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An improved above-knee prosthesis with functional versatility

K. K. CHAUDHRY, S. K. GUHA* and S. K. VERMA**

Department of Applied Mechanics, Indian Institute of Technology, New Delhi.
**Centre for Biomedical Engineering, Indian Institute of Technology and All India Institute of Medical Sciences, New Delhi.*
***Department of Artificial Limbs and Rehabilitation, All India Institute of Medical Sciences.*

Abstract

An above-knee prosthesis is described which is designed to permit the patient to assume easily the squatting and sitting cross legged postures which are a part of routine living in Afro-Asian countries. The prosthesis incorporates a multibar linkage mechanism which co-ordinates knee flexion and extension with ankle dorsiflexion and plantarflexion, and a thigh rotation system fitted at the level of the knee axis.

Introduction

The conventional above-knee prosthesis denies the user the freedom to squat and sit cross-legged (SCL). While this is not a serious limitation to Western users, in Afro-Asian countries where squatting and SCL postures (Fig. 1) are a part of routine living, the limitation is gravely felt. Therefore, there has been intensive research and development effort in this direction with the goal being near normal function with simplicity and economy in design. An above-knee prosthesis incorporating a thigh turntable with a manually operated lock was reported by Natarajan (1971). A unilateral amputee using this type of prosthesis first squatted on the normally functioning leg with the prosthesis extended forward, thereafter, following manual unlocking of the thigh turntable, the lower segment of the prosthesis was lifted by hand to the final cross-legged position (Fig. 2). When rising the reverse sequence was followed. The entire procedure was quite different from the normal and unaesthetic. Hence, there was a clear need for an improved system which did not involve any hand manipulations and looked normal as far as the movement was concerned.

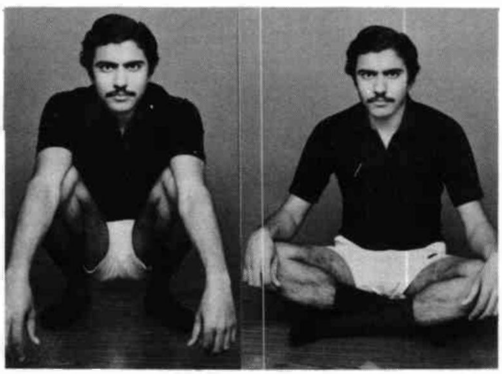

Fig. 1. Demonstration of normal symmetrical squatting posture and sitting cross-legged (SCL) posture.

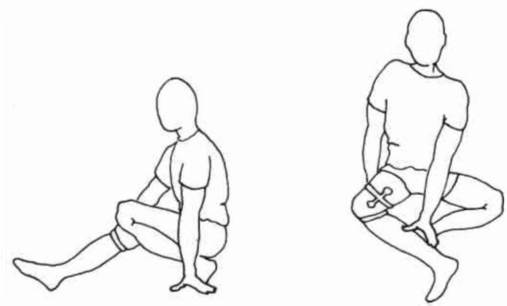

Fig. 2. Above-knee prosthesis with manually locked turntable (see text).

More recently some improved designs have been reported (Madhvan et al. (1977); Guha et al. (1977); Chaudhry et al. 1981). In these a spring loaded thigh turntable provided automatic rotation during the SCL manoeuvre and a cam-follower linkage between the knee and the ankle provided proper ankle flexion during squatting. Although these features

All correspondence to be addressed to Dr. S. K. Guha, Biomedical Engineering Unit, All India Institute of Medical Sciences, New Delhi, 110 029, India.

permit squatting and SCL without awkwardness, the system was found to have some practical problems. It was observed that during normal walking if the subject happened to step on a big stone, the thigh turntable would rotate. Increasing the tension in the spring was not a satisfactory solution because it led to slipping of the stump in the socket during SCL. Therefore, it was necessary to redesign the device with a totally new concept. In addition, the cam-follower arrangement necessitated a large cam area at the knee joint which resulted in poor cosmesis. Also, due to wear and tear at the cam surface after a moderate period of use the mechanism required periodic adjustments. Once again the need was felt for an alternative approach.

