EXPERIENCE WITH ENDOSKELETAL PROSTHESES
FOR LOWER EXTREMITIES abc

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INTRODUCTION

The idea for the first pylon limb replacement is probably as old as man himself. When man first survived a limb loss, he reached for that forked wooden stick to fashion a crude peg: an early concept of limb replacement put into practice to aid in ambulation. History has recorded such incidents as early as 500 B.C., surely not as memorable as the legendary story book character of Captain Ahab who wore a "peg leg" fashioned from a whale's tooth. While these early wooden pegs were usually fashioned by the disabled himself, the more sophisticated, articulating, skeletal structures of the 16th century were fashioned by metal craftsmen, skilled in producing body armor (Fig. 1). It is assumed that the difficulties associated with providing adequate cosmesis for these skeletal limbs were responsible for abandoning this technique in favor of today's commonly practiced crustacean construction approach.

In the early stages of our experience with immediate postsurgical

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*c An abstract of this paper "Cosmetic Finishing of Skeletal Systems," was presented at the National Assembly of the American Orthotic & Prosthetic Association, Portland, Oregon, October 2, 1970.
SKELETAL PROSTHESES FOR LOWER EXTREMITIES

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FIGURE 1.—The first known jointed leg prosthesis from the 16th century. (From Paré, A., Oeuvres Completes, Edition Malgaigne, Paris, 1840, from the copy in the Armed Forces Medical Library.)

This is a figure showing a jointed leg prosthesis from the 16th century.
prosthetic fitting (1) in 1964 at the Prosthetics Research Study in Seattle, Washington, interest was awakened as to the feasibility of incorporating the postsurgical pylon prosthesis as the basic skeletal component of the definitive prosthesis.

As a result of early (2) and immediate postsurgical prosthetic fitting, the concept of endoskeletal systems was thus reestablished and various designs soon became commercially available (Fig. 2 and 3). All of these prosthetic devices have basic similarities in components design, with either proximal or distal alignment adjustability, and in some instances both. Static and dynamic alignment requirements call for a sufficient range of adjustability in endoskeletal systems for immediate as well as early (3) postsurgical prosthetic fitting, including the definitive prosthesis. The ideal lower-extremity endoskeletal prosthetic unit is compact, lightweight, durable, and free from protruding parts. It should provide:

1. Angular adjustments in flexion-extension, adduction-abduction (tilt), or a combination of the two
2. Horizontal adjustment in the mediolateral and anteroposterior plane (slide), or a combination of the two
3. Length adjustment of the shank (pylon)
4. Toe-in and toe-out adjustment of the prosthetic foot
The feasibility of incorporating the basic skeletal component of the endoskeletal prosthesis in immediate postsurgical prosthetic fitting was thus reestablished and various models (Fig. 2 and 3). All of these advantages in components design, with adjustability, and in some instances, mobility requirements call for a sufficient system for immediate as well as long-term, including the definitive endoskeletal prosthetic unit, to conform to protruding parts. It should also be noted that the prosthetic foot (Fig. 4) demonstrates structures for the two basic movements of extension, adduction-abduction, mediolateral, and anteroposterior of the prosthetic foot.

5. A simple quick-disconnect mechanism, allowing the pylon and foot to be easily removed from and attached to a rigid dressing or cast socket without loss of alignment.

For maximum security the adjustments should be independent of each other.

While items 1, 2, 3, and 4 are equally important in aligning immediate and early postsurgical prostheses including definitive prostheses, item 5 is valuable only for immediate postsurgical prosthetic fitting to allow for maximum security.
removal of the endoskeletal prosthetic unit, including pylon and foot, while the patient is in bed, and to guard against unsupervised ambulatory activities. More recently, newer and more sophisticated endoskeletal prostheses of modular design have become available which allow for quick interchange of components to provide the required functions as the patient’s needs change. The impressive developments by VAPC (4) and others serve as excellent examples.

This discussion is limited to our experience at the Prosthetics Research Study in 1964, when only the U.S. Manufacturing Company above-knee and below-knee endoskeletal systems were commercially available and were considered practical for incorporation in immediate postsurgical prosthetic fitting and definitive prostheses (Fig. 4 and 5).
THE BELOW-KNEE ENDOSKELETAL DEFINITIVE PROSTHESIS

