


REHAB *T e c h*

Monash Rehabilitation Technology Research Unit



**Evaluation of
Trans Tibial
Suspension Systems**



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Requests for permission to make copies of any part of the work should be addressed to:

REHAB Tech- Monash Rehabilitation Technology Research Unit

C/- C.G.M.C.

260 - 294 Kooyong Road

CAULFIELD VIC 3162

AUSTRALIA

Email rehab.tech@eng.monash.edu.au

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ABSTRACT

Trans-tibial prosthetic suspension systems can be categorised into four classes - Vacuum, Anatomical, Strap and Hinged.

Whilst there has been many claims about the relative effectiveness of the various techniques for suspension, there are few comparative studies.

An experiment was devised which could be used to quantify the effectiveness of various suspension systems. To standardise the experiment a Trans-tibial limb was constructed to have similar anatomical features and skin surface characteristics as an anatomical residual limb. To this limb vacuum, strap and anatomical suspension Trans-tibial prosthetic sockets could be donned.

By using a tensile tester a graph of the tensile force required to displace the socket a given distance can be obtained. Extensive video footage was used to see how the suspension systems released from the "limb".

This tensile force can be related to the radial force produced by a prostheses of known weights at a variety of walking speeds.

More importantly the graph gives a comparison of various suspension classes for a given situation. This can complement other clinical considerations in the type of prosthesis prescribed for a given patient.

AIM

To quantify the differences in Trans-tibial suspension systems. Vacuum, Anatomical and Strap suspension systems were compared on a tensile tester and the way the suspension systems released from the limb.

TRANS-TIBIAL SUSPENSION

Suspension systems in prosthetics can be categorised into four different areas.

- 1) The first is hinge suspension and is best represented in the conventional thigh lacer where solid hinges transmit the suspension and often the weight bearing function to another part of the body.
- 2) Strap suspension which is most familiar in the above knee prosthesis as the silesian harness or the PTB strap on the Trans-tibial prosthesis.
- 3) The third is closely related to the strap system and is anatomical suspension where anatomical features are used such as the condyles in the PTS or PTK.
- 4) The final and most recent is vacuum or suction. This also includes systems which rely on skin adherence and includes valve suction and silicon liners.

All of these suspension systems are used in varying frequency in the Trans-tibial or trans-tibial prosthesis throughout Australia. The evaluation which is the subject of this presentation did not consider a hinged mechanism that is a thigh lacer but considered

examples from each of the other suspension categories that is strap, anatomical and vacuum or suction.

The six suspension systems that were tested.

- These were the PTB, with the strap set at two different tensions. One of 5 kg and the other a 10 kg force.
- A PTS - supra condylar suspension.
- A Silicon Suction Socket known as the SSS which is a custom made silicon liner with a shuttle lock system linking the liner to the socket.
- An ICEROSS system which is a prefabricated silicon liner also using a shuttle lock.
- An external sleeve which could seal against the limb incorporating a valve, creating a suction socket.
- The external sleeve with the valve removed.

The external sleeve is similar to that described by Giacinto 1976 and Pritham 1979 except a valve as used in an above knee suction socket was incorporated. A silicone external sleeve is rolled proximally beyond the proximal trim line, in this case on the conventional PTB. As the sleeve seals against the limb a valve was also placed in the socket producing negative pressures. To test the effectiveness of the sleeve alone the valve was simply removed.

METHOD

A literature search failed to find any articles which compared suspension variants using a quantitative techniques. Consequently an experiment was designed to do this. The first stage was to construct a Trans-tibial limb which would be similar to an anatomical stump. The loads that attempt to pull off the prosthesis were calculated. The final stage was to test the limb and sockets both statically and cyclically under tensile forces.

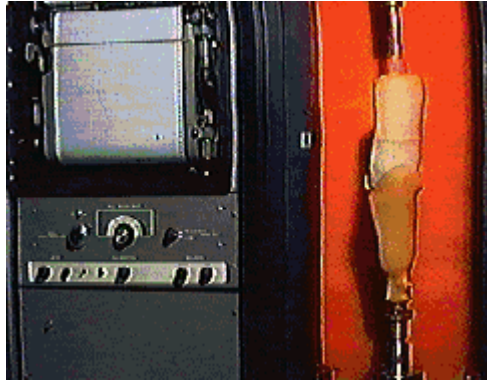
To standardise the experiment a Trans-tibial limb was constructed to have similar anatomical features and skin surface characteristics to an anatomical residual limb. This was done by building up layers of various density materials to match the required surface hardness of the limb. The surface hardness characteristics were checked for a comparable Shore A surface hardness. A number of points were taken and the limb was built up to match the surface characteristics of a natural limb, with the hardness varying with position on the limb.

The surface of the standardise limb had a similar friction coefficient to that of regular skin while also having similar porosity. This was done by covering the standardised limb with smooth treated leather.

Sockets were made to fit this standardised limb. The PTS and PTB sockets incorporated a Pelite liner in a laminated socket. The SSS and ICEROSS liners were used with laminated sockets. The sleeve sockets were incorporated into the PTB socket. All sockets had a uniform alignment.

Figure 1 shows the test set up.

Figure 1



The socket with approximately 5° of flexion was attached to an INSTRON TT-BM testing machine (EQ139-0171) so that a tensile force could be applied. The distal end of the stump was attached to an alignment plate which allowed the socket to freely rotate and slide perpendicular to the applied force, the plate was attached to the machine. This simulated a simply supported end. The other end was rigidly attached to the machine. A chart recorder would plot the load on the horizontal axis and the displacement on the vertical.

Two video camera's recorded the tests. One recorded the chart, while the other focused on the socket stump interface.

Each socket was statically tested three times with a crosshead speed of 10 cm / min and a load cell of 500 N. The "limb" was pushed back into the stump manually before each test. The load was released when the chart recorder indicated the socket had let go or the load had reached a suitably high value usually 250 N.

A last static test was conducted with a cross head speed of 1 cm / min. This was conducted to get a better view of the 'limb', socket and liner interface.

Finally Cyclic tests were performed on each of the systems in order to see how they behaved when loaded and unloaded continuously and also to see if they would return to the same point. For these tests a 200 N load cell was used with a crosshead speed of 5 cm / min. Due to the intricacies of the testing machine the load cell could not be put in compression. The cyclic test loaded the socket until the limb had displaced 2 mm and then returned to 0 mm displacement. Problems with the cyclic method will be discussed later.

CALCULATED LOADS

The second stage was the calculation of the normal force. This force represents the weight of the prosthesis swinging outward and can be estimated to be the dynamic force pulling the prosthesis off during gait. This is equivalent to the normal angular force of a simple pendulum. Table 1 gives the force for several legs with two different angular velocities from different studies. The calculations for table 1 can be seen in appendix A. The mass of the legs were measured for three Trans-tibial prosthesis, a and b where endoskeletal while c was an exoskeletal prosthesis. As can be seen the loads are very small. The values for angular velocity were found from previous studies by Winter 1979 and Winter 1974.

Table 1

Prosthesis	Mass	C.G. Distance	Angular velocity	Acceleration normal	Force Normal
	grams	mm	R/s	Ms ⁻²	Newtons
a	1595	340	-5.09 <i>Winter 79</i>	8.808	14.05
b	1505	350	-5.09	9.067	13.65
c	2050	160	-5.09	4.145	8.499
mean	1716.7	283.3	-5.09	7.341	12.60
a	1595	340	-7 <i>Winter 74</i>	16.66	26.57
b	1505	350	-7	17.15	25.81
c	2050	160	-7	7.84	16.07
mean			-7	13.88	23.83

A load of 25N was taken for average or typical walking speed.

Loads for running were also calculated using data from Smith 1990 for angular velocity. The suspension load for a typical runner was 93 N.

THE RESULTS

All the Suspension systems carried loads in excess of those encountered in normal walking. Sample load displacement plots are shown in appendix B. The following tables show a comparison for typical walking loads.

When loaded with a 25N load that is the load at a typical walking speed the results show that all of the suspension systems held on with displacements of less than one millimetre. The PTS displacement was twice that of the others at this load.

Table 2

Displacement of Socket with a 25 N Load in mm	
PTB 5 Kg	0.2
PTB 10 Kg	0.2
PTS	0.4
SSS	0.18
ICEROSS	0.16
REHAB Tech Suction	0.2
REHAB Tech Sleeve (valve released)	0.2

The external sleeve, called the **REHAB Tech** sleeve in the tables, showed exactly the same result when it was combined with suction and also when it was not. The SSS and the ICEROSS showed the best results however the differences over all were minimal at this load.

