JRRD
Volume 41, Number 3B, Pages 491–502
May/June 2004
Journal of Rehabilitation Research & Development

Comparative study between patellar-tendon-bearing and pressure cast prosthetic sockets

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Abstract—This study compared the pressure distribution at the residual limb and socket interface in amputees wearing a pressure cast (PCast) socket system with amputees wearing the patellar-tendon-bearing (PTB) socket. The PCast system requires the subject to place his or her residual limb in a pressure chamber. Pressure is applied to the residual limb while the subject adopts a normal standing position. Four unilateral male amputees were fitted with both PTB and PCast sockets. Using a specially built strain-gauge-type pressure transducer, we recorded residual limb and socket pressure profiles for each subject wearing the two types of sockets during standing and walking. While some subjects exhibited similar anterior-posterior or medial-lateral pressure profiles for both prostheses, especially during push-off, other subjects exhibited high pressure distally in the PCast socket or higher-pressure concentration at the proximal region in the PTB socket.

Key words: biomechanics, pressure, prosthesis, residual limb, socket, transtibial amputees.

INTRODUCTION

The socket portion of a transtibial prosthesis is important because the residual limb does not have the same weight-bearing capabilities as the foot. Therefore, the design and fit of a socket are important factors in the successful rehabilitation of a patient. However, many different opinions still exist regarding the weight-bearing characteristics that a prosthetic socket should possess. As reported by Schuch during the International Society for Prosthetics and Orthotics (ISPO) workshop [1], "there was considerable discussion on the hydrostatic concept, both pro and con, and it was not satisfactorily resolved."

The patellar-tendon-bearing (PTB) socket, which originated in the 1950s, used the design criterion that pressure should vary according to the pain threshold of different tissues in the residual limb [2,3]. Specific pressure-tolerant and -intolerant areas of the residual limb were identified, and socket biomechanics for different periods of gait cycle were defined. Further noted was that since soft tissues were displaced during loading, a socket that simply made equal contact with the surface area of the residual limb might cause more pressure over bony anatomy and less pressure over soft tissues [2], because force flow distributed itself proportional to the stiffness of the available paths. These bony areas may not be able to tolerate these high stresses [2].

However, there were inconsistencies in producing satisfactory PTB sockets. The difficulties were largely because of inadequate training of prosthetists in the PTB technique and because of the production of female casts

Abbreviations: AP = anterior-posterior, FS = full scale, GRF = ground reaction force, ICEROSS = Icelandic Roll On Silicone Socket, ML = medial lateral, PCast = pressure cast, PT = patellar tendon, PTB = patellar tendon bearing.

This material was based on work supported by the National Medical Research Council, Singapore.

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with linear tension lines produced by the inconsistent application of plaster wrap bandages around the residual limb [4]. Therefore, Murdoch introduced a pressure-casting (PCast) concept, where fluid was used as a medium to apply uniform pressure around the residual limb [4]. It was called the Dundee socket, and it was developed to remove some factors related to manual dexterity during the casting process. However, a patellar tendon (PT) “bar” was still implemented and a small addition of plaster was added over the anterior distal end of the tibia. In 1968, Gardner introduced a pneumatic pressure sleeve that wrapped the entire residual limb during cast taking [5].

Kristinsson used the PCast concept by using air as a medium in the Icelandic Roll On Silicone Socket (ICEROSS) system [6]. The socket shape was defined by casting plaster wrap over the residual limb wearing the ICEROSS silicone liner with the use of an air pressure chamber in a seated non-weight-bearing state. He did rectifications by adding padding over bony areas of the residual limb during the casting process. Kristinsson argued that a transtibial socket, designed to transfer loads primarily to limited areas of the limb such as the PT and the medial flare, was in most cases both ineffective and uncomfortable. The most effective socket, in his view, was one that relied on the hydrostatic principle for load transfer [6].

The hydrostatic principle for load transfer is possible when the volume of the soft tissues in a residual limb can be contained in the same volume in a socket so that no fluid is lost or tissue displaced from this volume; a closed system may then be achieved.

Another theory commonly proposed as a basis for the PCast concept is Pascal’s principle of fluid mechanics. This principle states that in a fluid at rest, the fluid pressure on any surface exerts a force perpendicular to that surface because of the absence of shear stresses. Fluid pressure is also often assumed to be transmissible when changes in pressure are transmitted equally to every point in the fluid.

However, these theories have limitations in being applied to hydrostatic weight-bearing in sockets. First, they assume that gravitational forces are negligible. Also, achieving a closed system is difficult when the residual limb is not a closed fluid system [1]. One should note that Pascal’s principle assumes a fluid at rest. Fluid in the residual limb is not at rest and therefore shear stresses cannot be assumed to be zero.

