

Advances in Lower Extremity Prosthetics

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The earliest reference to Lower Extremity Prosthetics is from the Rig Veda from the period 3500-1800 B.C. It gives the account of a militant Queen who lost her leg in a battle, had it replaced with an iron prosthesis and subsequently returned to combat. Ambrose Pare constructed a metal above knee prosthesis with articulated joints in the middle of the 16th century.

Contemporary advances in Prosthetics include simple but highly effective Solid Ankle Cushioned Heel (SACH) foot developed in 1956 and the Patella Tendon Bearing Below Knee Prosthesis in 1959, both from the University of California. The Hydra Cadence unit was developed in 1960 and helped commercialize Hydraulic Knee units. The Endoskeletal Prosthesis was introduced in 1971 and a new generation of Prosthetic feet was introduced in the 1980's.

Lighter and stronger materials have been developed in the fabrication of Prosthesis. Carbon fiber, Titanium, Thermoplastic material, Silicone to name a few has made the prosthesis lighter and improved function in the amputee.

The following will be discussed briefly :

1. Suspension and harness systems.
2. Socket designs for the above and below knee amputee including the flexible socket design.
3. New Knee units
4. Prosthetic feet Dynamic Elastic response (Energy storing feet)
5. Custom design in lower extremity prosthetic for athletic activity

6. Computer Automated Design and manufacture of Prosthesis

Suspension and Harness system

Good functioning of a prosthesis begins with a stable base of support. In general, the appropriateness of a given suspension system will depend on both the length and shape of the residual limb.

Silicone suspension :

Silicone liners offer a solution to those patients who could benefit from suction, but are unable to manage the often-difficult process of donning. A silicone locking liner used for the below knee amputee also can be used for the above knee amputee. It is used with a pin and shuttle lock. It allows for volume fluctuations through the addition of Prosthetic socks. Longer limbs may not allow sufficient space for the shuttle lock hardware and result in a knee center discrepancy. Rotational control caused by weak musculature or redundant tissue can be corrected by the addition of a belt.

Total Elastic Suspension :

A recently available alternative to Silesian suspension is the total elastic suspension or TES belt. It is made of Neoprene with reinforced elastic bands running in oblique angles anteriorly and posteriorly. No rivets are required to attach the belt to the socket. The belt is pulled up snugly around the proximal part of the socket. The patient wears the belt around his waist, and fastens it anteriorly with velcro. The belt is available in prefabricated

sizes ranging from infant to adult extra large. This can also be custom made for bilateral amputees. Sometimes the Neoprene does not conform well. Newer materials have elastic in them, which conform better. The TES belt also covers and spreads pressure over greater surface area. It is also a great auxiliary suspension for patients who need it only occasionally for higher activities such as sports, because it can be applied or removed by the patient as needed.

Socket Designs

The Flexible socket : Before 1980's all sockets were made from rigid materials which included laminated plastics or wood. Patients complained of inability to sit comfortably and lack of tactile feedback through socket walls. Kristinsson developed a technique to construct a socket with flexible walls. Working with colleagues in Scandinavia and the United States, they refined a technique of a rigid frame within which a thermoplastic liner resides. The Socket was termed the ISNY socket (Icelandic-Scandinavian-New York) socket. The 1987 consensus conference described flexible sockets as having the benefits of improved sitting comfort, improved proprioception, better heat dissipation, improved muscle activity, reduced weight and enhanced suspension if suction is used. Also the socket can be interchanged more readily without loss of alignment, should it require replacement because of wear or slight change in patient residual limb volume. A biomechanical study in 1986 showed that the femoral position was virtually identical in a flexible socket as that of a rigid socket.

Ischial Containment Socket

In 1975 Long noted that the adduction of femur in many instances did not match the adduction of the Quadrilateral prosthetic socket when observed through radiographs. This he concluded was the reason that many patients had an inefficient adductor lurch during gait. He

narrowed the medial-lateral dimension to gain better control of the femur. He also believed that when the ischium is located on the brim or seat, the quadrilateral socket tends to move laterally on weight bearing. Ischial containment sockets are also narrower from medial to lateral than their quadrilateral counterparts, hence the name Narrow M-L Socket.

Workshop on Above Knee Fitting Techniques held in Florida in 1987 reached the following consensus :

1. Maintain normal femoral adduction and narrow based gait.
2. Enclose ischial tuberosity and ramus in the socket so that forces involved in the maintenance of medial lateral stability are borne by the bones of the pelvis medially and not by the soft tissues.
3. Maximize effort to distribute forces along the shaft of the femur.
4. Decrease emphasis on a narrow anterior posterior diameter to maintain ischial gluteal weightbearing.
5. Provide total contact.
6. Use suction socket suspension where indicated.

The term ISCHIAL CONTAINMENT became widely used subsequent to this workshop and is now a generally accepted term.

Prosthetic Feet

There are a number of criteria to consider when deciding on a prosthetic foot with an amputee. The most universal criteria are shoe size, heel height, patient weight, left or right, activity level, and maintenance. Some of the subjectivity has been removed from the category of activity level with the creation of the Medicare HCFA prosthetic K levels. The levels Ko to K4 describe and define amputee activity levels from the non-prosthetic candidate Ko to high level athletes K4. K levels represent potential functional abilities as defined

by Medicare. Patient records must document the patients' current functional capabilities and his or her expected functional potential.

