

Total surface bearing self suspending above-knee sockets*

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Abstract

A new type of above-knee socket has been designed to provide total surface support and to dispense with ischial bearing as the primary weight bearing area. The socket is based upon the hypothesis that if the soft tissues of an above-knee stump are adequately supported in a suitably shaped container they will behave under load as an elastic solid with low stiffness.

A method has been devised for taking the cast for the new type socket using an elastic sleeve as a "compliant socket". The grip of the elastic sleeve and the use of traction weights deform the stump tissues to the required shape while the cast is setting. The results of laboratory measurements of the transinterface pressures in these sockets under axial loading conditions have correlated well with the figures forecast by calculation. The new socket is now available to patients at a number of Centres in England.

Introduction

In 1967 the then Director of the Biomechanical Research and Development Unit at Roehampton, Dr. D. S. McKenzie, agreed to the start of a project to develop a total surface bearing self-suspending above-knee socket in which the load would be distributed as evenly as possible, so avoiding the discomfort associated with high loads concentrated in local areas. The project required that retention of the socket on the stump should be achieved without a significant adverse pressure gradient i.e. there should be no proximal constriction and there should be adequate stability of the stump tissues within the socket.

At the start of the project the performance requirements for the stump/socket interface were defined as follows:

- (a) To transfer the axial load of the body weight and bending and rotational loads arising during the walking cycle.
- (b) To transfer the distraction loads due to the weight of the limb when the patient lifts the prosthesis off the ground.
- (c) To eliminate lost motion between the surface of the stump and the socket wall.
- (d) To reduce to a minimum the displacement of the femoral shaft within the soft tissues of the stump under the loads imposed during the walking cycle.

Axial compression loading

For the purpose of prosthetic fitting, the anatomy of the above-knee amputation stump was considered in a simplified form as consisting of an outer limiting envelope, the skin and deep fascia; a roof, the side wall of the pelvis; and a central rigid strut, the femoral shaft.

Contained within the outer envelope and surrounding the central strut is a composite of "soft tissues". At the "micro" level all the soft tissues are composed of a complex of fluid filled compartments, or cells. At the "macro" level the soft tissues are separated into various anatomical compartments by fascial layers and inter-muscular septa. It was suggested that the shape of the soft tissues of the stump could be altered, within limits, by applying minimal stress without changing their volume. Figure 1 shows diagrammatically the difference in the soft tissue distortion pattern when a proximal and a distal stress are applied to the free stump.

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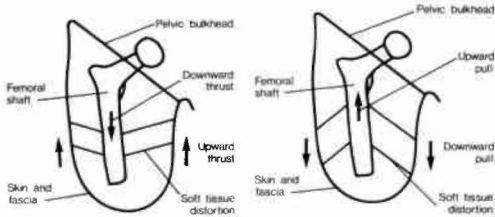


Fig. 1. Anterior views of free stump with, left, applied proximal stress and right, applied distal stress.

The changes in stump shape are limited by the arrangement of the tissue structures bounding the fluid compartments. Under minimal stress between points A and B on the stress/distortion curve (Fig. 2, left) the stump might be expected to behave as a "bag" containing fluid. When sufficient stress is applied to bring the tissue structures bounding the fluid compartments under tension the stress/distortion characteristics of the stump might be expected to change and exhibit a sharply increasing degree of stiffness in the direction of the applied stress.

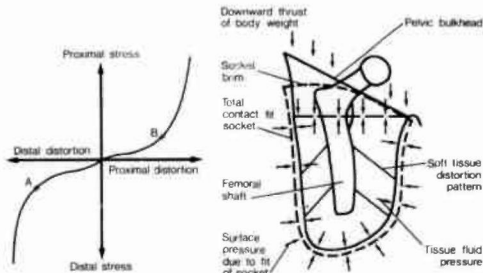


Fig. 2. Left, tissue/stress distortion relationship. Right, anterior view of total surface bearing left suspending above-knee socket.

If an above-knee stump were to be contained within a rigid total contact socket made to conform to the shape and volume of the stump between the two limits of distortion marked "A" and "B" on the curve in Figure 2, left, it was suggested that it should be possible to treat the stump, in respect of axial compression loads, as a fixed volume "bag of fluid" with a high bulk modulus which could be pressurized by the transference of the load of the body weight across the stump/socket interface. The patient would be supported upon the relatively incompressible volume of the stump contained within the socket (Fig. 2, right). Localized skeletal support in the form of ischial bearing

would not be necessary, and the pressure would be evenly distributed across the whole of the stump/socket interface.

In these circumstances the forces at the interface should be acting normal to the surface of the stump in all areas, and there should be no element of shear stress at the interface to cause discomfort to the patient. The pressure required to support the patient's weight on such a socket would be independent of the surface area of the stump/socket interface, but would be related to the projected area of the oblique side wall of the pelvis, the "roof" of the stump.

