LECTURES 15-16: Artificial Limb Replacement for Amputees

In the US, slightly over 0.5% of people are currently living with the loss of a limb, and about 500 amputations are done each day. This percentage is likely to increase because of the aging of the population and the associated increase in the incidence of diabetes mellitus and vascular disease.

15.1 Definition of Prosthesis

The term prosthesis is used in medicine to represent an artificial device that can be used to replace a missing body part. Although an artificial limb is often the first image that comes to mind regarding the term prosthesis, it can refer to the artificial replacement of any part of the body. For example, false teeth are known as dental prostheses and an artificial replacement of the jawbone is called a maxillofacial prosthesis.

Prosthetic limbs are valuable to amputees because they can help a person recover some capabilities that were lost with amputated legs or arms. While prosthetic devices can't match the same functionalities of biological limbs, their capabilities have advanced significantly in recent years. Research advances every day in the field of prosthesis development and technology, and artificial limbs are becoming increasingly much more like real limbs.

15.2 Types of Prosthetics

Prosthetics can be classified into three major categories for the patients: cosmetic prosthesis, body-powered prosthesis, and myoelectric externally powered prosthesis.

15.2.1 Cosmetic prosthetics

Cosmetic prosthetics can be inexpensive, but they offer limited movement and can only grip light objects passively. This type of prosthetic is designed for people who want to use their other limbs for most major functions.

15.2.2 Body-Powered Prosthetics

Body-powered prosthetics allow muscles relative to the area to control the prosthetic with cables. While it does allow a greater degree of freedom and enables patients to feel the force, a body-powered prosthetic can control just one movement at a time and can quickly cause user fatigue.

15.2.3 Myoelectric Prosthetics

The third type of prosthetic, which is a myoelectric externally powered prosthesis, picks up the electrical action potential in the residual muscles in the amputated limb. Upon receiving the action potentials, the prosthetic amplifies the signal using a rechargeable battery and uses the electric signals to power the motors operating the respective part of the arm.

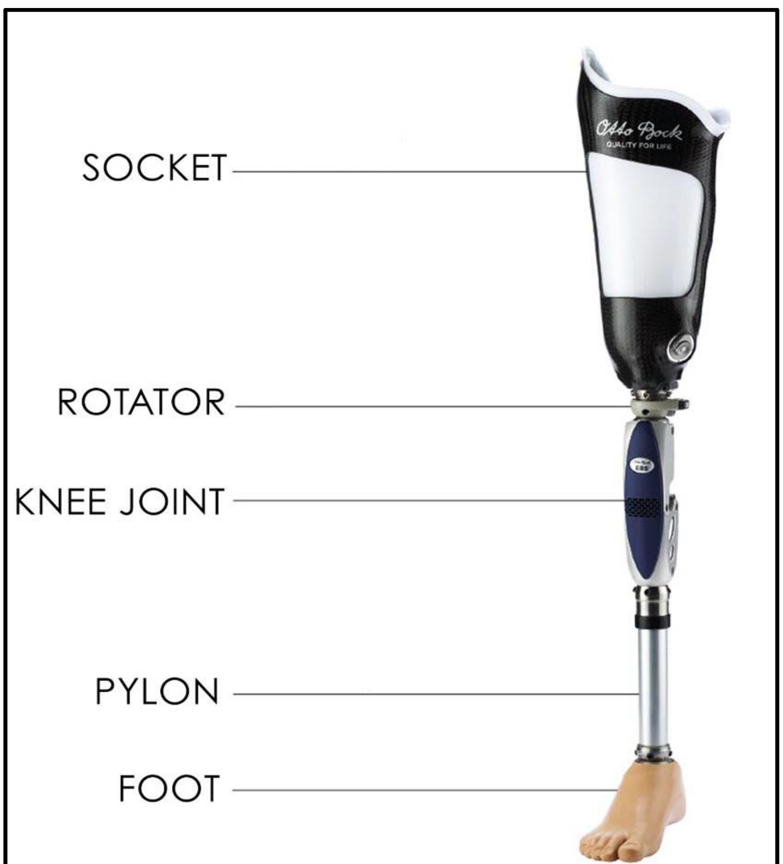
This allows for more freedom and doesn't require a patient to perform frequent, strenuous muscle contractions. However, they are heavier and more expensive than the other two categories. But they are some of the most advanced and effective prosthesis available for upper limbs.

15.3 Basic Prosthetic Limb Parts

Although new materials have replaced the old materials of past centuries, the basic components of prosthetic limbs remain the same.

