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Short communication

A new method to quantify liner deformation within a prosthetic socket for below knee amputees

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ABSTRACT

Many amputees who wear a leg prosthesis develop significant skin wounds on their residual limb. The exact cause of these wounds is unclear as little work has studied the interface between the prosthetic device and user. Our research objective was to develop a quantitative method for assessing displacement patterns of the gel liner during walking for patients with transtibial amputation. Using a reflective marker system and a custom clear socket, evaluations were conducted with a clear transparent test socket mounted over a plaster limb model and a deformable limb model. Distances between markers placed on the limb were measured with a digital caliper and then compared with data from the motion capture system. Additionally, the rigid plaster set-up was moved in the capture volume to simulate walking and evaluate if inter-marker distances changed in comparison to static data. Dynamic displacement trials were then collected to measure changes in inter-marker distance due to vertical elongation of the gel liner. Static and dynamic inter-marker distances within day and across days confirmed the ability to accurately capture displacements using this new approach. These results encourage this novel method to be applied to a sample of amputee patients during walking to assess displacements and the distribution of the liner deformation within the socket. The ability to capture changes in deformation of the gel liner will provide new data that will enable clinicians and researchers to improve design and fit of the prosthesis so the incidence of pressure ulcers can be reduced.

1. Introduction

In the United States, approximately 1.7 million people are living with limb loss (Ziegler-Graham et al., 2008). Following amputation, wound management and healing is essential because further amputation is a clinical concern due to infection or the formation of skin wounds called pressure ulcers (Dillingham et al., 2005). These ulcers are deep penetrating wounds that frequently occur on the residual limb at the socket interface (Fig. 1) (Bouten et al., 2003). Another problem associated with prosthetics is a movement called pistoning. Pistoning is where the prosthetic device translates vertically with respect to the residual limb (Gholizadeh et al., 2012). To reduce pistoning and improve comfort, a soft gel liner is commonly used between the skin and prosthetic device (Heim et al., 1997, Narita et al., 1997). While the gel liner interface provides clinical benefits, understanding its effects at the skin surface during ambulation is important as this high friction interface may be a source of tissue breakdown. Therefore, a need exists to understand how the liner moves relative to the prosthetic device and relative to the skin.

Skin movement and residual limb loading are ongoing throughout the day for prosthetic users, this loading, coupled with deformation and strain on the skin has been shown to play a role on ulcer formation (Gefen et al., 2008). In particular, for lower-leg prosthetic users, we hypothesize that there is uneven displacement of the gel liner within the socket with larger displacements occurring distally. Resulting from uneven displacements, non-uniform strains or slippage of one surface to another may result in regions of high shear forces on the skin and deeper tissues. To study the relative movement between the skin and the prosthetic device we must first develop a method that permits this assessment.

Previous research has provided limited information on the movement that occurs between the socket and liner interface (Childers and Siebert, 2015; Gholizadeh et al., 2012). Dynamic roentgen stereogrammetric analysis was also utilized to assess skin movement within the socket however this study was limited to small movements so the participant remained within the small

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Fig. 1. Distal anterior tibia region skin break down and ulceration.

capture region of the 3D digitizer (Papaioannou et al., 2010). None of these methods have studied the complete displacement field of gel liner or limb motion within the socket.

Motions occurring within the socket are not measured by prosthetists because the interface region is not visually accessible and a method for quantifying these motions is not readily available. Thus, the objective of this work was to develop and validate a quantitative method for assessing limb displacement patterns for patients with transtibial amputation while wearing a prosthetic device.

2. Methods

For the development of this method, research was focused on transtibial prostheses with a gel liner interface and pin locking suspension (Fig. 2) (Johnson and Davis, 2014; Gholizadeh et al., 2014).

2.1. Clear prosthetic and human limb models

To allow for measurement and capture of the limb motion and anatomical landmarks, the socket was manufactured out of a clear material called Thermolyn. Thermolyn is a transparent, thermoplastic material commonly used in fabrication of prosthetic "test sockets" for clinical use leading up to a definitive prosthetic socket. The same procedure was followed for the development of this clear socket as used for the individual's standard socket (Fig. 2b).