This area would not be easy to determine, and so it was considered acceptable to take the area of the cross-section of the stump at the level of the posteromedial socket brim as being an approximation that could be measured. For example, if the circumference of the stump at this level was 46 cm (18 in)—then the area of the cross-section would be approximately 180 cm² (28 in²) and a loading of 42 kN/m² (6 psi) would support the total body weight of a patient weighing 75 kg (168 lbs). The fraction of this total load supported by the area of the cross-section of the femoral shaft, would be transmitted back through the hip joint and might provide "feedback" of proprioceptive information.

If it was true to assume that the stump would behave as a hydrostatic system, the pressure throughout the system should be equal and therefore the pressure over all the area of the stump/socket interface should also be 42 kN/m² (6 psi), providing the load was a pure axial load and any inertial forces, bending loads or torque effects were excluded. The pressure would be expected to fall to 21 kN/m² (3 psi) if this patient stood with his weight evenly divided between both feet. To maintain a total contact fit under the distraction load of the weight of the prosthesis, it was suggested that the pressures across the stump/socket interface in the nil axial load state would have to be of the order of 2.1—3.5 kN/m² (0.3—0.5 psi).

Assuming that the arterial systolic inflow pressure to the stump, when a patient is standing, is about 150 mm Hg (21 kN/m² or 3 psi) the range of stump/socket interface pressures suggested seemed reasonable. It must be remembered that the patient only sustains all his weight on one leg transiently as he shifts his support from one foot to the other. The periods

of lower pressure across the stump/socket interface would permit adequate time for blood circulation through the stump. The variation in pressure should provide a pumping action that would promote the return of venous blood and lymph to the general circulation.

On the basis of the above hypothesis total surface bearing appeared to be a possible means of carrying the axial load of the body weight without the need to use skeletal support or support from soft tissue as in a plug fit socket.

Socket retention

It was suggested that retention of a self-suspending total surface bearing above-knee socket would depend upon two factors.

Firstly, friction at the stump/socket interface should retain the socket on the relaxed stump for levels of distraction loading up to the weight of the prosthesis. This factor could be augmented temporarily by voluntary contraction of the stump muscles to increase the pressure across the interface.

Secondly, for distraction loads in excess of the weight of the prosthesis when friction at the interface might not prevent the socket from slipping on the stump, atmospheric pressure could be an additional factor holding the socket in place. For the latter to be effective the socket wall would have to be airtight and a total contact fit maintained between the socket and the side of the stump. The end of the stump could not then separate from the bottom of the socket unless air was able to enter.

Under distraction loading the tissue distortion would take the form of an elongation of the stump which, if its volume remained constant, would be associated with a decrease in its diameter. If the socket was made to conform to the shape of the stump when it was not stressed or was stressed proximally, the application of a distraction load would cause the stump to draw away from the socket wall as the tissues elongated and the stump decreased in diameter.

To achieve the required fit the socket would have to be made to conform to the shape of the stump after a distal stress at least equal to the weight of the prosthesis has been applied to it, together with a radial compression of 2.1–3.5 kN/m² (0.3–0.5 psi) uniformly distributed over the sides of the stump. Under these conditions the stump would be distorted distally to the point "A" on the stress/distortion curve in Figure 2,

left, where its stiffness to distal stress was rising steeply, and therefore any increase in distraction loading would cause little further distortion to occur. The surface of the stump should therefore stay in contact with the socket wall. In this manner the friction fit and the airtight seal along the length of the stump/socket interface should retain the socket securely on the stump without an adverse pressure gradient.

Stump/socket stability

Elimination of lost motion between the surface of the stump and the socket wall would be achieved if the socket was a total contact fit, but in addition there should be minimal internal lost motion between the femoral shaft and the stump/socket interface. Anteroposterior and mediolateral stability of the femoral shaft should be greatest if the horizontal distance from the shaft to the interface is a minimum in all directions. The effect of the philosophy proposed for the new socket would promote this situation.

It was also suggested that the increased stiffness of the soft tissues consequent upon distal stressing could be a factor maintaining skeletal stability within the stump. In respect of the bending loads, it was suggested that horizontal displacement of the distal femoral shaft might be resisted by a rise in pressure within the soft tissue on the side to which the bone is trying to move. These tissues could not displace to accommodate the femoral shaft because superficial distortion would be prevented by the fit of the socket, and internal displacement would be limited by internal tissue connections. These factors would be expected to modify the uniform pressure distribution exhibited over the stump/socket interface under axial load alone.

Vertical stability of the femoral shaft remnant, i.e. internal piston action under axial loading, should be achieved because the distortion resulting from the distal stressing of the soft tissue would prevent further upward movement of the skeleton in relation to the socket when an axial distraction load is applied (Figs. 1 left and 2 left). Downward movement of the skeleton in relation to the socket under an axial compression load would be prevented by the relatively incompressible volume of the stump being contained within the rigid, fixed shape, fixed volume total contact socket. These factors should ensure that there is minimal "internal

piston action" of the femur within the stump tissues. Rotational stability about a vertical axis would depend upon "locking" the socket to the stump by the shape of the socket brim.

If the above hypotheses are true the concept of total surface bearing does not appear to produce a conflict between the requirements for weight bearing, socket retention and stability.