- First, the skeleton part of the limb, which is the basic internal frame of a prosthetic limb, is known as a pylon. It gives structural support and is made out of metal rods. Lighter carbon fibers are now also used to make the pylon. Usually, the pylon is covered using a foam-like material. This cover is usually shaped and colored to match the skin tone of the person who is going to use the prosthetic limb so that it looks natural.

- The next component of a prosthetic limb is known as a socket, which interfaces with a person's limb stump or residual limb. This part transforms the forces from the artificial limb to the user's body. The socket needs to be placed and fitted perfectly so that no irritation occurs with the skin or any tissues. A soft liner is usually given with the interior of the socket, and the patient usually wears a prosthetic sock to get a better fit.
- The next part of a prosthetic limb is called the suspension system. This part keeps the limb attached to the body of the user. This suspension system can use several mechanisms, namely straps, belts, and sleeves. Often, the suction mechanism is used in the suspension where the limb fits easily with the residual limb using the help of an airtight seal.



- If the amputation were below the knee or above or below a major joint, the requirement of the type of prosthetic would vary dramatically. An amputation above the knee is known as transfemoral amputation, which would require a device with a false knee, while an amputation below the knee, called transtibial amputation, would not need an artificial knee, as the patient could use their knee.

10.4 What Is a Prosthetist?

The responsibility to customize a prosthetic device according to the need of the patient is given to a professional known as a prosthetist. This person is an expert and specializes in the fabrication and installation of prosthetic limbs. This person is usually skilled in engineering along with anatomy and physiology.

The design and fabrication process consists of several stages. The prosthetist can already begin working with the patient before the amputation. He or she can begin taking measurements and start the fabrication process. When the wound of the surgery has healed after several weeks, a plaster mold made from the residual limb is used as a template for making the duplicate limb.

Computerized digital measurements are then taken for perfection in design. More attention is given to the structure of a patient's residual limb along with the location of muscles, tendons, different bones, and the patient's health and skin conditions.

15.5 Physical Therapy and Prosthetic Adjustments

It is extremely important to undergo physical therapy after the installation of a prosthetic device to help the patient get used to using the artificial limb.

The person responsible for this task should give close attention to the interface between the residual limb and prosthetic socket of the patient. The residual limb can shrink after the amputation or due to the lack of use of the muscle. Therefore, a new socket may be required to accommodate the size reduction.

If the patient is a child, the prosthetist must give special attention to and work closely with them to ensure that the limbs are resized and replaced as needed to keep up with the natural growth of the child.

Typically, a patient needs to visit the prosthetist regularly for different reasons like an adjustment, change of shape, or replacement of the prosthetic device. An average prosthetic device has a three-year lifespan according to the National Limb Loss Information Center.

15.6 Artificial Limb Design

The technology involved in prosthetic limb design and development is a dynamic and rapidly changing field of research.

If the prosthetic limb is body-powered then cables connecting them to other parts of the body can control them. An arm can be controlled using a healthy shoulder for instance. The working shoulder can be moved in certain ways to control the prosthetic device.

Motors and servos externally power prosthetic limbs and may be controlled by a patient in different ways. The patient can use a switch to control the prosthetic device by adjusting the switch or button.

Another way that allows a person to control their prosthetic limb is by listening to the muscles remaining in the residual limb that the patient can still contract. Prosthetic limbs that function like this are called myoelectric.

One of the most advanced technologies that are now being used to control prosthetic limbs is something called targeted muscle re-innervation (TMR).

Your brain controls the muscles in your limbs by sending direct electrical signals down your spinal cord and then through your peripheral nerves to your muscles. But for an amputated person, their peripheral nerves would still carry signals generated in the brain, but those signals would stop where the amputation started and wouldn't be able to reach the amputated muscles.

The TMR surgical process redirects these amputated nerves to control a substitute healthy muscle elsewhere in the body. Advancements in brain-computer interfacing will allow these artificial devices too much more effectively simulate the nerves and brain, which may be able to restore a sense of touch and allow patients to feel their artificial limbs. This ability will reduce the gap between the prosthetic limbs and the normal limbs they're replacing.

15.7 Fitting Your Prosthesis

Fitting the prosthesis can involve two major phases: the temporary or preparatory prosthesis and the final prosthesis. The longer phase is the first one, which we discussed earlier involving physical therapy and fitting the temporary socket.