Sockets produced with these theories are known as hydrostatic sockets. They usually include small rectifications on the anterior distal tibia, fibula head, and the tibia crest. The sockets produced are significantly different in shape than the traditional PTB socket (see **Figure 1**). One difference was that the hydrostatic sockets were not indented proximally in the PT region and in the posterior popliteal region of the socket [7,8]. Another difference was that while the PTB socket biomechanics were developed with respect to each of the progressive phases of gait, the hydrostatic socket simply assumed that pressure at one point would be transferred by the fluid principle to other accommodating soft tissues [7].

In this study, a PCast system was developed with the use of water as the fluid medium. However, no rectifications were done on the socket. Using residual limb and socket interface pressure as a performance measure, this study compared the pressure distribution of the PCast socket with that of the PTB socket.

METHODS

Subjects

Four unilateral transtibial amputees volunteered for this study. All subjects were male and had a unilateral amputation at least 5 years before this study. The detailed particulars of the subjects are shown in **Table 1**. The subjects signed an informed consent conforming to the rules of the ethics committee of the hospital.

Figure 1.
Top view of PTB socket (left) and PCast socket (right) fabricated for one subject during clinical trials.

Table 1.
Particulars of study subjects (gait data from prosthetic side).

Variable	Subject							
	1		2		3		4	
Age (yr)	54.0		41.0		31.0		34.0	
Age at Time of Amputation (yr)	49.0		29.0		20.0		29.0	
Body Weight (kg)	76.2		75.4		87.0		62.8	
Height (m)	1.67		1.70		1.72		1.67	
Years Since Amputation	5.0		12.0		11.0		5.0	
Amputation Side	Left		Left		Right		Right	
Length of Residual Limb (cm) (from Mid-Patellar Tendon to End of Residual Limb)	14.0		15.0		11.0		12.5	
Length of Residual Limb (cm) (from Mid-Patellar Tendon to End of Tibial)	13.0		14.0		8.0		10.0	
Prosthesis Tested First	PTB		PCast		PTB		PCast	
Body Weight on PTB Socket During Standing (%)	38.0		34.2		42.7		47.7	
Body Weight on PCast Socket During Standing (%)	48.4		35.1		43.9		44.6	
Reason for Amputation	Vascular disease		Traumatic injuries		Traumatic injuries		Traumatic injuries	
Gait Data	**PTB**	**PCast**	**PTB**	**PCast**	**PTB**	**PCast**	**PTB**	**PCast**
Cadence (steps/min)	93.00	92.00	88.00	90.00	100.00	102.00	97.00	94.00
Walking Speed (m/s)	0.86	0.86	0.95	0.97	1.12	1.12	1.17	1.15
Standard Deviation (m/s)	0.02	0.02	0.04	0.06	0.01	0.00	0.07	0.03
Stride Time (s)	1.28	1.30	1.35	1.33	1.19	1.18	1.23	1.27
Step Time (s)	0.65	0.65	0.71	0.70	0.62	0.61	0.63	0.66
Single Support (s)	0.31	0.33	0.35	0.35	0.39	0.37	0.43	0.43
Double Support (s)	0.56	0.53	0.50	0.47	0.38	0.36	0.32	0.33
Stride Length (m)	1.10	1.11	1.28	1.29	1.33	1.32	1.45	1.47
Step Length (m)	0.60	0.62	0.67	0.72	0.74	0.71	0.79	0.81
Stance (%)	68.23	65.64	63.34	62.00	64.60	62.14	60.56	60.20

Fabrication

One PTB [2] and one PCast socket were fabricated for each of the subjects. One prosthetist fabricated the PTB sockets, while one technician with no formal training in prosthetics fabricated the PCast sockets. Both were hard sockets, fabricated with the use of lamination methods.

For the fabrication of the PCast socket, a PCast system was used. The PCast tank is 0.65 m tall and made of aluminium with a circular opening at the top. Provisions were made for a water inlet and outlet by rubber hoses at the bottom of the tank. A narrow rubber hose for air to escape was made at the top of the tank. A circular stump bushing with an internal diameter 0.16 m was secured at the top of the tank with tightening screws. Before the stump bushing was tightened to the tank, a layer of polyethylene bag was placed between them. A rubber gasket and rubber O-ring were also placed between the stump bushing and the tank to prevent water from leaking out at the top. A pressure gauge was incorporated in the tank as well.

A plaster wrap cast was first applied over the residual limb. The subject then placed his residual limb in the tank. When the water level in the tank was lowered, it created a vacuum such that the bag would cling to the tank wall, creating an accessible space for insertion and positioning of the residual limb. In the meantime, the subject supported himself using the handrail while the tank was being pumped with more water. If the tank was filled with water and more water was pumped in, his amputated side would rise. This demonstrated that the water was supporting the weight of the amputee and not the polyethylene bag, although the tension of the polyethylene bag was not monitored during the casting process. He was then requested to stand in his normal standing position without any aid (see **Figure 2**). Estimating the height of the right and left anterior-superior iliac spines ensured level standing. A pressure of 2 psi* was easily achieved when the subject placed half his body weight on the system. The contralateral limb was positioned over a weighing scale to ensure this happened. Once the plaster wrap hardened, the PCast tank was depressurized and the residual limb with the plaster wrap was removed from the PCast tank. The plaster wrap was then removed from the residual limb. A positive cast was generated from the wrap cast, smoothed where necessary without introducing rectifications, and a socket was fabricated with the use of traditional lamination methods.