To test the ability to capture motion data of the gel liner, through the transparent socket, two limb models were used: (1) an anatomical replica made of rigid plaster (Fig. 3a) and (2) a deformable limb model (Fig. 4a) which mimics the anatomical structure and deformable nature of a transtibial limb (Burner et al., 2013; Dombroski et al., 2014).

2.2. Markers

The production of the clear sockets allowed reflective thin-disc motion capture markers (0.1 mm thick and 9.5 mm diameter) to be positioned inside on the gel liner directly beneath the surface of the transparent socket and spherical markers on the outside of the socket so that static anatomical locations could be measured. Anatomical locations of interest included: anterior tibial tuberosity, anterior tibial crest, distal end of the tibia, lateral proximal fibular head, distal fibula, intersegmental locations along the lateral fibula, medial tibial condyle, soft tissue medial limb border to distal end, and gastrocnemius muscle soft tissue locations on posterior calf are shown on Figs. 3 and 4 while the displacement measures are presented in Table 1. The plaster model was tested first with an initial marker set-up consisting of sixteen reflective thin-disc markers beneath the clear, transparent socket (Fig. 3). Following data collection and analysis from the plaster limb, the deformable limb model had marker placements adjusted to improve the representation of transverse and longitudinal inter-

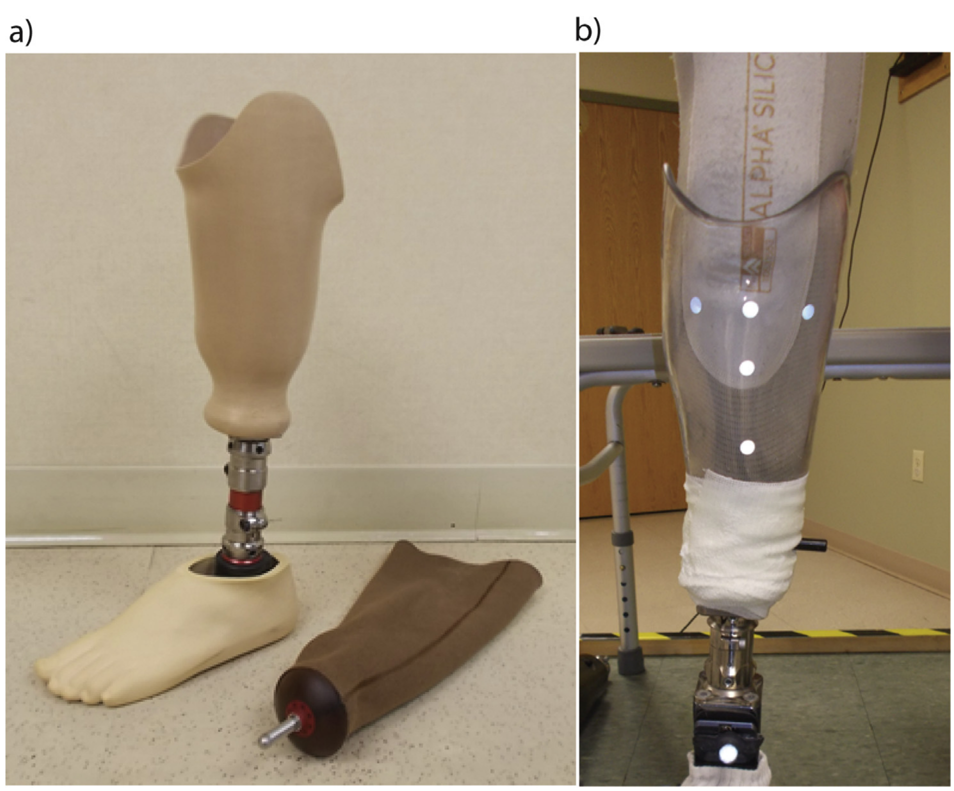

Fig. 2. (a) Below knee prosthesis with pin suspension and gel liner. (b) Clear Thermolyn prosthesis developed for this research.