

Knee mechanisms for through-knee prostheses

K. ÖBERG

Biomechanics Laboratory, College of Health and Care, Jönköping, Sweden.

Abstract

The most widely used knee mechanisms for through-knee amputees can be characterized as three principal types of design. These types are metal side bars with heavy duty joints, conventional knee mechanisms for above-knee amputees and special polycentric linkage mechanisms for through-knee amputees. An investigation in Sweden in 1979 showed that over 50% of the fittings were using the special polycentric linkage mechanisms for through-knee amputees.

The stability diagram illustrates how voluntary and involuntary stability can be utilized by using different polycentric linkage mechanisms for through-knee amputees. The polycentric linkage mechanism can be designed for different stance phase characteristics as well as incorporation of different swing phase control mechanisms. The cosmesis of the available designs is acceptable but there is need for lighter and more compact designs especially for the young and small amputee.

Introduction

Since the technical development of prosthetic components and mechanisms has paid attention to the needs of the through-knee (TK) amputees, the variety of knee mechanisms has increased. Many are designed for above-knee (AK) amputees and adapted to the TK amputee but there are also knee mechanisms that are originally designed for TK amputees. These mechanisms can in turn also be used by the AK amputee.

Design principles

The most widely used knee mechanisms for TK amputees can be characterized as three principal types of design (Fig. 1). The first type, and in early years the most common prosthesis, incorporates a leather socket with metal *side bars and heavy duty joints* similar to those used in some types of knee orthoses or below-knee prostheses. The prosthesis often has a lumpy and unc cosmetic appearance at the knee because of the width and the bulge. With these side joints it is also impossible to incorporate any type of device to control the stance and swing phase characteristics of the knee.

The second type, and still often used prosthesis for TK amputees, employs the large variety of *knee mechanisms for AK amputees*. The major and decisive disadvantage of this type is the lengthening of the thigh and the consequent shortening of the shank. This affects the comfort and cosmesis when sitting as well as the functional characteristics in walking. The advantages are however the availability

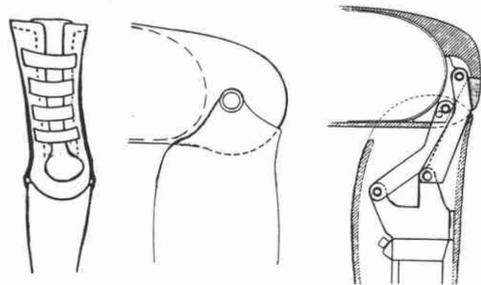


Fig. 1. Three principal types of knee mechanisms for TK amputees. Left, side bars with joints. Centre, conventional mechanism for AK amputees. Right, specially designed polycentric linkage for TK amputees.

All correspondence to be addressed to Dr. K. Öberg, Biomechanics Laboratory, Munksjökolan, Box 1030, S-551 11, Jönköping, Sweden.

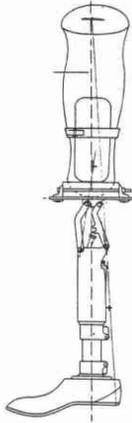


Fig. 2. The OHC polycentric knee disarticulation prosthesis.

and the variety of functional characteristics. Mechanisms which allow the mounting of the stump socket as near the pivot as possible are preferably used. The lengthening of the thigh will then be minimized.

The third, and a more recently offered, type of knee mechanism for TK amputees is the *polycentric linkage mechanism*. The most common type of mechanism is the four-bar linkage, which has been used in knee mechanisms for AK amputees. Their advantages and functional characteristics are analysed and

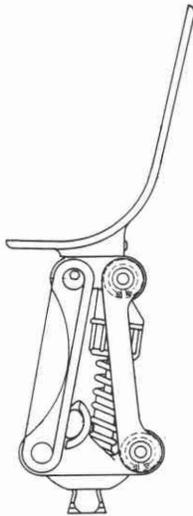


Fig. 3. The Otto Bock modular polycentric knee disarticulation prosthesis.

