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Socket/stump interface dynamic pressure distributions recorded during the prosthetic stance phase of gait of a trans-tibial amputee wearing a hydrocast socket

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Abstract

Force sensing resistors (FSR) have been used to measure dynamic stump/socket interface pressures during the gait of a trans-tibial amputee. A total of 350 pressure sensors were attached to the inner wall of a hydrocast socket. Data were sampled at 150Hz during approximately 0.8 seconds of prosthetic stance of gait. The dynamic pressure distributions within a hand cast socket reported by Convery and Buis (1998) are compared with those monitored within a hydrocast socket for the same amputee. The pressure gradients within the hydrocast socket are less than that of the hand cast Patellar-Tendon-Bearing (PTB) socket. The proximal "ring" of high pressure in the hand cast PTB socket is replaced with a more distal pressure in the hydrocast socket.

Introduction

The characteristics of the Tekscan FSR transducer, which incorporates 96 sensors, has been previously reported by Buis and Convery (1997). By adopting a strict test protocol, 4 transducers may be bonded to the inner socket wall and calibrated *in situ*. This calibration technique minimises inaccuracies. When subjected to repeated pressures of 100kPa the variation of the "average" pressure of a transducer was ±2% with a maximum variation of ±10% for any individual sensor in the array of 96.

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The hydrocast socket is based on a system developed by Murdoch (1968). One of the uncertainties of pressure casting in general has been to determine the pressure magnitude and duration required in order to create a good socket fit. Gardner (1968) recommended an applied pressure of 13kPa. Kristinsson (1993) proposed pressure levels of 23 to 34kPa, commenting that applying pressures of less than 23kPa often resulted in a slack fit. Krouskop *et al.* (1987) stated that stump tissue is not compressible which implies that tissue fluid will migrate from the stump with the application of constant pressure.

Method

Figure 1 illustrates the hydrocast procedure. Weight transfer through the stump may be supported if the stump is immersed in a sealed water tank. Increasing or decreasing the volume of water within the sealed tank raises and lowers the stump. The Icecast pressure cylinder was modified by introducing a flexible sleeve as a barrier between the water in the cylinder and the plaster of Paris (POP) covering the amputee's stump. A close fitting template was fitted to the amputee's thigh in order to ensure that, during weight bearing, minimum support was being provided by the sleeve. Immediately after application of the POP, the stump was inserted into the cylinder and the cylinder was raised until the brim contacted the template on the amputee's thigh. The template was locked to the cylinder brim and the cylinder was then filled with water at body temperature. As the amputee transferred full body weight through the stump, the volume of water in the cylinder was increased until the stump was lifted marginally

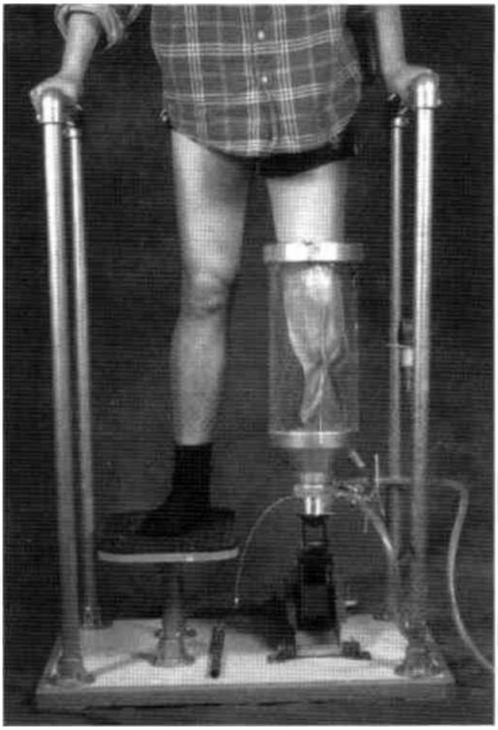


Fig. 1. Hydrostatic casting

out of the template. As the POP cured, the amputee maintained weight bearing through the stump, while resting his hands on adjacent hand rails. The positive cast was not rectified but was used directly for socket lamination.

