Clinical Prosthetics and Orthotics, Vol. 12, No. 3, pp. 99–108

Component Selection Criteria: Lower Limb Disarticulations

by John Michael, M.Ed., C.P.O.

Because disarticulations comprise only a small percentage of the lower limb amputations performed each year[1], questions sometimes arise regarding the most appropriate components to select. This paper will present a brief overview in an effort to clarify the criteria involved.

Hip Disarticulation/Hemipelvectomy Components

For the hip disarticulation or hemipelvectomy case, component selection is generally analogous to the more familiar above-knee patient. Endoskeletal components are preferred for the high level amputee because they offer light-weight and enhanced cosmetic appearance. A clear trend away from steel components to the much lighter titanium or carbon fiber versions is apparent. Most systems (particularly the Otto Bock "Modular") also permit subtle realignment, even in the definitive prosthesis. This can be an advantage due to the complex interplay between the mechanical hip, knee, and foot mechanisms.

Hip Joint Mechanisms

In general, a free motion hip joint is preferred, as originally proposed by McLaurin in 1954.[2] Careful attention to alignment details results in a very stable configuration by virtue of the weight line and reaction line forces. This permits very safe weight-bearing, yet allows easy hip flexion during swing phase.

Stride length is generally controlled by a spring or elastic flexion limiting apparatus, sometimes called an "extension bias." In modern practice, the joint is placed near the anterodistal quadrant of the socket, which sometimes requires a slightly shorter thigh segment for the best appearance when sitting.

Manual locking hip joints are also available but should be reserved as the component of last resort, even for bilateral amputees. In addition to disrupting swing phase, locked joints require the use of one hand on the unlocking mechanism during sitting. This often makes a difficult task more complicated, particularly for the double amputee.

More importantly, a locked hip joint may place the patient in a more dangerous position during a fall backwards. If the joint prevents flexion at the hips, the head rather than the buttocks may strike the ground first. In our last 50 consecutive fittings at Duke, both unilateral and bilateral hip/hemi patients have never required a locked joint to ambulate securely.

Two variations in hip joint design warrant mention. Peter Tuil of the Netherlands advocates the use of a reversed polycentric knee disarticulation joint (Otto Bock 3R21) as a hip joint.[3] Benefits claimed are parallel to those expected from a polycentric knee unit: in creased ground clearance during swing phase due to the inherent "shortening" of the linkage in flexion and enhanced stability at heel strike (Figure 1).

This view has been corroborated in a number of fittings over the past few years at the Royal

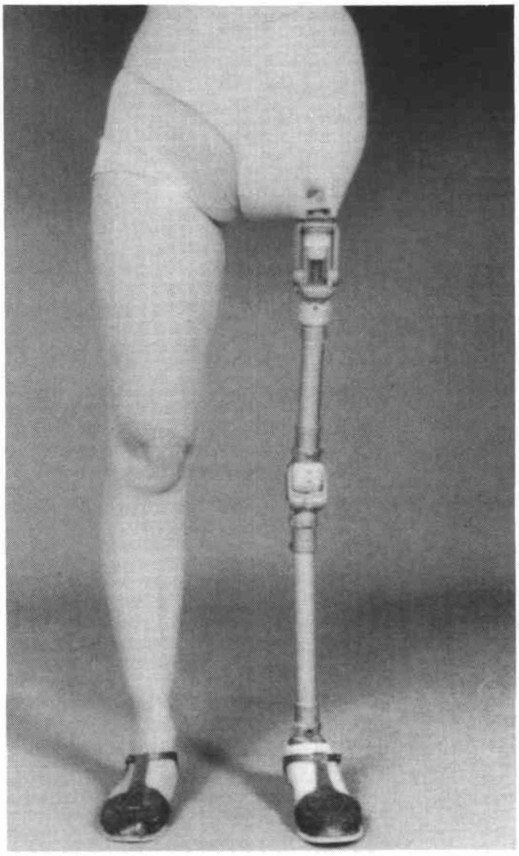

Figure 1. Prosthesis utilizing reversed polycentric knee disarticulation mechanism at the hip, as proposed by Peter Tuil of the Netherlands. (Courtesy of *Orthotics & Prosthetics*, 38/1, p. 33.)

Ottawa Regional Rehabilitation Centre in Canada.[4] Such a technique has also worked well in our hands at Duke, although we are not certain the benefits fully justify the special effort involved.

