Lecture # 4

Artificial Limbs I

Prosthetic Feet

Introduction

Just as every person is unique, every person with an amputation presents a different set of characteristics that should be considered when selecting a prosthetic foot. This selection should be made carefully as safety, performance, and patient satisfaction can be impacted if the foot is not well matched to the patient. To make an effective selection among the multitude of choices offered by prosthetic foot manufacturers and to succeed in matching the right foot to the right recipient, it is important to thoroughly consider each individual's current and potential abilities and needs.

The aim of providing a prosthetic foot is to maximize every patient's rehabilitation potential so that they may return to their daily activities and work at a level comparable to their peers. Ideally, the function of a prosthetic foot should match that of an anatomical human foot. It should **offer shock absorption, compliance to uneven terrain, push-off, and shortening during the appropriate points in the gait cycle, all in a lightweight, low-maintenance package**. In reality, no prosthetic foot available today matches the human foot in all these characteristics. The final choice is always a compromise, as no single prosthetic foot performs optimally for all activities and conditions. The most appropriate foot is one that best serves the user's unique needs at the time of selection.

Once a specific foot design is selected it must be ordered to meet the specific weight and activity level of each person. If patients experience physical or lifestyle changes, the foot should be replaced to match their new functional needs. For example, a weight gain of 20 or more pounds or substantial increase in activity or loads carried may result in the catastrophic failure of the structural element of a foot. All the parts of a prosthetic system, especially feet, should be checked regularly for wear and tear and replaced immediately if any cracks or other signs of structural failure occur. It is difficult to predict the useful life span of a foot because of the wide range of users and the way they are used.

FACTORS IN SELECTING A PROSTHETIC FOOT

- **Functional Level**

  Medicare guidelines describe functional levels into which all persons with lower-limb amputation fall and are widely accepted by most payers.

  - **Level 0:** Does not have the ability or potential to ambulate or transfer safely with or without assistance and a prosthesis does not enhance their quality of life or mobility.
  - **Level 1:** Has the ability or potential to use a prosthesis for transfers or ambulation on level surfaces at fixed cadence.

- **Level 2:** Has the ability or potential for ambulation with the ability to traverse low-level environmental barriers such as curbs, stairs or uneven surfaces.
- **Level 3:** Has the ability or potential for ambulation with variable cadence. Typical of the community ambulator who has the ability to traverse most environmental barriers.
- **Level 4:** Has the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels.

- **Activities of Daily Living and Work Requirements**

  No single foot can meet a person's needs in all situations. By determining the most frequent and important activities a balance of performance features can be achieved. For example, someone who works in an office and who also plays golf on weekends should be provided with a multiaxial ankle to accommodate uneven terrain.

- **Patient's Weight**

  Weight should be recorded at every patient encounter to insure that a foot is still appropriately matched to the patient.

- **Amputation Level and Residual Limb Characteristics**

  Foot selection can bear directly on the health of the person's residual limb. Ground reaction forces that are transmitted through a person's body can be damaging to the person's residual limb, knee, hip, or back. Choosing a foot with compliant heel action can reduce these impact forces.

- **Comorbidities**

  The deflection dynamics of a foot can have an effect on the health and well-being of a person's joints. Excessive toe stiffness can cause hyperextension of the knee. The contralateral limb should also be taken into consideration as too soft of a prosthetic toe can cause increased impact on the sound side.

- **Environmental Stresses and Durability**

  People exposed to extreme environments need a foot that will not deteriorate under those conditions.

- **Shoe Choices (Heel Heights and Shoe Shape)**

  A heel height-adjustable foot can make a significant difference for someone who wants to wear high heels or switch between different heel-height shoes, depending on the formality of the occasion or work requirements.

- **Interaction with Other Prosthetic Components**

  The foot is part of a closed chain in which ground reaction forces are transmitted through the prosthesis. The characteristics of the foot will affect the way a prosthetic knee and hip joint respond to ground forces. For example, a foot with a stiff heel will send more flexion force to the knee at heel strike.

PERFORMANCE FEATURES AND APPEARANCE OF AVAILABLE PROSTHETIC FEET

K1 Feet

The solid-ankle, cushion-heel (SACH) (Figure 1) foot is the most basic prosthetic foot available. It is recommended only for those with limited functional ability and potential to ambulate. The SACH foot is provided primarily for transfers and limited ambulation. This foot's immovable ankle and soft heel give it the ability to absorb the impact of heel strike but provides minimal energy return.