A more serious problem was encountered in patients with long stumps including those with through-knee amputations. The combination of the cam-follower arrangement and thigh turntable occupied a fairly large space and therefore long stumps could not be accommodated. A design which incorporated the mechanism at or about knee level and yet permitted all the required functions was called for.

Design of the squatting mechanism

Detailed trials were carried out to evolve an optimum type of linkage mechanism which would give co-ordinated flexion of the ankle with respect to knee flexion so as to bring about a smooth squatting posture. The additional requirements to be met were simplicity in operation and maintenance, light in weight and of a size so as to fit completely within the shank portion of the prosthesis. A multibar linkage mechanism (Fig. 3) meets the requirements more or less fully. The first link connects the knee axis to the auxiliary axis which is slightly below the knee axis. The auxiliary axis movement caused by the knee flexion/extension is transmitted by the upper link to another movable link (circular disc) which is constrained to rotate only about a fixed axis. To this movable link is attached the lower link which causes downward movement of the posterior portion of ankle causing it to rotate from plantarflexion to dorsiflexion as the knee flexion increases progressively and vice versa. Thus, flexion and extension of the knee causes dorsi- and plantarflexion of the ankle respectively. From

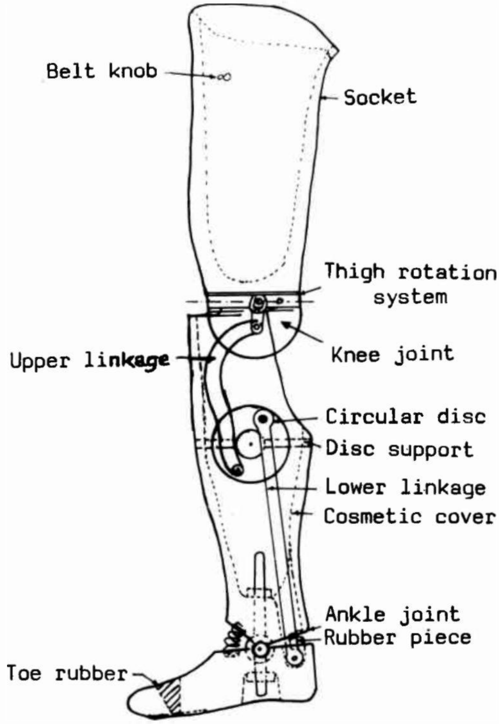

Fig. 3. Above-knee prosthesis with squatting and SCL mechanism.

the work of Lamoreux (1971) it can be seen that during stance phase, which accounts for 60% of the walking cycle, the knee angle varies from 3° extension at heel strike to 37° flexion at toe off. The ankle angle was set at 3° dorsiflexion at the mid stance phase (that is, from 10% to 40% of the gait cycle) and the multibar linkage mechanism was carefully set so that the ankle angle remained more or less the same with respect to knee flexion throughout the stance phase. This ensured a stable stance phase for the amputee. The soft rubber heel cushion allows the knee angle to be in its neutral position at heel strike and at around 4° of plantarflexion at foot flat. In addition the soft toe rubber in the anterior portion of the foot allows about 10° extension which, combined with 3° of dorsiflexion of ankle, gives effectively 7° of plantarflexion at toe-off. With this the gait looked more or less natural. As the ankle flexion is increased progressively to 165°, the multibar linkage mechanism causes 50° dorsiflexion at the ankle and a smooth squatting posture takes place. In addition a coil spring was incorporated anterior to the ankle axis to facilitate return of the ankle to the initial stage.