The below-knee application procedure required socket fabrication in the conventional manner. The socket was then located in a pre-flexed and adducted attitude on the socket attachment plate, and the socket attachment straps were bent and shaped to follow the general exterior contours of the socket. Next, the socket was secured with glass filament tape and the socket attachment straps were covered with a mixture of polyester resin and Solka floc (Fig. 6 and 7). Bench alignment was completed by cutting the pylon tube to the appropriate length and by attaching the prosthetic foot (Fig. 8). Upon completion of both static and dynamic alignment, final lamination of the socket was optional before securing the adjustable portion of the prosthetic unit with several machine screws. In several instances, a commercially available semi-rigid plastic shell cover was used for cosmetic finishing (Fig. 9). The covers,
made for either left or right, came in one shade of flesh color only. Negroid colors were available on special request from the manufacturer. While the below-knee cover was semi-rigid distally, it became increasingly more flexible at its proximal portion. For application, the proximal portion was heated with a heat gun, stretched over the prosthetic socket, and trimmed proximally according to socket contour. Semi-rigid cosmetic shell covers (Fig. 10), as described, have the obvious disadvantage of a restricted cosmetic appearance, since they could not be radically altered or customized. Therefore, inability to duplicate the sound extremity was a limiting factor in this approach.

To achieve a more acceptable cosmetic effect the entire cavity between foot and prosthetic socket was filled with polyester or polyurethane plastic foam after final alignment had been achieved. For example, Hosmer foam of 4-lb. density, which could be compared to balsa wood with a fairly low strength-weight ratio, was found to be suitable for this purpose. Cosmesis was achieved by custom-shaping, and the final finish consisted of an inexpensive, thin, production-leg cover which was heated and pulled over the prosthesis. The cover was secured proximally with glue and trimmed flush with the socket walls (Fig. 11 and 12). For female patients the cover was left to extend proximally over the knee to be retained by garters. Color tone was altered with an appropriate underhose.
or by using a color chart and selecting a better quality cosmetic leg cover. The disadvantage in this particular approach was in the loss of easy access to the pylon tube and adjustable prosthetic unit, which necessitated complete dismantling of the cosmetic cover including removal of the plastic foam to accomplish servicing, repairs, or realignment of the prosthetic unit and pylon structure.

It was also noted that this system resulted in a heavier prosthesis as compared to the conventional crustacean type. Problems encountered were: occasional breakage of foot-attachment bolts, which was resolved by the manufacturer's redesign of the pylon base plug; noise; and occasional loosening of the wedge disks and hose clamps, which was persistent and only partially resolved by periodic maintenance and check-ups.
THE ABOVE-KNEE ENDOSKELETAL DEFINITIVE PROSTHESIS

Our experience with endoskeletal prostheses for the above-knee amputee is rather limited. In one instance a prosthesis consisting of a Hydra-Knee swing-phase-control unit, mounted in a Hydra-Cadence frame with adjustable prosthetic unit, including quick-disconnect, was provided immediately postsurgically and was subsequently incorporated into the definitive prosthesis (Fig. 13, 14, and 15). The prosthesis was attached to the socket by means of the socket attachments straps, with remaining open cavity between distal socket end and socket attachment plate filled with polyester plastic foam. Through an anterior opening, the yoke segment of the shank portion of the prosthesis could be connected to or disconnected from the socket by means of a screw (Fig. 16). Cosmesis was achieved by using a standard Hydra-Cadence shank cover (Fig. 17 and 18). Shape could not be altered without damage to the...
cosmetic cover finish. The resulting weight of the prosthesis was considered excessive and not applicable for a geriatric amputee; however, service requirements in this particular case were rather minimal. Aside from occasional loosening of the foot bolt and distal hose-clamp connection, the patient liked the prosthesis and wore it for 3 years. Although very active working daily in a junk yard, he did not object to the weight of the prosthesis.


FIGURE 14.—U.S. Manufacturing Company above-knee endoskeletal prosthesis with Hydra-Knee swing-phase-control unit for immediate postsurgical prosthetic fitting.
DISCUSSION

Overall, in our rather limited experience, a definite time-saving factor was evident in construction and assembly of endoskeletal prostheses. However, the initial time saved in construction was partially compromised by increased service demands after delivery of the prostheses to the patients. The difficulties encountered were relatively minor and strictly the result of improper techniques that could have been resolved with proper pursuit and appropriate changes.

Since the problems encountered with endoskeletal systems were absent in the conventional crustacean construction approach, and in view of other more urgent priorities, these initial attempts were abandoned. Nevertheless, it was felt that endoskeletal and modular construction were
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FIGURE 17.—Definitive above-knee endoskeletal prosthesis, anterior view.

FIGURE 18.—Close-up (posterior view) of Figure 17. Note retention of wedge disk alignment unit.

