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A Swedish knee-cage for stabilizing short below-knee stumps

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Abstract
Stump length is an important factor in attaining successful prosthetic rehabilitation in below-knee (BK) amputees. Stability of the stump-prosthesis complex is impaired in the case of a stump shorter than 10 cm. Thus, fitting a prosthesis to a BK amputee with a stump which is very short often requires the use of different prosthetic techniques. In this work, the authors suggest the use of a Swedish knee-cage attached to a conventional patellar-tendon-bearing prosthesis as an alternative solution in the case of a short BK stump. Objective evaluation was performed by an analysis of gait and the foot-ground reaction forces. The results obtained indicate an improvement in all the measured parameters resulting from the modified stump-prosthesis complex.

Introduction
When the stump of a below-knee (BK) amputee is very short, the horizontal and longitudinal dimensions are similar. In such cases, the stump acquires a round shape and becomes unstable inside the prosthetic socket. A short stump inside a conventional patellar-tendon-bearing (PTB) prosthesis is often unstable during ambulation. Instability of the stump-prosthesis complex even during short ambulation creates shear forces with resulting pain, blisters or friction sores.

A basic mathematical model of such a stump was described by Nissan (1977). The problem of instability, especially evident in the mediolateral direction, can be resolved by some technical methods in current use. The first of these is a thigh corset with side-bars attached to a conventional PTB prosthesis. Such a construction creates an upper extension to the prosthetic socket. The stability of the stump is achieved by means of the forces applied by the corset to the amputee's thigh. Secondly a supracondylar PTB prosthesis may be provided. The proximal extensions of the socket's lateral borders create an effective lengthening of the prosthetic socket and add mediolateral stability to the stump. A third solution was proposed by Seliktar *et al.* (1980) using a posterior shutter which deepens the posterior wall of the socket. This shutter can be pushed down during sitting and it is pulled upwards by a rubber band during walking.

In this work the authors propose an alternative solution to the problem. A prefabricated Swedish knee-cage (SKC) is used, attached to a conventional PTB prosthesis. The SKC was first described in 1968. It is a device employing a three-point pressure system constructed originally for controlling hyperextension of the knee during ambulation in patients with a Charcot joint deformity. It was assumed that when added to the PTB prosthesis improved stability in the mediolateral and posterior directions could be accomplished. Analysis of gait and foot-ground reactive forces was performed to evaluate the subjects' performance objectively.

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Table 1. Subjects' characteristics.

Subjects	Age	Sex	Stump length (cm)	Affected side	Amputation (years)
C.A.	69	M	9	left	45
G.A.	51	M	8	right	16
K.E.	40	M	6	right	3
A.I.	28	M	10	left	11
S.B.	42	M	9	left	6
K.A.	43	M	9	left	16

Subjects and methods

Six BK amputees volunteered to participate in this investigation. All had a stump length of 10 cm or less, measured by x-ray. Characteristics of the subjects are presented in Table 1. All had been visiting the outpatient clinic frequently, complaining of severe stump pain, recurrent pressure or friction stump sores and a sensation of instability of the stump-prosthesis complex during ambulation. Current prosthetic mechanical solutions for prevention of stump instability were found to be ineffective. Therefore they were all fitted with a SKC attached to their own conventional PTB prosthesis.

The SKC consists of two plastic coated aluminium side bars connected posteriorly by a semicircular horizontal bar (Fig. 1). When attached to the prosthesis socket rim, it provides the stump with mediolateral and posterior stability, both during standing and ambulation (Figs. 2 and 3). For evaluation of the SKC+PTB prosthesis combination, analysis of gait quality was performed using two methods. First, by measuring gait parameters as suggested by Mizrahi *et al.*, (1982). Time-distance and speed were measured by a 5 m long electrical contact system installed within a 10 m walkway. Stance-phase time, stride distance and velocity were all measured.

Secondly, the foot-ground reaction forces were measured (Mizrahi *et al.*, 1986). For this purpose, a force measuring system consisting of two "Kistler" Z-4305 platforms were used. The foot-ground reaction forces (Fig. 4) in the vertical (Fz), anteroposterior (Fy) and mediolateral (Fx) directions were

Fig. 1. Swedish knee-cage.

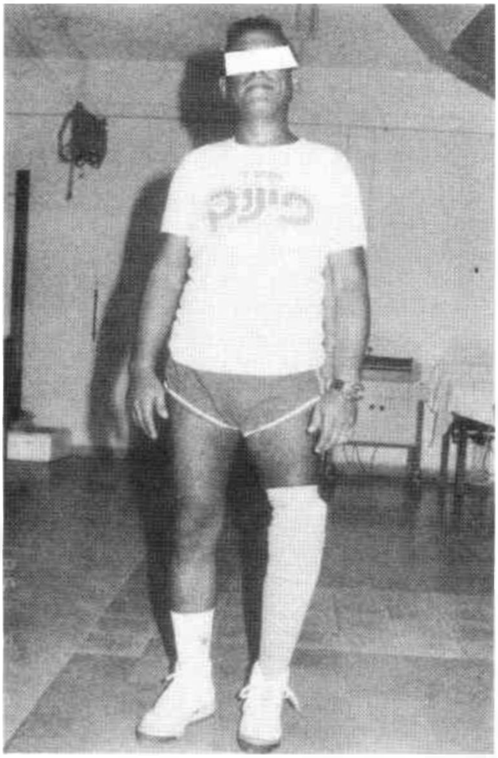

Fig. 2. Severe lateral instability of the stump-prosthesis complex during standing.