Socket casting

Work done on total contact ischial bearing sockets has shown that it is essential to make these sockets to a cast of the stump. At present this is the only simple way for the prosthetist to record the shape/volume relationship of the stump.

If a socket is made direct from a simple "laid on" cast, it usually appears to be too large to be self-retaining, even when a casting jig has been used to impose a brim shape. This is because the cast reproduced the shape and volume of the stump either unstressed or under proximal stress if the cast was taken under conditions of weight bearing.

For a successful self-suspending socket to be made by these casting techniques, it is necessary to carry out a "reduction rectification" procedure on the positive cast to sculpture it to the shape and volume the stump would assume on the application of at least part of the distraction load due to the weight of the limb and a radial compression load to maintain the total contact fit of the socket. Sockets cast with a casting brim usually depend primarily upon the tightness of their top fit to hold the suction seal. Appoldt and Bennet (1967) have shown in their studies on the stump/socket interface pressures that these sockets often have an adverse pressure gradient along the length of the stump, being tighter at the brim than distally. The rectification procedures entail removing plaster in certain areas, either according to tables arrived at on an empirical basis, or depending upon the skill and experience of the individual carrying out the plaster work. Plaster may have to be added to the distal end of the cast to avoid the risk of excessive end loading and to accommodate the distal displacement of soft tissue. It was felt it would be difficult to achieve the degree of accuracy for the stump/socket shape/volume relationship for a total surface bearing socket if such techniques were used to define the final shape of cast.

The philosophy of total surface bearing self-suspending sockets called for the stump to be stretched distally when the cast is taken, making the stump longer and thinner as compared with its shape in the unstressed state. It was therefore suggested that if calculated stresses could be applied to the stump tissues, and the tissues allowed to deform to a point of balance with them, the shape could then be "fixed" by applying a plaster soaked wrap over the stump. In this manner the stump itself would dictate the physical dimensions of the socket necessary to produce the required conditions at the stump/socket interface.

To achieve the necessary distortion it was proposed that the stump should first be fitted with a "compliant socket" made from an open-ended sleeve of elasticated material, the stretch/tension characteristics of which could be related to stump diameters and so to the required radial loading. The radial pressure on the stump would be achieved by the hoop stress resulting from the elastic pressure sleeve being stretched over the surface of the stump. When an elastic material is stretched over a curved surface the radial pressure produced against the surface varies directly as the tension in the elastic and inversely as the radius of curvature of the surface, (Fig. 3, top). A factor contributing to distal stressing of

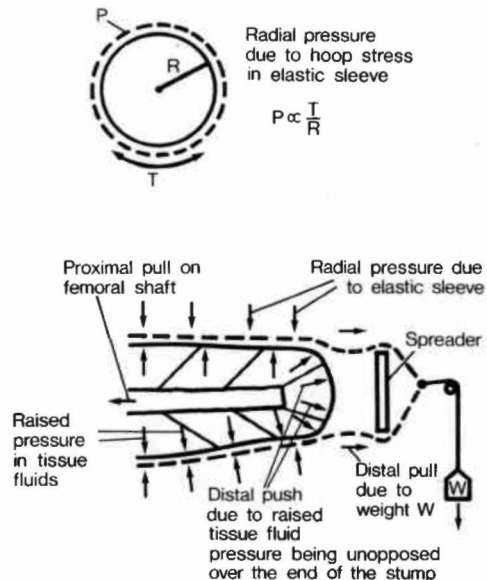


Fig. 3. Tissue stressing. Top, radial pressure. Bottom, additional distal force applied by means of a weight (see text).

the tissues would be the hydrostatic pressure raised within the tissues as the result of the radial pressure exerted by the elastic pressure sleeve.

This force, acting distally, would depend upon the area of the open distal end of the pressure sleeve and upon the shape of the end of the stump. This force alone might not be sufficient to provide adequate distal stretching of the tissues, and an additional distal force might have to be applied by pulling on the surface of the stump (Fig. 3, bottom). It was suggested that the additional distal stretching force should equal the weight of the prosthesis plus a safety factor. A total figure of $4\frac{1}{2}$ kg. (10 lbs) might be suitable for the average British above-knee prosthesis.

The cast could be taken with the patient standing but it was suggested it might be better done with the patient lying down because:

It would be more comfortable for the patient and would make it easier for him to relax the stump muscles to allow the distal distortion of the stump tissues.

It would give the prosthetist ample time to work, without the patient becoming tired.

The development of gravitational oedema in the distal stump tissues would be avoided.

It should be easy to impose any desired deformation to brim shape by means of a simple casting board adjustable for height and angle of flexion, on which could be mounted adjustable formers as required. There should be no need to have a complete proximal casting brim with the associated risk of proximal constriction. The final brim shape could be achieved by rectification to the positive cast.

Alternative methods of obtaining the brim shape would be to cast the stump with the patient standing and to mould the negative cast by hand while the plaster cast was setting on the stump, or to combine the use of an adjustable brim shape with an elastic sleeve as a "compliant" socket.