Figure 1: K1 foot: the solid-ankle, cushion-heel (SACH) foot.

K2 Feet

Some of the of prosthetic feet used for persons with amputation who are at the K2 functional level are as follows:

- Ossur Flex-Foot K-2 Balance (Figure 2 - A).
- Otto Bock 1M10 Adjust (Figure 2 - B).
- Endolite Navigator.

- Trulife Kinetic.
- Dycor FMA.
- College Park Celsus.

There is an array of different feet suited for persons with amputation at function level K2 who are able to walk inside their homes and outside in the community at a slow pace. Most K2 feet are lightweight, have a flexible keel, a multiaxial ankle, and provide some energy return. A full-length toe mechanism lends stability while providing smooth transitioning from heel strike to toe-off.

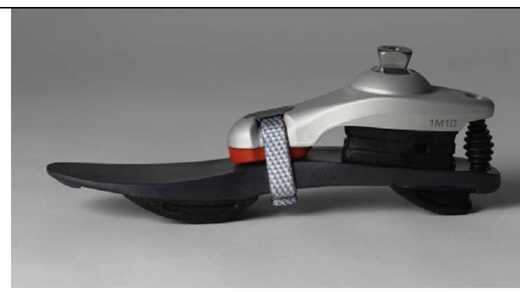


Figure 2: Prosthetic feet for persons with amputations at the K2 functional level. A, Flex-Foot Balance. B, Otto Bock 1M10 Adjust.

K-3 Feet

Functional level K3 feet are appropriate for patients with the ability or potential to do all daily activities and walk with variable cadence. They are fabricated from lightweight flexible carbon fiber, which is very responsive and extremely durable. The integrated pylon foot (Figure 3) is the lightest of all foot prostheses. It is one continuous carbon fiber composite material unit from the toe to the top of the pylon, including a heel segment that allows significant plantarflexion/dorsiflexion.

Figure 3: K3 foot with integrated pylon - Freedom Innovations Silhouette.

K-4 Feet: High Activity

A number of specialized prosthetic feet (Figure 4) are available for the serious athlete and weekend runner. Different configurations are available for sprinting and running. The sprinting foot, with a stiffer, springy character, is designed for powerful bursts of speed. The running foot combines stiffness that is gentler and serves as a distance running foot for marathon or half-marathon challenges. Choice of design depends on the patient's activity and special interest.

Figure 4: Specialized prosthetic feet. A, K3 foot with multiaxial ankle and rotation (College Park Venture, Fraser, MI). B, Swim foot with moveable ankle. C, Adult climbing foot. D, Running feet.

Partial Foot and the Syme Amputation

Partial foot and Syme-level amputations present advantages and challenges to the patient and the rehabilitation team. Preservation of the ankle and heel (in partial foot amputation) and most of the length of the lower limb (in Syme amputation) has an important advantage of distal weight-bearing capability: The individual with partial foot or Syme-level amputation is often able to ambulate without a prosthesis if necessary. The prosthesis, however, provides protection for the vulnerable distal residual limb for patients with vascular compromise and neuropathy.

Prosthetic Management

In recent decades, a wide variety of prosthetic options for individuals with partial foot amputation have emerged. The prescribing physician and patient care team must familiarize themselves with the broad array of options available in prosthetic components and design so that prescription considerations can best accommodate the special needs of each patient.

The length and degree of flexibility of the prosthetic forefoot affect the anterior lever arm and consequently foot and ankle motion. The biomechanical goal is to allow anterior support in the area of the lost metatarsals as well as a controlled fulcrum of forward motion as the foot-ankle complex pivots over the area of the lost metatarsal heads in the third rocker of late stance. An additional goal is to minimize pressure at the amputated distal end within the socket or shoe.

Toe Fillers and Modified Shoes

If a simple filler is prescribed, an extended steel shank or band of rigid spring steel should also be placed within the sole of the shoe, extending from the calcaneus to the metatarsal heads. The challenge that faces the prosthetist is to match the appropriate degree of forefoot flexibility to the needs of each patient. For an energy-efficient and cosmetic gait, relative plantar rigidity should give way to at least 15 degrees of forefoot flexibility distal to the metatarsal heads. The extended steel shank is helpful in providing a limited degree of buoyancy that substitutes for the lost anterior support of the foot. Stiffening the sole with a spring steel shank increases the lever arm support, but often at the expense of additional pressure on the distal end of the residual limb.