*Pressure of 2 psi (13.79 kPa) was introduced. Gardner [5] described that applied pressure of 13 kPa gave the best results. Although Kristinsson [13] used 23–34 kPa for the ICEROSS casting system and Buis [12] used a high 80 kPa, the authors had decided to be cautious and start with only 2 psi.

Figure 2.
Typical subject with stump in plaster wrap dip in PCast tank. Note that sound limb is on a weighing machine. This is to ensure that 50% body weight is maintained on sound limb.

Each test socket was fabricated with 16 pressure measurement sites (see **Figure 3**). Each site incorporated a threaded mounting bracket with an opening so that a transducer could be mounted flush with the socket wall and in contact with the residual limb. Araldite glue was used to ensure that the transducer-mounting bracket did not shift during fabrication of the socket. The socket shape was not altered to accommodate any of the pressure transducers.

Location of Pressure Measurement Sites

PTB Socket

The anterior-posterior (AP) plane was defined by the mid-PT, mid-popliteal crease, and the distal end where the socket connector was placed. The medial-lateral (ML) plane was perpendicular to the AP plane with reference to the distal end.

Figure 3.
Stump/socket pressure measurement system with pressure transducers embedded in socket.

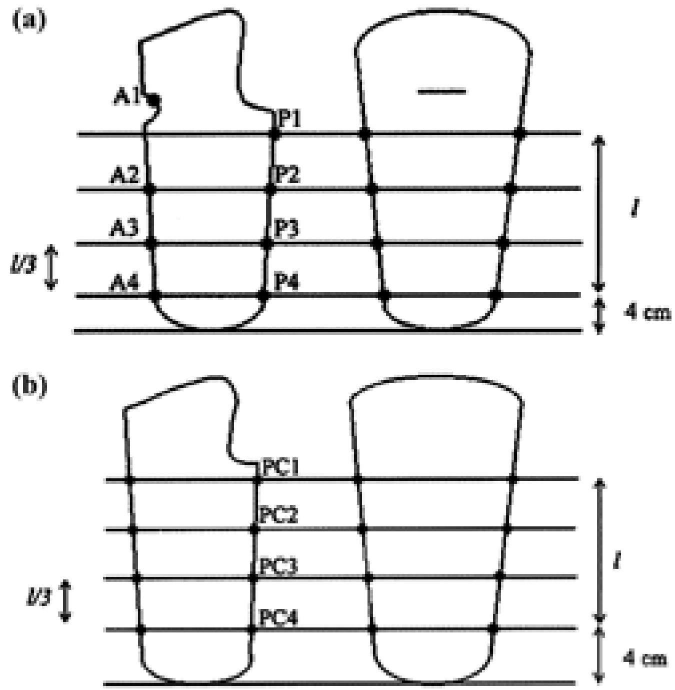

Figure 4.
(a) Placement sites of pressure transducers on PTB socket. At posterior side, site P1 was chosen at popliteal depression and site P4 was chosen 4 cm from distal end. Sites P2 and P3 were evenly spaced between P1 and P4. Anterior side A1 was placed at mid-PT, and other three sites A2, A3, and A4 were at same level as P2, P3, and P4, located at posterior side, respectively. Distance between sites P1 to P4 is *l*. **(b)** Placement sites of pressure transducers on PCast socket. At posterior side, site PC1 was chosen 2 cm from edge of posterior wall and site PC4 was chosen 4 cm from distal end. Two other sites PC2 and PC3 were evenly spaced between sites PC1 and PC4. Sites chosen for anterior, medial, and lateral sides were at same level as posterior side. Distance between sites PC1 to PC4 is *l*.

At the posterior side, we chose one site (P1) at the popliteal crease and another site (P4) 4 cm from the distal end; this was to ensure sufficient space for the socket connector. We chose another two sites (P2 and P3) that were evenly spaced between P1 and P4. The sites chosen for the medial and lateral sides were at the same level as the posterior side. The anterior side is unique because one site (A1) was placed at the mid-PT and the other three sites (A2, A3, and A4) were at the same level as P2, P3, and P4 located at the posterior side (see **Figure 4(a)**). The distance *l* between P1 to P4 is given in **Table 2**.

PCast Socket

At the posterior side, we chose one site (PC1) 2 cm from the rim of the posterior wall that gives relief to the hamstrings and another site (PC4) 4 cm from the distal end to ensure sufficient space for the socket connector. Another two sites were chosen (PC2 and PC3) evenly spaced between PC1 and PC4. The sites chosen for the anterior, medial, and lateral sides were at the same level as the posterior side (see **Figure 4(b)**). The distance *l* between PC1 to PC4 is given in **Table 2**.