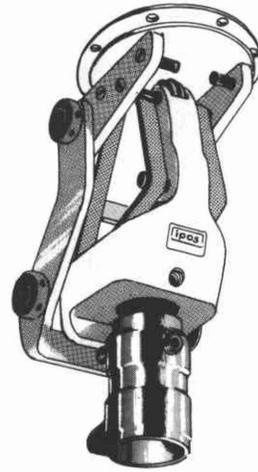


Fig. 4. IPOS-Balgrist polycentric disarticulation knee joint.

described by Radcliffe (1957 and 1970). The behaviour of the linkage mechanisms with regard to the location of the centre of rotation offers the possibility of placing the mechanism of a TK prosthesis within the shank but below the stump in the sitting position. The first design for this purpose was the OHC Polycentric Knee Disarticulation Prosthesis developed by Lyquist at the Orthopaedic Hospital in Copenhagen (Fig. 2). This knee mechanism is now produced by United States Manufacturing Company. Later, other knee mechanisms of this type for TK amputees were introduced to the market, for example from Otto Bock (Fig. 3) and IPOS (Fig. 4) in West Germany. These mechanisms provide acceptable cosmesis and different stance phase stability characteristics. Different swing phase controls are also incorporated, such as pneumatic, hydraulic or friction controls. For geriatric TK amputees a manual lock is incorporated in the four-bar mechanism.

Experimental investigations and clinical use of other types of knee mechanisms for TK amputees can also be found. At the University of California, Berkeley, the possible advantages of using six-bar linkage mechanisms have been investigated (Fig. 5). This linkage offer the possibility of increased range of knee motion, better cosmesis, improved stance phase stability and swing phase control as compared to four-bar designs. These advantages are achieved at the expense of added weight and complexity.

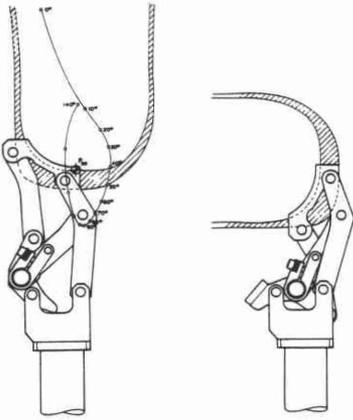


Fig. 5. A compact six-bar linkage from University of California, Berkeley.

Another interesting design made in Holland has been used in both West Germany and Holland. The tube of the shank is connected by rolls to a track in a metal arch that is fixed to the posterior part of the end of the socket. The centre of rotation between the shank and the thigh will then be located within the femoral condyles. For information on clinical experience Dr. Georg Neff, Orthopädesche Klinik und Poliklinik der Universität Tübingen, West Germany is recommended as reference.

TK-mechanisms fitted by Een Holmgren and LIC Orthopaedic companies 1979

In order to investigate what influences the choice of prosthetic knee mechanism when fitting TK, AK and hip disarticulation amputees a survey of the clinical practice was carried out at the orthopaedic clinics in Sweden that are served by the orthopaedic companies Een-Holmgren and LIC. This survey was presented at the ISPO World Congress in Bologna (Haggland and Öberg, 1980) and by Öberg (1980). A total of 471 fittings were investigated of which only 28 (6%) were TK prosthetic fittings. The knee mechanisms used for the TK amputees are presented in Table 1 and divided into three categories with regard to stance phase stability.

Free single axis and unstabilized knees made up 13 (46%) of the fittings and were dominated by the special TK designs such as the OHC knee. There was also one single axis Otto Bock modular knee designed for long stumps. It should be noted that the Otto Bock modular polycentric knee 3R21, which belongs to this category, was not available on the Swedish market at the time.

Weight-bearing controlled single axis and stabilized polycentric knees made up 8 (29%) of the fittings and were of different types but 4 of them were a special TK mechanism known as the

Table 1. TK mechanisms fitted by Een-Holmgren and LIC orthopaedic companies, 1979.

| Stance phase stability | Producer | Item | Number |
|--|---|--|--------|
| Free single axis knee or Understabilized polycentric knee | Blohm Otto Bock | Orthotic joint (pair) | 1 |
| | | 3R16 Modular knee | 1 |
| | United States Manufacturing Comp ,, ,, | Disarticulation knee | 1 |
| | | OHC-knee with pneumatic swing phase control | 1 |
| | | OHC-knee with hydraulic swing phase control | 9 |
| | | | 13 |
| Weight-bearing controlled single axis knee or stabilized polycentric knee | Otto Bock ,, | 3P23 Jüpa knee | 1 |
| | | 3R15 Modular brake knee | 2 |
| | IPOS ,, | 3P31 Lang condylar knee | 1 |
| | | 0955 Balgrist polyc. knee | 4 |
| | | | 8 |
| Knee with manual lock | Protesindustri Otto Bock Custom made | P450-30 Geriatric knee | 1 |
| | | 3R17 Modular knee | 4 |
| | | without knee mechanism | 2 |
| | | | 7 |
| | | Total | 28 |

Balgrist knee made by IPOS from West Germany.