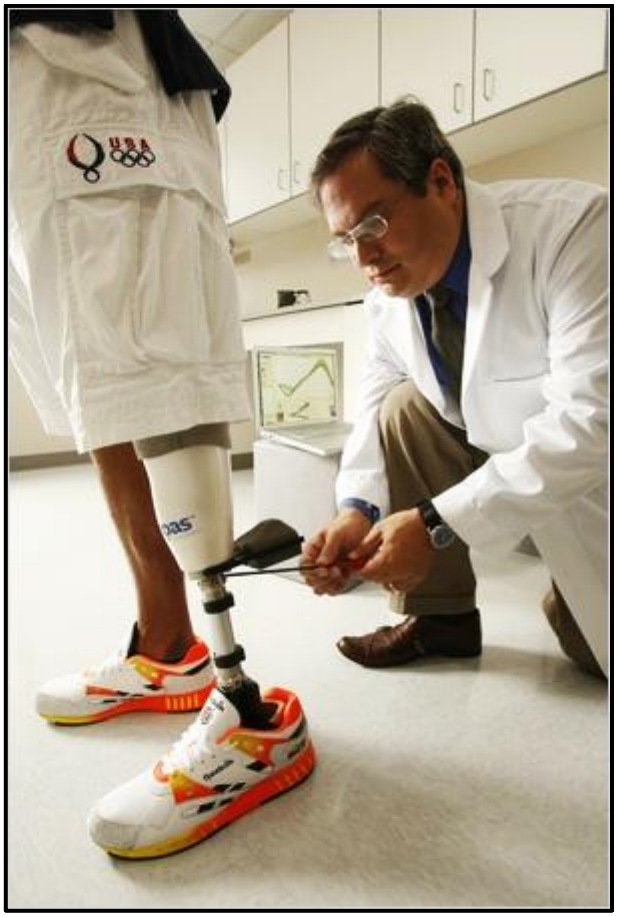
In the final prosthesis-fitting phase, the prosthetist decides when the right time comes for the final prosthesis.

Follow-up visits to a prosthetist can be a normal part of your new life. A change in a residual limb, like shrinkage or swelling, or an even significant change in your body weight, may require a follow-up visit with the prosthetist to adjust the fit of the socket.

Small adjustments can make a big difference. Proper fit and alignment will go a long way to be sure that your prosthesis always works correctly.

The design of a prosthesis typically starts with the consideration of how well it will fit. People with different needs may require an advanced socket and total contact fit of gel liner. Factors like cost, ease of use, different available sizes and cosmetics are also considered in the design.

Also, issues like the weight of the device, rotation of the device in different directions, energy absorption due to the impact on the musculoskeletal system, etc. is also considered when manufacturing a high-performance prosthesis design.



The goals of prosthesis fitting include comfort, stability while standing and walking, and enabling performance of various daily activities. Recent advances in cushioning materials, prosthetic socket design, and foot, ankle, knee, hand, wrist, and elbow component technology have significantly improved comfort and function.

Successful prosthesis use depends on the following:

- Patient's underlying medical conditions and physical and cognitive capabilities
- Anatomy (eg, length and condition of the amputation stump)
- Fit of the prosthesis socket (eg, comfort and stability)
- Function and biomechanical efficiency of the components of the prosthesis

15.8 Amputation rehabilitation team

Early rehabilitation facilitates recovery and future success in using a prosthesis. When possible, rehabilitation begins before the amputation and as early as the first postoperative day.

Success is most likely when an interdisciplinary clinical team works with the patient. The composition of the team varies depending on the patient's needs. At a minimum, core members include the surgeon, prosthetist, and therapist. Prosthetists evaluate the patient and design, fit, fabricate, and provide lifetime follow-up care to maintain the prosthesis and provide advice and instruction on care. For more complex cases, the team could also include a physiatrist, physical therapist, occupational therapist, social worker, psychologist, and family members.

15.9 Interface between the residual limb and prosthesis

The prosthesis attaches to the body by direct skin contact or by an interface made of various thin viscoelastic cushion materials worn over the residual limb.

- A **gel cushion interface** is worn over the residual limb (stump) to provide skin protection and modulate and more evenly distribute pressure. Custom molded interfaces may be necessary to accommodate irregular stump contours (eg, deep scars, sharp bones, burns). Interfaces are typically recommended to be replaced every 6 months and, for very active patients, every 4 months.