P1 and PC1 were placed at the same posterior plane. P1 was specifically situated at the popliteal crease where the indentation was made. PC1 was situated 2 cm below the rim of the posterior wall, so as to give ample space for the pressure transducer. Because PC1 was not specifically chosen for its anatomical landmark, we would like to stress that PC and PC1 were not at the same exact landmark of the residual limb.

Table 2.
Range of *l* values (in centimeters) of both sockets.

Subject	*l* (PTB)	*l* (PCast)
1	9.8	9.5
2	11.3	11.5
3	6.0	5.8
4	8.0	7.3
Average	8.8	8.5

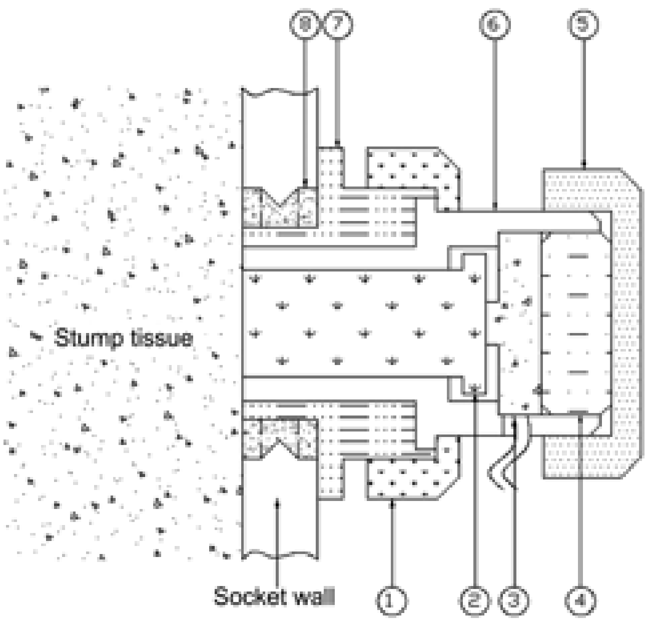

Figure 5.
Pressure Transducer Assembly: (1) transducer holder, (2) piston, (3) load cell (with shielded wires), (4) stopper, (5) stopper cap, (6) load cell housing, (7) transducer mounting bracket, and (8) socket adaptor.

Pressure Transducer Assembly

The pressure transducers were constructed as shown in **Figure 5**. The housing made of Delrin was designed to avoid cross-sensitivity to shear loads. The pressure transducer assembly included a load cell, model ELFM-B1-5L (Entran International, US). The load cell is a sensitive diaphragm onto which miniature electrical resistance strain gauges in a full Wheatstone bridge configuration were bonded. The specifications of the load cells are as follows:

- Range: 5 lb (25 N)
- Nonlinearity: ±0.25% full scale (FS)
- Hysteresis: ±0.25% FS
- Sensitivity: 1.777 mV/FS (unique to individual load cell)
- Operating temperature: –50 °C to 120 °C
- Thermal sensitivity shift: 0.02%/°C

The complete assembly included a cylindrical piston (of diameter 5.6 mm) that transferred pressure from the residual limb tissues to the load cell. A nylon housing, which housed the load cell, was locked to the transducer-mounting bracket to keep it secured and flush with the inner surface of the socket. The transducer assembly was similar to that described in Lee et al. [9]. Calibration of the fully assembled transducer was performed with the use of dead weights from 0 to 200 kPa in 20 kPa increments. The error of the transducer was estimated to be ±1.02 kPa. Because the diameter of the piston was relatively small, the stresses were assumed to be distributed uniformly over the surface of the piston.

Gait Analysis

The pressure transducers were connected to the VICON 370 (Vicon Motion Systems, United Kingdom [UK]) 3D motion analysis system in conjunction with two Kistler (Kistler Instruments, Switzerland) force platforms. Ground reaction forces (GRFs) and pressure data were all acquired simultaneously at 250 Hz. The motion analysis system uses five infrared cameras that tracked 17 retroreflective markers attached to the following body landmarks: shoulder, anterior-superior iliac spine, sacrum, mid-thigh, lateral knee center, mid-tibia, heel, second metatarsal head, and lateral malleolus. Markers were placed on the prosthetic socket at positions corresponding to the lateral knee center, mid-tibia, heel, second metatarsal head, and lateral malleolus. The marker motion was captured at a sampling rate of 50 Hz.

Testing Procedures

During the data acquisition session, each subject wore socks without a liner. Thus the transducers measured socket-sock interface stresses, not stresses directly on the residual limb surface. Each subject wore the same number of socks in both PTB and PCast sockets, but the number of socks was not consistent among subjects. As shown in **Figure 3**, each socket was assembled on a pylon attached to an Endolite Multiflex ankle foot system (Blatchford, UK). Alignment was performed to the satisfaction of one trained prosthetist and the subject. The final alignment of PTB and PCast prostheses was not expected to be identical. However, differences in alignment were not recorded. All sockets prescribed for the subjects were suspended with the use of a cuff suspension system.