Custom Shoe Inserts and Toe Fillers

A custom-molded, flexible, plantar shoe insert is one of the options for individuals with amputation of the hallux or first ray. This orthotic approach is typically used in combination with extra-depth shoes. The goal is to provide a flexible anterior extension to compensate for a missing or shortened first ray to improve the third rocker and yet support and protect the amputation site during the simulated metatarsophalangeal hyperextension in late stance and preswing.

Cosmetic Slipper Designs

The slipper, one variation of which has been referred to as the slipper-type elastomer prosthesis, is fabricated from semiflexible urethane elastomer. These designs may be appropriate for individuals with trans-metatarsal amputations or disarticulations. They are ideal for swimming or water sports because most are water impervious, cosmetic, and capable of providing a flexible whip action, which is useful with swim fins.

Prosthetic Boots

The prosthetic boot, with laced or hook-and-loop material ankle cuff closures, has greater proximal encompassment to reduce distal motion and increase control. This design is appropriate for individuals with a Lisfranc or transmetatarsal disarticulation or amputation.

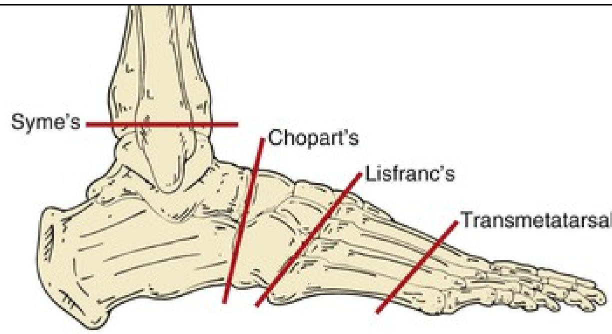


Figure 4: Types of feet amputations.

Ankle-Foot Orthoses

The AFO is another option for persons with partial foot amputation. The polypropylene or copolymer shell supports the plantar aspect of the foot, incorporates the heel, and extends up the posterior leg to the belly of the gastrocnemius. It offers enhanced stability and control because of its high proximal trim line. It has been an excellent solution for many patients with partial foot amputation and may be the prosthesis of choice for the active patient.

SYME AMPUTATION

The Syme amputation is a disarticulation of the talocrural joint. The forefoot is completely removed, but the fat pad of the heel is preserved and anchored to the distal tibia. This allows distal end bearing and some degree of ambulation without a prosthesis.

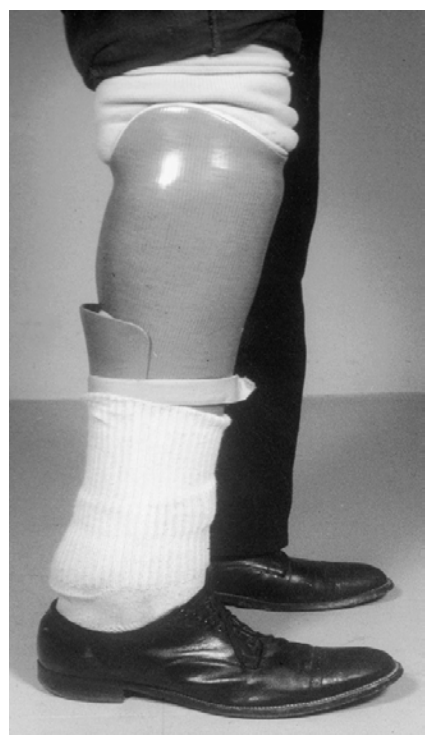
Two possible problems exist in amputations at the Syme level: migration of the distal heel pad and poor cosmetic result. The resurgence of popularity of the Syme amputation today is from an increased awareness of its energy efficiency in gait compared with transtibial levels as well as improved vascular evaluation techniques and medical procedures that increase the likelihood of more distal primary wound healing.

Prosthetic Management

The prosthesis for the Syme amputation must be strong enough at the ankle section to withstand the forces of tension and compression that are produced by the long tibial lever arm throughout the gait cycle and at the same time provide an acceptable degree of cosmesis over the bulbous expansion at the ankle. All prosthetic designs strive to encompass the tibial section above the distal expansion firmly and still permit donning and doffing.