The patient, an active 37 year old male, was a traumatic, unilateral amputee with 10 years prosthetic experience and typical stump characteristics. He was fitted with a trans-tibial prosthesis incorporating an acrylic resin laminated hydrocast socket. The hydrocast prosthesis was aligned to the satisfaction of the patient and two prosthetists. The alignment was measured using a socket axis locator. A duplicate prosthesis was fabricated so that the hydrocast prosthesis that incorporated the transducers was used only during the pressure studies. The alignment was duplicated on the instrumented hydrocast prosthesis. Figure 2a illustrates the alignment of both hydrocast prostheses. Figure 2b illustrates the alignment of a conventional hand cast/rectified PTB socket used in a previously reported pressure study (Convery and Buis, 1998). No socket liners were supplied with either prosthesis to avoid any effect the liner might have on pressure distributions. A single towel sock was used with both types of socket and a silicone sleeve was supplied for suspension of the prostheses.

A sensor reference grid was established for positioning the 4 transducers, using a socket axis locator. As in the case of the hand cast prosthesis, the 350 sensors were positioned with an accuracy of ±0.75mm and attached to the inner socket wall using non-aggressive spray adhesive. The transducers were to the anterior, posterior, medial and lateral walls of the hydrocast socket. The lower posterior socket brim permitted some sensor cells from the posterior transducer to be located at the distal end of the socket.

A strict test protocol was adopted. The patient used the non-instrumented hydrocast prosthesis for approximately 3 hours in the morning to become accustomed to the socket. The pressure

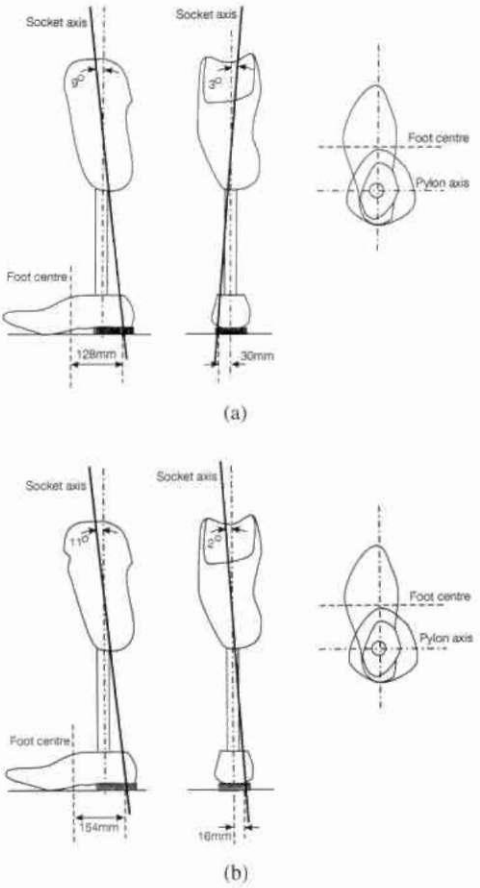


Fig 2(a). Alignment of hydrocast prosthesis.
(b). Alignment of hand cast prosthesis.

study with the hydrocast prosthesis incorporating the transducers was undertaken that afternoon. A pre-conditioning sequence of taking approximately 30 steps was adopted before simultaneously recording data of walking velocity, pressure and the force plate outputs. After each recording session the patient was seated for at least 3 minutes to allow the pressure