We had the subjects test both prostheses on the same day. Two subjects tested the PTB socket first while the other two subjects tested the PCast socket first. Each subject was required to walk with the prosthesis for at least 15 minutes to become accustomed to the test socket. All data collection was performed on the same day without the subject removing the test socket at any interval during the test. The tests were divided into static (standing) and dynamic (walking) stages. During the static test, pressure measurements were taken when the subject was in a normal standing position with the prosthetic limb on the force plate. The positions of both the feet were outlined to ensure that he was standing in the same position for all static trials. For the dynamic test, the subject was requested to walk a distance of approximately 10 m at a normal self-selected speed, stepping on the Kistler force plates approximately midway through the walk. A minimum of three trials was recorded for each static and dynamic test for each subject.

RESULTS AND DISCUSSION

This study used pressure measurement sites at locations that were based on the general geometry of each subject's residual limb, rather than specific anatomical locations. It should be noted that these locations are important, because a small shift can result in a different pressure reading. Furthermore, the test sockets used were different from the subjects' regular prostheses. One also should note that an exact match of the measurement sites was not possible and that the pressure distributions therefore should only be viewed qualitatively.

Static Pressure Profile

Table 3 gives the range of pressure values for both types of prostheses during standing. The PCast socket exhibited lower or comparable pressure values with the exception of subject 3. **Figure 6** shows the static pressure profiles of all subjects. The angle at which the ground reaction forces (GRFs) were acting on both sockets was found to be similar, although the magnitude or the percentage of body weight on each socket was found to be different. Subject 3 displayed high pressure distally in the PCast socket. One observation made from his residual limb was that the transected end of his fibula was clearly protruding, which could explain the high-pressure concentration at the lateral distal end. Despite this, subject 3 commented that he found the PCast socket more comfortable than the PTB socket and has been wearing the PCast socket since the clinical evaluation of the PCast socket. The static ML pressure profiles were similar for all subjects with the

Table 3.
Range of pressure values (in kilopascals) during standing.

Subject	PTB Socket	PCast Socket
1	0–72	2–51
2	1–31	0–2
3	0–49	6–90
4	0–46	2–16

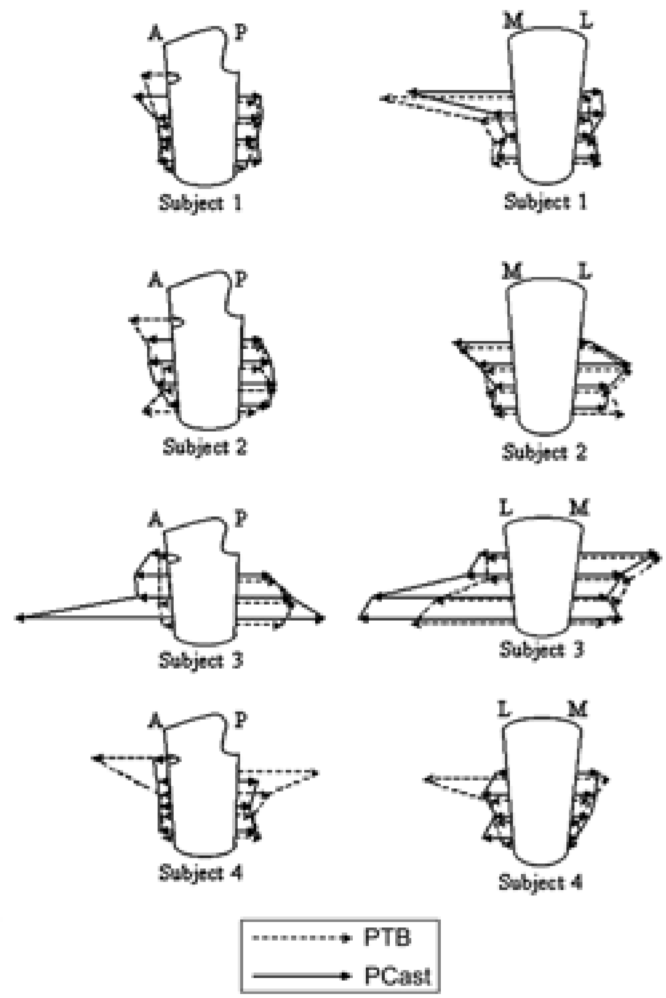

Figure 6.
Static pressure profiles of all subjects at all sites in AP and ML planes. Length of arrows represents magnitude of pressure measured. Example: subject 3 displayed high pressure distally in PCast socket. A = anterior, P = posterior, M = medial, and L = lateral.

exception of subject 4 who experienced a "tight" fit proximally in the PTB socket. High pressure found at the lateral proximal region could possibly be due to alignment, which was not measured in this study but could explain the differences in pressure profiles between his PTB and PCast sockets. He preferred the PTB socket to the PCast socket. Subject 4 commented that the PTB socket prevented pistoning of the residual limb and that he found it "easier to control" while walking. Because subject 4 had a considerable amount of soft tissue in his residual limb that could have possibly reduced or complicated his rotational control of the socket, the PTB socket might have allowed better control of the artificial limb during gait.

