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Research Article

Design and Fabrication a Pneumatic Suspension System in Transtibial Supracondylar Prosthesis and its Effect on Residual Limb Pistoning

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ABSTRACT

Introduction: Transtibial amputation is the most common amputation in lower limbs. Volume loss of residual limb occurs during daily use of prostheses, which results in pistoning between residual limb and prosthetic socket. The goal of this study was to design and fabricate a pneumatic suspension system in transtibial supracondylar prostheses and to evaluate its effect on residual limb pistoning.

Material and Methods: Five unilateral transtibial amputees were participated in this study. After designing and fabricating pneumatic suspension system, its effect on residual limb pistoning was evaluated using photographic method in five static stages including full weight bearing, semi weight bearing, non-weight bearing, 30 N and 50 N loads.

Results: Residual limb pistoning was reduced using pneumatic suspension system during non-weight bearing, 30 N and 50 N static loading.

Conclusion: The use of pneumatic suspension system would reduce pistoning in supracondylar transtibial prostheses.

Keywords: Transtibial supracondylar prostheses; Prosthetic suspension; Pistoning (vertical movement)

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Introduction

Amputation is removing a body limb partially or totally through the surgery. Amputation can be congenital or is caused due to reasons such as vascular diseases, trauma, or cancer.

Transtibial amputation is the most common amputation in lower limbs (1). To receive prosthesis is one way to cure and rehabilitate transtibial amputees. The suspension system is a major component in the transtibial prosthesis (2). A suitable suspension system improves socket fit, function and also helps the amputee to have a secure and independent gait with less energy expenditure (3-7).

The daily volume loss of the stump occurs during repetitive use of the prosthesis (1). Volume loss leads to a poor socket fit and function that causes pistoning between the residual limb and socket (3). Pistoning (vertical movement) has undesirable effects on the residual limb. Shear stresses on the skin, gait abnormalities, and pain is some of these effects (8, 9). A successful suspension system can decrease pistoning and its unpleasant effects.

Various types of prosthetic suspension have been used in transtibial prostheses such as pin/lock, suction, vacuum, and magnetic lock in the total surface bearing socket (1, 10-13).

However, using the atmospheric suspension systems (i.e., vacuum, pin and lock, and suction liners) cause a better sense of proprioception and less pistoning (14). They lead to skin problems such as perspiration and itching. They are only used for stable volume stumps and are not usable for stumps with fluctuating volume (15). To fabricate a suction suspension socket is more time-consuming and expensive in relation to traditional suspension socket such as patellar-tendon-bearing prostheses (16).

We consider a suspension system to compensate for volume loss of the residual limb. To evaluate this system clinically, we measured the pistoning between the residual limb and socket in transtibial amputees.

Materials and methods

Five transtibial amputees agreed to participate in the study as a sample of convenience and were asked to sign a written consent form. Ethical approval was obtained from the University of Iran Ethics Committee before the study. The inclusion criteria were unilateral transtibial amputees with at least 13 cm stump length (inferior edge of the patella to distal end of the stump), intact upper limbs (hand strength), no pain or wound in their stumps, and mobility without assistive devices such as cane (17).

First, each subject wore a comfort socket liner (silicone liner) over the residual limb. Then, the prosthetist cast a negative plaster and prepared a positive plaster (Figure 1).

Figure 1. Provided air bladder

A positive mold of the air bladder was composed of wax (toughened-pink dental modeling wax, crystal, Tehran, Iran) and was designed according to the anatomical shape of the medial supracondylar of the positive plaster of the residual limb (Figure 2).

Figure 2. Place of air bladder

After fabricating a positive wax mold of the air bladder, three layers of Perlon Stockinette were applied (2.4 mm thickness) over the mold. Before manufacturing the new socket, a dummy of the air bladder was placed in the supermedial portion of the positive mold. Then, lamination was done using acrylic lamination resin (Figure 3).

Figure 3. Transtibial supracondylar prostheses and inserted air bladder

In this study, a single socket was fabricated and an air bladder was in place in all of the stages. Using pneumatic suspension system indicates an air bladder with air pressure inside it and not using pneumatic suspension system represents an air bladder without air pressure.

Each subject was fitted with the new socket and the prosthetist ensured that there was no gait abnormality, and the fit of the prosthetic socket was satisfactory (Figure 4).