- A **prosthetic sock** may be worn instead of or with a gel interface. Socks are made of wool, nylon, or synthetic fabrics, sometimes with gel sandwiched between the layers of fabric. Socks are available in different thicknesses (plies). Prosthetic socks are used to manage volume changes during the day as a result of muscle atrophy, weather, or activities.
- An **integrated suspension system**, which may be part of the cushion interface, is used to help hold the prosthesis on securely. The following suspension systems are commonly used:
  - **Vacuum:** An electric or mechanical vacuum pump removes air from the socket. This is the most effective method for holding a prosthesis to the residual limb and also provides greater fluid volume stabilization in the residual limb.
  - **Suction:** When the residual limb is put in the socket, the air is forced out through a one-way expulsion valve at the bottom of the socket, which results in suction that holds the prosthesis in place.
  - **Interface with a locking pin:** A cushion interface with an integrated suspension pin at the bottom is inserted into a locking mechanism embedded in the bottom of the plastic socket. A release button disengages the pin to remove the prosthesis.
  - **Belts and straps:** Sometimes the prosthesis is attached by a belt and/or straps if keeping the prosthesis on with vacuum, suction, or pin is difficult or cannot be tolerated.

15.10 General types of upper extremity prosthesis

There are 5 general types of upper extremity prosthesis:

- **Passive prostheses** assist in balance, stabilization of objects. They look like a natural limb, are the lightest and cheapest, but they provide no active hand prehension.
- **Body-powered prostheses** are the most often prescribed because they tend to be less expensive, more durable, and require less maintenance. A harness-cable system suspends the prosthesis and captures scapular and humeral motion to operate the hook, hand, or elbow joint. People involved in physical labor typically favor this type.
- **Externally powered myoelectric prostheses** provide active hand and joint movement without the need of scapular, humeral, or trunk motion. Sensors and other inputs detect muscle movement of the residual limb or upper body and control-powered actuators provide greater grasp force than body-powered prostheses.
- **Hybrid prostheses** are typically prescribed for higher-level upper-limb amputations. They combine specific features of body power and myoelectric power, for example, a body-powered elbow might be combined with an externally powered hand or terminal device.
- **Activity-specific prostheses** are designed to allow participation in activities that would otherwise damage the patient's residual limb or everyday prosthesis, or when the everyday prosthesis would not function effectively. These prostheses often include a specialty design interface, socket, suspension system, and terminal device. Activity-specific terminal devices can allow the patient to grasp a hammer and other tools, a golf club, or baseball bat, or hold a baseball glove. Others aid in various specific activities (eg, swimming, fishing). These devices can be passive or controlled by the amputee.

15.11 Preparing for a Limb Prosthesis

When amputation is elective, certain preparatory measures can help optimize recovery. It is important to educate the patient and family members as early as possible regarding the necessity of amputation and to review the entire process from preoperative preparation to prosthetic fitting and living with a prosthesis. Such education helps increase the patient's commitment to the process, which is essential to a successful outcome and also maximizes family support. Meeting with a peer counselor who has had an amputation can be helpful for the patient.

Preoperative management includes

- Functional assessment
- Planning
- Exercise program

A functional assessment evaluates patients' current capabilities along with their goals. Using the functional assessment, the surgeon, prosthetist, and physical therapist formulate a preoperative and postoperative plan.

Postoperative management goals are to

- Protect the residual limb from accidental trauma (eg, bumping, falls)
- Control edema
- Promote healing
- Maintain strength, cardiovascular endurance, and joint range of motion

A physical therapist will work with the patient before and after hospital discharge as needed based on the patient's abilities and specific amputation. Training may include standing balance, walking in parallel bars, use of a walker, crutches, and/or wheelchair, and self-care skills including transfers and personal hygiene.

The prosthetist will see the patient weekly to monitor progress and residual-limb readiness for fitting a preparatory prosthesis, which is done when the residual-limb fluid volume is reasonably stable.

15.12 Preparatory prosthesis

When the residual limb has healed and fluid volume has reached an initial level of stability—usually 6 to 10 weeks postoperatively, but longer if there are complications—a preparatory prosthesis can be fitted. A preparatory prosthesis is a temporary prosthesis that allows progressive weight-bearing and switching of components to match patients' changing functional requirements as they become accustomed to walking and doing other activities. The socket of the preparatory prosthesis may need to be refit several times during this period.

In addition to improving mobility and independence, advantages of early prosthesis fitting include achieving better acceptance of the amputation, restoring body image, reducing phantom pain, increasing proprioception and phantom sensation, and hastening maturation of the residual limb.

The residual limb of adults continues to undergo considerable volume and shape change for 12 to 18 months after amputation. At this time the preparatory prosthesis can be exchanged for a permanent or definitive prosthesis, which often uses the same joint and appendage components that were identified as optimal during the preparatory phase.

15.13 Learning to use a limb prosthesis

The patient initially learns how to function with a prosthesis during the fitting process. The process involves several appointments to achieve acceptable levels of comfort and stability.