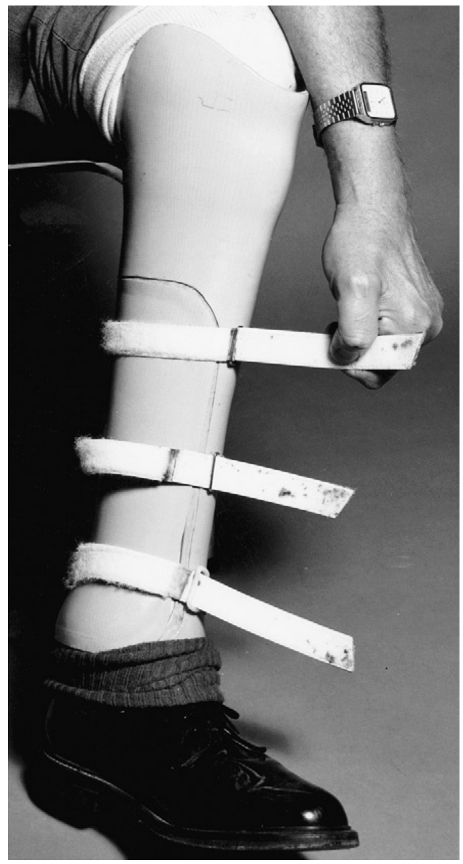
Canadian Syme Prostheses

The Canadian Syme prosthesis design was introduced during the 1950s as the first major improvement over the traditional steel-reinforced leather (Figure 5). When viewing the ankle in the coronal plane, no obvious buildups, windows, or hardware is present to increase the ankle diameter. The Canadian Syme prosthesis has a removable posterior panel to facilitate donning and doffing. This donning window extends from the apex of the distal expansion, moving proximal as far as necessary to provide clearance for the bulbous end.



Breakage may be higher than with other Syme prostheses because the ankle area, which undergoes the most compression and tension during ambulation, is weakened by the window cutout around the ankle in the posterior region.

Medial Opening Syme Prostheses



The medial opening Syme prosthesis, also known as the Veterans Administration Prosthetic Center Syme prosthesis, followed the introduction of the Canadian Syme prosthesis. Developed at the New York City Veterans Administration Medical Center in 1959, it has a removable donning door that extends proximally from the distal expansion to a level approximately two thirds of the height of the tibial section on the medial side (Figure 6). Like the Canadian design, the medial opening prosthesis is relatively cosmetic at the ankle and compares favorably with the Canadian design. The medial placement of the donning panel provides much more opportunity for anteroposterior strengthening of the prosthesis. All other factors being equal, this design is stronger than the Canadian and is the approach of choice for many patients with The Syme amputation.

Sleeve Suspension Syme Prostheses

The sleeve suspension Syme prosthesis is sometimes referred to as the stovepipe Syme prosthesis because of the cylindrical appearance of its removable liner. It is constructed with an inner flexible insert or sleeve that has filler material in the areas just proximal to the distal expansion. The sleeve suspension prosthesis is bulky and not very cosmetic, but its strength is significantly better because no window is present to create a structural weakness. It is often chosen for the obese or very heavy-duty wearer or for the patient with recurring prosthetic breakage with other designs.

Expandable Wall Prostheses

The flexible, expandable wall, and bladder Syme prostheses, of which several varieties are available, vary more by materials used than by mechanism of action. All are based on the concept of an inner socket wall just proximal to the distal expansion that is elastic or expandable enough to allow entry of the limb into the prosthesis and still provide a level of total contact around the ankle once donned. This design normally requires a double prosthetic wall. The Syme residual limb presents greater pressure distribution challenges to a prosthetist than do other types of lower-limb prosthetics.

Tucker-Winnipeg Syme Prostheses

The Tucker-Winnipeg Syme prosthesis, rarely seen in the United States, ignores the traditional requirement of comprehensive total contact by introducing lateral and medial donning slots. A loss of total contact can also affect proprioception and control of the prosthesis. In general, the method permits a prosthesis that is relatively cosmetic, easy to don, and not prone to the noises that are sometimes created by rubbing at the window covers of the medial opening and Canadian Syme prostheses.