prosthesis user through the plantar pressure by comparing the plantar pressures of the prosthesis and foot sides in a standing position⁹⁾. However, no research has investigated the identification of alignment abnormalities through measuring the plantar pressures of the prosthesis and foot sides when walking.

In this study, an analysis of the relationship between trans-femoral prosthesis alignment abnormalities and the center of trajectory of plantar pressures of the foot and prosthesis sides during walking was performed. Trans-femoral prosthesis alignment adjustment in the frontal plane is particularly difficult. Similar phenomena can occur by changing the adduction angle of the socket or by changing the positional relationship of the side of the socket to the foot. Skilled intuition is required to visually detect a difference between these two alignment abnormalities. This study focused on alignment abnormalities in the frontal plane and aimed to identify whether prosthesis alignment abnormalities were attributable to the adduction angle or the positional relationship between the socket and foot by evaluating the plantar pressure.

SUBJECTS AND METHODS

The subjects consisted of 4 trans-femoral unilateral amputees. All the subjects agreed to participate in the study after receiving explanations regarding the purpose and procedures of the experiment, and signed an informed consent statement before its start. The selection criteria were as follows:

- Adult male
- Amputee period and cause definitely known
- Activity level: Russek's classification score of 4 or more
- Regular use of a prosthesis
- Consent to participate in the study

The exclusion criteria were a history or signs of peripheral vascular disease, an orthopedic disease that limited walking, and neurological disorders.

A force plate (AMTI Inc.: Watertown, MA, USA) was used to record the center of trajectory of plantar pressure (center of pressure, COP) of the prosthesis and contralateral sides during gait. Four measurements were made per subject with a gait distance of 10 m.

For the prosthesis to be used in the measurement, a socket was produced, fitted, and constantly reviewed by an expert prosthetist to minimize problems caused by socket incompatibility in the present study. The knee joint used was the 3R15 (Otto Bock Inc.) with no major features other than the load brake. The foot used was the 1D10 (Otto Bock Inc.) single axis foot having only dorsal and plantar flexion functions.

Measurements were taken under 5 conditions. Bench alignment was assessed as an initial state. Bench alignment (adduction and flexion of the socket by 5 degrees each) has been accepted generally in the industry as the initial state of alignment adjustment. This is determined numerically before adjusting the device to suit the user. The other conditions involved increasing or decreasing the alignment of the adduction angle increased or decreased by 3 degrees and adjusting the position of the foot by 5 mm medially or laterally compared to the socket. The amount of change is close to the minimum amount that is conducted in clinical practice. All subjects were measured after performing the walking exercises until they were fully familiarized with each exercise. In addition, to remove the effects of fatigue, all subjects rested for more than 5 min between measurements.

The difference between the maximum and minimum values in the lateral direction of the COP was calculated as the displacement of the COP in 1 walking period. For each subject, the average value obtained in the 4 trials was calculated. For each subject's data, a t-test was used to compare the bench alignment and alignment abnormalities produced by changing the adduction angle, which are attributable to the positional relationship in the socket and foot, to detect the presence or absence of a significant difference. In particular, it has been said that on visual observation, there are similarities between a state in which the foot is located on the lateral against the sockets and the adduction angle is increased and a state in which the foot is located on the medial against the sockets and the adduction angle is reduced. Therefore, these combinations were analyzed.

This research method was examined and approved by the Hokkaido University of Science ethics review committee (No. 68).

RESULTS

Table 1 illustrates the amount of COP displacement in the lateral direction in bench alignment, in the state with a decreased adduction angle, and the state in which the foot was located on the medial side against the socket on the prosthesis and contralateral sides. A significant difference between the bench alignment and the 2 alignment state variations was observed on the prosthesis side in all 4 subjects. In all 4 subjects' data for the contralateral side, no significant difference was observed

Table 1. The amount of center of pressure displacement in the lateral direction in bench alignment, in the state with a decreased adduction angle, and in the state in which the foot was located on the medial side against the socket on the prosthesis and contralateral sides

	Subject							
	A		B		C		D	
	Prosthesis	Contralateral	Prosthesis	Contralateral	Prosthesis	Contralateral	Prosthesis	Contralateral
Bench alignment	44.9±3.94	71.7±3.02	35.6±3.55	64.0±5.24	40.3±1.09	68.0±3.16	45.5±2.69	79.3±2.17
Decreased adduction angle	75.2±3.19*	78.0±8.20	51.0±1.87*	68.3±6.65	59.5±1.12*	74.8±5.45	58.75±2.49*	84.0±3.39
Foot located medial	65.7±4.28*	134.0±7.78*	55.3±4.0*	114.8±11.08*	61.2±1.09*	134.0±4.64*	64.25±3.27*	138.3±3.11*