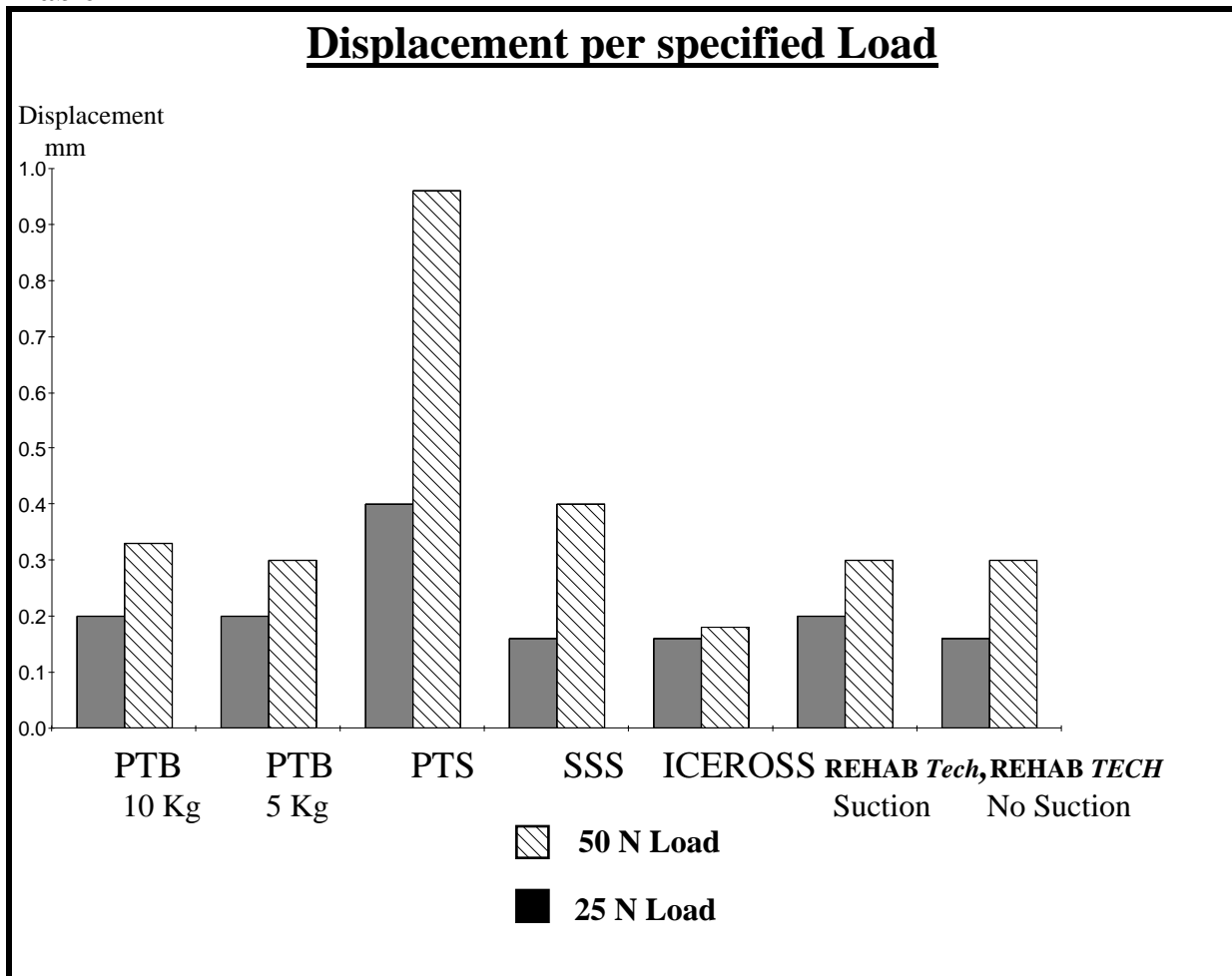
At 50N, which would be the load at vigorous walking, the displacements increased. All of the values have increased slightly. The PTS shows the greatest increase by doubly the displacement to just under 1 mm. The **REHAB Tech** external sleeve again showed no difference between variants as did the PTB strap for the two different tensions. The ICEROSS shows the least amount of displacement at this load however with the exception of the PTS all of the systems displaced by .4 of a millimetre or less.

Table 3

Displacement of Socket with a 50 N Load in mm	
PTB 5 Kg	0.33
PTB 10 Kg	0.3
PTS	0.96
SSS	0.4
ICEROSS	0.18
REHAB Tech Suction	0.3
REHAB Tech Sleeve (valve released)	0.3

If we look at this graphically we see the dark blue representing the 25 Newton or typical walking speed and the green representing the 50 Newton or vigorous walking speed.

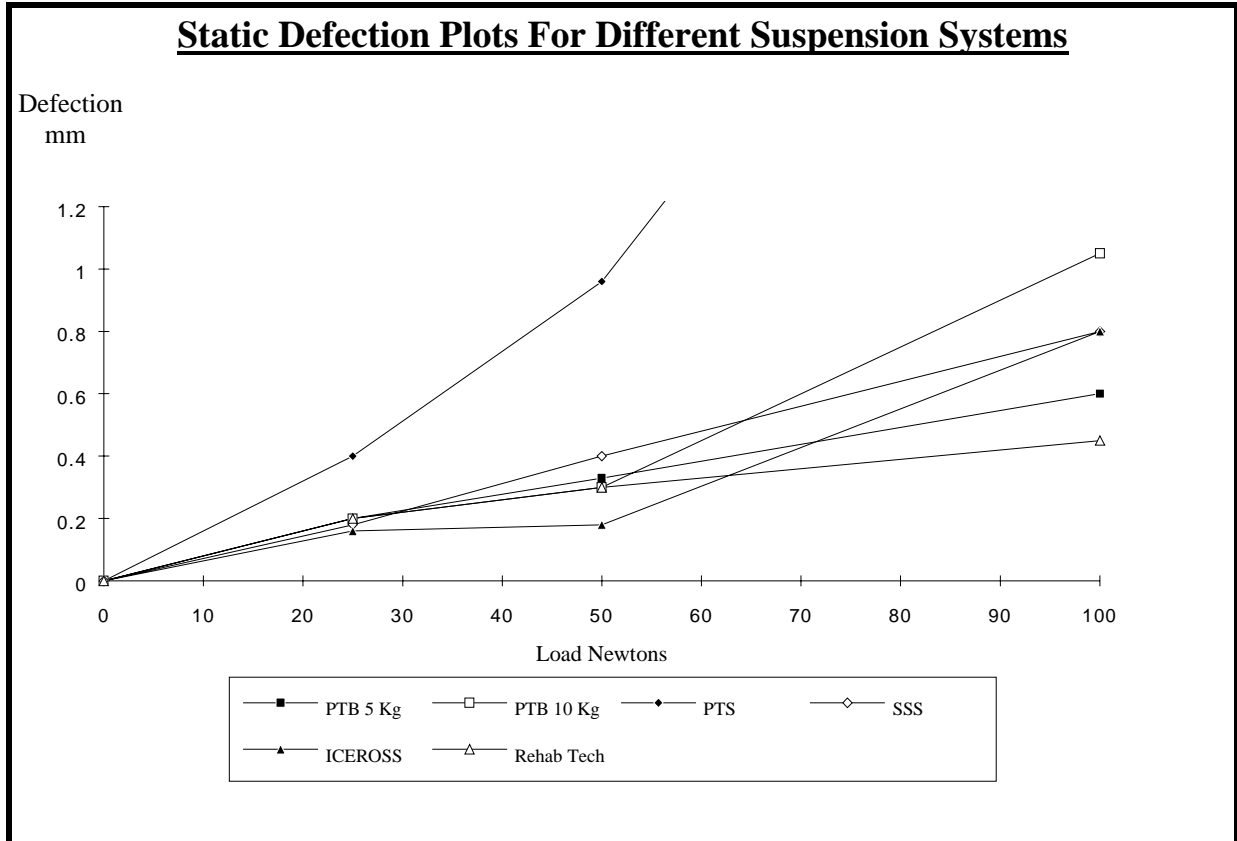
Table 4



The PTS socket shows the greatest displacement in both cases. In each case it can be seen that there is no difference between the different tensions on the strap of the PTB. The ICEROSS displacement remains minimal in both cases and it is only in the higher load that the SSS increases caused initially by the stretching of the liner.