Prosthetic K Levels

K0: Does not have the ability or potential to ambulate or transfer safely with or without assistance and a prosthesis does not enhance the quality of life or mobility.

K1: Has the ability or potential to use a prosthesis for transfers or ambulation on levels surfaces at fixed cadence. Typical of the limited and unlimited household ambulator.

K2: Has the ability or potential for ambulation with the ability to traverse low level environmental barriers such as curbs, stairs, or uneven surfaces. Typical of the limited community ambulator.

K3: Has the ability or potential for ambulation with variable cadence. Typical of the community ambulator who has the ability to traverse most environmental barriers and may have vocational, therapeutic, or exercise activity that demands prosthetic use beyond simple locomotion.

K4: Has the ability or potential for prosthetic ambulation that exceeds basic ambulation skill, exhibiting high impact, stress, or energy levels. Typical of the prosthetic demands of the child, active adult, or athlete.

The Energy storing (Prosthetic Feet) have the characteristics of storing energy during stance and releasing it during toe off. Compared to the SACH foot it allows a small increase in stride length and subsequent walking velocity and it is more amenable to passive dorsiflexion in mid stance, hence allowing a normal extensor movement at the knee. The following feet will be briefly discussed :

The Flex Foot

The Variflex

Springlite

Carbon 2

Arthroglide systems

Total Concept

Custom Design in Lower Extremity Prosthetics for Athletic Activity

Prosthetic adaptations can be made specifically to help the amputee to be physically more active, enhancing the quality of life and health of the individual. An increasing interest on the part of the amputee to extend the scope of physical activity, in particular, sports and recreation prompted a survey asking lower limb amputees what functions they missed most and what areas of prosthetic improvement should be addressed to improve quality of life. The survey overwhelmingly indicated that the most needed function was the ability to move quickly and to run. Most blamed the socket and the foot.

Different sports require the amputee to perform at different levels of activity, and his or her prosthesis should be designed to the level of demand placed on it. The runner requires the prosthesis to attenuate the impact of heel strike, to allow a long stride length and to provide propulsive impulse at the end of stance. Golf has different demands. The golfer must be able to endure long period of standing and ambulating over uneven terrain and must be stable when twisting. A basketball player needs significant shock absorption at heel strike. For someone who desires to enter a walking programme and has no intention of running or jogging, shock absorption through heel compression is very important. There are numerous components available that can reduce the shear on the residual limb. One such liner currently available uses a urethane material. Shock absorption can also be increased by use of a telescoping pylon in the prosthesis. Vertical displacement is allowed in the prosthesis to decrease the effect of high impact on the residual limb. This design has a telescoping pylon with adjacent leaf spring.

Some sports generate more torsion and the amputee benefits from rotation within the

prosthesis. Golfers are one group that appreciates this motion when trying to achieve a smooth swing with appropriate transfer of body weight. A rotator allows the amputee athlete to achieve a desired body position with a natural degree of pivot at the toe.

Water sports present a unique prosthetic requirement. Everyday prostheses do not fare well in water. Prostheses made of plastic and composite materials can be used; though even these absorb moisture at the molecular level. Covering a prosthesis makes it buoyant, which can make swimming and diving difficult. For underwater use, it is advisable to create a prosthesis that fills with water to compensate for buoyancy and then drains when out of the water.

Special feet for rock climbing have been fabricated that incorporate the specific traits suitable for that sport. These feet must be rigid to the end of the toe to support body weight. Standard prosthetic feet have a flexible toe break to facilitate roll over after mid stance, so are not optimal for climbing.

3C100 C-Leg System by Otto Bock

The C leg is the world's first completely microprocessor controlled prosthetic knee/shin system with hydraulic swing and stance phase control. The product is so revolutionary that amputees who have been fitted with this often state that its most obvious benefit is that they do not have to think about walking any more.

The unique relationship between the

microprocessor and the hydraulic pneumatic system enable the C leg to offer amputees the closest possible approximation to their natural gait. Electronic sensors in the C leg collect real-time data that control stance and swing phase movements of the knee, while meeting the full range of stability and functional needs. The electronic systems monitor how the amputee is walking and creates a smooth, harmonious movement of the prosthetic limb, similar to that of the sound leg, immediately adapting to different walking speeds and providing knee stability.

Individual adjustments are optimized during the fitting by interfacing the knee with a personal computer. Unique software algorithms determine the phase of gait, then immediately adjust the knee function to compensate. Multiple sensors in the C leg record this information 50 times per second during a typical gait cycle, greatly reducing the risk of the amputee making a mistake. This is perhaps the most advanced knee to date. It samples information on knee position; velocity and strain generated in the pylon and adjusts the hydraulic resistance for proper swing rate and stance control.

The product is designed for a broad spectrum of lower limb amputees. It can be used by extremely mobile individuals as well as those who need additional stance stability. The leg is recommended for amputees weighing up to 220 lbs. who have a moderate or higher functional level.

The lithium-Ion battery in the knee provides 25 to 30 hours of use before needing a recharge.