An even more intriguing concept is the "Hip Flexion Bias" modification promulgated by Haslem, et al. of Houston, Texas.[5] In this system, hip extension from heel strike to midstance compresses a specially selected spring, which encircles the endoskeletal pylon. At toe-off, this kinetic energy is released and the thigh segment is propelled briskly forward (Figure 2).

Not only does this result in a much more cosmetically "normal" gait, it also significantly improves ground clearance in swing phase.

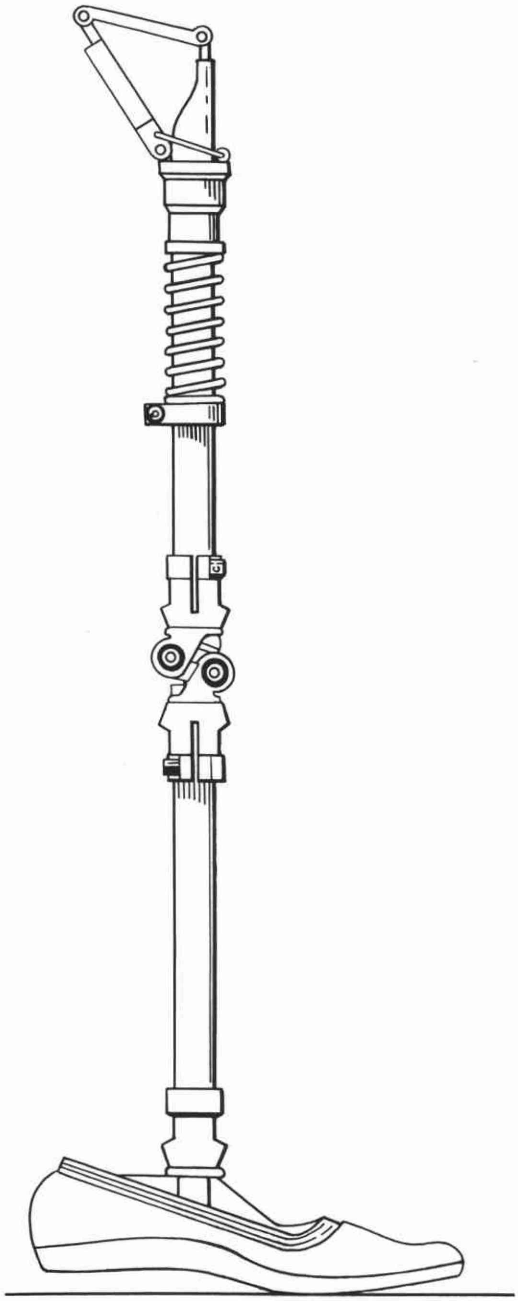

Figure 2. Hip Flexion Bias system designed by Haslam et al. of Houston, Texas. Note compression spring encircling thigh tube, which propels the limb forward during swing phase. (Redrawn from reference 5)

One of the inherent limitations of the Canadian hip disarticulation alignment system is the prosthesis must be significantly short (1cm+) to avoid forcing the amputee to vault for toe clearance.

Figures 3 and 4 illustrate the biomechanics of the Canadian design. At toe-off, the heel rises up during knee flexion and pulls the hip joint firmly against its posterior (extension) stop. The thigh segment remains vertical until the knee has reversed its direction of motion and contacted the knee stop. Only then does the thigh segment rotate anteriorly, causing the hip joint to flex. In essence, the prosthesis is at its full length during midswing. Since the patient has no voluntary control over any of the passive mechanical joints, the prosthetist is forced to shorten the limb for ground clearance.

The hip flexion bias system neatly avoids this dilemma. As a result, the prosthesis can be lengthened to a nearly level configuration in most cases. However, two potential problems have been noted with this approach. One is the development of annoying squeaks in the spring mechanism after a few months of use, which sometimes tend to recur inexorably.