Experimental procedure

The object of the investigation was to examine the distribution and level of loading across the stump/socket interface under axial compression load alone, excluding as far as possible any static bending loads in an anteroposterior or mediolateral plane, or any torque load about a vertical axis. The pressure transducers selected were Ferranti silicone etched diaphragm type ZPT50A ($7/8$ " long \times $1/4$ " diameter), chosen

because they exhibited high linearity and a good frequency response over the pressure range 0— 350 kN/m^2 (0—50 psi), while being small in size and weight. Sixteen holders for the pressure transducers were built into the walls of each socket (Fig. 4). Nine transducers were available and plugs were screwed into the empty holders to maintain the suction seal. The sockets were fitted into trial legs incorporating facilities for alignment adjustment. A simple adjustable

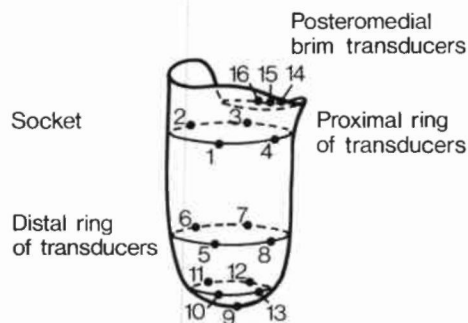


Fig. 4. Transducer locations.

socket mounting system was used that left the socket fully exposed (Fig. 5, left). The experiments were carried out using the apparatus shown in Figure 5, right.

The patient stood on the platform of the experimental rig with the prosthetic foot on a weighbridge, and with his own foot placed so that he was balanced and felt that his stump was

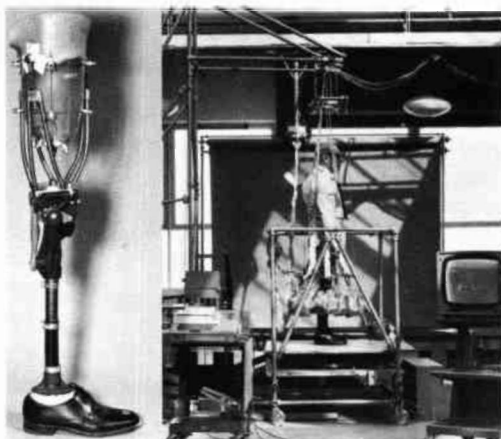


Fig. 5. Left, trial prosthesis showing adjustable socket mounting, transparent socket and built-in transducers. Right, subject on experimental rig, note overhead hoist and harness with weights attached.

pressing straight into the socket with no sense of twisting. The patient was asked to adjust his weight on the prosthesis until the weighbridge recorded half his body weight.

To increase the axial compression load on the prosthesis up to full body weight, an adjustable overhead hoist was used to load an increasing weight on to a strong shoulder/waist belt harness worn by the patient. When the added weight was equal to the patient's body weight, the patient's own leg and his artificial limb were each supporting an axial compression load equal to the patient's own weight. The added weight was then removed progressively.

To reduce the axial load on the prosthesis below half his body weight, the patient was lifted by the shoulder suspension harness attached to the overhead hoist. The weight on the prosthesis was decreased progressively until it was less than 5 kilograms.

The patient was then lowered until he was again standing with his weight equally divided between his two legs. Throughout the loading cycle a series of simultaneous readings were recorded from the 9 pressure transducers and from the weighbridge under the prosthetic foot.

When the 9 transducers were mounted in holders 1, 2, 3, 4, 5, 6, 7, 8 and 9 (Fig. 4), information was recorded on the level and distribution of pressure over the side walls of the socket with a spot check on the terminal pressure from the transducer in holder 9.

When the transducers were mounted in holders 1, 2, 3, 4, 14, 15, 16, 8 and 9 (Fig. 4), information was recorded on the level and distribution of pressure over the posteromedial socket brim with a check on the pressures on the side wall and distal end of the socket.

When the transducers were mounted in holders 1, 2, 3, 4, 9, 10, 11, 12 and 13 (Fig. 4), the terminal pressure distribution was recorded in more detail and a check was kept on the side wall pressures in the proximal part of the socket.

Clinical observations

During the experimental sessions the surface of the stump was examined through the transparent wall of the socket.

The socket was an accurate total contact fit on the stump at all levels of axial compression loading and there was no movement of the skin of the stump in relation to the socket wall. When there was no applied load the whole surface of

the stump was a normal pink colour. As an axial compression load was applied, the surface of the stump, including the distal end, became uniformly pale. With the removal of the load a uniform pink blush reappeared over the whole surface of the stump. None of the patients complained of any discomfort at the stump/socket interface during the loading cycles.

Repeatability of the results

If the results of the experiments were to be meaningful they should be capable of being reproduced at repeated experimental sessions.

The first two graphs are examples of plots done to demonstrate this. Graph 1 shows the general pattern of pressure distribution at the stump/socket interface for various applied loads, and Graph 2 shows the results of a repeat experiment done 3 months later on the same patient wearing the same socket.

The main features of the plots for these two experiments are similar. The maximum difference in pressure recorded at any one of the transducers for similar applied loads during the two experiments was about 7 kN/m² (1 psi) while many of the transducers recorded almost identical pressures throughout the range of loading.

