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Comparison of the effects of patellar tendon bearing and total surface bearing sockets on prosthetic fitting and rehabilitation

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Abstract

Patellar tendon bearing (PTB) and total surface bearing (TSB) sockets have been used respectively in the prosthetic treatment of 20 trans-tibial amputees to investigate the effectiveness of both sockets on prosthetic fitting and rehabilitation. Data analysis showed that prostheses with TSB sockets were lighter than the prostheses with PTB sockets and better suspension was obtained from TSB prosthetic socket ($p<0.05$). It was also found that weight acceptance on the amputated side advanced to a more normal value with TSB prostheses ($p<0.05$). There was a statistically significant difference between the two socket types in walking and in other ambulation activities except sitting and standing up from a chair, in favour of the TSB socket ($p<0.05$). Consequently, due to the outcome of this study it can be said that TSB prosthetic sockets can be used effectively in the rehabilitation of trans-tibial amputees.

Introduction

PTB sockets became popular in trans-tibial prostheses in 1957 (Radcliffe, 1961). Body weight is mainly borne on the patellar tendon area and partially on the lower border of the tibial medial condyle (Radcliffe, 1961; Foort, 1965; Gleave, 1972; Convery and Buis, 1998). Although the PTB socket provides a good fit, it has problems of suspension and sometimes provides untolerable pressure on the patellar tendon. The limited weight bearing areas produce a stretch effect over the soft tissues and permit piston motion of the stump inside the socket leading to skin abrasions (Radcliffe, 1961; Foort, 1965; Gleave, 1972; Lilja *et al.*, 1993; Convery and Buis, 1998; Sanders and Daly, 1999).

Variations of the PTB socket have been developed to provide better fit and suspension. Patellar Tendon Supra-Patellar-Suprakondylen (PTS) or Kondylen Betung Münster (KBM) were not fully effective to overcome the above mentioned complaints (Kapp and Cummings, 1992).

To resolve these problems, the TSB prosthetic socket, in which weight is borne by the entire surface of the stump was developed (Kristinsson, 1993). Researchers stated that the TSB socket eliminates the piston movement by providing a real total contact during walking (Sabolich and Guth, 1986; Kristinsson, 1993; Cluitmans *et al.*, 1994; Datta *et al.*, 1996; McCurdie *et al.*, 1997; Narita *et al.*, 1997; Hachisuka *et al.*, 1998).

Patients and methods

Twenty unilateral trans-tibial amputees whose ages were between 15 and 37 years and with a mean of 27.8±7.0 years were the subjects of the study. Nine (45%) amputees were amputated on the right side and eleven (55%) were amputated on the left side. Seven (35%) patients were female and thirteen (65%) were male. Mean height was 169.5±8.9 cm and mean body weight without the prosthesis was 62.5±9.5 kg. Subjects signed an informed consent form before participating in the study.

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The following criteria were applied in the selection of the subjects after a detailed history and physiotherapy assessment:

- amputation resulting from traumatic injuries,
- attending for the first prosthetic fitting,
- muscle strength of at least "4" value in stump, trunk, abdominal and intact limbs,
- having no joint limitation, muscle shortening, stump oedema, stump pain and problems in stump shape,
- stump length of 12.5-17.5 cm,
- able to stand up in the parallel bars and able to walk with Canadian crutches.

After the stump-socket fit was checked, PTB and TSB sockets with soft liners were attached to a modular system including dynamic foot in all patients.

Prosthetic training was given for 10 days with PTB and TSB socket respectively and the treatment programme consisted mainly of balancing activities, weight shifting, gait exercises and training of other ambulatory activities besides strengthening, stretching and dynamic exercises. Subjects were evaluated after treatment with each socket. Assessment included weight bearing on the amputated side, time required to perform ambulatory activities, volume and suspension of the socket, prosthetic weight bearing and temporal distance (TD) characteristics of gait and balance evaluation.

The weight-bearing characteristics of the amputated side were calculated using the Gruendel's method which was previously applied to determine the amount of weight borne on hemiplegic legs (Gruendel, 1992). This method can be used where there is unequal weight acceptance from any cause as an objective economic and practical evaluation tool. Minimal (min WB) and maximal (max WB) weight bearing values on the amputated side were recorded while the subject was standing on two juxtaposed scales for three consecutive minutes. (Max WB+Min WB)/2 gave the average weight bearing of the amputated limb (M1). The percentage of TBW borne through the amputated limb was calculated using the formula M1/TBWx100 (Gruendel, 1992; Jones *et al.*, 1997).