Design of the SCL mechanism

A kinematic study was carried out on a number of male and female normal subjects to identify the distinct phases of movements in the SCL cycle (Guha and Kaur, 1978). This cycle starts with a stance phase followed by squatting phase, knee spread, foot slide and finally the SCL posture. In addition the forces and torques arising during the sitting cross-legged posture were also analysed. It was found that the floor reactions on two legs were not equal and consequently the forces and torques on both legs were not equal. This asymmetry is primarily due to the fact that one leg crosses in front of the other leg. This data has been further quantified by electromyographic studies (Guha, 1979). The data thus obtained from the normal subjects was quite useful in the design of the squatting mechanism for the unilateral amputees.

A special turntable provided with a spiral spring was designed in such a way so as to be incorporated at the knee joint axis (Fig. 4) to allow cross-legged posture. In this way the design was suitable for all stump lengths. Further the spring was so selected that it allowed adjustment in the initial torque over the range necessary for different subjects. This turntable system is novel in that it provides rotation of the upper segment but at the same time provides a firm foundation for coupling the links of the ankle-knee linkage system which does not rotate about the longitudinal axis. At the same time another arrangement keeps the thigh locked against any rotation during normal walking. However, during the squatting phase of SCL, in the mid-squat phase, the lock is automatically released. A spring loaded pin projects from the turntable system and gradually glides over an inclined plane formed by the stirrups of the leg. Thus, while the subject is going into the squatting posture, the pin is pressed at mid-squat phase (around 80° flexion) and releases the thigh lock. Once again while the thigh rotates, the pin mechanism does not rotate. With this arrangement, the subject could go from the erect posture to the SCL posture in the normal manner simply by placing the prosthetic leg ahead of the normal leg at the beginning of the SCL posture. During rising also, no hand manipulation is required and the spring torque itself restores the leg to the zero rotation state where it is locked automatically by the spring loaded pin as rising takes place. Thus to an observer, both sitting and rising look quite natural as if performed by an individual with no disability.

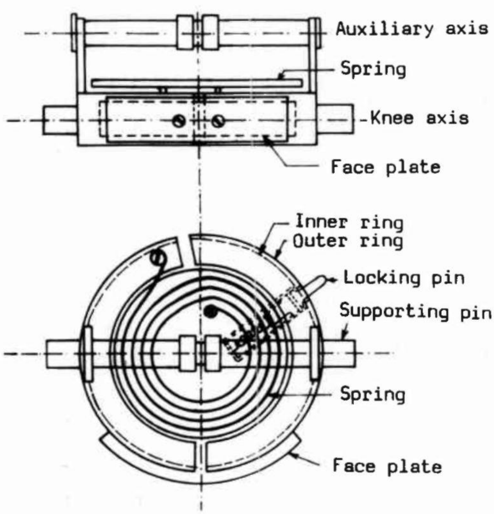

Fig. 4. Thigh rotation system at knee axis.

Clinical trials

The first phase of clinical assessment was carried out on two unilateral amputees. One amputee with a very heavy body build and another amputee with an average Indian light body build were selected. Both patients had medium stump length. Figures 5 and 6 show the first subject using the prosthesis. For most positions, a simple pelvic belt support was seen to be quite adequate. Even in asymmetrical squatting (Fig. 5), there was no stump slippage. However, during symmetrical squatting (Fig. 6), there was a tendency for the stump to slip out from the socket. Suitable strapping extending over the gluteal region prevented slippage. An alternative solution, which has still to be tried might be the use of a suction socket.

When kneeling on a smooth floor, there is a problem of the prosthetic leg slipping backward on the floor because the area of contact is limited to the upper margin of the shin and the front edge of the toe of the shoe of the prosthesis. This situation can be corrected by providing rubber padding at the outer periphery of the top edge of the shin so as to enhance the coefficient of friction of the prosthesis with the floor.