A more significant concern is that as the spring compresses between heel strike and midstance, it creates a strong knee flexion moment. Unless this is resisted by a stance control knee with friction brake or a polycentric knee with inherent stability, the patient may fall. Since the friction brake mechanisms lose their effectiveness as the surface wears, the polycentric knee is the preferred component with this hip mechanism.[6]

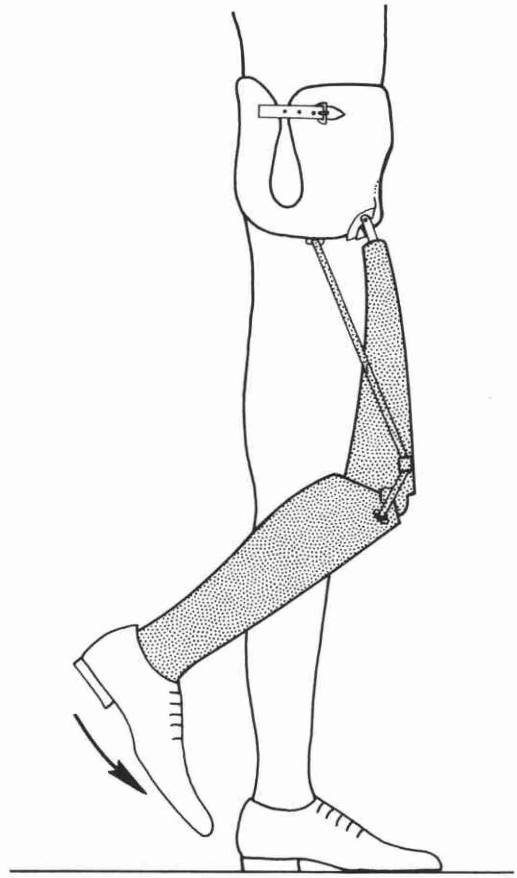

Figure 3. Canadian prosthesis in early swing phase. Hip joint remains neutral as shank swings forward. (Redrawn from reference 13)

Knee Joint Mechanisms

Other than the exception discussed above, knee mechanisms are selected by the same criteria as for above-knee amputees. The single axis/constant friction design remains the most widely utilized due to its light weight, low cost, and excellent durability. The friction resistance is often removed to ensure the knee reaches full extension as quickly as possible. A strong knee extension bias enhances this goal, offering the patient the most stable biomechanics possible with this mechanism.

Although this was proposed as the knee of choice for the Canadian hip disarticulation design, more sophisticated mechanisms have proven their value and are gradually becoming more common. The friction brake stance control knee (Otto Bock 3R15 or equivalent) is probably the second most frequently utilized component.

Because there is very little increase in cost or weight and reliability has been good, many clinicians feel the enhanced knee stability justifies this approach—particularly for the novice amputee. Mis-steps causing up to 15° knee flexion will not result in knee buckle, making gait training less difficult for the patient or therapist.

The major drawback to this knee is that the limb must be non-weight-bearing for knee flexion to occur. Although this generally

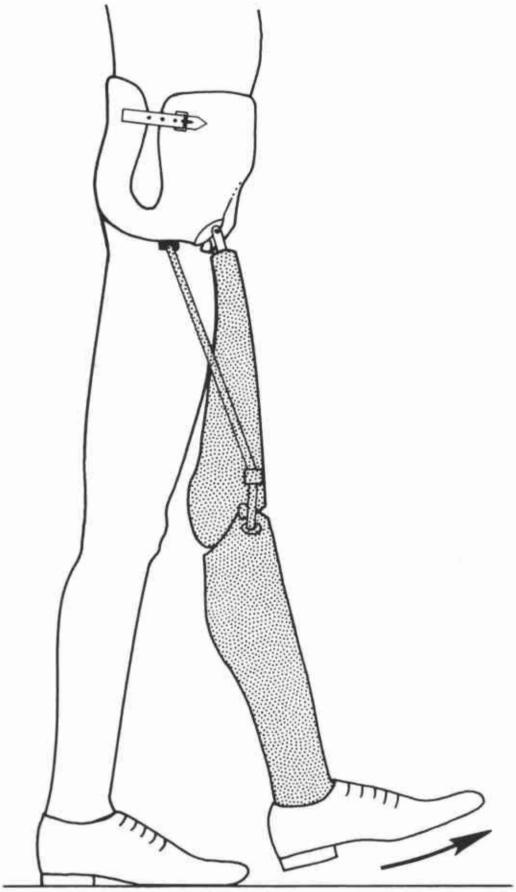

Figure 4. Canadian prosthesis just after mid-swing. Hip joint does not flex until shank motion is arrested by terminal extension stop. Prosthesis is fully extended at the instant of mid-swing. (Redrawn from reference 13)