In evaluating the time required to perform ambulatory activities, donning and doffing the prosthesis, climbing up and down the stairs (10 steps), ascending and descending a six-metre incline of 40°, crossing an obstacle of 20cm height and 30cm depth, picking up an object from the floor, sitting and standing up from a chair were chosen (Kegel *et al.*, 1987; May, 1996).

TD values were obtained through footprints. Amputees walked along a 12m walkway at a self-selected comfortable speed. The measures were recorded from the central 7m to ensure a constant velocity. Three (3) successive right and left footprints were analysed. Two (2) measurements of amputated-side step length from sound heel to subsequent amputated side heel, 2 measurements of sound-side step length from amputated heel to subsequent sound side heel, 4 measurements of step width as the horizontal distance between the two heels, 4 measurements of stride length from left heel to subsequent left heel and from right heel to subsequent right heel. The number of steps taken in one minute was counted while the amputees were walking at a self-selected comfortable speed and self-selected fast speed respectively. This procedure was repeated three times and averaged for statistical analysis. Velocity (cm/s) was calculated by step length x cadence/60 (Shores, 1980; Whittle, 1991).

Balance was evaluated for thirty seconds while the amputee was standing on the sound side with eyes opened and closed respectively. Body oscillations towards each side and anteroposterior direction, arm swing or compensatory motions of lower limbs were taken as the end point of the test and the time elapsed to the beginning of compensatory motions was recorded in seconds.

Prosthetic mass was measured by a sensitive scale in grammes.

To assess the sufficiency of suspension, the anterosuperior border of the socket was marked on the stump sock while the patient was in the standing position and at the beginning of swing phase respectively. The difference between stance and swing phase was recorded in centimeters (Wirta *et al.*, 1990; Narita *et al.*, 1997).

To evaluate the socket volume, sockets were filled with water up to tibial plateau and then the water was transferred into the measurement cup which gives the volumes in cubic centimeters.

PTB socket measurements were taken in the sitting position with 30° stump flexion while TSB socket measurements were performed with Otto Bock measurement apparatus, during

Table 1. Comparison of temporal-distance characteristics in the patients using PTB-TSB sockets (N=20).

Temporal-distance characteristic	Socket Types		Wilcoxon
	PTB X ± SD	TSB X ± SD	
Amputated side step length (cm)	58.4±6.9	56.6±5.2	**
Intact side step length (cm)	52.1±6.7	55.4±5.1	*
Difference of amputee and intact side step lengths (cm)	5.0±2.1	1.1±0.5	*
Stride length (cm)	109.2±14.2	112.6±10.1	**
Step width (cm)	14.0±2.2	10.5±2.3	*
Free cadence (step/min)	72.2±7.7	78.9±8.6	*
Fast cadence (step/min)	80.7±7.7	93.1±12.1	*
Walking velocity (cm/s)	65.6±10.7	74.1±11.1	*
Stride length/lower limb length	1.2±0.1	1.2±0.1	**
Amputee side step length/lower limb length	0.6±0.0	0.6±0.0	**
Intact side step length/lower limb length	0.5±0.0	0.0±0.0	*
Amputee side step length/strike length x 100 (%)	52.2±0.8	50.2±1.0	*

* p<0.05
** non-significant

weight bearing in static alignment position (Zettl and Traub, 1971; Otto Bock, 1981; Boot and Young, 1985).

Wilcoxon rank test and Pearson's Correlation Analysis were used in statistical evaluations. The alpha level was set at 0.05 ($\alpha=0.05$).

Results

According to the data obtained from foot-print analysis, there were statistically significant differences between the two socket types in favour of the TSB socket. Intact side step length, cadence during free and fast walking and walking velocity increased ($p<0.05$) and step width showed a diminution ($p<0.05$) in walking with the TSB prosthetic socket. There was also improvement in amputated side step length and stride length in the TSB prostheses but the difference was not found to be statistically significant ($p>0.05$) (Table1).

It was determined that weight acceptance on the amputated side advanced to a more normal value with TSB prostheses ($p<0.05$) and the prostheses with TSB socket produced more balanced stance than the prostheses with PTB socket ($p<0.05$) (Table 2).