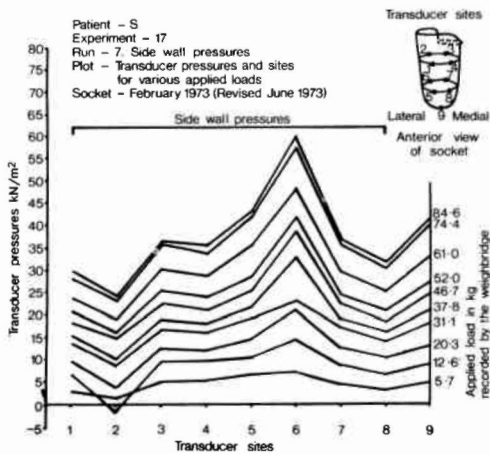
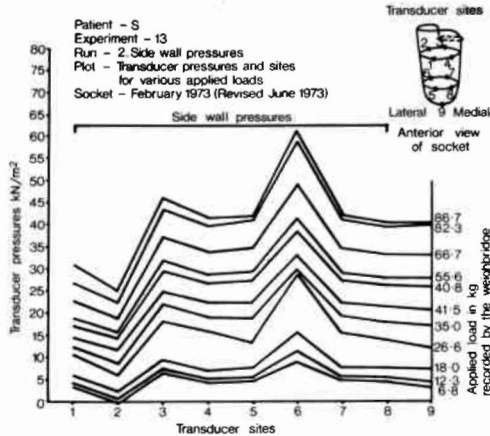
The effect of changes of limb alignment on pressure distribution at the stump socket interface.

A prime requirement of the experiments under discussion was that the applied load should be an axial compression load alone and that as far as possible other directions of loading should be excluded.

It was felt at the time of setting up the experiments that the patient's sensations were as good an indication as any that the stump was pushing straight into the socket under a direct axial compression load, without any unwanted bending loads.

To check whether this was a valid assumption, three loading cycles were carried out consecutively on one patient with the same application of the socket, each with the patient's feet separated by a different amount.

Graph 3 top, centre and bottom, show examples of the results obtained from a patient when his heels were separated by 14 cm, 24 cm and 57 cm.



Graphs 1 and 2. Plots to demonstrate repeatability of the experiment. Graph 1, top: general pattern of pressure distribution for various applied loads. Graph 2, bottom: repeat experiment three months later on the same patient with the same socket. The main features of the plots are similar (see text).

The overall pattern of the 3 plots is similar, but a closer examination of the pressures recorded under maximum load at transducer sites 2 and 4, and 6 and 8 in Graph 3, top shows that at the proximal pair of transducers there was a nett pressure difference of 7.8 kN/m² acting laterally, and that at the distal pair of transducers there was a nett pressure difference of 4.0 kN/m² acting medially. These figures indicate the presence of a lateral bending load.

If the pressures recorded at the same sites in the next two graphs are examined in a similar manner, the figures were 7.5 and 2.3 kN/m² for Graph 3, centre and 4.5 and 1.7 kN/m² for Graph 3, bottom showing that as the patient's feet were moved further apart the lateral bending load

decreased. The nett pressure differences recorded in Graph 3, top at transducer sites 1 and 3 and 5 and 7 under the maximum applied load were 7.5 kN/m² acting anteriorly and 0.8 kN/m² acting posteriorly. The comparable figures are 6.8 and 0.9 on Graph 3, centre and 5.4 and 1.1 on Graph 3, bottom. These figures indicate the presence of a posterior bending load, but its relation to the anterior/posterior position of the foot cannot be inferred as the feet were kept level throughout the experiments presented on Graph 3, top, centre and bottom.

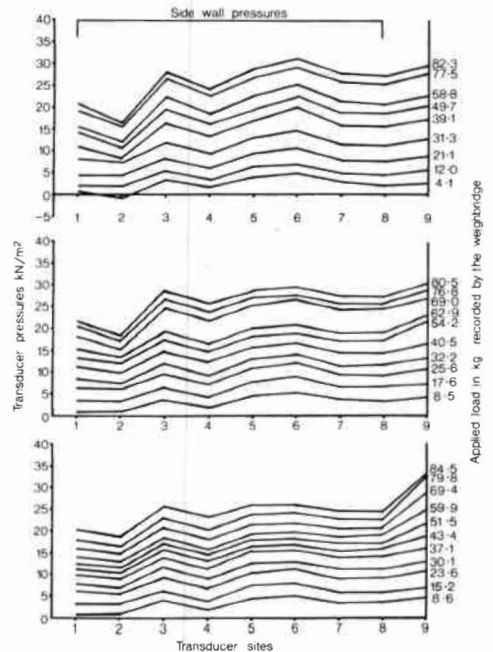
It was therefore concluded that it must not be assumed that the patient can detect the presence of minor bending loads. An examination of Graphs 1, 2 and 4 shows that bending loads were also present in these experiments.

Results

Pressure distribution

Graphs 1—4 show typical distributions of pressure over the side walls of sockets recorded at several different experimental sessions.