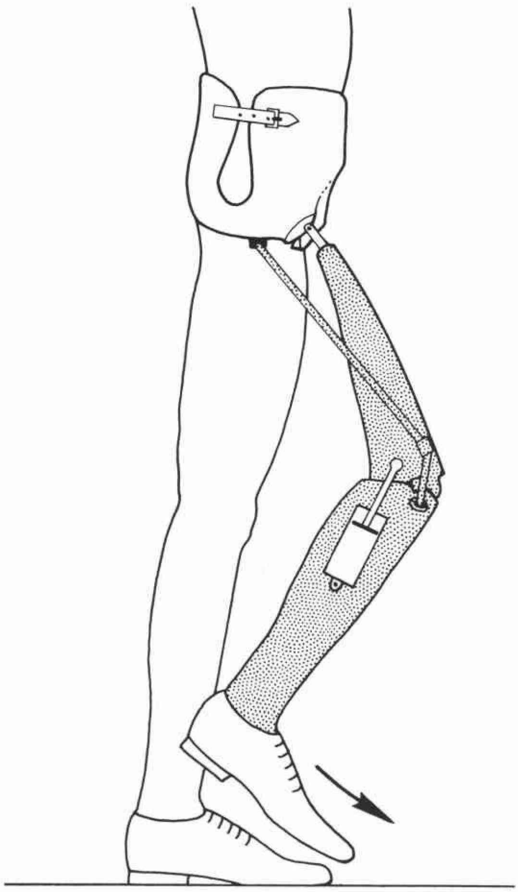

Figure 5. Canadian prosthesis with fluid controlled knee mechanism at mid-swing. Hydraulic extension resistance allows shank momentum to flex hip joint. Increased ground clearance may result. (Adapted from reference 13)

presents no problem during swing phase, some patients have difficulty mastering the weight shift necessary for sitting. It should be noted that use of such knee mechanisms bilaterally must be avoided. Since it is impossible for the amputee to simultaneously unload both artificial limbs, sitting with two stance control knees also becomes nearly impossible.

A third class of knee mechanisms which has proven advantageous for this level of amputation is the polycentric group (Otto Bock 3R20 or equivalent). Although slightly heavier than the previous two types, this component offers maximum stance phase stability. Because the stability is inherent in the multi-linkage design, it does not erode as the knee mechanism wears during use.

In addition, all polycentric mechanisms tend to "shorten" during swing phase, adding slightly to the toe clearance at that time. Many of the endoskeletal designs feature a readily adjustable knee extension stop. This permits significant changes to the biomechanical stability of the prosthesis, even in the definitive limb.

Because of the powerful stability, good durability, and realignment capabilities of the endoskeletal polycentric mechanisms, they are particularly well suited for the bilateral amputee.[8] All levels of amputation, up to and including bilateral hemipelvectomy (hemicorporectomy), have successfully ambulated with these components.

At first glance, a manual locking knee seems a logical choice. However, experience has shown this is rarely required, and should be reserved as a prescription of last resort. Only multiple medical disabilities (e.g. concomitant blindness) will require this mechanism. The complications in unlocking a joint for sitting by the unilateral have been discussed previously; expecting a bilateral amputee to cope with dual locking knees and dual locking hips can be an overwhelming task.

For many years, the use of fluid controlled knee mechanisms for high level amputees was considered unwarranted, since these individuals obviously walked at only one (slow) cadence. The development of the hip flexion bias mechanism and more propulsive foot designs have challenged this assumption. Furthermore, a more sophisticated understanding of the details of prosthetic locomotion has revealed an additional advantage for the hip/hemi amputee.

It is well accepted that any fluid control mechanism (hydraulic or pneumatic) results in a smoother gait.[9] Motion studies conducted at Northwestern University revealed that a more normal gait for the hip/hemi patient is also a by-product.[10]

The preferred mechanism has separate knee flexion and extension resistance adjustments. A relatively powerful flexion resistance limits heel rise and initiates forward motion of the shank more quickly. In essence, the limb steps forward more rapidly.

As the shank moves into extension, the fluid resistance at the knee transmits the momentum up the thigh segment, pushing the hip joint forward into flexion. In essence, the fluid controlled knee results in a hip flexion bias effect (Figure 5).