For patients with an upper extremity prosthesis, once comfort and stability are achieved, the prosthetist works to provide maximum functional capacity with appropriate spatial positioning of joints and appendages. An occupational therapist then works with the patient to optimize function for the patient's specific daily activities.

For patients with a lower extremity prosthesis, once residual limb comfort and stability are achieved, a prosthetic hip, knee, ankle, and/or foot is introduced to achieve balance and posture. The patient initially begins ambulation within parallel bars. The prosthetist ensures that sufficient biomechanical efficiency is achieved before the patient is seen by the physical therapist for gait training.

As the patient learns to ambulate effectively, the prosthetist will modify the socket to compensate for morphologic changes in tissues and in the biomechanical alignment of joints and appendages. In addition, as the patient acclimates and can ambulate more aggressively, the prosthetic hip, knee, ankle, and/or foot may require changes to provide optimal, efficient ambulation and function.

Counseling or psychotherapy may help when patients have prolonged difficulty adjusting to the loss of their limb and to prosthetic use.

15.14 Fitting the Prosthesis

There are many options for limb prostheses, but after a functional evaluation results in a treatment plan, the fitting process typically follows the same steps regardless of which limb prosthesis is chosen.

A prosthesis has 7 basic component parts:

- Residual-limb gel cushion interface: A silicone gel or viscoelastic material that protects the skin and modulates pressure
- Suspension system: Connects the prosthesis to the body
- Socket: Rigid plastic receptacle into which the residual limb with gel interface is inserted (there may be an inner primary flexible socket that helps modulate forces)
- Joints (ankle, knee, wrist, elbow) and terminal appendage (hand, foot)
- Modular endoskeleton system connection couplings: Connect prosthetic joints and terminal appendages and provide adjustability

- Anatomic shape: Soft foam material that simulates muscle contours and protects endoskeleton components
- Synthetic skin: Thin, tone-matching layer applied over the anatomic shape

During the fitting process, an impression of the residual limb is made either by hand-applied plaster bandages or digital imaging.

15.15 Skin Care of the Residual Limb

Skin that comes in contact with the socket of the prosthesis must be cared for and monitored meticulously to prevent skin breakdown and skin infection. Pain is the first indication of a problem, and the patient should remove the prosthesis and inspect residual-limb skin when an unpleasant sensation is initially felt.

Skin problems can be serious and should be evaluated and treated as necessary by the patient's health care practitioner in consultation with the prosthetist. As patients become familiar with recurrent problems, they may be able to identify which problems are minor and manage them on their own. However, anything unusual, persistent, painful, or worrisome should be evaluated by the practitioner.

15.16 Risk factors for skin problems

Disorders that decrease circulation to the lower extremities (eg, peripheral vascular disease, diabetes) and put patients at risk of amputation also increase the risk of skin breakdown and infection after amputation.

Disorders that impair sensation (eg, diabetic neuropathy, other neurologic disorders) can delay diagnosis by preventing patients from feeling discomfort or pain from skin breakdown or infection. Patients with a sensory disorder should remove their prosthesis several times a day to check the skin for redness and other signs of breakdown or infection. Other patients should check for these signs at least once daily.

Skin problems and difficulty fitting the prosthesis are more likely when the residual limb has certain features, including excessive distal tissue beyond bone termination, loose skin, thick scars, skin and tissue invaginations, skin and tissue adherences, and terminal bone exostoses. These outcomes should be avoided as much as possible during surgery, although this is not always possible in traumatic cases.

If the prosthetic socket fits optimally, skin problems are minimal. But even with good fit, normal morphologic changes such as muscle atrophy and fluid volume fluctuation can alter the stump-to-socket relationship and increase risk of problems. Proximal constriction of the socket leads to vascular and/or lymphatic congestion and distal edema, with increased pressure over the distal residual limb.

15.17 Loosening of the Prosthesis

The prosthesis socket may become loose because of

- Morphologic changes in the residual limb (eg, atrophy, fluid volume change)
- Mechanical problems with the prosthesis

Mechanical problems may be due to a loss of suspension or connection to the residual limb or body. A suction valve or vacuum pump may be malfunctioning. The suction or vacuum sealing sleeve may have developed a hole allowing air to enter and the prosthesis to slip off slightly. In upper limb cases, a harness or strap may have stretched or torn.

Patients typically have instructions from their prosthetist on how to troubleshoot problems with their specific prosthesis. If these steps do not remedy the problem, patients should see their prosthetist to assess and correct the problem and thus prevent injury to skin or loss of stability and falling.