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Introduction to Prosthetic Limbs

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Many people incur an illness or experience an accident that results in the loss of a limb. They may also have been born with a congenital condition in which one or more of their limbs are missing. Fortunately, there are artificial limbs that enable those people to still do things such as run, walk, reach, and grip. These apparatuses are known as prosthetics.

Causes of Amputation

There are many reasons why a person may lose a limb. In the United States, the most common cause of amputation is diabetes. Additionally, every year, at least 15,000 people lose feet or legs due to land mines in past war zones. The wars in Iraq and Afghanistan also contribute the vast amount of people who have lost limbs; soldiers, as well as civilians, have lost legs and feet due to the war. Finally, congenital conditions, diseases, industrial accidents, and car accidents are among the other causes of lost limbs.

History and Development of Prostheses

The first written record of an artificial leg was made by the Greek historian Herodotus; this record was a documented story of a prisoner who escaped by amputating his foot. The prisoner found and used a wooden limb to assist him in walking. In a later discovery, researchers found a prosthetic device in Egypt which was used to replace a big toe; this prosthesis was made out of leather and carved wood. Researchers believe that it is approximately 3000 years old. An artificial leg, made of wood and copper, was found in Italy in 1858, and it is believed to be from around 300 B.C. (Bryant, 2014).

In the primitive era of prosthetic limbs, wooden or iron rods were attached to the stump of the leg. Straps were usually used to keep the rod in place. During the Middle Ages, peg legs and hook arms were available for amputees to use. During the age of the Renaissance, prosthetic device construction improved, and prostheses were beginning to be made out of materials such as iron, copper, steel, and wood (Demello, 2009). Ambroise Paré, a surgeon who lived in France during the sixteenth century, was dedicated to treating injured soldiers who had lost limbs in battle (Bryant, 2014). Paré also created new methods of amputation. Instead of cauterizing arteries, which was the common practice at the time, he suggested tying off the arteries. Additionally, he developed the first mechanical hand, as well as the first artificial leg with locking knees. At this time in history, materials such as leather were being used in the construction of prosthetic limbs in order to make them lighter. During the seventeenth century, a Dutch surgeon by the name of Pieter Verduyn invented the first non-locking, below-knee prosthesis (DeMello, 2009).

Prosthetic limbs have greatly improved since the time of Paré and Verduyn. In 1800 a man named James Potts constructed an artificial leg that was made out of wood and included artificial tendons that were made from cat guts. This prosthesis and its artificial tendons permitted movement of the foot. In 1812, an artificial arm, which was attached to the opposite shoulder by means of straps, allowed the wearer to move the artificial appendage with his shoulder movements (Demello, 2009). In 1863, the rubber hand was invented; it was significantly more realistic than the models preceding it (Bryant, 2014). Prosthetic limb technology improved during the Civil War because of the number of soldiers who had lost appendages. The creation of anesthesia in the 1840s allowed for amputation surgeries to last longer. This increased the rate of survival for patients. Also during this decade, James Syme created a method for amputation. Instead of amputating at the thigh, amputation was done at the ankle, thereby allowing more people to keep their legs. In 1898, an artificial arm was created by an Italian named Vanghetti. This arm could be controlled via movements of the muscles

(DeMello, 2009). Once again, prosthetic technology began to increase after World War I and World War II due to the increase in amputees. A special sock, which improved comfort and stability, was invented for above-knee prosthesis. In the years that followed, better materials were made to construct prosthetics. Carbon fiber was a stronger and more lightweight material. Also, silicone was used to produce realistic-looking skin (Bryant, 2014).

The first hook that could open and close and that was operated by flexing muscles in the opposite shoulder was invented in 1909 by D. W. Dorrance. After World War II, the Artificial Limb Program began to do research regarding prosthetic limbs and to develop prostheses. The Veterans Administration offered grants to private corporations to make new prostheses. As a result, the older wooden and leather models were replaced by new prostheses. New methods for attachment and fitting were also developed (DeMello, 2009).

Materials for Prostheses

In the 1900s, prostheses started to look and feel more realistic because they were beginning to be made from materials such as plastic, silicone, and PVC. This allowed them to be stronger and lighter. Today, most prostheses are made out of plastic that encases the interior structure, and they are attached by straps and sock. This sock cushions and protects the stump. If the socket is not fixed by straps, it is fixed via suction to the stump. Most prosthetic feet are made with wood; however, they now consist of also foam and plastic (DeMello, 2009).