Figure 4. Fitted prosthesis

According to the previous studies, pistoning was measured using the photographic method with a digital camera and two markers and a reference ruler in static conditions and to stimulate gait a 30 N and 50 N loads were used (18-21). Photographs were taken from a fixed distance in such a way that the markers and the ruler could be clearly observed. One reference ruler was attached on the lateral side of the socket as a reference to measure the real displacement on the photos. Markers were placed on the following positions: proximal lateral end of the liner, proximal lateral end of the socket.

First, the subjects walked on a treadmill with self-speed for 20 minutes. This amount of walking was a stimulation to reduce the volume, similar to the daily volume loss of the residual limb (22).

Following that the pistoning occurred between the socket and the residual limb in each static condition was determined before using pneumatic suspension system.

The static positions consisted of (1) Full weight bearing, (2) semi-weight bearing, (3) non-weight bearing, (4) after applying a 30 N load, and (5) after applying a 50 N load (Figure 5).

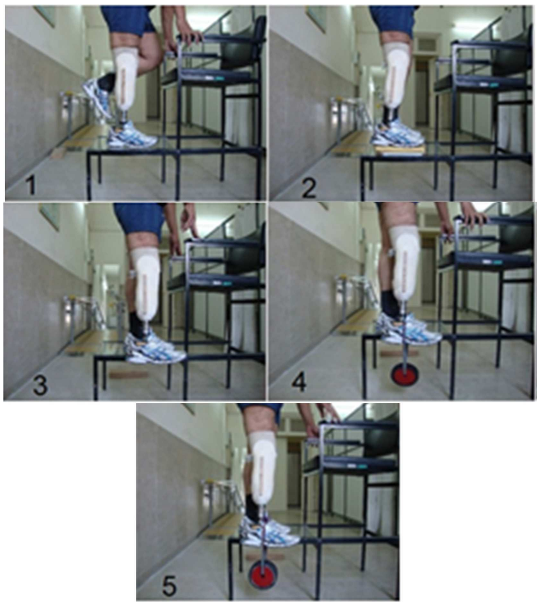

Figure 5. The five condition of pistoning test

These conditions were repeated three times (three trials) and the average values were used for a statistical analysis. The values obtained in full weight bearing were considered as a baseline with which all other positions were compared.

The assumption of normality and homogeneity of variance was verified using the Kolmogorov–Smirnov test. Paired-samples t-tests were used to compare mean peak pistoning in different two statuses (before and after using pneumatic suspension system).

This study was done on five transtibial amputees. A pneumatic suspension system in transtibial supracondylar prosthesis was designed and fabricated. The goal of this study was measuring pistoning between residual limb and prosthetic socket using this pneumatic suspension system. Subject characteristics are listed in table 1.

Results

The results obtained from the static evaluation of pneumatic suspension system in transtibial supracondylar prostheses showed that there was a significant difference ($P < 0.050$) between two conditions (before and after using pneumatic system). The average displacements in five subjects between two conditions are listed in table 2.

Discussion

Statistical analyses revealed that there was a significant difference in pistoning before and after using this system in non-weight bearing, and after adding 30 N and 50 N loads to the prosthesis. It might be concluded that the air bladder inserted in medial supracondylar transtibial prosthesis has increased its suspension effect and has confined residual limb downward movement in the socket.

It seems that using 30 N loads before using pneumatic suspension and due to the residual volume loss, more pistoning occurred between residual limb and prosthetic socket (12.2 ± 5.2). Suspension effect of air bladder would increase and results in reducing downward movement and finally decreases this amount of pistoning. Although it occurred after using pneumatic suspension, it showed a significant decrease (7.0 ± 3.8).

In this study, a pneumatic suspension system in transtibial supracondylar prostheses was designed, fabricated, and evaluated.

In 2001, Jason Tanner compared tibia displacement and soft tissue by radiographic method in two different suspensions (23). Tibia displacement was recorded in 3 conditions which consisted of full weight bearing, semi weight bearing, and non-weight bearing. Tibia displacement was the same in two suspension system. In neoprene suspension tibia and soft tissue, displacement was more in silicone suspension. The result of this study accords the previous study and it seems that minimum difference is due to the difference in suspension system.

In 2011, Gholizadeh et al. (19) used the photographic method and 3 N, 6 N, and 9 N loads in three transtibial amputees. The results showed pistoning decrement in 3 conditions (non-weight bearing and 3 N, 6 N, and 9 N loading).