There is also no difference between the **REHAB Tech** external sleeve with or without the valve applied meaning that the suspension load was carried by the sleeve with suction having little influence.

Table 5



Cyclic load

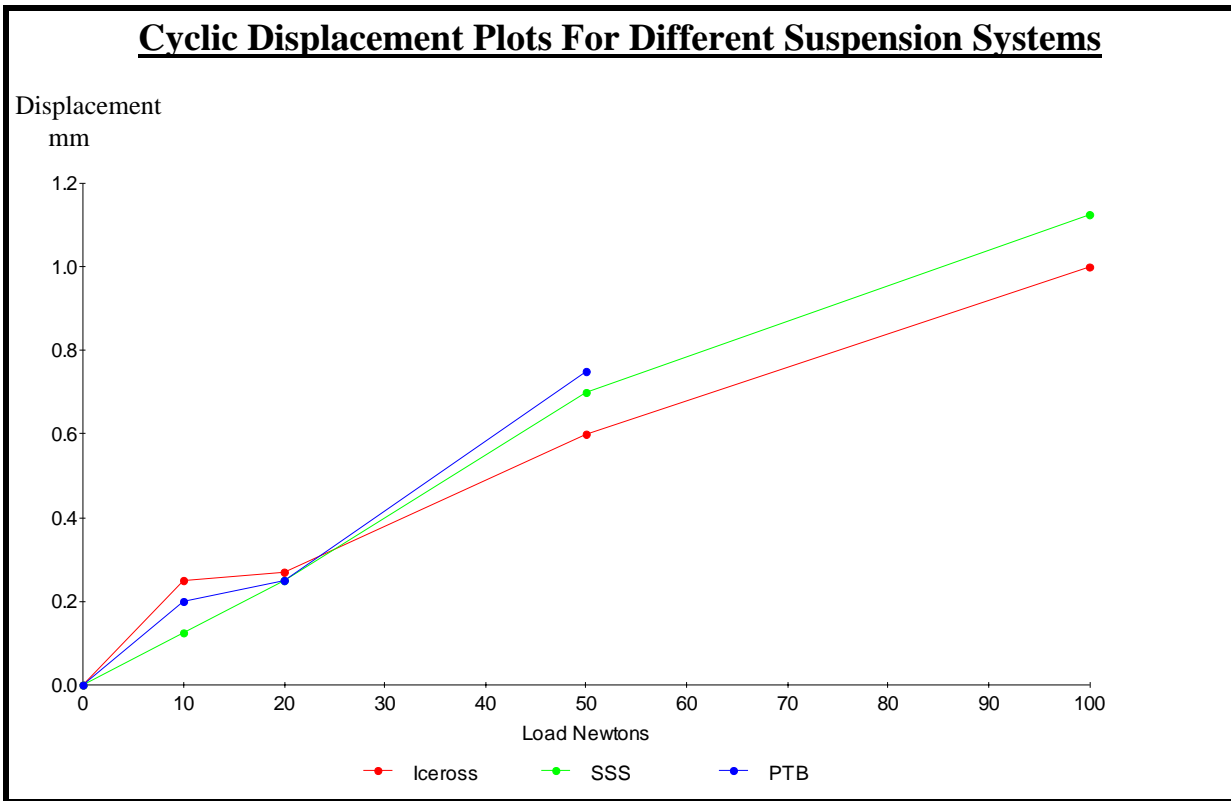
In the cyclic results the PTS was the only suspension variant which had poor return to the original position. All of the other suspension types showed repeatable displacements and consistent return to the starting position across the range of loading.

Cyclic displacement of 0 to 2 mm per cycle

Table 6

LOAD	10 N	20 N	50 N	100 N
SOCKET DISPLACEMENT mm				
PTB 5 Kg	0.2	0.25	0.75	Displacement greater than 2 mm
SSS	0.125	0.25	0.7	1.125
ICEROSS	0.25	0.27	0.6	1

Table 7



However, another very important factor is the socket liner relationship which was viewed by a close up recording of the socket when the load was being applied .

The SSS and the ICEROSS were the only two suspension variants where the displacement listed was due to the socket moving without the liner moving along the limb. The close up video shows no detectable movement of the liner for the greatest part of the deflection test for either the SSS or the ICEROSS.

The PTB, the PTS and the **REHAB Tech** external sleeve both with and without the valve showed that the displacement consisted of movement both of the socket and the liner when loading and unloading. This has obvious clinical considerations as it would increase the

skin friction with a continuous cyclic tension compression displacement of half a millimetre motion on average.

DISCUSSION

The sockets were all loaded above the loads encountered in normal use. For all sockets except the PTS the amount of displacement encountered in normal use was comparable between suspension systems, as can be seen in appendix B.

The ICEROSS socket shows a typical force displacement plot for a viscoelastic material. This indicates the silicone is stretching and not slipping. However once the seal has been broken the socket offered no resistance to displacement. It is interesting to note that a pocket of air was evident at the distal end of the socket after each test, indicating good vacuum suspension. If the "limb" was not pushed back into the socket after the test the ability for the socket to hold on was reduced dramatically. Video footage of the socket, "limb" liner interface confirm the liner stretched over the limb and did not slide along the "limb". This has clinical benefits as it reduces the shear stress imposed on the "limb" by the liner. This is also referred to by Kristinsson 1993, where *"The interface between skin and socket is free of friction, which has been transferred to the interface between the ICEROSS and the socket. As a result considerably less strain is exerted on the skin."*

The SSS socket behaved similarly to the ICEROSS socket. This is hardly surprising as it only varies from the ICEROSS by being custom fitted with a fibre reinforcement for the silicone. It also displays a typical force displacement curve for silicone. Again indicating the material is stretching and not slipping. The small kinks on the plot are due to two reasons. One the reinforcing material not allowing the silicone to stretch naturally. Two the reinforcing material hinders the silicones ability to stretch over bumps in the "limb" as it is custom fitted. These kinks in the curve are small and in general the SSS behaves similarly to the ICEROSS. The SSS also showed similar interface conditions to the ICEROSS resulting in a reduction of shear stress on the "limb".

The PTB socket had almost identical plots regardless if the strap was tensioned to 5 Kg or 10 Kg. The load displacement curve displayed an almost linear relationship in the region of regular use. The straps carried the load while friction between the "limb", liner and socket allowed them all to move relative to each other. Looking at the socket, liner 'limb' interface the video footage confirmed the movement of all three component promoting pistoning and higher shear stresses for the "limb".

The PTS socket displayed the worst suspension characteristics of the systems tried. The socket released at around 60 newtons force while the other systems released at 200 newtons or more. The PTS also displayed the largest displacement for loads encountered in typical use. This has clinical considerations for very active amputees as around 93 newtons of suction is required for a running amputee. The reason is the PTS's ability to hold is reduced once the medial and lateral brims have passed the femoral condyles. The suspension could be improved with a more drastic build up over the condyles however other clinical considerations could prohibit this. The PTS suffered similar problems to the PTB on the socket liner "limb" interface, with large movements and resulting shear stress between the liner and "limb".

The two **REHAB Tech** sleeve sockets with or without the valve behaved identically. This indicates that no suction was present or the sleeves adherence to the stump was too strong. Pritham 1979 mentions a study using sleeve suspension were one subject showed no degradation of suspension affect the sleeve was punctured. The force displacement plots show two almost linear gradients. The second gradient is after the sleeve starts to slip. The

sleeve was of a stiffer composition than the ICEROSS or SSS resulting in the material stretching similar to a linear material over small displacements. The **REHAB Tech** sleeves had the same problems as the PTB at the socket liner "limb" interface.

The cyclic tests attempted to see how the sockets behaved over a number of cycles, in comparison to the static results. Due to the testing machine being restricted to either compression loads or tension loads only, a cyclic displacement was used instead of a cyclic load scheme. Resulting in the "limb" being displaced 2 mm then returning to zero displacement without a compressive load.

This proved satisfactory for all systems except for the PTS as a compressive force is required to push the socket past the condyles after each cycle. The other sockets did not require compressive loading to return to the zero displacement line as the elastic properties of the liners, sleeves and straps wanted to return the zero displacement line. The sockets that were cyclically tested showed uniform load displacement plots between each cycle. These plots differ to the load displacement plots for static loading with a generally larger displacement per specified load in the cyclic plots. This is probably due to the lack of a compressive force after each cycle which was applied to the static tests. This also explains why the plots test required one to two cycles to settle down to a uniform load displacement plot.