Sophisticated gait analyses have demonstrated that this results in significantly more normal range of motion at the hip joint during the walking cycle.[11] Clinical observations suggest that a more varied cadence is possible, and the prosthesis can usually be fabricated to nearly full length without swing phase difficulties.

Richard Lehneis, et al. have reported on a coordinated hip-knee hydraulic linkage using a modified hydrapneumatic unit.[12] This was designed to create a hip extension bias, and resulted in a smooth gait. We have no experience with this particular component at Duke.

Finally, a number of new components have been developed recently which combine the characteristics of some of the above classes of knee mechanisms. For example, Teh Lin manufactures a "Graphlite" knee consisting of a polycentric set-up with pneumatic swing phase control in a carbon fiber receptacle.

Foot Mechanisms

Traditionally, the Solid Ankle Cushion Heel (SACH) has been considered the foot of choice for the Canadian hip disarticulation design due to its light weight, low cost, and excellent durability.[13] Provided the heel durometer is very soft, knee stability with this foot has generally been quite acceptable.

In those cases where slightly more knee stability was desired, a single axis foot with a very soft plantar flexion bumper was preferred.[14] Added weight, maintenance, and cost, plus reduced cosmesis are the liabilities of this component.

Multi-axis designs (such as the Greissinger) have similar liabilities to the single axis versions, but add extra degrees of freedom via hindfoot inversion/eversion and transverse rotation. In addition to accommodating uneven ground, absorbing some of the torque of walking, and protecting the patient's skin from shear stresses, multi-motion feet seem to decrease the wear and tear on the prosthetic mechanisms as well.[15]

In the last five years, more sophisticated foot mechanisms have reached the market, and all have been demonstrated to function successfully for the high level amputee. The Solid Ankle Flexible Endoskeleton (SAFE) foot inaugurated a class that could be termed "Flexible Keel" designs.[16] Other members of this class include the STEN foot and the Otto Bock 1D10 Dynamic foot. All are characterized by a softer, more flexible forefoot, resulting in a smoother rollover for the patient. The SAFE version offers some transverse rotation as well.[17]

In general, a softer forefoot requires special care during dynamic alignment to ensure that knee buckle does not occur inadvertently. However, when used in concert with a polycentric knee, the reverse occurs: the prosthesis actually becomes safer during late stance phase.

The polycentric knee mechanism strongly resists a bending moment, which leads to its powerful stability at heel strike. It flexes during swing phase only if the forefoot remains firmly planted on the floor as the body "rides" the prosthesis over it.[18] This creates a shearing force which disrupts the linkage and permits easy flexion of the knee. Because the softer flexible keel delays this shearing moment, the polycentric knee is actually more stable in late stance than with a more rigid foot.

Dynamic Response feet, which provide a subjective sense of active push-off, can also be used to advantage for the hip/hemi amputee.[19] Carbon Copy II, Seattle foot, and Flex-Foot™ have all been successfully utilized for this type of patient. They seem to provide a more rapid cadence, as evidenced by one long-term hip disarticulation wearer, who stated after receiving a Seattle foot, "For the first time in my life, I can pass someone in a crowd."[20]

Once again, the interaction between the foot and knee must be carefully monitored. In general, the more responsive the foot mechanism, the more important the knee unit resistances become. Many practitioners prefer a fluid controlled knee, or at least one with powerful friction cells.[21] Otherwise, much of the forward momentum of the shank can be wasted as abrupt terminal impact of the knee. Presumed reductions in energy consumption have not yet been documented by scientific studies.

In addition to the foot mechanisms, several ankle components have recently reached the American market. These can be paired with most of the feet mentioned above, adding additional degrees of motion as desired. Examples include the SwePro ankle from Sweden, the Blatchford (Endolite) Multiflex ankle from England, and the recently announced Seattle ankle.

Torque absorbing units are often added to hip/hemi prostheses to reduce the shear forces transmitted to the patient and components.[22] Ideally, they are located just beneath the knee mechanism. This increases durability by placing the mechanism away from the sagittal stresses of the ankle, yet avoids the risk of introducing iatrogenic swing phase whips.

The major justification for such a component is that the high level amputee has lost three biological joints and, hence, has no way to compensate for the normal rotation of ambulation. Torque absorbers can be combined with virtually any foot available, if desired.