The same overall pattern is shown to a greater or lesser degree on all the plots. The lowest pressures were always recorded at transducer site 2 on the lateral side of the proximal part of



Graph 3. Consecutive loading cycles on the same patient with heels separated by different amounts. Top 14 cm, centre 24 cm and bottom 57 cm.

the socket, and the highest pressures were always recorded at transducer site 6 on the lateral side of the distal part of the socket. None of the stumps in question were myoplastic stumps and transducer holder 6 was positioned opposite the area on the stump overlying the lateral side of the distal end of the femoral shaft. It seems likely that a contributory factor to the higher pressures in this area was the small amount of soft tissue cushioning available to distribute the load.

On Graphs 1 and 2, under an applied load of about 85 kg, transducer 6 recorded 60 kN/m^2 (8.6 psi) and transducer 2 recorded 25 kN/m^2 (3.6 psi) giving a pressure range on these plots of 35 kN/m^2 (5 psi). If the results from the patient shown in Graph 3, top are looked at in the same way, the maximum side wall pressure recorded at transducer 6 under an applied load of about 84.5 kg was 26.5 kN/m^2 (3.8 psi), and the lowest pressure recorded at transducer 2 was 18 kN/m^2 (2.6 psi), giving a pressure range on this plot of 8.5 kN/m^2 (1.2 psi). If future experiments could achieve a total absence of bending loads, these pressure differences might be expected to decrease considerably or even disappear.

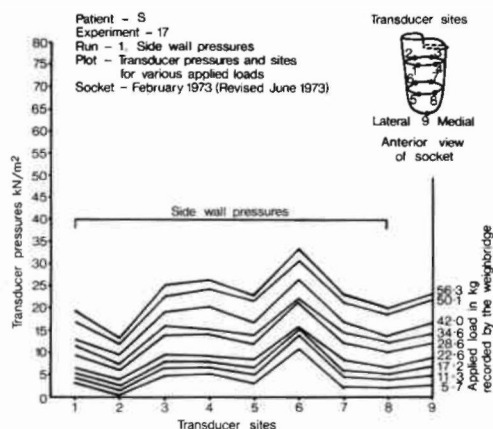
Graphs 4–10 show in more detail the results of an experiment on one patient carried out without removing the socket, making it possible to compare the various plots. Graph 4 shows the typical pattern of pressure distribution over the side wall of the socket previously described. Graph 5 shows a repeat run with transducers moved from holders 5, 6 and 7 in the side wall of the socket to holders 14, 15 and 16 around the posteromedial socket brim.

This plot demonstrates clearly that the pressures around the posteromedial brim of the socket were of the same order of magnitude as those over the side wall of the socket and the same as those recorded by the central terminal transducer in holder 9.

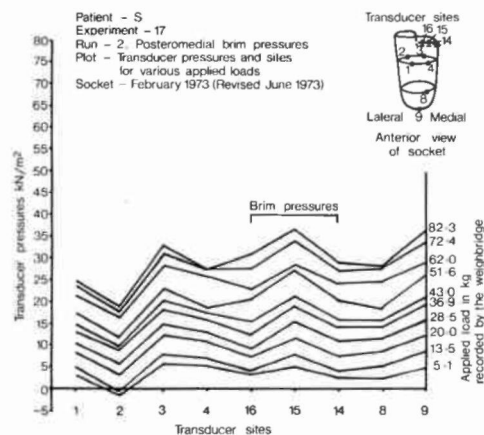
The average of the pressures recorded at the three brim transducers under an applied load of 82.3 kg was 32.2 kN/m^2 (4.6 psi) which compares with the average of the pressures recorded by the other 6 transducers of 28 kN/m^2 (4 psi).

The maximum pressure over the posteromedial socket brim recorded at transducer site 15 under an applied load of 82.3 kg was 36.6 kN/m^2 (5.2 psi) compared with 36 kN/m^2 (5.1 psi) at the terminal transducer.

Appoldt and Bennet (1967), in their studies of static socket pressures on a patient wearing a



Graph 4. Typical pattern of side wall pressure distribution.

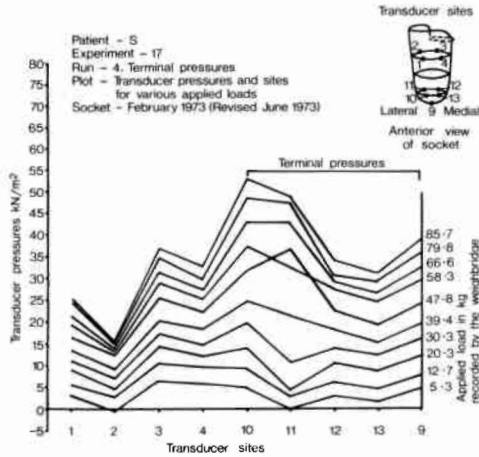


Graph 5. Repeat run with same socket as in Graph 4 with transducers moved from side wall holders 5, 6 and 7 to holders 14, 15 and 16 in the posteromedial brim.

brim bearing total contact socket, recorded a maximum pressure over the posterior socket brim of 42 kN/m^2 (6 psi) when half the patient's weight was on the limb.