CONCLUSION

In conclusion the PTS showed the greatest displacement over the normal and vigorous walking range. Adjusting the PTB strap tension between the 5 kg tension and 10 kg tension representing firm and very tight made no difference to the displacement of the socket under load.

The SSS and the ICEROSS were the only two suspension variants which showed no liner movement when the socket was being displaced by the force therefore skin friction would be minimised and finally all of the suspension variants showed how displacements at normal walking velocities.

Thanks to Orthopaedic Techniques and the Dept. of Mechanical Engineering for their assistance and collaboration in this evaluation.

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APPENDIX A

Calculation for simple pendulum.

$$s = r\theta \quad \text{displacement}$$

$$v = \frac{ds}{dt} = r \frac{d\theta}{dt} = r\dot{\theta} \quad \text{velocity}$$

$$a_t = \frac{dv}{dt} = \frac{d(r\dot{\theta})}{dt} = r\ddot{\theta} + \dot{r}\dot{\theta}$$

$$\dot{r} = 0$$

$$dv_n = v d\theta$$

$$a_n = \frac{dv_n}{dt} = \frac{vd\theta}{dt}$$

$$a_n = r\dot{\theta}^2 \quad \text{Normal acceleration}$$

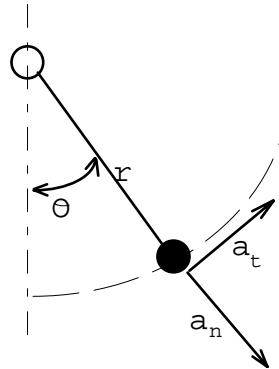
$$a_t = r\ddot{\theta} \quad \text{Tangential acceleration}$$

$$a = \sqrt{a_t^2 + a_n^2}$$

r = length from pivot to C.G.

$\dot{\theta}$ = Angular velocity

$\ddot{\theta}$ = Angular acceleration



Sample Calculations for leg a using angular velocity from Winter 1979 for walking and Smith 1990 for running.

Walking

$$r = 340mm$$

$$\dot{\theta} = -5.09Rs^{-1}$$

$$a_n = r\dot{\theta}^2 = -8.808ms^{-2}$$

$$M_{leg} = 1595g$$

$$F = Ma$$

$$F_n = M_{leg}a_n = 14.05N$$

Running

$$r = 340mm$$

$$\dot{\theta} = -13Rs^{-1}$$

$$a_n = r\dot{\theta}^2 = -57.46ms^{-2}$$

$$M_{leg} = 1595g$$

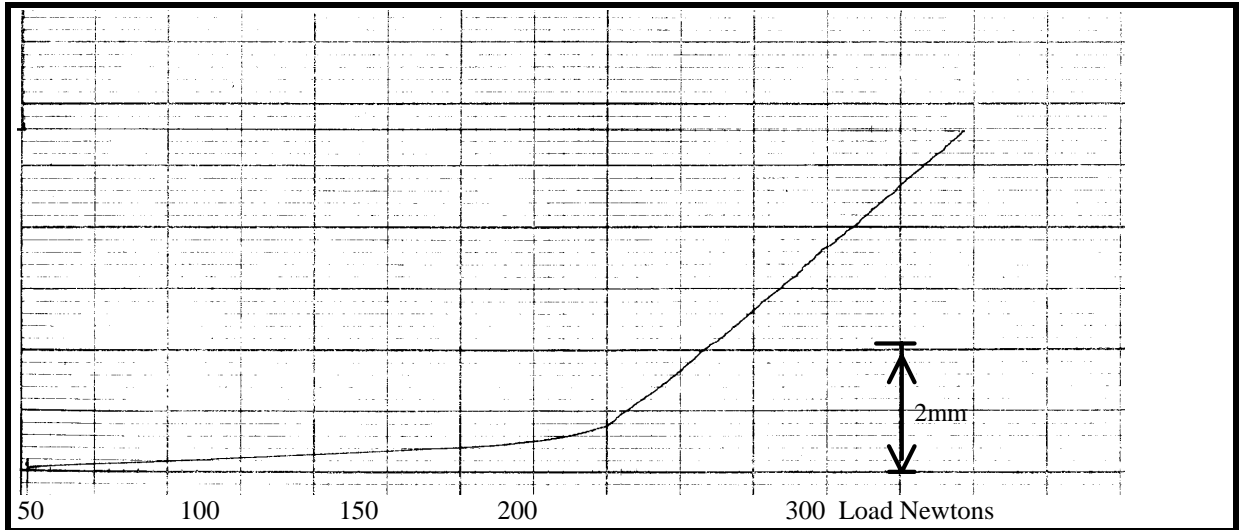
$$F = Ma$$

$$F_n = M_{leg}a_n = 91.65N$$

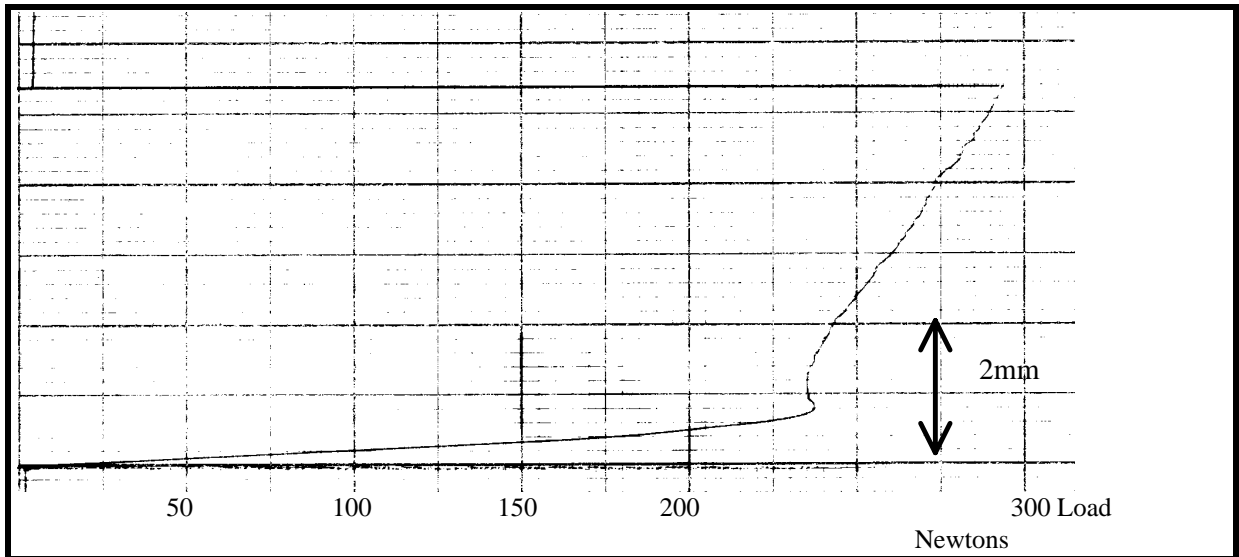
APPENDIX B

Sample load displacement plots for static loading.