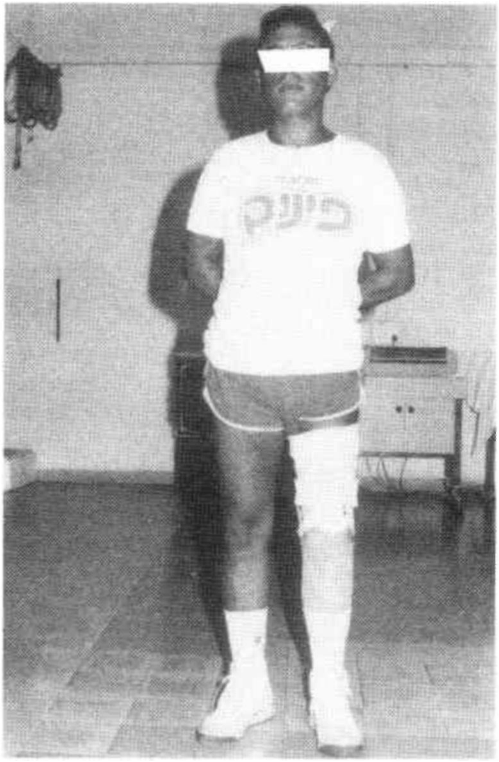

Fig. 3. **Excellent alignment of** the lower limb achieved when using a SKC attached to a conventional PTB prosthesis.

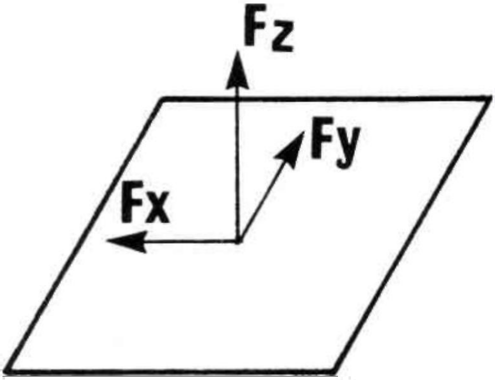

Fig. 4. Schematic diagram of the "Kistler" force plates and the measured variables.

simultaneously monitored for both limbs. Signals from the electrical contact system walkway and from the "Kistler" force plates were routed to an on-line IBM PC and analysed. The subjects were tested in a random order, while ambulating with conventional PTB prosthesis only, and with SKC+PTB prosthesis combination. Each test was composed of 3 trials. The subjects rested for at least 15 minutes between each trial. The results presented were the average obtained for all subjects.

Table 2. Overall mean results of gait parameters. Note also percentile improvement in gait quality obtained with PTB+SKC prosthesis.

Parameters	PTB Prosthesis	PTB+SKC Prosthesis	Improvement
Stance phase* (sec)	0.49	0.20	145%
Stride distance (cm)	80	114	45%
Velocity (m/min)	30.3	48.3	59%

*(Expressed as mean difference between left and right leg stance phase.

Results

Three different parameters of gait were analysed (Table 2). The results presented were the averages obtained for all 6 subjects. The differences between sound and amputated leg stance time, obtained by separately measuring for the sound and amputated legs, were 0.49 seconds while walking with the PTB prosthesis only and 0.20 seconds with the PTB+SKC complex. Stride length improved from 0.80 to 1.14 m. Speed of ambulation improved from 30.3 to 48.3 m/min.

Symmetry between limbs foot-ground reaction forces, expressed in percentages, are detailed in Table 3. Complete symmetry is obtained whenever the acting forces are of equal magnitude, 50% in each leg. Symmetry improved in all measured forces while ambulating with the PTB+SKC complex. Asymmetry in the mediolateral force (Fx) decreased to only 1.6%, the anteroposterior force (Fy) asymmetry decreased to 15% and the vertical force (Fz) asymmetry became only 6.9%.

Table 3. Percentile representation of the foot-ground reaction forces as divided between legs during ambulation.

Force	PTB Prosthesis		PTB+SKC Prosthesis		Improvement in symmetry
	R	L	R	L	
Fx	57.7	42.3	51.6	48.4	7.7 → 1.6
Fy	71.2	28.8	65.0	35.0	21.2 → 15.0
Fz	58.4	41.6	56.9	43.1	8.4 → 6.9

Discussion

Stump length is the major factor determining stability of the BK stump inside the prosthetic socket and consequently the quality of gait. Although amputation surgery is a constantly improving process, there are still cases where it is not possible to construct a sufficiently long BK stump. Even though an unduly short BK stump might create prosthetic problems, it is still advisable to make efforts to save the knee joint. The presence of the knee joint provides the amputee with proprioceptive information, a better equilibrium and most of all, a lower energy demand in ambulation (Waters *et al.*, 1976; Huang *et al.*, 1979; Isakov *et al.*, 1985).

From the point of view of the rehabilitation team, an amputee with a short BK stump is still a prosthetic challenge. A firm stump inside the prosthetic socket is very important for preventing stump pain, sores and scars. In fact, a successful fitting of a prosthesis for amputees whose stumps are shorter than 10 cm is difficult. The different mechanical techniques used in attempting to create a good stump-socket adaptation and stability sometimes fail.

In this study, the SKC+PTB prosthesis combination has been evaluated as the suggested technical solution in cases of a short BK stump. The results in 6 patients demonstrated an improvement in all the measured gait parameters. Differences between the stance time of both legs decreased by as much as 145%, the mean stride length improved by 42% and the speed of ambulation improved by 59%.

Symmetry in foot-ground reaction forces between both limbs also improved when using the SKC+PTB prosthesis. These forces tend to be equal in both limbs in the normal subject. Improvement was noted in all the three force directions measured.

As compared to a corset, the SKC is less cumbersome, more aesthetic, does not interfere with the knee joint range of motion, is lightweight, and easy to fit. A better stump stability allows an improved control during each step, together with a better gait performance. Therefore, in cases of a short BK stump, the combination of SKC+PTB should be considered as an alternative technical solution.

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