The ML weight-bearing characteristics of the PCast socket are possibly similar to those of the PTB socket during standing. However, it would be interesting to study whether it occurs during gait as well.

Dynamic Pressure Profile

In the dynamic tests, pressures were only considered over the gait cycle when the subject stepped on the force plate. Before the results were averaged, the data were first normalized to 100 percent of the gait cycle. The VICON 370 3D motion analysis system and the Kistler force platforms were determined the timing over the gait cycle considered.

At certain periods of the gait cycle, we compared pressure profiles at the typical double peaks and trough related to the GRF as measured by the Kistler force platform. During weight acceptance, the first peak occurs when the body's center of mass reaches its peak downward displacement and maximum upward acceleration. The trough results from a decrease in the vertical reaction force when the contralateral foot leaves the ground and swings over the ipsilateral limb at midstance. The second peak is due to push-off and occurs during an upward acceleration of the body's center of mass as weight is transferred to the contralateral limb.

Figures 7 to **9** show the AP pressure profiles of all subjects. **Figures 10** to **12** show the respective ML pressure profiles for all subjects.

Dynamic AP Pressure Profile

The pressure profiles at the anterior socket wall for subject 1 were different at weight acceptance, although the pressure profiles at the posterior wall were similar. However, at midstance, an increase in pressure occurred at the anterior-proximal region, which was more pronounced at push-off. The pressure profiles became similar at push-off.

Subject 2, however, exhibited high-pressure concentration at both proximal and distal regions of the anterior wall in the PTB socket. Rectifications were done to the lateral aspect of the tibia (i.e., along anterior tibial muscle) as well as the medial aspect of the tibia (i.e., along tibia facet), and relief was given to the distal end of the

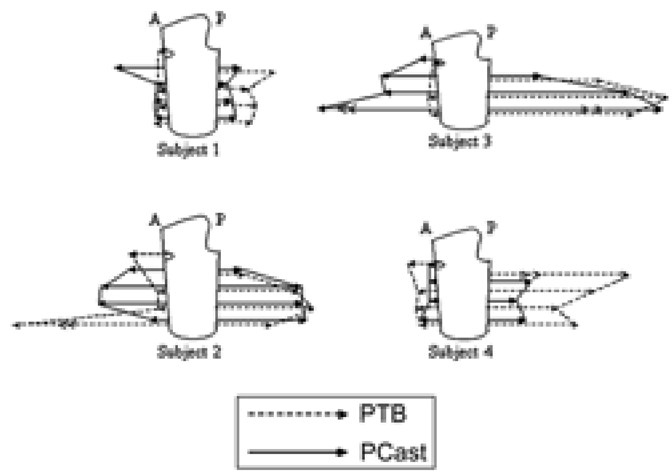

Figure 7.
Dynamic pressure profiles of all subjects in anterior (A) and posterior (P) plane recorded at first peak of ground reaction force vectors during level walking. This is weight acceptance phase of gait cycle when an upward acceleration of body's center of mass occurs. Length of arrows represents magnitude of pressure measured.

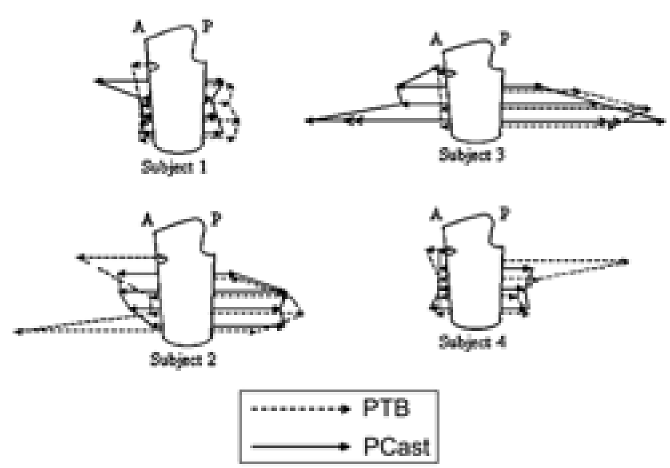

Figure 8.
Dynamic pressure profiles of all subjects in anterior (A) and posterior (P) plane recorded at trough of ground reaction force vectors during level walking. This is midstance of gait cycle. Length of arrows represents magnitude of pressure measured.

tibia. The subject had concurred that the socket was comfortable before the test was done. Therefore, we could not explain the high pressure measured at the anterior-distal region, which decreased from weight acceptance to push-off. Furthermore, the test socket was not expected to be similar to his regular prosthesis. We are not certain that after a long period of time, he might feel some discomfort in the anterior-distal region. Subject 3 consistently exhibited high pressure distally in the PCast socket.