The most commonly used materials in current prosthetic devices are leather, metal, wood, thermoplastic and thermosetting materials, foamed plastics, and viscoelastic polymers. Five characteristics are considered when deciding what materials to use to construct a prosthesis: strength, stiffness, durability, density, and corrosion resistance. Strength, which is determined by the amount of weight that the material can withstand, is important in lower appendage prostheses. Stiffness is the amount of bending that is allowed when the material is loaded. For example, a stiffer material is desired for a rigid prosthetic frame, but a more flexible material is desired for a flexible transfemoral prosthetic socket. Durability, or fatigue resistance, is determined by its ability to withstand repeated loading and unloading. Density, the weight per unit of volume, is important because it is a determinant of energy cost while a person is wearing the prosthesis. If a material is susceptible to corrosion, it is vulnerable to be damaged by chemicals. Prosthetic limbs are often made from materials that preserve heat, thereby creating the problem of perspiration. This is why it is better to make prostheses out of materials which are resistant to moisture; prostheses that are made of materials that are resistant to moisture are more readily cleaned than porous substances (Lusardi, et al., 2013).

Further Developments

Although it was not available for public use until the 1960s, the first biomechanical prosthesis, which used myoelectricity, was created in the 1940s. The product continued to be tested and perfected before being sold. Prostheses such as these are connected to the body in a manner that permits electrical impulses to go from the muscles into the prosthesis, causing movement in the prosthesis. Additionally, the nerves in the appendage are surgically adapted to direct movement in a muscle that has been attached with biosensors. Biosensors sense movement that occurs in a muscle and convey it to a controller that is located in the prosthesis. A flexed muscle, therefore, causes the prosthetic to move (DeMello, 2009).

There is now a new way to attach prostheses to the body; a titanium bolt is screwed into the bone of the stump. The bolt gets attached to an abutment, or support, that is then attached to the prosthesis. This method reduces pain for the patient since it reduces the pressure on the stump; following this practice also permits greater control of the prosthesis by muscles. Once a doctor prescribes a prosthesis to a patient, a prosthetist then custom-fits an artificial limb for the patient. It is much more difficult for people who have lost their leg above the knee to walk and do other activities, as opposed to those who have only lost a foot or the lower leg (Demello, 2009). Therefore, physical therapy is then necessary for the patient to be taught how to utilize the prosthetic limb. It usually takes a numbers of weeks for a patient to acquire the skills needed to walk, drive, and do other daily activities (DeMello, 2009).

Athletes who are missing legs now have access to special apparatuses that can help them run. Known as Cheetah blades, these devices are made out of carbon fiber and formed like sickles. They do not imitate the look or feel or real lower limbs; rather, they are made to permit running. Much controversy has risen over this technology as to whether or not it gives disabled athletes an advantage over other “normal” athletes. They are also unaffordable for many people (DeMello, 2009).

Types of Prostheses

A transtibial prosthesis replaces the lower leg and foot; a transfemoral prosthesis replaces the entire leg and foot. A transradial prosthesis replaces a missing lower arm and hand; a transhumeral prosthesis replaces the entire arm and hand. There are specific needs that lower limb and upper limb prostheses need to meet. Although prosthetic legs and feet may be less complicated since they do not need to grip and handle objects such as upper limb prostheses, they do, however, need to sustain the weight of the body and provide for locomotion (Demello, 2009).

There are four basic levels of prosthetic feet: K1, K2, K3, and K4. Persons at the K1 level possess limited functionality; they have the potential to use a prosthesis on level surfaces.

Persons at the K2 level have the capacity to walk around at home and in the community at a slow speed. If a patient is able to participate in all daily activities and to walk at a varying tempo, they are classified with K3 feet. K4 feet are for serious athletes and weekend runners (Lusardi, et al., 2013).

Transtibial prostheses are composed of a socket design, shin-socket interface, suspension strategy, and additional modular components, such as, feet, shock absorbers, torque absorbers, and dynamic pylons. Patellar tendon-bearing socket and total surface-bearing socket are two socket designs. Hard sockets, socks and sheaths, soft inserts, flexible inner sockets, expandable wall sockets, and gel liners are interface materials. Waist belts, joints and corsets, cuff straps, supracondylar suspensions, supracondylar/suprapatellar sockets, sleeves, suction, locking liners, semirigid locking liners, and elevated vacuum are suspension techniques (Lusardi, et al., 2013).