Data analysis showed that prostheses with TSB sockets were lighter than the prostheses with PTB sockets and better suspension was obtained from TSB prosthetic socket ($p<0.05$) (Table 3).

Socket volume was found to be smaller in TSB than PTB when two types of prosthetic fitting were compared (Table 3).

Performing ambulation activities, a statistically significant difference was observed between the two socket types in favour of the TSB socket. It was found that shorter time is required by the amputee to complete the ambulation activities, except sitting and standing up from a chair and crossing an obstacle, using the TSB prosthetic socket ($p<0.05$) (Table 4).

In the authors' opinion, an important result was achieved with the suspension systems used in the study. There was no need to use suspension aids in the TSB sockets while

Table 2. Comparison of PTB and TSB sockets in balance and weight bearing percentage (N=20).

Weight bearing and balance	Socket Types		Wilcoxon
	PTB X ± SD	TSB X ± SD	
Weight bearing through the amputated side (%)	38.0±3.9	42.6±3.2	*
Balance on amputated side with eyes opened (s)	13.3±6.2	17.8±5.6	*
Balance on amputated side with eyes closed (s)	7.5±3.1	10.2±3.3	*

* p<0.05

Table 3. Comparison of the prosthetic mass, suspension and socket volume in PTB and TSB sockets (N=20).

	Socket Types		Wilcoxon
	PTB X ± SD	TSB X ± SD	
Prosthetic mass (g)	1114.9±117.2	1044.4±96.6	*
Suspension (cm)	1.6±0.4	0.4±0.5	*
Socket volume (cm^3)	772.2±238.2	600.0±182.8	*

* $p<0.05$

reversed Y strap was used in 90 percent of the patients during walking with PTB prosthesis.

According to Pearson Correlation Analysis, there was no correlation between the sufficiency of suspension and step length, stride length, gait velocity and mass of the prosthesis ($p>0.05$).

Discussion

In this study, PTB and TSB sockets have been used respectively in the prosthetic treatment of 20 trans-tibial amputees and comparisons made of the balance, weight acceptance on the amputated side, ambulatory activities and the characteristics of the prostheses.

The amputated side step length showed a decrease and came closer to normal values in the TSB socket when compared with the PTB socket. However there was no significant difference between the two type of sockets when the amputated side step lengths were evaluated statistically ($p>0.05$). This result showed that the amputees could accept more weight through the amputated side. The difference of intact and amputated side step length was found to be 5.0±2.1 cm in PTB, while this value was 1.1±0.5 cm in TSB prostheses. This data led to the conclusion that better weight acceptance could be attained by TSB prostheses and the amputees could advance their normal limb forward more than before. Intact side step length with the TSB socket was increased when compared with the PTB socket. It is very difficult to make a statement in such a small group of patients but it can be said that this outcome could be related to the efficacy of rehabilitation with the prolongation of amputated side stance phase and weight borne through the amputated side.

Walking with unequal step length is the most important gait problem in lower limb amputees. This uneven step length usually arises from the tendency of not bearing adequate weight through the amputated side (Whittle, 1991; Berger, 1992). The intact side step length showed an increase and the two step lengths became closer. This result can be related to the sufficiency of suspension which is a result of secure fitting on the skin. Proprioception might also be increased because of the weight bearing capability and overall the socket walls facilitating good pressure distribution.

Table 4. Comparison of the ambulation activities in amputees wearing PTB and TSB sockets (N=20) (unit=second).

Ambulation activities	Socket Types		Wilcoxon
	PTB X ± SD	TSB X ± SD	
Donning the prosthesis	8.6±2.0	6.8±1.5	*
Doffing the prosthesis	4.2±0.9	2.2±0.9	*
Ascending the stairs (15 steps)	14.4±1.1	10.5±1.1	*
Descending the stairs (15 steps)	11.3±1.4	8.8±1.1	*
Crossing obstacles	1.3±0.4	1.2±0.4	**
Picking up an object from the floor	1.5±0.4	1.4±0.4	*
Sitting on and standing up from a chair	1.5±0.4	1.4±0.4	**
Descending an incline	14.3±3.4	11.6±2.2	*
Ascending an incline	13.7±3.7	10.5±2.7	*

* $p<0.05$
** non-significant

In the study, it was found that in the TSB socket, amputated side step length was equal to 50.2% of stride length. This ratio was calculated at 52.2% in PTB. The result attained from the TSB socket was found closer to normal values.