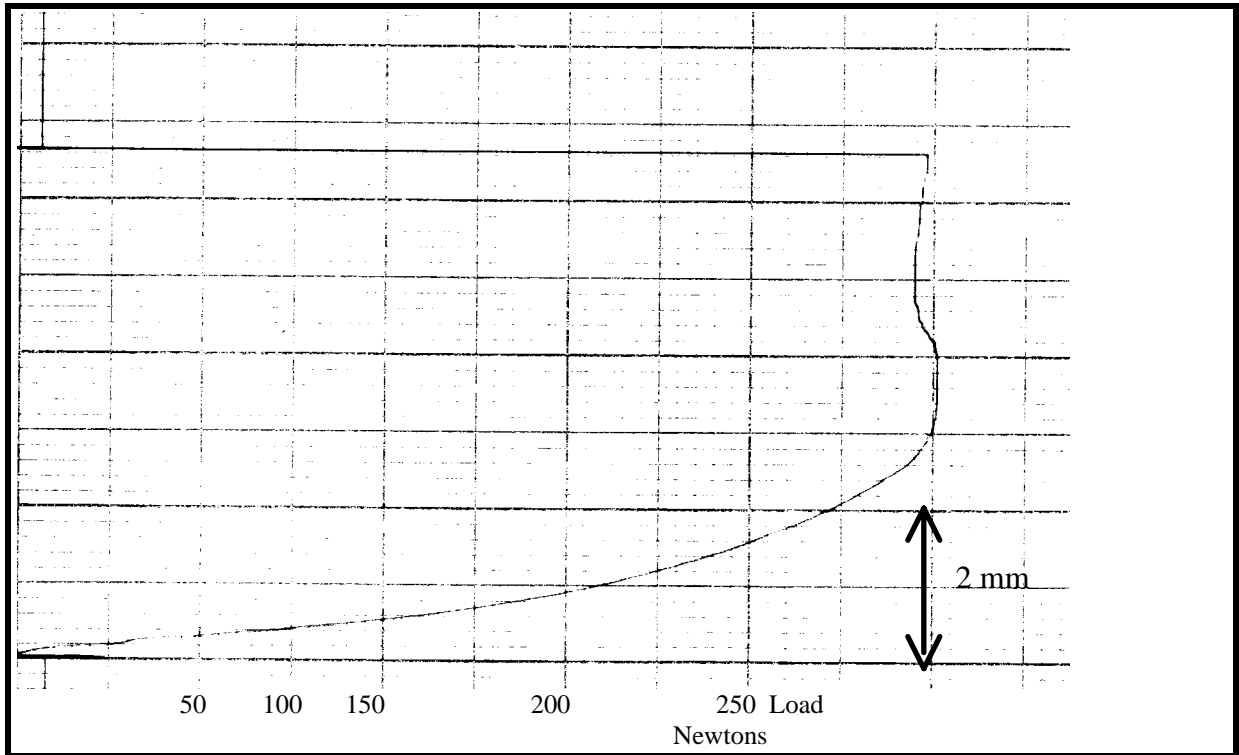
REHAB Tech SLEAVE and REHAB Tech SUCTION SOCKETS



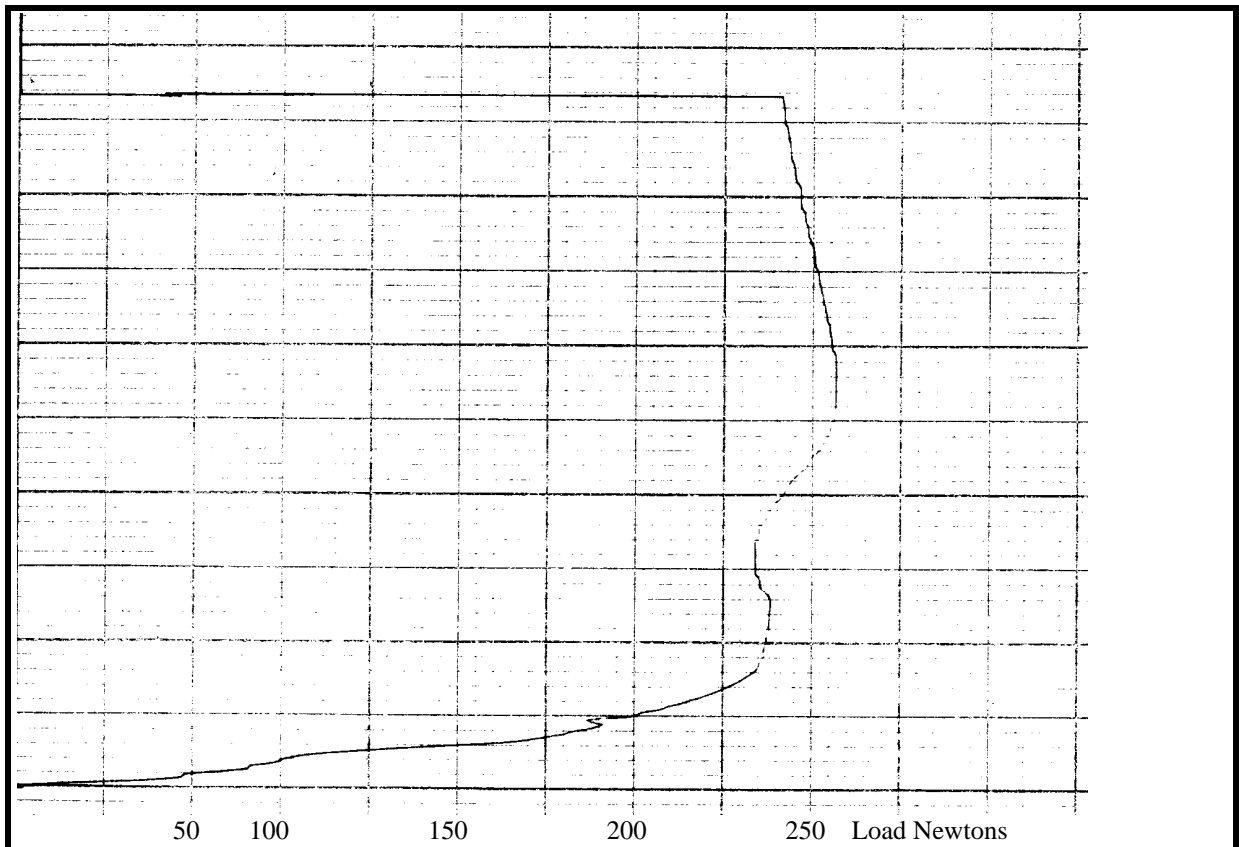
PTB SOCKET



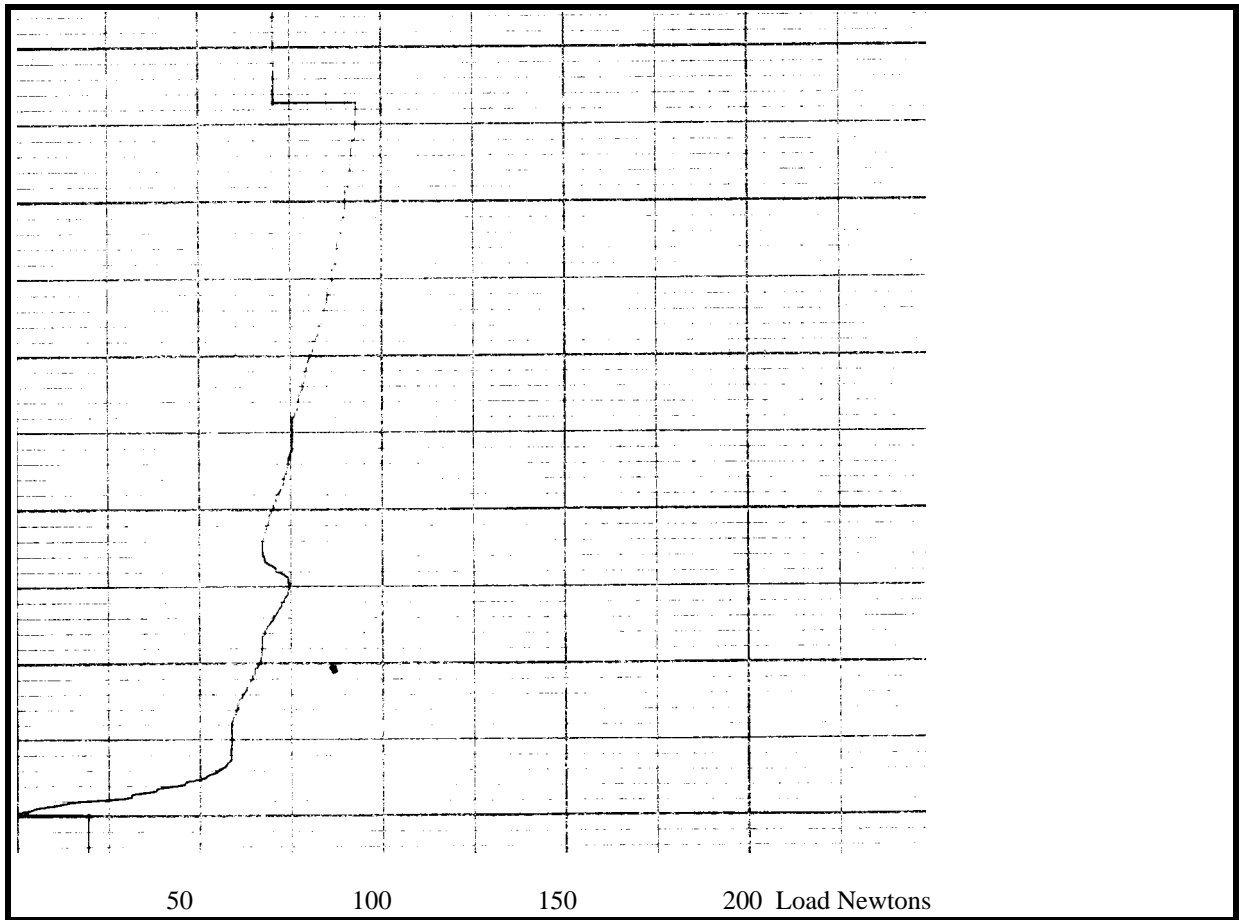
ICEROSS SOCKET



SSS SOCKET



PTS SOCKET



Clinical Placement - Assignment

***TRANS-TIBIAL SUSPENSION
EVALUATION -
CLINICAL ASPECTS***

REHAB *Tech*, Placement Project.