Finally, transverse rotation units originally developed for the Oriental world have become available. Installed above the knee mechanism, these devices permit the amputee to press a button and passively rotate the shank 90° or more for sitting comfort. They not only facilitate sitting cross-legged upon the floor, but also permit much easier entry into automobiles and other confined areas.

Knee Disarticulation Components

Although it is generally agreed that knee disarticulation offers the possibility of increased function over an above-knee amputation,[23] it clearly restricts patients' options in knee mechanisms and results in cosmetic compromises as well. For these reasons, its advisability remains hotly contested among knowledgeable surgeons and prosthetists.

Knee Mechanisms

The traditional knee mechanism for disarticulation has been the single pivot external hinges. Inherent disadvantages have been the lack of swing phase control (no friction adjustments) and rapid wear due to the small bearing surface compared to the typical 4″ long axle of the above-knee set-up. Even with the addition of a posterior "back check" to limit extension, rapid wear of the extension stops is common.

The major virtues of this design are its simplicity and low cost. It probably functions best for small children. Although the knee ball does not protrude when sitting, external hinges result in a slightly wider mediolateral configuration which some patients find objectionable. Heavy duty wearers can quickly destroy these relatively slender joints.

One manufacturer provides a yoke attachment permitting the use of a fluid-controlled cylinder with these hinges (Figure 6). This improves swing phase significantly, but long-term durability remains problematic.

The only other type of knee possible is a special polycentric design. By using longer linkage arms, the shank appears to fold back under the thigh when sitting, thus minimizing the apparent protrusion of the knee (Figure 7). Since no mechanism is alongside the knee, the mediolateral silhouette is more acceptable as well.

Several manufacturers offer the option of fluid controlled units along with the polycentric mechanism, and almost all have friction control options as well. For this reason, swing phase functioning is much better than the simple external hinge design (Figure 8).

All polycentrics offer powerful inherent stance phase control, and this group is no exception. However, because distal weight-bearing dramatically simplifies the biomechanics of knee control, this feature is seldom of great value to the patient. One manufacturer offers a manual locking module as well, but this should be used only as a last resort.

One subtle problem with knee disarticulation polycentrics is that the relative "shortening" of the shank in sitting may lift the foot completely off the floor, particularly for husky individuals who are less than 5′ 6″ tall. The resulting sense of insecurity can be very disconcerting to the amputee and may result in rejection of the prosthesis.

Durability can sometimes be a problem, although it is generally better than for external hinges. Most knee disarticulation polycentrics work quite well for geriatric patients but can become increasingly problematic for extremely vigorous individuals.

In some cases, the only effective solution to chronic breakage problems is to switch to a conventional above-knee set-up. This results in protrusion of the knee ball by at least 2″, making sitting in tight spaces (such as bus seats) nearly impossible. Although the function and durability are excellent, the cosmetic liability of such malalignment is obvious to the casual observer as well.

Foot Mechanisms

Knee disarticulates can utilize all the feet and ankle options of the higher level amputee, as previously discussed. Knee stability is rarely a concern, but reducing stress on the relatively fragile knee mechanism is a concern. For that reason, the author favors flexible keel designs,

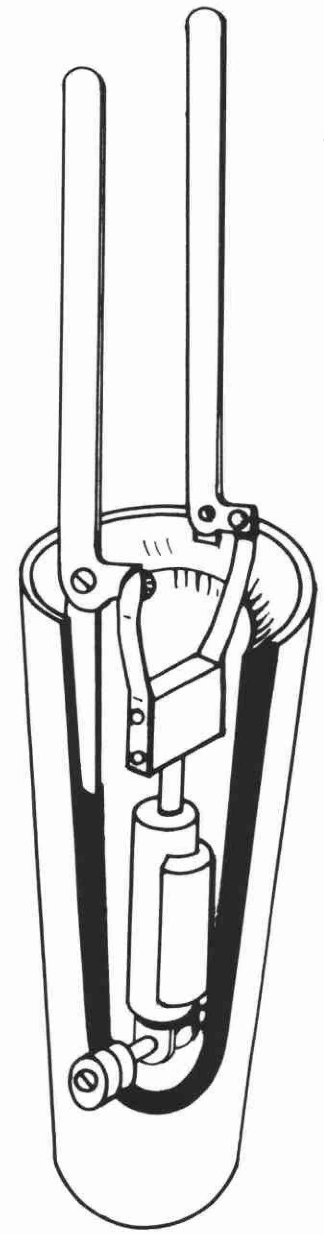

Figure 6. Cut-away drawing of special hydraulic mechanism with yoke, permitting swing phase control for knee disarticulations with single pivot external hinges. (Redrawn with permission of Hosmer-Dorrance Corporation)

with or without a torque absorbing unit, since these components reduce the forces transmitted to the limb.