In the total surface bearing socket under study in Graph 5 the peak pressure on the posteromedial socket brim under an applied load equal to about half the patient's body weight (43 kg), was 21.5 kN/m^2 (3.1 psi) which is half the figure recorded by Appoldt and Bennett, although as they do not state the weight of their patient or the applied load, it is not possible to make an exact comparison.

Graph 6 shows that the highest pressures in this socket were recorded over the lateral side of the distal surface of the socket at transducer sites 10 and 11. The maximum pressure of 53.3 kN/m^2



Graph 6. Same socket as graphs 4 and 5 with transducers in terminal holders 10, 11, 12 and 13.

(7.6 psi) occurred at transducer 10 under an applied load of 85.7 kg. The corresponding figure for transducer 11 was 48.6 kN/m² (6.9 psi).

The other terminal transducers at sites 9, 12 and 13 recorded pressures of 38.6 kN/m² (5.5 psi), 34.2 kN/m² (4.9 psi), and 31.2 kN/m² (4.4 psi) respectively, which are comparable with 36.9 kN/m² (5.3 psi) and 32.5 kN/m² (4.6 psi) recorded at transducer sites 3 and 4 in the side wall of the socket.

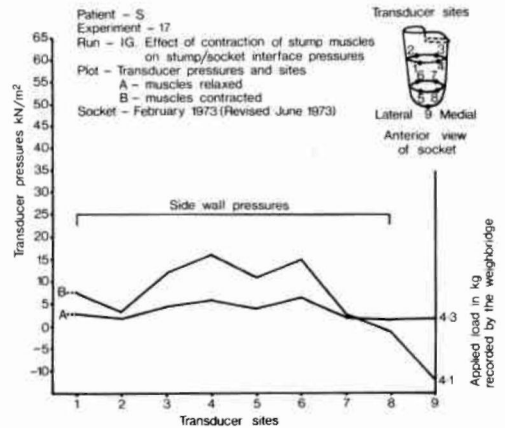
The higher pressures recorded by transducers 10 and 11 may be related to the non-myoplastic nature of the stump, providing only skin and subcutaneous tissue to separate the end of the femur from the socket wall. The patient felt no discomfort over the end of the femur and there was no mark on the skin due to the higher pressure in this area when the stump was examined after removal of the socket at the end of the experiment.

The effect of muscular contraction

Graph 7 shows how the patient was able to raise the pressures generally over the side wall of the socket by tensing his stump muscles. With the muscles relaxed the average of the side wall pressures recorded at transducers 1-7 under an applied load of 0.5 kg (weighbridge reading of 4.3 kg less the weight of prosthesis of 3.8 kg=0.5 kg) was 3.6 kN/m² (0.5 psi), with a peak pressure of 6.1 kN/m² (0.9 psi) recorded at trasducer 6.

When the patient tensed his stump muscles, the average side wall pressure was raised to 9.6 kN/m² (1.4 psi), with a peak pressure of 15.6 kN/m² (2.2 psi) at transducer site 4.

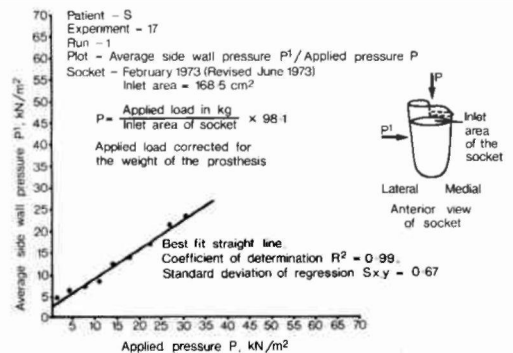
increased pressures occurred in spite of a decrease in the applied load of 0.2 kg. At the same time, the terminal pressure recorded at transducer 9 dropped from 1.9 kN/m² (0.3 psi) to -12.3 kN/m² (-1.7 psi) as the tensed muscles attempted to shorten. The pressure recorded at transducer 8 dropped in a similar manner probably because of the retraction of the distal end of the adductor muscle group in this non-myoplastic stump.



Graph 7. Effect on side wall pressure of patient tensing his stump muscles.

The relation between side wall pressures and applied loads

Graph 8 shows a plot of the average of the pressures recorded by the transducers in the side wall of the socket against the calculated pressure which should result from the even distribution of the applied load over the area of the inlet to the socket. There appears to be a simple straight line relationship between the two sets of figures.



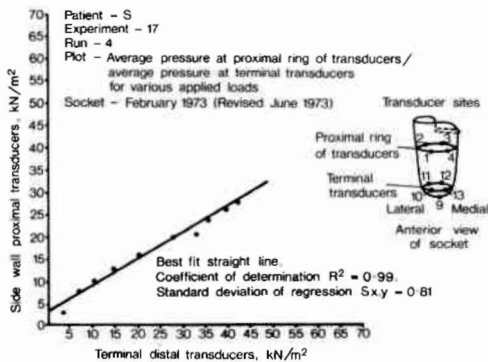
Graph 8. Average side wall pressures plotted against pressure resulting from even distribution of applied load over socket inlet area.