Subject 4 consistently exhibited high pressure at the proximal brim in the PTB socket throughout stance. This could be because the proximal brim was too small, although he found the PTB socket comfortable. We are not certain whether the subject would have preferred one with

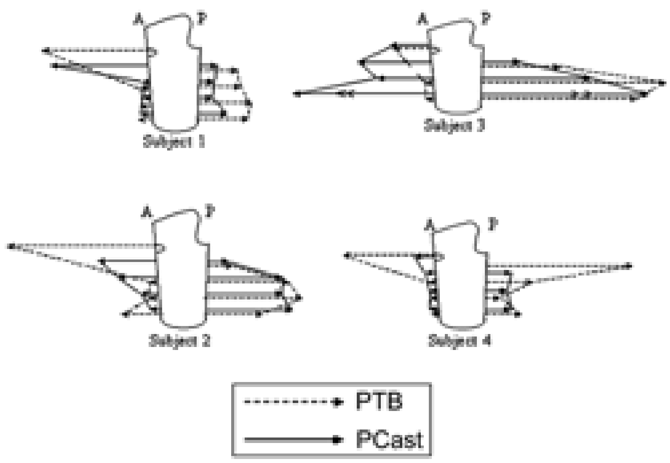

Figure 9.
Dynamic pressure profiles of all subjects in anterior (A) and posterior (P) plane recorded at second peak of ground reaction force vectors during level walking. This is push-off phase of gait cycle where an upward acceleration of body's center of mass occurs as weight is transferred to contralateral limb. Length of arrows represents magnitude of pressure measured.

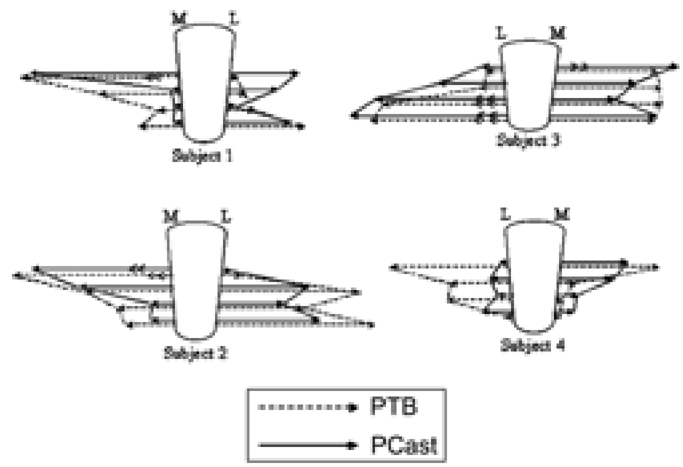

Figure 11.
Dynamic pressure profiles of all subjects in medial (M) and lateral (L) plane recorded at second peak of ground reaction force vectors during level walking. This is push-off phase of gait cycle where an upward acceleration of body's center of mass occurs as weight is transferred to contralateral limb. Length of arrows represents magnitude of pressure measured.

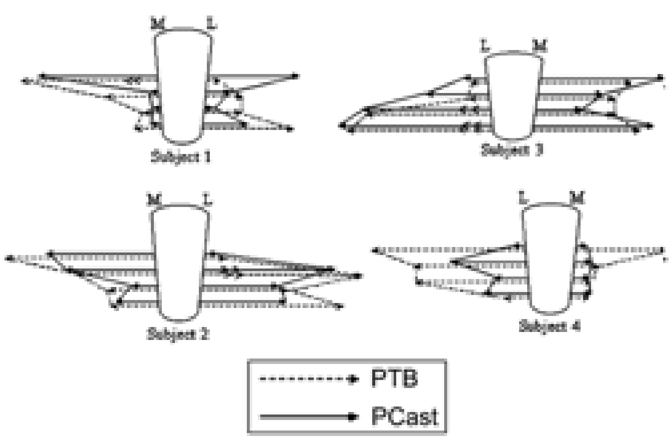

Figure 10.
Dynamic pressure profiles of all subjects in medial (M) and lateral (L) plane recorded at first peak of ground reaction force vectors during level walking. This is weight acceptance phase of gait cycle when an upward acceleration of body's center of mass occurs. Length of arrows represents magnitude of pressure measured.

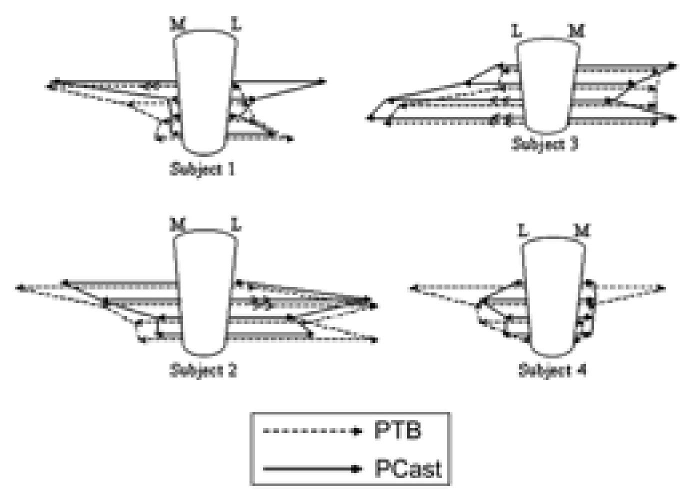

Figure 12.
Dynamic pressure profiles of all subjects in medial (M) and lateral (L) plane recorded at trough of ground reaction force vectors during level walking. This is midstance of gait cycle. Length of arrows represents magnitude of pressure measured.

a wider proximal brim, but this further demonstrates the current PTB practice of fabricating a comfortable fitting socket by trial and error, which highly depends on the skills and experience of a prosthetist.