Unit (mm). Mean ± SD. *p<0.05, compared with the bench alignment

Table 2. The amount of center of pressure displacement in the lateral direction in the bench alignment, in the state with an increased adduction angle, and in the state in which the foot was located on the lateral side against the socket on the prosthesis and contralateral sides

	Subject							
	A		B		C		D	
	Prosthesis	Contralateral	Prosthesis	Contralateral	Prosthesis	Contralateral	Prosthesis	Contralateral
Bench alignment	44.9±3.94	71.7±3.02	35.6±3.55	64.0±5.24	40.3±1.09	68.0±3.16	45.5±2.69	79.25±2.17
Increased adduction angle	55.5±5.12*	84.5±4.15	63.5±1.80*	76.5±2.96	58.8±2.28*	74.2±3.03	58.8±1.92*	82.0±1.86
Foot located lateral	46.3±2.17	109.0±7.11*	61.5±3.90*	103.0±4.30*	37.2±1.92	109±4.21*	52.8±2.49	111±4.23*

Unit (mm). Mean ± SD. *p <0.05, compared with the bench alignment

between the alignment variation attributable to a decreased adduction angle and the bench alignment, but a significant difference was observed between the alignment variation when the foot was located on the medial side against the socket and bench alignment.

Table 2 presents the amount of lateral COP displacement in bench alignment, in the state with an increased adduction angle, and in the state in which the foot was located on the lateral side against the socket on the prosthesis and contralateral sides. In subject B, a significant difference was observed between the bench alignment and the 2 alignment state variations on the prosthesis side. In the other 3 subjects (A, C, and D), a significant difference was observed only between the alignment variation attributable to the adduction angle and bench alignment. In all 4 subjects' data for the contralateral side, no significant difference was observed between the alignment variation with an increased adduction angle and the bench alignment, and a significant difference was observed between the alignment variation in which the foot was located on the lateral side against the socket and the bench alignment.

DISCUSSION

On the prosthesis side, it was found that it was possible to distinguish bench alignment from alignment variation using the lateral COP displacement of the prosthesis side. However, as a significant difference occurred in both alignment variations, it was not possible with these data to determine whether the variation was caused by the adduction angle or the foot position. It is considered that this demonstrates that these 2 alignment variations appear to be similar on visual observation.

It was found that it was possible to distinguish between the 2 alignment variations by measuring the amount of lateral COP displacement on the contralateral side.

In subject B, it was not possible to distinguish between the 2 alignment variations, as seen in Table 2. In addition, because a significant difference occurred between variations in the adduction angle and bench alignment in all 4 subjects, similar to that illustrated in Table 1, this suggested the existence of a similar phenomenon between both variations.

It was found that it was possible to distinguish between the 2 alignment variations by measuring the amount of lateral displacement of the COP on the contralateral side (Table 2).

When an alignment abnormality is present, the prosthesis user experiences an abnormal gait and tries to control the gait as much as possible using the residual limb to avoid falling. It is often said that focusing on the prosthesis is important for identifying prosthesis alignment abnormalities. However, in such cases, the contralateral foot has an important role in stabilizing gait. This confirms that the contralateral foot allows the alignment abnormality to be more clearly determined. However, as the contralateral foot has greater muscle strength and greater control than the prosthetic limb, it is difficult to visually assess

compensatory mechanisms. For that reason, such mechanisms need to be represented by objective data using force sensors or other modalities. The results measured in this study reveal that compensatory motion is present in the contralateral foot and demonstrate the potential of the motion of the contralateral foot to be used to determine prosthesis alignment abnormalities.

Previously, when adjusting the alignment of the trans-femoral prosthesis, the prosthetist primarily focused on the prosthesis itself and confirmed the phenomenon appearing in the prosthesis. However, it is difficult to determine alignment abnormalities in detail by examining only the prosthesis. Prosthetists therefore need experience and intuition to make adjustments.

This study focused on the center of trajectory of plantar pressure of the contralateral foot at the time of gait and analyzed the relationship between the bench alignment and alignment variations that appear visually similar. This revealed that the prosthesis side alone was not sufficient for determining alignment variation and that the data of the contralateral side were useful to identifying variations. Thus, it was suggested that various data from the contralateral foot could be useful in alignment adjustment.

Tables 1 and 2 reveal that it is possible to distinguish between the 2 alignment variations by using the data of the healthy foot side, but it is difficult to determine whether the foot is laterally or medially located against the socket through these data. It may be possible to discriminate in more detail by analyzing plantar pressure distribution or plantar pressure.

The number of subjects in this study was 4, and thus, the outcome of this study cannot be generalized. In the future, the patterns for determining alignment abnormalities may be determined by recruiting more subjects and by storing the obtained data.

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