The remaining 7 (25%) fittings were of manually locked knees, including two prostheses without knee mechanisms. None of them were however polycentric linkage mechanisms. Only one prosthesis was fitted with sidebars and orthotic joints. In only 28 prosthetic fittings there were 11 different knee designs from 5 different producers. Fifteen (54%) of the fitted prostheses used specially designed polycentric linkage knees for TK amputees. However, 1979 might be considered an early year for these designs on the market and it could be expected that they are more used in TK prostheses nowadays.

Biomechanics of polycentric knee mechanisms

A polycentric knee joint is polycentric because the instantaneous centre of rotation between the thigh and the shank changes as the knee flexes. This change of knee centre location is designed in a linkage mechanism to move in a manner which combines an improved stability of the knee and a good sitting cosmesis for a TK amputee. The polycentric linkage mechanism also allows an increased range of knee flexion and swing control devices of different types can be added.

The most common type of linkage mechanism for polycentric knees is the four-bar linkage. The location of the instantaneous knee centre can easily be found at the intersection of the two lines that pass through a pair of joints respectively that are connected by a linkage between the shank and thigh (Fig. 6).

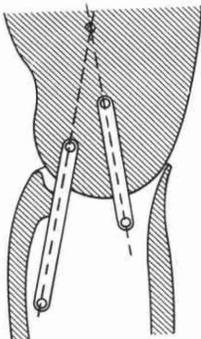


Fig. 6. The four-bar knee linkage and the instantaneous centre of thigh-shank rotation.

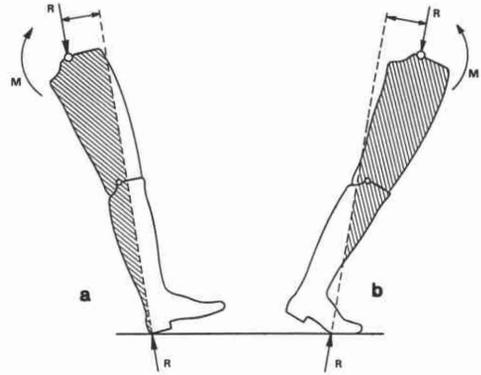


Fig. 7a. The load line at heel contact and hip extension moment. Fig. 7b. The load line at push-off and hip flexion moment.

The stability characteristics of any prosthetic knee can be described by the relationship between four factors:

- the muscular hip moment
- the load line
- the instantaneous centre of thigh-shank rotation
- the brake moment generated by the knee mechanism.

A muscular hip extension moment gives in addition a forward floor reaction force which changes the direction of the loadline ahead of the hip joint as shown in Figure 7a. A muscular hip flexion moment gives a backward floor reaction force which changes the direction of the load line behind the hip joint (Fig. 7b). When the amputee is exerting a hip extension moment at heel contact and the load line has moved in front of the knee joint, knee stability has been achieved (Öberg and Lanshammar, 1982). When the amputee is exerting a hip flexion moment at push-off and the load line has moved behind the knee joint, the prosthetic knee will be flexed while the prosthesis is still supporting the body weight. Voluntary knee flexion under load at push-off is important in achieving an aesthetic and energy saving gait.

When the load lines from heel-contact and push-off are drawn on the leg in the same diagram a stability diagram has been achieved according to Professor C. W. Radcliffe at the University of California, Berkeley, USA (Fig. 8). When combining the two regions for the knee centre when it is stable during heel-contact and can be flexed under load at push-off a common

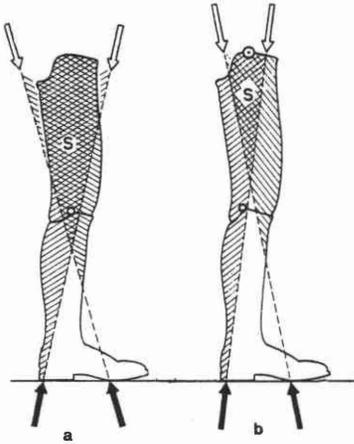


Fig. 8. Stability diagram (after Radcliffe), a) large zone of voluntary stability, S b) less hip muscle contraction and a reduced zone of voluntary stability, S.

region is defined. Radcliffe has called this region, the zone of voluntary stability. In Figure 8a the voluntary hip muscular extension and flexion moments exerted by the amputee are of such magnitude that they give a large zone of voluntary stability. In this case a simple single axis knee is sufficient for maintaining stability at heel contact and ease of flexion during push-off.