Dynamic ML Pressure Profile

From the gait data, the ML component of the GRF of all subjects always acted medially toward the contralateral limb, causing an adduction moment about the knee. High pressures at the medial-proximal and lateral-distal regions of the socket were expected.

Subject 4 consistently exhibited higher pressure at the proximal region in the PTB socket. This finding is similar to the study done by Convery and Buis [10]. While subjects 1, 2, and 3's PTB and PCast sockets exhibited similar ML pressure profiles during static tests, only subject 2's continued to do so during gait. Subject 3's medial pressure profile was more uniform in the PTB socket. Although subject 1 exhibited similar pressure profiles at the medial wall, higher pressure at the lateral proximal region was recorded in the PCast socket. These could also be due to differences in socket alignment, which was not measured in the study.

Effects of GRF on AP Dynamic Pressure Profile

The ML pressure profiles just described concentrated on the effects of socket design that could cause differences in the resulting pressure profiles. However, the line of action of the GRF could also affect the pressure distribution.

Radcliffe [11], based on the assumption that a below-knee amputee is able to walk similarly to a normal person, analyzed that during heel contact, the line of action of the GRF acting anterior to the knee would cause the knee to extend. The hamstrings, acting to prevent knee hyperextension, would cause high-pressure concentration at the PT and the posterior-distal region. During midstance, the GRF would be acting posterior to the knee. In such an instance, the knee would buckle. However, this buckling is resisted by action of the quadriceps and forceful extension of the hip where high-pressure concentration would occur at the PT, anterior-distal, and the popliteal region. During toe-off, where the line of action of the GRF remains posterior to the knee, the same three areas would experience high-pressure concentration [2,11].

While the line of action of the GRF was similar for both prostheses, two incidences occurred where the line of action of the GRF differed. They occurred during weight acceptance for subject 1 and at push-off for subject 2.

Subject 1's GRF line of action was acting posterior to the knee, thus creating a tendency to flex the knee in the PTB socket during weight acceptance. However, the GRF line of action was observed to be acting anterior to the knee in the PCast socket during weight acceptance, thus creating a tendency to extend the knee. Theoretically, this knee extension moment would cause high-pressure concentration at the anterior-proximal and posterior-distal regions. This finding is verified by the higher pressure concentration measured at the anterior-proximal region in the PCast socket.

Subject 2's GRF was anterior to the knee in the PCast socket and posterior to the knee in the PTB socket during push-off. However, both sockets exhibited pressure concentrations in the anterior-proximal region and the PTB socket exhibited high-pressure concentration in the anterior-distal region as well.

Note that all subjects exhibited a sudden increase in pressure at the anterior-proximal region at push-off regardless of the line of action of the GRF. This included subject 3, who, despite exhibiting high pressure distally in the PCast socket consistently throughout stance, showed an increase in pressure concentration at the anterior-proximal region from midstance to push-off.

CONCLUSION

This paper compared the pressure distribution of the PCast socket with the traditional PTB socket. To fabricate a PCast socket, we required the subject to place his residual limb in a tank filled with water. Pressure was then applied to the residual limb. Pressure cast has the potential to "let nature dictate the most realistic and achievable pressure distribution" [8,12]. During the casting process, manual dexterity and interprosthetist variances were eliminated without any need for rectifications. Such a method would minimize the skills needed and reduce time and costs in fabricating prosthetic sockets.

Four subjects volunteered for this study. One subject consistently exhibited a "ring" of high pressure at the proximal brim in the PTB socket, while another subject consistently exhibited high pressure distally in the PCast socket.

The other two subjects had instances during gait where pressure profiles were similar for the two types of sockets. One subject had similar AP pressure profiles, while the other had similar ML pressure profiles.

We should emphasize that many other factors besides GRF can help determine a subject's pressure profile. They can include factors such as alignment, shape of the residual limb, and thigh muscle strength, which were not measured in this study.

While there are still different schools of thought on the weight-bearing characteristics that a prosthesis should have, determining which is the best is difficult because dynamic forces are constantly at work in a socket during walking. There are still questions on the mechanical stability and internal dynamics of the limb, enclosed in a prosthesis, which have yet to be answered [13].

ACKNOWLEDGMENTS

The National Medical Research Council, Singapore, supported this research. We would also like to thank Mr. Cheung Sze Kwong, Mr. Pan Seng Kie, Ms. Grace Lee, Mr. Wang Jit Beng, Mr. Hazlan Bin Sanusi, and Mr. Azmee Murat for their technical assistance.

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Submitted for publication March 25, 2002. Accepted in revised form June 23, 2003.