There was no statistical difference between the stride lengths during walking with PTB and TSB prosthetic sockets; stride length was measured longer in TSB than PTB socket. The mean value of stride length was 109.2 cm in PTB while it was 112.6 cm in TSB prosthetic socket. This result is very close to Barth *et al's* findings. Barth found stride length to be 1.1m during walking with TSB socket (Barth *et al.*, 1992). The results are also in accordance with the outcome of the study of Isakov *et al.* (1996) who stated the value of stride length as 123.2±12.1cm in the TSB prosthetic socket. The reason for the higher step length values achieved by Isakov may be due to the lower limb lengths which are not given in the study. This result may also be related to their patients who were already prosthetic users while the patients in the present study were using their first prostheses.

Step width was found to be larger in prostheses with a PTB socket. Step width was found to be normal while walking with TSB prostheses. This outcome was thought to result from improvement in suspension, proprioception, balance and stabilisation.

Cadence in free and fast walking was found closer to normal values in the TSB when compared with the PTB (Table 1). The reason for this was the total contact attained in the TSB socket because of the hydrostatic stability produced between stump and socket which leads to minimal longitudinal displacement of the stump during swing phase (Whittle, 1991).

Walking velocity was determined to be 65.6±10.7 cm/s in the prostheses with PTB socket and 74.1±11.1cm/s in the prostheses with TSB socket. Barth found the walking velocity as 75cm/s in his research (Barth *et al.*, 1992). The authors' results are in parallel with Barth's study.

When a comparison was made for weight acceptance, it was determined that more weight was borne through the TSB prosthesis.

The percent of weight acceptance through the amputated limb was measured as 42.6±3.2 and this percentage was close to the normal weight acceptance ratio of 50%. Although there were studies in the literature researching the biomechanical aspects of fitting and weight acceptance the authors could not find a study comparing the effects of different socket designs on weight bearing.

Balance was found to be better in the TSB socket than the PTB when eyes were either opened or closed. This could probably be due to the TSB socket's overall contact with the skin, facilitating a good pressure distribution and improving proprioception.

Amputees could perform the basic ambulation activities in a shorter period during walking with TSB prosthetic socket. This is also thought to be the result of total contact, leading to improved suspension and proprioception and finally a feeling of security.

The mass of the prosthesis was less with the TSB prosthetic socket than the PTB, however it was not found to be statistically significant ($p>0.05$).

In this study, requirements for extra suspension systems were very few. Narita *et al.* (1997) stated that suspension was better in prostheses with TSB socket. Finally the control of the prostheses will also be improved.

When the correlation analysis between the ambulatory activities and sufficiency of suspension was evaluated, a positive significant correlation ($r=0.53$, $p<0.05$) was determined between the suspension and donning the prosthesis while using TSB socket. There was no correlation between the suspension and other ambulatory activities ($p>0.05$). This result could be related to the required degree of suspension depending upon the type or level of activity. Individual characteristics of the patients, especially motivation during the activity, could be also effective in performing the ambulatory activities. The future follow-up studies should be conducted from this point of view.

Due to the correlation between the mass of the prostheses and the ease in performing the activities, a correlation was found between the two socket types in climbing up and down the stairs ($r=0.48$, $p<0.05$). The authors could find no other correlation which can be related with a lighter prosthesis and this was probably due to the limited number of patients.

According to correlation analysis between balance and step width, balance and prosthetic mass, lower limb length and the weight acceptance percentage, there were no correlations ($p>0.05$).

Finally, the patients were discharged with the socket design in which they were more comfortable. 75% of the amputees returned to their homes using the prostheses with TSB socket design.

Although it is not possible to give accurate statistical data and statements in such a limited number of patients, the outcome of this study revealed that the suspension of the sockets and balance of the patients were advanced with the TSB prostheses. However fabricating a TSB socket is more difficult than the PTB and therefore will preferably be applied to stumps without oedema and pain problem. The postoperative stump care should be performed and the stump should be prepared for a prosthetic fitting. This is of course the key point of successful rehabilitation and if the knowledge, ability, technology and patient selection are appropriate, the amputees will have an active life style and their quality of life will be improved.

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