Matt Fleming

9242527W

ABSTRACT

In an overview of BK Suspension, Michael (1991), states that there are four generic classes into which Trans-tibial prosthetic suspension systems may fall - Vacuum, Anatomical, Strap and Hinged.(5)

As Stewart (1993) points out, whilst there has been many claims about the relative effectiveness of the various techniques for suspension, there are few comparative studies for this area.(4)

This project serves as a follow-up to the study carried out by Stewart in 1993 involving evaluation of Trans tibial prosthetic suspension systems. In that study an experiment was devised which could be used to quantify the effectiveness of various suspension systems. To standardise the experiment a Trans-tibial limb was constructed to have similar anatomical features and skin surface characteristics to an actual anatomical residual limb. To this limb vacuum, strap and anatomical suspension Trans-tibial prosthetic sockets could be donned. By using a tensile tester the amount of tensile force required to displace the socket a given distance was obtained.

This follow-up project involves carrying out a similar experiment though in this case a real Trans-tibial prosthetic patient is the subject on which the suspension systems are tested. The original study may be considered the technical test and this project is testing Trans-tibial suspension in a clinical setting.

The subject was cast and fitted with four different suspension systems. In the experiment each socket was donned by the subject and the displacement of the socket/liner was measured with various weights added to the set-up. Extensive video footage was used to accurately measure the displacement for each given weight with each suspension system. This could give a reasonable indication of which suspension systems 'hold on' better than others.

So the results can give a comparison of various suspension classes for a given situation. This can complement other clinical considerations in the type of prosthesis prescribed for a given patient.(4)

This experiment effectively tries to repeat as closely as possible the experiment carried out by Stewart except it is applied to a real subject. Therefore another aim of this experiment is to obtain results which can be used for comparison with the results obtained in the technical tests.

INTRODUCTION

As mentioned before suspension systems in prosthetics can be categorised into four generic classes:

- 1. Hinged** - eg. conventional thigh lacer.
- 2. Strap** - eg. PTB strap on a Trans-tibial prosthesis.
- 3. Anatomical** - eg.'s PTS or PTK.
- 4. Vacuum or Suction** - eg.'s valve suction, silicon liners.⁽⁴⁾

In accordance with the study carried out by Stewart this project did not consider a hinged mechanism (thigh lacer) but considered examples from each of the other three classes. While Stewart tested six different suspension systems this project only considered four.

The six suspension systems tested by Stewart were:

- *PTB - with the strap set at two different tensions. One of 5 kg and the other a 10 kg force.
- *PTS - Supracondylar suspension.
- *ICEROSS - a prefabricated silicon liner using a shuttle lock system to link the liner to the socket.
- *SSS - Silicon Suction Socket, a custom made silicon liner also employing a shuttle lock system.
- *External Sleeve - which seals against the limb incorporating a valve, creating a suction socket. and
- *External Sleeve - with the valve removed.

The four suspension systems tested in this project were:

- *PTB
- *PTS
- *ICEROSS, and
- *SSS

A literature study carried out for the previous study failed to find any articles which compared suspension variants using quantitative techniques and subsequently an experiment was devised to do this. The first stage was to construct a Trans-tibial limb which incorporated similar anatomical features and skin surface characteristics to an anatomical residual limb.

Sockets were made to fit this standardised limb. The PTB and PTS sockets incorporated a Pelite liner in a laminated socket. The ICEROSS and SSS were used with laminated sockets. All sockets had a uniform alignment.

The socket with approximately 5° of flexion was attached to an INSTRON TT-BM testing machine (EQ 139-0171) so that a tensile force could be applied. The displacement of the socket/liner was then measured for different loads applied. Results were then collated and evaluated. As mentioned before this investigated suspension in a technical situation, the next was to evaluate from a clinical aspect.

METHOD

A male below-knee amputee with an average length stump and no stump complications agreed to volunteer as the subject for the experiment. The subject was cast and a check socket was fabricated. When the fit was deemed to be optimal, each of the four sockets was then fabricated. All sockets were fabricated using the same methods as those used in the previous experiment carried out by Stewart so as to ensure that the two experiments could be compared with as much consistency as possible. The PTS and PTB sockets incorporated a Pelite liner in a laminated socket. The SSS and ICEROSS liners were used with laminated sockets.

A system was devised where a plastic container was attached to the bottom of a pylon which could be attached to each of the four different suspension systems. With the subject having donned a socket, lines were drawn at the socket/liner interface for all four systems and at the liner/leg interface for the PTB and PTS systems only. The subject used a physiotherapy standing frame to maintain balance while lead balls were added to the plastic container up to a weight of 10 kg at intervals of 1 kg. This weight included the pylon/container set-up as well. The subject was instructed to ensure that his stump remained relaxed throughout the experiment to ensure that there was less margin for error due to inconsistency.

A video was set up which focused in as accurately as possible on the socket/liner and liner/leg (where appropriate) interface so that displacement at both could be monitored. At each 1 kg interval, video footage was taken for approximately ten seconds after the weight had been added. Included in the picture for each interval was a small piece of paper informing the viewer of the total weight that had been added and also an accurate metal ruler. The ruler was included as a reference for when results would be obtained from the video footage.

The displacement was measured accurately by using an electric Vernier to measure the distances between the lines drawn at the socket/liner and liner/leg for each weight interval from the television screen.

This explains the presence of the ruler in the picture. Because the video image created from the footage was larger on the television screen than in real life some sort of reference was needed. Firstly the distance between lines on the screen at the starting point before any weight was added was measured, as was the distance that a 5 mm interval on the ruler covered on the screen. This screen measurement was then converted to an actual measurement using the following equation:

$$\text{MEASUREMENT (mm)} = 5/A \times C$$

Where : 5 represents mm measurement from ruler

A is the distance that 5 mm on the ruler covers on the screen, and

C is the distance between the lines at the start.

From here it was possible to formulate an equation which could convert the displacement between the lines for socket/liner and liner/leg for each weight interval into an actual measurement also. This equation reads as follows:

$$\text{DISPLACEMENT (mm)} = 5/A \times (B - C)$$

Where : 5 represents mm measurement from ruler

A is the distance that 5 mm on the ruler covers on the screen
B is the total distance between the lines on the screen, and
C is the distance between the lines at the start.

Included in the preparation for this project was the formulation of a budget to give an indication of the costs involved with the project. Overleaf is a copy of the budget for this project. It should be noted that this is only a rough estimate of the cost and should not be assumed to be 100% accurate. There were additional costs which have not been taken into account here.

Table 1. Budget

3S Shuttle lock Kit Reg 1"	\$97.35
3S 35 Silicone Resin (Comp."A")	\$137.8
3S 35 Silicone Resin (Comp."B")	\$21.30
Silicone Oil	\$30.65
Inhibitor	\$30.65
ICEROSS Silicone Socket	\$298.00
Distal Attachment Piece	\$40.50
Plastic Suspension Strap	\$27.60
Prosthetic Sock-Natural wool for BK	\$16.10
Prophetic Sock-cotton-white for BK	\$7.60
PVA Bags-BK Prostheses	\$75.00
Nylon Stockinet-white	\$65.30
Fibreglass Stockinet	\$65.30
Pedilen Duplicating Plastic	\$24.20
Hardener	\$23.60
Orthocryl Lamination Resin 80:20	\$36.90
Hardener Powder	\$2.90
Pigment Paste-skin colour-Caucasian 9 Tube)	\$13.80
Durr-plex Sheet 4'x4' 1/4" thick	\$194.00
Pelite Sheet 750 x 15 mm 5 mm thick	\$36.90
Standard SACH Foot	\$102.90
SACH Foot-Adaptor-Titanium-with cap screw (foot bolt)	\$84.00
Tube Adaptor-Titanium	\$130.00
Tube Clamp Adaptor-Titanium	\$141.90
Socket Adaptor with pyramid-Titanium	\$79.80
Modular Adaptor for Vacuum formed Sockets-Aluminium	\$93.00
Total	\$1877.10

RESULTS

As with the study carried out by Stewart all of the suspension systems carried loads in excess of those encountered during normal walking. The values for normal walking having been obtained using angular velocity values found in previous studies by Winter (1979) and Winter (1974). (4)

Following are two tables of results. The first shows the overall displacement for each weight interval including values for both socket/ liner interface and liner/leg interface displacements where appropriate.