Ankle Disarticulation (Symes)

Like his knee disarticulate brethren, the Symes amputee has a very limited range of choices in prosthetic componentry. In addition, a significantly poorer cosmetic result is inevitable. These disadvantages must be weighed against the functional advantages of distal weightbearing and the documented reduction in energy consumption over the below-knee amputee.[23]

Foot Mechanisms

The Symes amputation generally precludes the use of any articulated ankle mechanism, due to space limitations. The heavy metal frame of yesteryear is virtually extinct.

Most of today's Symes amputees are fitted with a SACH foot. The specially designed Symes version suffers from reduced durability due to the greater stresses the end-bearing residual limb can exert on the prosthesis. However, it can often be replaced economically if broken.

The external keel SACH design limits inversion and eversion almost completely but can be more durable and more cosmetically pleasing than the standard SACH. Since its use precludes any alteration of alignment after transfer and finishing, great care must be exercised during the fitting.

The Stationary Ankle Flexible Endoskeleton (SAFE) foot, discussed earlier, has a Symes version. This offers a flexible keel and much smoother roll-over. This reduces the forces transmitted to the prosthetic socket, increasing both patient comfort and socket durability. Reliability is adequate, and replacement is possible. The author prefers this design for Symes amputees for the reasons cited.

The Carbon Copy II has recently developed a dynamic response design suitable for many adult male Symes. Patient response has been favorable, as they sense the dynamic push-off it offers. External appearance is excellent, as is the weight reduction. Our experience at Duke is too short to comment at this time on durability of this component or its effect on socket stresses.

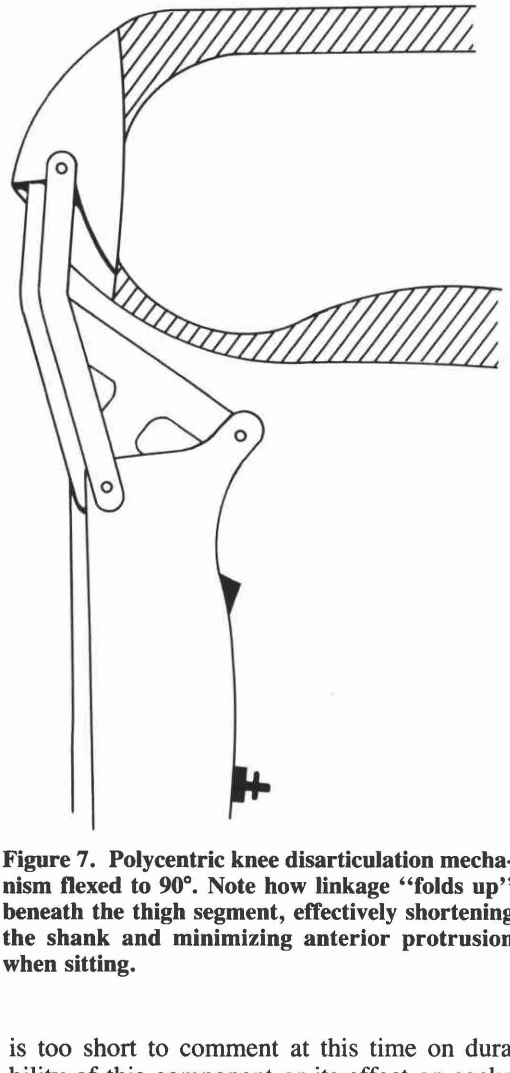

Figure 7. Polycentric knee disarticulation mechanism flexed to 90°. Note how linkage "folds up" beneath the thigh segment, effectively shortening the shank and minimizing anterior protrusion when sitting.

Summary

Although disarticulations represent less than five percent of the lower limb amputees fitted annually,[25] appropriate components can be selected based on logical criteria. Both Symes and knee disarticulates, however, have limited component options, often with decreased reliability plus cosmetic limitations compared to more conventional amputation levels.