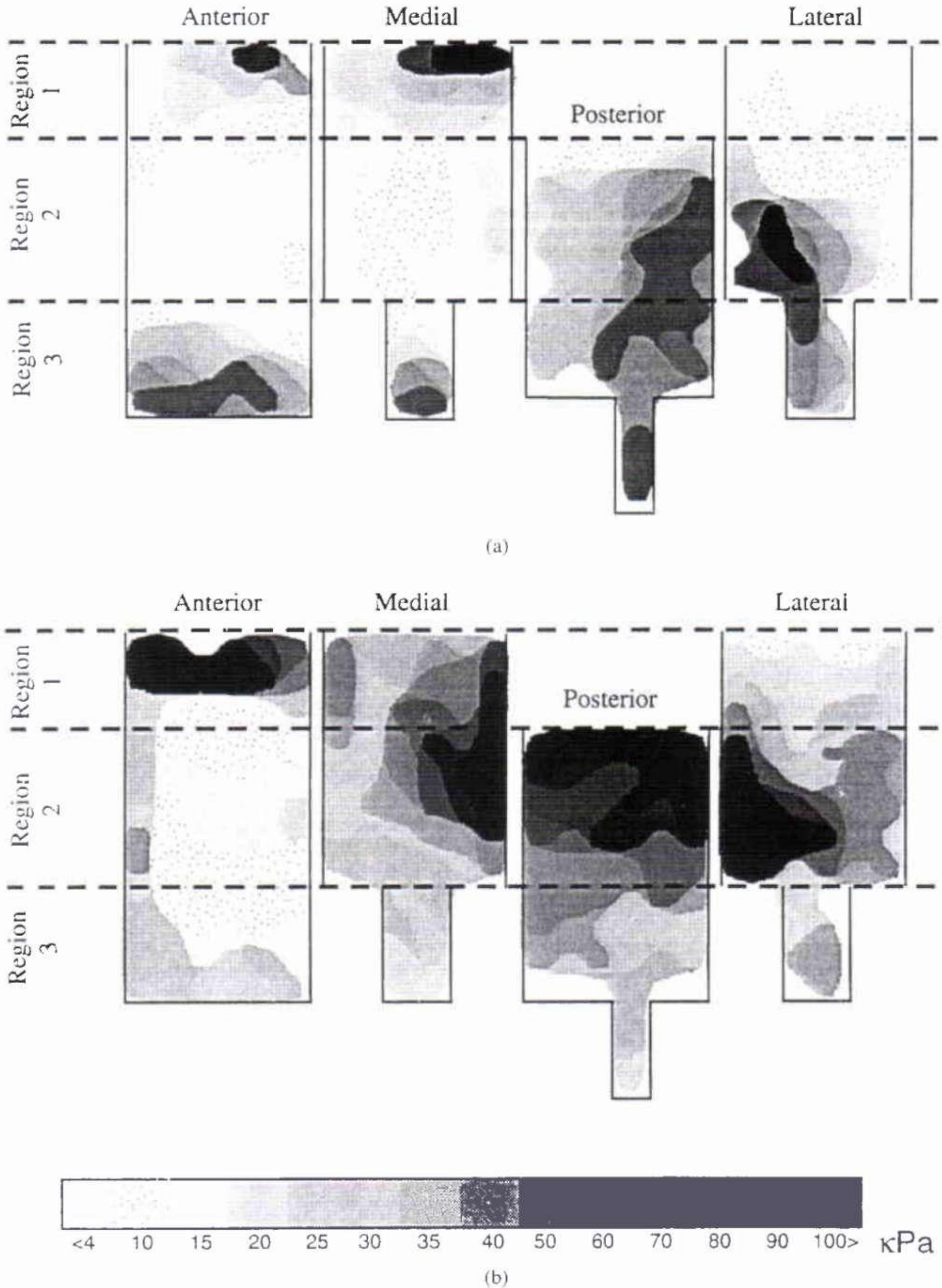


Fig. 3(a). Hydrocast socket pressure distribution after mid-stance.
(b). Hand cast socket pressure distribution after mid-stance.

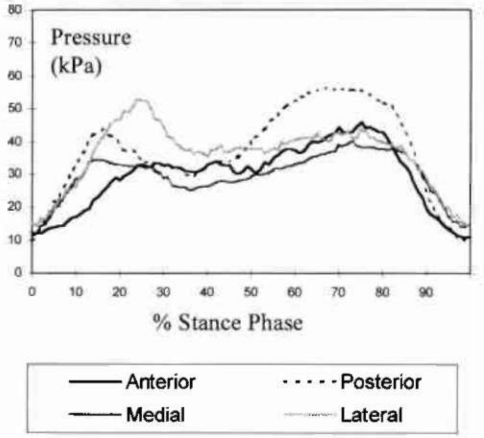
sensors to recover before repeating the exercise. This procedure was repeated 15 times, monitoring the 2 transducers attached to the anterior/posterior aspects of the socket and then 15 times monitoring the 2 transducers attached to the medial/lateral aspects of the socket. The force plate and walking speed data were reviewed and, using statistical analysis, 2 particular steps were selected which were considered to be most representative of the patient's average gait. The pressure data from these 2 selected steps were combined to provide a pressure distribution from all four transducers during a "single" prosthetic stance phase of gait. The pressure studies of the hand cast prosthesis and the hydrocast prosthesis were completed on consecutive days.