Table 2. Overall Displacement At Each Weight Added -Measurements in (mm).

Suspension	Weight (kg)									
	1	2	3	4	5	6	7	8	9	10
Supracondylar A	0.27	0.32	0.33	0.33	0.42	0.86	1.38	1.92	2.65	4.00
Supracondylar B	0.40	0.40	0.43	0.45	0.95	1.09	1.11	1.17	1.41	0.58
Total Supracondylar	0.67	0.72	0.76	0.88	1.37	1.95	2.49	3.09	4.06	4.58
ICEROSS B	0.01	0.15	0.15	0.67	0.70	1.21	1.43	3.30	4.30	4.95
SSS B	0.11	0.43	1.33	1.84	2.71	4.20	4.85	6.61	7.09	7.22
PTB A	0.17	0.42	0.71	1.02	1.31	1.54	2.11	3.64	4.40	5.51
PTB B	0.02	0.12	0.15	0.16	0.21	0.28	0.28	0.34	0.40	0.45
Total PTB	0.19	0.54	0.86	1.18	1.52	1.86	2.39	3.98	4.80	5.96

**Where A is the relationship between liner and leg,
and B is the relationship between socket and liner.**

The second shows a comparison of the clinical and technical tests giving measurements for values of both 25 Newtons and 50 Newtons.

Table 3. Comparison Between Clinical And Technical Tests.

SOCKET	CLINICAL		TECHNICAL	
Supracondylar	~25N	0.74	at 25N	0.40
	~50N	1.37	at 50N	0.96
ICEROSS	~25N	0.15	at 25N	0.16
	~50N	0.70	at 50N	0.18
SSS	~25N	0.88	at 25N	0.18
	~50N	2.71	at 50N	0.40
PTB	~25N	0.70	at 25N	0.20
	~50N	1.52	at 50N	0.30

As with the study carried out by Stewart, all suspension systems held on with displacements of less than one millimetre when loaded with the equivalent of a 25 N load, that being the load encountered during normal walking. Of the four suspension systems tested here, the ICEROSS "held on" the best for an applied load of 25 N with a displacement of just 0.15 mm followed by the PTB, the PTS and then the SSS.

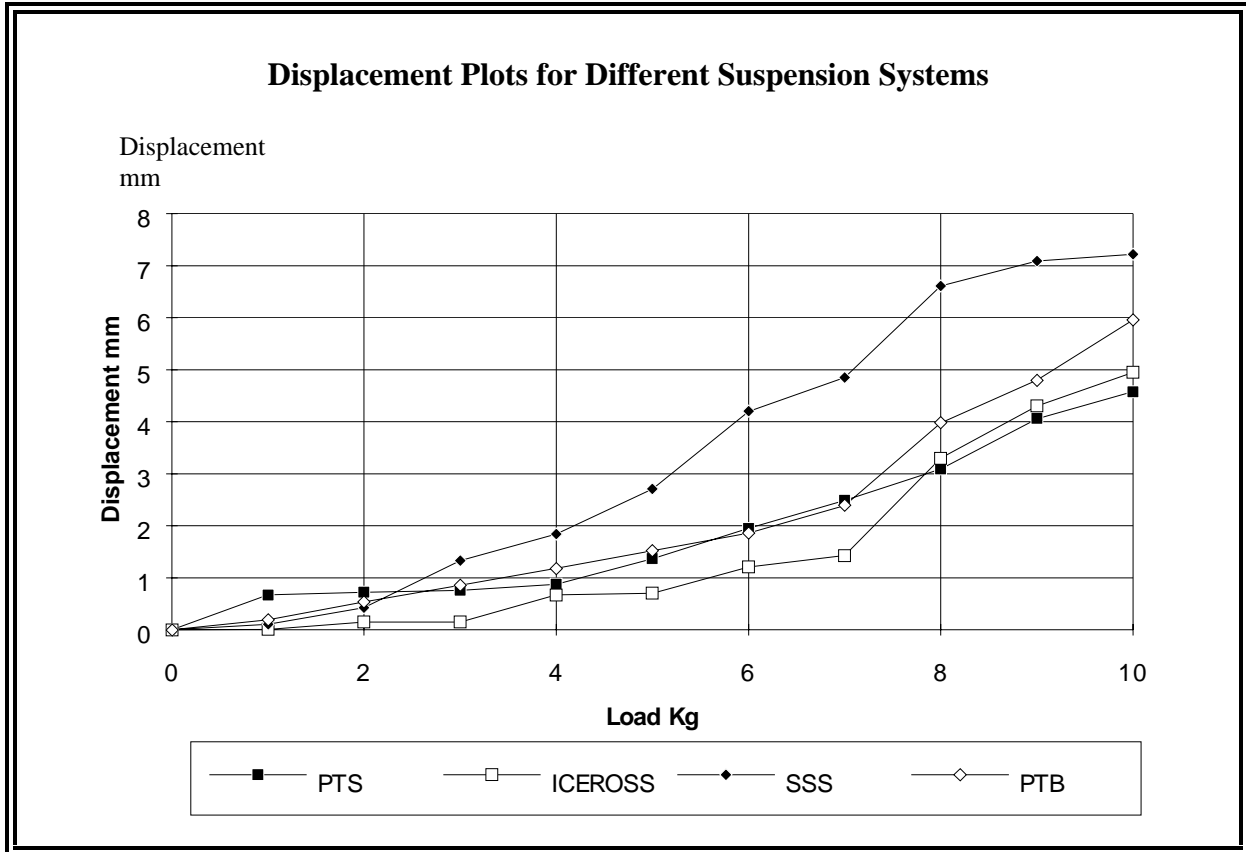
For an applied load of 50 N, which may represent the load for vigorous walking (4), there was a significant increase in the displacement for all systems compared to the displacement for a 25 N load. The suspension system with the least displacement was again the ICEROSS, followed by the PTS, then the PTB and again the SSS. All systems except the PTS had more than double the displacement here than with a 25 N load.

These results differed somewhat from those obtained in the previous study by Stewart. The displacements encountered by each of the suspension systems in this experiment were greater than those found in the technical test in every instance except one, that is, for the ICEROSS socket with a load of 25 N applied the displacement for the clinical test was 0.15 mm compared to 0.16 mm for the technical test. This is significantly small and probably a negligible difference but interesting just the same considering the comparatively large differences in the other values compared for the experiments.

As the weight added progressed through to 10 kg the displacement of some of the systems increased dramatically with the PTS having the least displacement at 4.58 mm through to the SSS having a displacement of 7.22 mm.

Table 4 is a graph plotting the displacements of each system.

Table 4



DISCUSSION

As with Stewart's study the sockets were all loaded above the loads encountered in normal use. It was not until the larger weights had been added (the 8 or 9 kg mark) that any of the sockets began to displace any great amount.

The performance of the SSS liner was interesting in this experiment as it encountered a significant amount of displacement as compared to the other sockets and compared to the results for the study by Stewart. Where the SSS was the second best performed at 25 N in the technical test it was the worst in the clinical test and was then easily the worst performed for the clinical test at 50 N having a displacement of over a millimetre more than the other sockets. It is felt that this could be due to the fabrication process as it was felt that we should have made the liner more silicon rich which would have assisted in improving the fit of this socket.

It could be assumed that any displacement which occurs in the ICEROSS and SSS liners would be due to stretching of the liner as both have a mechanical locking device at their attachment to the hard socket, but it is possible that movement may have occurred at the liner/leg interface which was not monitored although in the technical test it was noted that the ICEROSS stretched over the skin and did not slide along the "limb". This movement at the liner/leg interface is quite a possibility for the SSS however, due to the relatively poor fit of the socket. In the case of the ICEROSS any movement observed at the socket/liner interface may be due to the elongation of the stump as when the liner is rolled over the stump, the silicone sleeve forces the skin in a distal direction, stabilising soft tissue and minimising pistoning.(1)

In the technical test the PTB socket was tested using two different tensions on the suspension cuff but it was found that the resultant displacements were almost identical anyway so this experiment used one tension. This seeming lack of dependence on the tension of the suspension cuff may be due to the fact that the PTB socket relies on suspending itself on anatomical features - over the patella - so as long as the cuff is tight enough to suspend the socket over these features then any movement that occurs will be regardless of the tension of the cuff. It should be noted that although this was not the worst socket as far as displacement was concerned, the subject stated that this was the socket in which he could "feel" the most weight. It may be assumed that this could be due to the direct anatomical suspension but, interestingly, he had no such complaints about the PTS socket. This may be simple patient preference.