As a result of our experiences, the following observations and recommendations for endoskeletal and modular lower-extremity systems are made: Endoskeletal or modular systems should be divided into three distinct categories of varying requirements:

1. The immediate postsurgical prosthesis
2. The preparatory or intermediate prosthesis
3. The definitive prosthesis

1. For the immediate postsurgical prosthesis, we expect relatively short use with less active demands by the patient requiring the all-important provisions of a quick-disconnect feature, a manual knee-locking mechanism for the above-knee patient, and simple and efficient adjustability for static and dynamic alignment. The unit should be reusable.
2. Preparatory or intermediate prosthetic application is also of a relatively short and limited duration, but with increased patient demands requiring more of the general features of a definitive prosthesis. Adjustability, which is required for both static and dynamic alignment,
should be maintained and the prosthesis should remain reasonably secure and stable under these more demanding conditions. This type of prosthesis might be used for several months until stump maturity is achieved. In view of its relatively limited use, it should also be reusable.

3. For definitive prosthetic application, we expect long-term use with maximum demands on adjustability, function, and durability. However, once satisfactory alignment has been achieved, readjustments are usually no longer required or seldom performed unless socket replacement is indicated. For this reason the adjustable prosthetic segment of the endoskeletal system should be replaced with a simple pylon structure assuring a lightweight prosthesis with a minimum of mechanical parts that could loosen and/or create noise. Endoskeletal and modular systems, regardless of their intended use as immediate, early, preparatory, or definitive prostheses, must be directed to fill three distinctly different patient needs:

A. The child
B. The juvenile and adult
C. The geriatric

The scaled-down unit for the child must be equally as rugged as the standard juvenile and adult size unit. For the geriatric amputee, emphasis must be placed on a lightweight unit with a less complex structure, and should possibly incorporate assistive devices such as manual-locking knee mechanisms, or other appropriate safety devices, particularly for the above-knee patient.

Development should proceed on an orderly basis by qualified and experienced centers and manufacturers. This should result in designs that provide for ease and speed of assembly and adjustability. It should prove rugged, stable, and noise-free. General components, tube dimensions, and tool requirements should demonstrate uniformity. Provision should be made to allow removal of the alignment component upon completion of alignment requirements to keep the weight factor to a minimum for all patients, but especially for the geriatric. A definite need is evident for a modular system that allows quick and easy installation of various units, including fluid-controlled mechanisms (swing and/or stance phase), as well as mechanical friction systems for above-knee amputees. Current efforts should be expanded and accelerated, as all these demands tend to make skeletal and modular systems more intricate and complex, and maximum effectiveness is usually the result of simplicity.

The cosmetic finishing also adds further complexities. Finishing of endoskeletal and modular systems can be divided into two general categories:

1. The prefabricated, pre-formed hollow shell system with a variety of sizes.
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2. The block or bulk type that can be custom-shaped for individual anatomical requirements. Both systems are applicable for the major lower-extremity endoskeletal and modular prostheses.

Cosmetic finishing of below-knee endoskeletal or modular systems is relatively simple. The flexible block or bulk type, with a core removed for pylon insertion, might show certain advantages over the pre-formed hollow shell system in that it can be customized to match the sound extremity. The additional material thickness will provide a more durable, flesh-like feel and texture. The pre-formed hollow shell cover systems, however, can be extended past the proximal socket trimline for the below-knee amputee to improve appearance about the knee, especially for females. However, inability to custom-shape offsets this advantage appreciably.

In the above-knee application the pre-formed hollow shell system should provide sufficient room for the various knee-control mechanisms. The aim here should be for a flexible cosmetic cover which extends over the knee joint to the proximal aspect of the socket covering the junction of knee and shank (particularly for female amputees). This cover should be thick enough in critical areas about the ankle and calf to allow for some customization. By using the above-knee endoskeletal system in conjunction with the block application, an excellent opportunity for maximum cosmesis is provided in that it encompasses the total prosthetic structure from foot to socket and can be custom-shaped. A slightly modified approach should be applicable as well for the hip-disarticulation modular system.

Closed-cell vinyl foams or similar materials show excellent possibilities for this purpose. Cosmetic covers made of these plastic materials should have a flesh-like feel and texture, stain resistance, and reasonable durability. Development and efforts by experienced manufacturers should continue to be encouraged. While basic flesh-tones vary appreciably among individuals, a touch-up color kit for the prosthetist might be well worth considering for maximum customization when indicated.

If today’s commonly practiced prosthetics system is to be changed, it can only be justified through an improved system. With the wealth of new materials available today, the transition should result in speedier service and less cost to the patient, improved function, and a more natural appearing prosthesis.

**SUMMARY**

An experience of the transitional use of endoskeletal below- and above-knee prostheses from immediate postsurgical prosthetic fitting to definitive prostheses has been described. The experience, while only partially
successful, has served well in pointing out definite requirements for improvement of this form of prosthetic fitting. The recommendations are in support of the opinion that endoskeletal and modular prosthetic designs are both feasible and practical. The system, properly developed, will provide the patient not only with speedier and more economical service, but also will result in a more functional and cosmetic prosthesis.

REFERENCES