Results

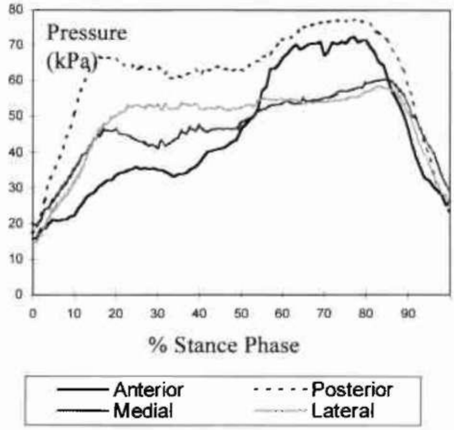
Three axial regions within the socket may be identified, similar to that adopted previously with the hand cast prosthesis. Figure 3a illustrates the typical pressure distribution of all 4 transducers displayed in a 2D configuration for the hydrocast prosthesis. For comparison Figure 3b illustrates the typical pressure distribution of all 4 transducers displayed in a similar 2D configuration for the hand cast prosthesis. The anterior, medial, posterior and lateral pressure data results are illustrated, from left to right, during an instant shortly after mid-stance. During gait, some areas within the physical boundary of the transducers may be displayed in "white". The white scale indicates that the pressures experienced in these areas are below the minimum measurable threshold pressure of 4kPa. This does not imply that there is no contact between the stump tissue and socket wall in these regions.

The pressure distributions, illustrated in Figures 3a and 3b, vary throughout the stance phase of gait. A sample rate of 150Hz for 0.8 seconds provides for each socket a total of 120 versions of pressure distribution patterns throughout prosthetic stance.

Figure 4a illustrates the variation of the "average" pressure of each of the four transducers in the hydrocast socket during the stance phase of gait. Figure 4b illustrates the variation of the "average" pressure of each of the four transducers in the hand cast socket. However, the "average" pressures in Figures 4a and 4b indicate the mean of approximately 96



(a)



(b)

Fig. 4(a). Hydrocast socket – transducer "average" pressures during stance.
(b). Hand cast socket – transducer "average" pressures during stance.

sensors and therefore peak pressures within the sensor array are concealed.

Discussion

Significant differences in pressure magnitude and pressure distributions were noted for the hand cast and hydrocast sockets. Both prostheses were considered satisfactory by the patient and the prosthetist. One would not expect the final alignments of both prostheses to be identical. The difference in final dynamic alignment of both prostheses, as demonstrated in Figures 2a and 2b, will influence pressure data.

Relative to the socket of the hydrocast prosthesis the prosthetic foot of the PTB prosthesis was dorsiflexed an additional 2° and the foot was aligned with an additional anterior displacement.

Relative to the socket of the hydrocast prosthesis the prosthetic foot of the PTB prosthesis has been everted by 5° and the foot was aligned with an additional lateral displacement. A review of the pressure data suggests no obvious influence resulting from this difference in alignment. The effect of the additional 2° dorsiflexion of the foot may have been nullified by the additional anterior displacement of the foot. No reduction of lateral/distal and medial/proximal pressure due to the "wider" walking base in the PTB prosthesis was noted. No alternating pressure patterns were recorded in the sagittal or coronal planes.

Detailed stump pressure distributions, such as those illustrated in Figures 3a and 3b, have not previously been published. Although this study was restricted to only one patient, for a particular socket the pressure patterns were repetitive.

Interpretation of these pressure distributions is possible if influencing factors are recognised. The relationship of the line of action of the ground reaction force (GRF) to the socket during the stance phase of gait may influence the pressure data. Throughout the prosthetic stance phase of gait the line of action of the GRF always passed ahead of the socket of both prostheses, for this particular patient. This relationship is not typical of trans-tibial gait.

Generally, the dynamic pressure levels during gait were lower and more evenly distributed in the hydrocast socket. It may be assumed that the weight transfer force applied by the same stationary patient is approximately common to both sockets. Studies of GRF data during gait suggest similar weight transfer through both prostheses. Therefore the higher pressures recorded in the hand cast socket may be due to dynamic stabilising forces. A review of the pressure distributions during gait did not indicate a logical explanation or agreement with the biomechanical principles proposed by Radcliffe (1961).