It is interesting to note the relative plateauing out of the displacement of the PTS between the 1 and 4 kg weights - see graph in results. This may be due to the socket displacing at first (between 0 and 1 kg) so that it is now firmly suspended over the femoral condyles and experiencing little displacement until the weight then becomes great enough to again displace the socket a relatively substantial amount. The PTS's ability to hold is reduced once the medial and lateral brims have passed the femoral condyles.(4)

While the technical test found that the PTS displayed the largest displacement for loads encountered in typical use and that the socket released at around 60 N force while the other systems released at 200 N or more, in the clinical test it was very well performed even ending up with the least displacement with 10 kg added. These fairly significantly differing results for the two experiments could be due to a couple of things. Firstly, the relative inaccuracy of this clinical experiment as compared to the precisely accurate technical test must be taken into account. There was great margin for error in this experiment whereas there was very little for the previous study. The other possible reason for these marked differences was that the Trans-tibial limb which was constructed for the

technical test may not have given an accurate representation of how a real limb may act under these circumstances.

CONCLUSION

It was found that the ICEROSS socket had the least displacement for both a load of 25 N and for a load of 50 N which was in accordance with the previous technical test carried out by Stewart.

In this experiment the suspension system which encountered the greatest displacement at both a 25 N load and a 50 N load was the SSS socket. This was not the case for the technical test however, where the Supracondylar or PTS socket encountered the greatest displacement at both loads.

Thanks to:

- Everyone at **REHAB TECH** for all their help
 - Kerry O'Connor for being an extremely willing and helpful subject
 - Liz Laird for her assistance
 - Orthopaedic Techniques
 - Otto Bock
 - Reis Orthopaedics,
 - James Arnott.
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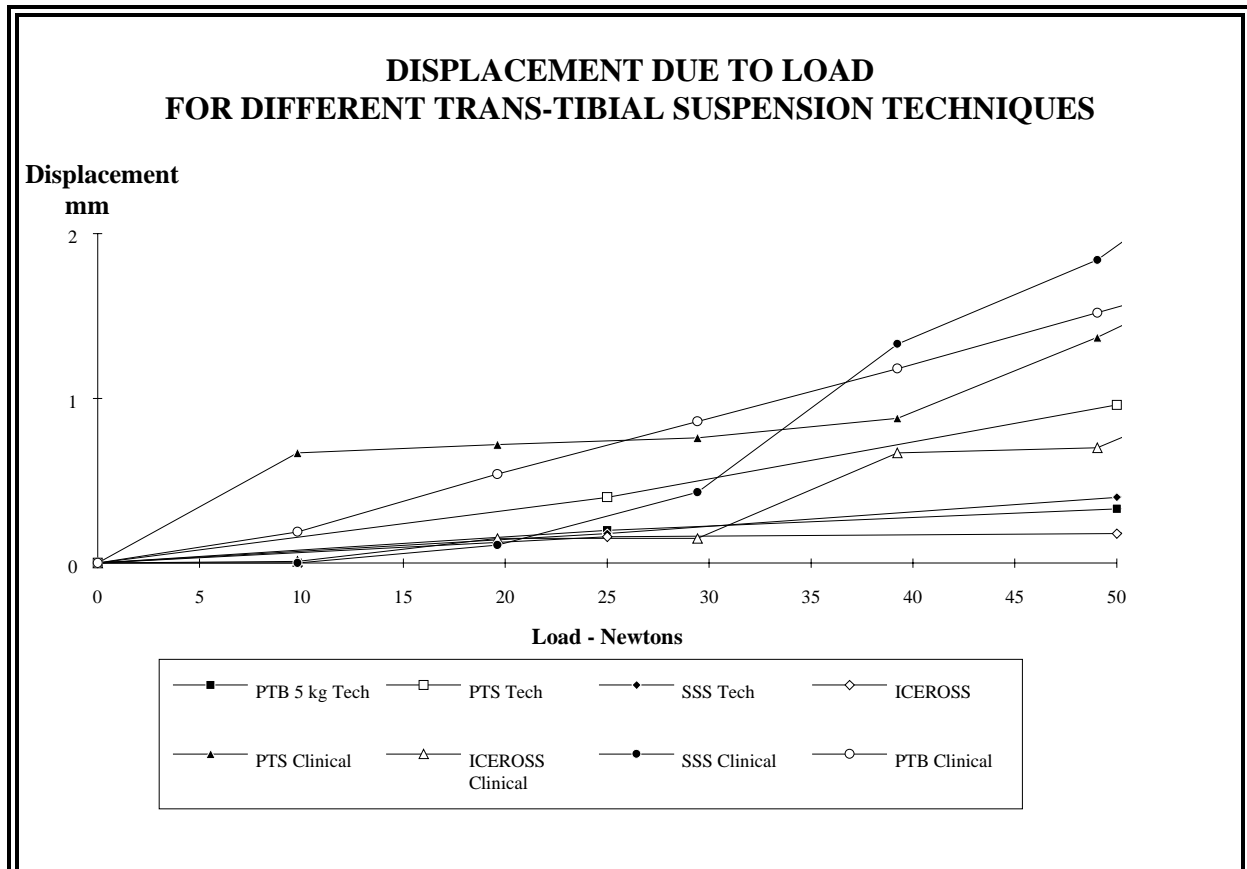
Discussion

Ross Stewart

DISCUSSION

All the suspension systems held the Trans-tibial prosthesis to the leg. The displacements for loads encountered for normal use were less than 1 mm. For higher activity loads slightly larger displacements occurred. In the clinical test all suspension systems supported a weight of 10 Kg without releasing. This is well over the loads likely to be encountered in regular use.

Table 1



The ICEROSS suspension system performed the best in both the clinical and technical tests. It appeared to adhere to the stump with displacements being the result of the silicon stretching. As this system does not rely on any manufacturing variables for suspension it would be the most consistent in use.

The SSS liner in these tests show dramatic differences between the technical and clinical tests. In the technical tests the liner behaved similarly to the ICEROSS, however in the clinical test this comparison could not be drawn. The probable reason is the reduced amount of silicon in the clinical liner. The liner in the clinical test contained little silicon compared to the liner in the technical test. This reduced the amount of suction imposed on the stump by the liner, while also reducing the stretch of the liner. Silicon rich SSS liners should be manufactured according to these tests.

Manufacturing variables would influence the suspension properties of the other suspension systems also. The PTS suspension is vary susceptible to this. The amount of pressure on the condyles influences the suspension markedly. The discrepancies between the clinical and

technical test are a result of this. The clinical test had the benefit of good socket fit (check sockets) , combined with patient feedback on the fit, optimising the PTS suspension. Another variable was the artificial stump which may not match the anatomical stump as well as we would like. However a good fit should minimise the problem. Regardless the PTS still had the most displacement for loads encountered during walking.

The PTB behaved similarly in both tests, with movement being irregular. Displacements were governed by when and how the strap grips.

Video footage in both tests gave a good indication of socket liner and liner stump movement. The liner stump displacement is generally the movement that causes discomfort, while pistoning can be a result of both. The PTS and PTB systems both display movement between the liner socket and liner stump. The silicone based liners due to being rigidly attached to the socket distally tend to stretch instead. Suggesting shear forces are absorbed by the silicon.

The accuracy of both test methods needs to be considered. Low loads and corresponding very small displacements made accurate displacement measurements difficult. Although good comparisons between systems could be made. Errors due to parallax for the clinical evaluation have been ignored.

CONCLUSION

The clinical test supported the results of the technical test although displacements for the clinical test were greater. All systems adequately carried the loads encountered in regular use. All suspension systems held weights up to 100 Kg.

The ICEROSS suspension performed the best in both tests. The PTS performed the worst for loads likely to be encountered in regular use.

Socket and liner manufacturing processes vary the suspension characteristics of the PTS and SSS. A silicon rich SSS liner gave better suspension while the use of check sockets improved the PTS suspension.