There are four main socket designs for transfemoral prostheses: quadrilateral, ischial-ramal containment (IRC), Marlo Anatomical Socket (MAS), and subischial (elevated vacuum) socket. There are also many transfemoral suspension systems: traditional pull-in suction suspension, roll-on suspension liners, shuttle lock systems, lanyard system, cushion liner with air expulsion valve, elevated vacuum, Silesian belt suspension, total elastic suspension belt, and pelvic belt and hip joint. There is also a variety of prosthetic knee units: single-axis, polycentric, manual locking, hydraulic, and pneumatic knee units (Lusardi, et al., 2013).

Lusardi, Jorge, and Nielson explain the wonder of microprocessor technology for knee units:

> Microprocessor knees are typically equipped with sensors that monitor the knee position during swing; they are also equipped with pressure sensors detecting and evaluating ground related forces during stance. Sensor technology is capable of measuring angels,

> moments, and pressures at the rate of 50 times per second. Customized adjustments are commonly made to microprocessor knees using a laptop or handheld computer. Unique software algorithms determine the phase of gait, then immediately adjust the knee functions to compensate during both the stance and swing phases of gait. Most knee mechanisms provide a stumble recovery feature that limits unintentional bending of the knee that sometimes occurs when walking on uneven terrain. (2013, p. 665)

Conventional (body-powered) systems consist of any prosthesis that uses a control cable system to translate volitional muscle force and shoulder or arm movement in order to operate a prosthetic elbow (Lusardi, et al., 2013, p. 800). Externally powered systems consist of an electric power cell that provides electrical current to prosthetic components (Lusardi, et al., 2013, p. 805). Hybrid prostheses that combine conventional and externally powered systems may be the best solution for some individuals (Lusardi, et al., 2013, p. 809).

Prosthetic Limb Construction

> The process of construction a prosthesis consists of six steps:
>
> 1) Taking accurate measurements of the limb
>
> 2) Making a negative impression (cast)
>
> 3) Creating a three-dimensional positive model of the limb or body segment
>
> 4) Modifying the positive model to incorporate the desired controls
>
> 5) Fabricating the prosthetic socket around the positive model
>
> 6) Fitting of the device to the patient. (Lusardi, el al., 2013, p. 152)

It is important that a prosthetis be properly constructed, for the following factors affect energy expenditure: 1) weight of the prosthesis, 2) quality of the socket fit, 3) accuracy of alignment of the prosthesis, and 4) functional characteristics of the prosthetic components (Lusardi, el al., 2013, p. 653).

Rehabilitation

The level of rehabilitation success after amputation is influenced by factors such as age, health, cognitive status, sequence of the onset of the disability, concurrent diseases, and the level of the amputation. The preprosthetic phase consists of managing the part of the limb that remains, and this includes tasks such as caring for the wound, controlling edema, shaping, desensitizing, and increasing joint and muscle flexibility. Besides strengthening the extremities for use of the prosthesis, it is also extremely important to strengthen the trunk, or core. Physical therapists are responsible for deciding whether a patient is ready for prosthetic fitting, coordinating prosthetic training, and consulting with prosthetists if issues with alignment result (Lusardi, et al., 2013).

When a person undergoes an amputation, many people are included in the rehabilitation process. Individuals that are part of this health care team involve people such as physicians, nurses, prosthetists, orthotists, physical therapists, occupational therapists, dietitians, vocational rehabilitation counselors, and caregivers. One of the main topics that this team should be concerned with is patient education. By providing information about the health condition, treatment, management, and prognosis, the patient can become an active participant in the rehabilitation process, rather than passively receiving care (Lusardi, Jorge, & Neilsen, 2013).

Conclusion

Every year, prosthetic technology improves. For example, next generation prosthetic knees feature motors which dynamically raise and excite the patient’s muscles in order to participate in activities such as walking up stairs and ramps. “Artificial intelligence” qualities allow systems to predict and direct movement (Lusardi, et al., 2013). Researchers are also working on prosthetic limbs that can be operated by the brain.

Although it is a difficult and long process to recover from losing a limb, with advances in technology and improving physical therapy methods, individuals are now able to once again participate more fully in the everyday activities of life.

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