Table 1. Subject characteristics

Subject no.	Age (year)	Height (cm)	Mass (kg)	Cause of amputation	Amputated side	Stump length (cm)	Mobility grade (K-level)*
1	53	160	62	Congenital	Left	16	K3
2	36	174	73	Trauma	Left	16	K3
3	41	190	98	Trauma	Right	21	K3
4	47	175	62	Trauma	Right	14	K4
5	54	170	70	Trauma	Left	13	K3

*K-level: Based on American Academy of Orthotist and Prosthetist

Table 2. Average displacements in millimeters and t value

Static condition	Sample	Mean ± SD	T value	P value
Pistoning comparison in semi weight bearing before and after pneumatic suspension system	5	−0.6 ± 1.9	−0.688	0.525
Pistoning comparison in non-weight bearing before and after pneumatic suspension system	5	4.6 ± 3.2	3.205	0.033
Pistoning comparison in 30 N loading before and after pneumatic suspension system	5	5.2 ± 3.2	3.555	0.024
Pistoning comparison in 50 N loading before and after pneumatic suspension system	5	4.2 ± 2.2	3.833	0.031

SD: Standard deviation

In this study, more pistoning occurred when full weight bearing changed to 30 N loading to the prosthesis (5.2). This finding contradicts Gholizadeh et al. (17) findings.

In a study by Gholizadeh, it was indicated that pistoning more displacement occurred when static condition changed from full weight bearing to non-weight bearing and this was because of rapid knee angle change. Muscle contraction in non-weight bearing caused knee flexion and resulted in sudden displacement.

In current study, this pattern occurred after adding 30 N loads and decreased after 50 N loading. It can be conferred that decreasing pistoning is because of knee angle stability and knee muscle adaptation. Any other difference between this study and the previous study is due to the different in suspension types. Mean pistoning displacement in Gholizadeh study was 9 mm and in this study, it was 5.2 the difference is because different loading were used in two studies.

The mean piston between no weight bearing and semi weight bearing before using pneumatic suspension system was 8.6 and it decreased after using pneumatic suspension system to 3.4. These findings were contrary to Gholizadeh et al. (17) that suggest 2 mm of pistoning was recorded between semi-weight bearings to non-weight bearing in Dermo liner suspension. Whereas this amount of pistoning was lower in seal in liner suspension, It is clear that after using seal in suspension as the beneficial suspension the amount of pistoning decreased. Any other difference in findings may be due to different measurement tools and liners.

A study by Eshraghi et al. (24) showed that the use of new magnetic suspension decreased pistoning compared to common suspension system (pin and lock).

The amount of pistoning which was decreased in new magnetic suspension was 5 mm and it occurred when amputees changed from semi weight bearing to non-weight bearing. Our finding was congruent to Eshraghi finding.

In this study, semi-weight bearing in static condition was simulated to loading response and pre-swing in dynamic gait and semi weight bearing to non-weight bearing was simulated to initial swing of gait. Hence, the results were compared to another study which was done by Gholizadeh in 2012 (14). There was an agreement in findings as there was no pistoning in suspension in pre-swing and loading response and the same results were found in current study.

As another study shows, there is no pistoning between full weight bearing and semi weight-bearing (20). It can be inferred that in full weight bearing distal of residual limb impacts to distal of socket and the friction between the liner and the socket in both conditions of using or not using pneumatic suspension system prevents any pistoning. The greatest change of piston has been shown to occur at initial swing (5.4 ± 0.6 in Dermo and 2.5 ± in seal-in) which was compatible with the results of this static study evaluation.

A study by Brunelli et al. (21) evaluated pistoning in different static conditions with two different suspension systems. In that study, the mean difference pistoning after adding 30 N between two suspension systems was 5.7 mm, whereas our study showed the mean difference pistoning after adding 30 N before and after using pneumatic suspension system was 5.2 mm. Although there is similarity in the pattern, the variation of findings might be due to the variety of suspension systems.

There was some limitation in this study such as small sample size and not measuring other variables like interface pressure some long-term effects of using this pneumatic suspension system like evaluating the quality of this system through prosthetic questionnaire could not achieved due to non-cooperation of amputees.

Conclusion

The current study introduced a pneumatic suspension system for those amputees who use transtibial supracondylar prosthesis and suffer from difficulties due to their daily volume loss. Our findings showed that using pneumatic suspension system may reduce pistoning within the socket after volume loss.

Conflict of Interests

Authors have no conflict of interests.

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