Peak pressures (>100kPa) may be considered potentially dangerous. This patient demonstrated peak pressures (>100kPa) just after mid-stance. Using Tekscan software, 2 specific areas of the hydrocast socket which experienced pressures in excess of 100kPa were identified, namely the medial knee at mid-knee level and the fibular head. Table 1a highlights the number of sensors within these 2 specific areas, the maximum "average" pressure experienced and the maximum pressure experienced by an individual sensor within both areas of the hydrocast socket. Four (4) specific areas of the hand cast socket experienced pressures in excess of 100kPa.

Table 1(a). Hydrocast socket: pressures in excess of 100kPa
(b). Hand cast socket: pressures in excess of 100kPa

Local area	No. of sensors within local area	Maximum "average" pressure of all sensors within area (kPa)	Maximum pressure of single sensor within area (kPa)
Medial knee	12	111	121
Fibular head	8	126	148

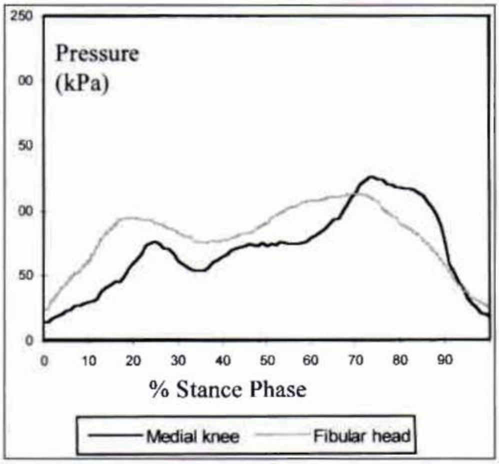
(a)

Legend	No. of sensors within local area	Maximum "average" pressure of all sensors within area (kPa)	Maximum pressure of single sensor within area (kPa)
Patellar bar	12	244	417
Proximal popliteal	8	128	168
Posterior medial flare	10	119	132
Fibular head	9	103	114

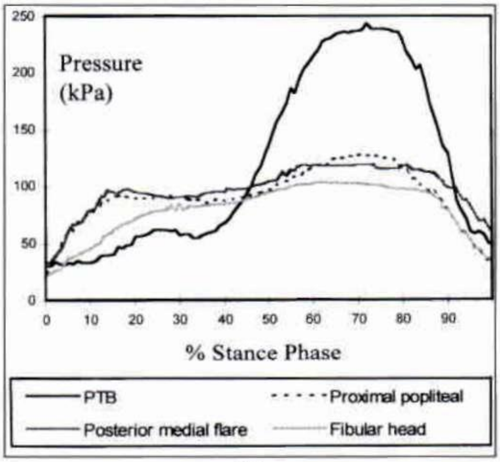
(b)

Table 1b lists the number of sensors within these 4 specific areas, the maximum "average" pressure experienced and the maximum pressure experienced by an individual sensor within each of the 4 local areas of the hand cast socket. The variation of the average pressure in these localised areas may be compared from Figures 5a and 5b.

Tekscan software system has improved such that all 4 sensors may be recorded simultaneously. This will avoid the need in future to undertake a series of 15 tests to "combine" data to simulate pressure distributions for a typical prosthetic stance.



(a)



(b)

Fig. 5(a:) Hydrocast socket - localised "average" pressures>100kPa
(b:) Hand cast socket - localised "average" pressures >100kPa

Conclusions

Distinctly different pressure patterns were demonstrated in this study of a single patient fitted with hand cast and hydrocast sockets.

A ring of pressure at the patellar bar level in the hand cast socket was noted with no major distal end pressure. The pressure gradient was less pronounced with the hydrocast socket and more distal pressure was noted.

Higher localised pressures were noted on the hand cast socket as compared with the hydrocast socket.

Both prostheses incorporate different alignments. The effect of these alignment changes on socket pressure distribution is inconclusive.

Recommendations

The effectiveness of different socket designs may be confirmed by investigating interface pressures with a wide range of stump characteristics.

FSR technology provides future studies with the potential of examining the effect of alignment modifications and long term volume changes on stump/socket interface pressure.

Additional studies are necessary to confirm the anticipated differences in alignment between prostheses incorporating hand cast and hydrocast sockets.

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