Movements in walking, squatting and sitting cross-legged were normal. At times, while

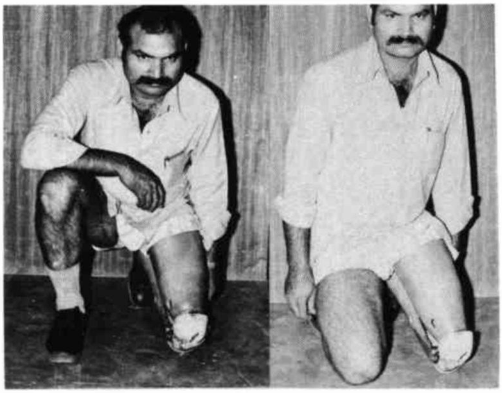

Fig. 5. Amputee in asymmetrical squatting and kneeling postures.

getting up from the floor, a slight upward thrust using the arm was necessary. The only complaint from the patients was that when sitting on a chair with the normal foot flat on the floor, the prosthetic foot remained somewhat dorsiflexed. Although a casual observer did not notice any abnormality, the patients themselves were concious of this deviation from the normal position of the foot. Work is underway to find the appropriate prosthesis linkage parameters which would enable this defect to be rectified without compromising the requirements of ankle-knee relationships during walking, squatting and sitting cross-legged.

Conclusions

The above-knee prosthesis described is simple in construction and has considerable functional versatility, it provides two additional important features of squatting and sitting cross-legged which are necessary for Indian conditions. Further it enables the user to assume the squatting and SCL positions as well as to rise from these positions without any manual intervention and with movements very much like normal.

Acknowledgements

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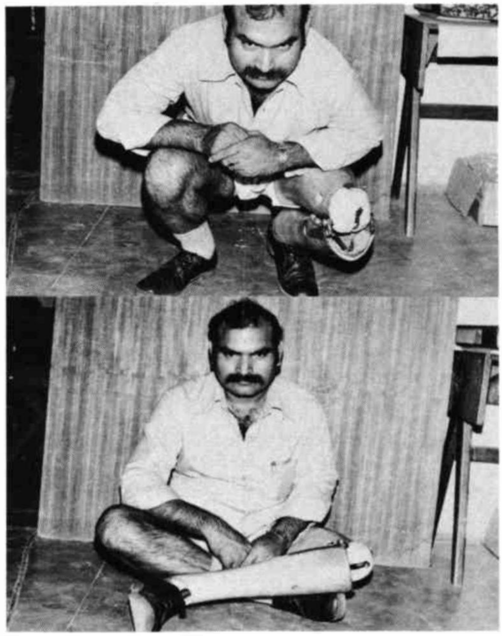

Fig. 6. Amputee in symmetrical squatting and SCL postures.

REFERENCES

Chaudhry K. K., Guha S. K., Verma S. K. (1981). Modular concept in a multi-functional above-knee prosthesis. *Eng, Med.*, **10,** 155–157.

Guha S. K., Chaudhry K. K., Madhvan P. G., Verma S. K. (1977). Above-knee prosthesis permitting squatting. *Med. Life Sci. Eng.* **3(1),** 25–33.

Guha S. K., Kaur H. (1978); Biomechanics of sitting cross-legged, normal and with above-knee prosthesis. In-Trends in Biomedicl Engineering, Eds. Guha S. K., Anand Sneh and Mahajan Sudha. CBME Publications IIT, Delhi, 59–69.

Guha S. K. (1979). Body movements and muscle activity in sitting cross-legged *Ergonomics,* **22(10)** 1115–1124.

Lamoreux L. W. (1971); Kinematic measurements in the study of human walking. *Bull. Pros. Res.*, **10–15,** 3–84.

Madhvan P. G., Chaudhry K. K., Guha S. K. (1977); New concepts in A. K. prostheses. *Med. Life Sci. Eng.* **3(2),** 97–102.

Natrajan M. (1971). Prosthetic requirements for social conditions of Indian amputees. In-Final Report No. VRA-IND 21/65 on Research and Demonstration Project for the Rehabilitation of the Orthopaedically Handicapped, Artificial Limb Centre, Madras, 111–117.