Previously it had been suggested that when there is no applied axial load the average pressure over the side wall of the socket should be between 2.1—3.5 kN/m² (0.3—0.5 psi).

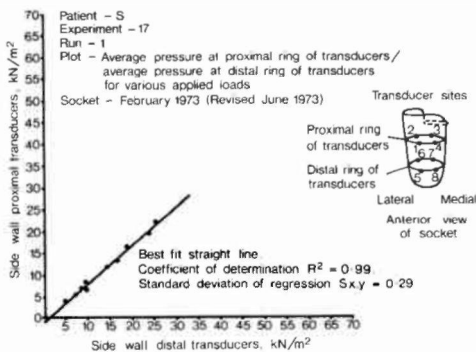
This best fit straight line cuts the vertical axis at 2.34 kN/m² (0.33 psi) which would be the average side wall pressure in this socket without an applied load. The ratio of the side wall pressure to the applied pressure when the applied load was 51 kg was 0.74:1 which is consistent with the tissues of the stump behaving as an elastic solid with low stiffness rather than as a fluid.

Pressure gradients along the long axis of the socket

Graph 9 and 10 examine the pressure distribution along the length of the socket. In Graph 9 the average pressures at the proximal ring of transducers in the side wall of the socket are plotted against the average terminal pressures. This best fit straight line cuts the vertical axis at 2.85 kN/m² (0.4 psi). For side wall



Graph 9. Average pressure at proximal transducers plotted against average pressure at terminal transducers.



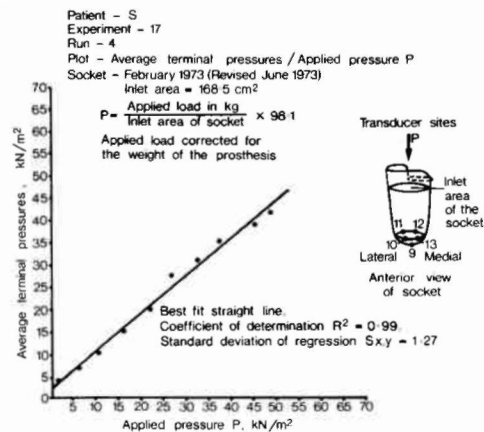
Graph 10. Average pressure at proximal transducers plotted against average pressure at distal transducers.

pressures of less than 7.5 kN/m² (1.1 psi), when the applied load is 20.3 kg, there is a small adverse pressure gradient between the terminal and proximal side wall transducers, but for applied loads of more than 20.3 kg there is a small positive pressure gradient.

Graph 10 examines the pressure distribution along the length of the socket wall by plotting the readings recorded at the proximal ring of transducers against those recorded at the distal ring of transducers. Throughout the range of loading the average pressures recorded at the distal ring were slightly higher than those recorded at the proximal ring, indicating a small positive pressure gradient along the length of the side wall of the socket.

The relation between terminal pressures and applied loads

Graph 11 is a plot of the average terminal pressures in the socket against the calculated pressures due to the distribution of the applied load over the area of the inlet to the socket. The plot shows that the ratio of the average terminal pressure to applied pressure is very close to 1:1, for example under an applied load of 51 kg it is 0.92:1.



Graph 11. Average terminal pressures plotted against pressure of applied load over socket inlet area.

Conclusions

The results of the experiments on these patients and their sockets indicate the following:

The experimental technique used was capable of giving consistent results from repeated experimental sessions.

Small changes in mediolateral limb alignment affect the pressure distribution in the socket.

The aim to produce a more uniform distribution of pressure at the stump/socket interface under static axial compression loads than exists in present brim bearing and total contact fit sockets, appears to have been achieved in spite of the presence of small lateral and posterior bending loads. In particular ischial bearing has been avoided. The higher pressures recorded in the region of the cut end of the femur may have been aggravated by the non-myoplastic nature of the stumps under examination. It is felt that these pressure inequalities would not have occurred if the load had been an axial compression load alone applied to a properly fashioned myoplastic stump in which the distal end of the femoral shaft had been stabilized and adequately covered with soft tissues.

The soft tissues of the stump behaved generally as an elastic/solid with a high bulk modulus and a low stiffness rather than as a fluid.

When there was no applied axial load, the stump tissues were pre-stressed by an average radial pressure of 2.34 kN/m² (0.33 psi), which accorded with the figures suggested in the original hypothesis.

The patient was able to increase the average radial pressure on the side wall of the socket by a factor of 2.7 when the applied load was 0.5 kg, thus demonstrating his ability to increase at will the security of socket retention on the stump.

There was no adverse pressure gradient recorded between the terminal transducers and the proximal side wall transducers at applied loads of less than 20.3 kg is not considered significant.

Clinical experience

Total surface bearing above-knee sockets were fitted experimentally to volunteer patients from 1969 to 1972, during this period some 200 casts were taken.

Since 1974 the sockets have been available for routine issue at a number of limb Centres in England.

The stumps of patients using these sockets have remained healthy and there is no evidence of progressive wasting of the soft tissues of the stump as a result of using total surface bearing sockets for up to 10 years.

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