Hip disarticulates and hemipelvectomies have as broad an array of choices as the above-

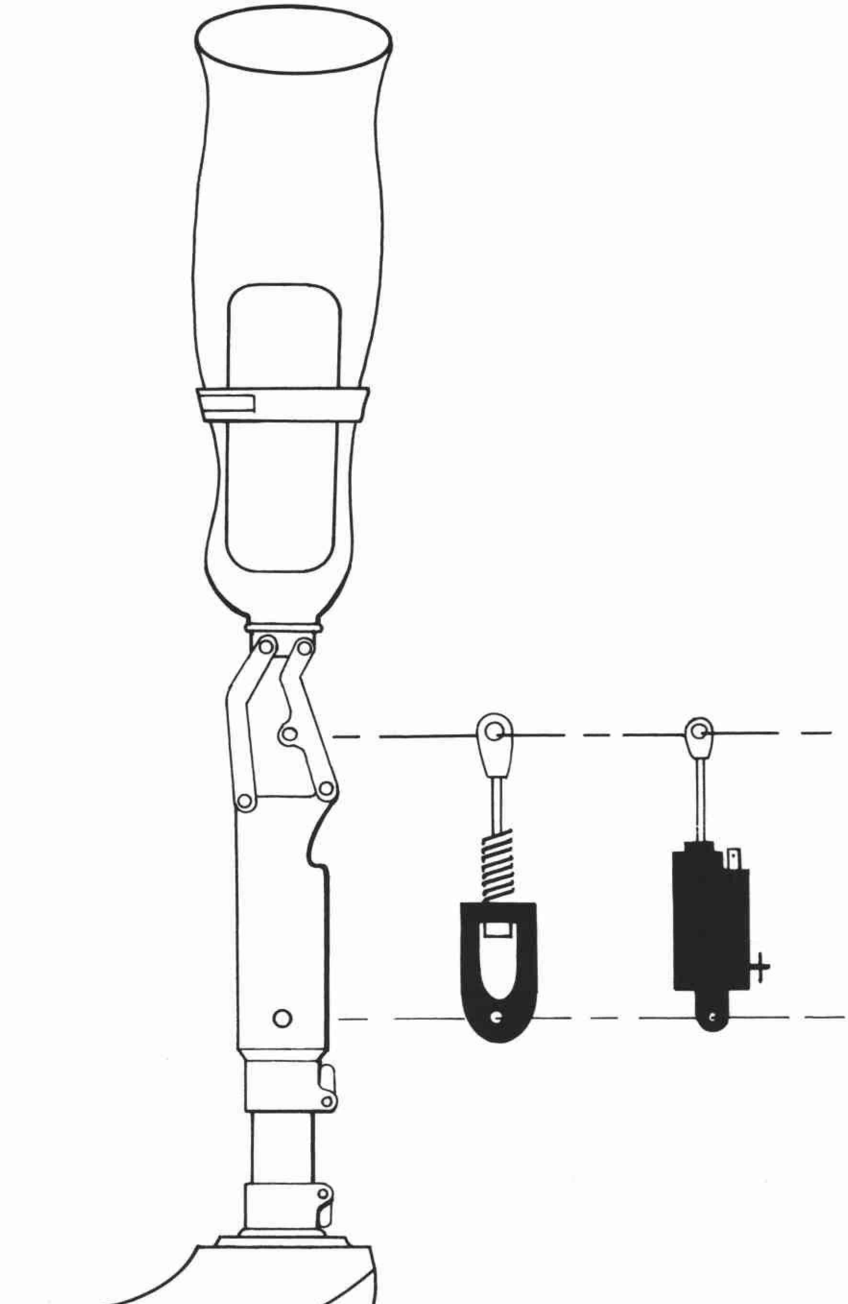

Figure 8. Example of polycentric mechanism permitting interchange of mechanical and fluid control swing phase units. (Designed by Orthopedic Hospital of Copenhagen; redrawn with permission of United States Manufacturing Company)

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knee, prescribed for generally analogous reasons. As our understanding of biomechanics has improved, more sophisticated mechanisms have been successfully provided to this group of patients. Current state-of-the-art requires careful consideration of the subtle interactions between the foot, ankle, hip, and ancillary mechanisms to ensure the optimum result for each patient.

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