Figure 8b shows a more typical situation where the amputee either has reduced hip moment capabilities or prefers to use his hip musculature at less than maximum strength under ordinary conditions. In this case the zone of voluntary stability is dramatically reduced. The prosthetist must under these circumstances, when fitting a single axis prosthetic knee joint, align the knee joint with its centre behind the load line for heel contact in order to ensure knee stability. Such a location is also behind the other load line. The result is a stable knee at heel contact but a knee which is difficult to flex under load at push-off.

These stability diagrams indicate that less hip muscular contraction gives a reduced zone of voluntary stability. A reduced zone of voluntary stability would require a higher location of the instantaneous centre of knee rotation in order to maintain voluntary control of knee stability. Single axis knees provide little or no opportunity to make practical use of this fact because a significant change in the vertical position of the knee joint is cosmetically unacceptable. The polycentric knee however can be designed with

the initial instantaneous centre of rotation located above the usual knee joint and within the zone of voluntary stability (Figure 9). This type of prosthesis requires reduced hip muscular contraction for knee stabilization and can be classified as an under-stabilized knee.

When there is no hip muscular extension ability or the amputee is not willing to depend upon this muscular contraction, the knee mechanism must be stabilized in an automatic way. For AK amputees it is very common to use some sort of weight-bearing controlled friction brake knee. For TK amputees this type would be unacceptable because of the cosmetic consequences. A polycentric linkage mechanism would also here offer an acceptable solution by locating the initial instantaneous centre of rotation behind the hip moment free load line between the heel and the hip joint. A knee design of this sort can be classified as a stabilized polycentric knee.

When involuntary knee flexion or uncertain knee extension happens, as for geriatric amputees, a manual lock incorporated in a polycentric linkage knee mechanism would be a suitable solution.

Discussion

When fitting a TK amputee with a polycentric linkage, the thigh lengthening will be 25–30 mm because of the proximal joints of the mechanism.

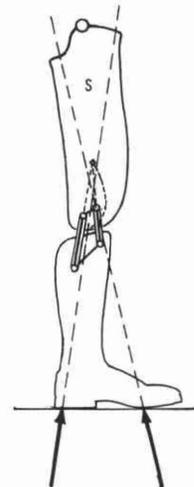


Fig. 9. Understabilized four-bar linkage for voluntary control of knee stability.

This disadvantage is acceptable and the cosmesis that nowadays can be achieved with such mechanisms is usually superior to that achieved with any of the other types of mechanisms.

It has been shown that varying stability and stance phase characteristics can be achieved with the polycentric linkage knee mechanism with regard to functional demands of amputees with different activity level. Also a variety of swing phase mechanisms can be used in these special designs for TK amputees.

Young, small, but active amputees can have difficulties in utilizing the functional features of the TK mechanisms because of the weight of the mechanism and the space in the leg that is required by the mechanism. In general it seems that most of the mechanisms that are available today are heavy. A good exception is the 25 mm system with a four-bar linkage knee from Hanger, England. This design can be used for younger and smaller amputees. For the future, lighter and more compact knee mechanisms are to be wished for the TK amputees.

It is thought that the specially designed knee mechanisms of today for TK amputees have

made an important contribution to their rehabilitation. These mechanisms might even be expected to have influenced the increase of TK amputations as an alternative to AK amputations.

REFERENCES

- HÄGGLAND, L., ÖBERG, K. (1980). Prosthetic fitting of KD, AK and HD amputees related to type of knee mechanism: a survey in Sweden. Abstracts 1980 World Congress, International Society for Prosthetics and Orthotics, 107.
- ÖBERG, K. (1980). Studier av protesknäleder. (Available in English). *Ortopediskt Maqasin*, 3.
- ÖBERG, K., LANSHAMMAR, H. (1982). An investigation of kinematic and kinetic variables for the description of prosthetic gait using the ENOCH system. *Prosthet. Orthot. Int.* 6, 43-47.
- RADCLIFFE, C. W. (1957). Biomechanical design of an improved leg prosthesis. Berkeley, CA: University of California. Institute of Engineering Research. Biomechanics Laboratory. (National Research Council. Prosthetics Research Board. Series 11, Issue 33).
- RADCLIFFE, C. W. (1970). Prosthetic-knee mechanisms for above-knee amputees. In: Murdoch, G. (ed), *Prosthetic and orthotic practice*. London: E. Arnold 225-249.