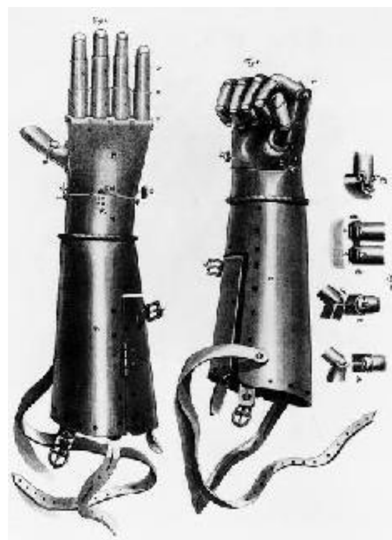
Artificial Limbs

An artificial limb is a type of **prosthesis**, an artificial substitute, that replaces a missing extremity such as arms or legs. The type of artificial limb used is determined largely by the extent of an amputation or loss and location of the missing extremity. Artificial limbs may be needed for a variety of reasons, including disease, accidents, and congenital defects. A congenital defect can create the need for an artificial limb when a person is born with a missing or damaged limb. Industrial, vehicular, and war related accidents are the leading cause of amputations in developing areas, such as large portions of Africa. In more developed areas, such as North America and Europe, disease is the leading cause of amputations. Cancer, infection and circulatory disease are the leading diseases that may lead to amputation.

History

The first specimen discovered archaeologically, known as the **Roman Capua Leg**, was found in a tomb in Capua, Italy, dating to 300 BC, and was made of copper and wood. Two artificial toes found on Egyptian mummies are even older, dating to 1295–664 BC; these are being tested (as of July 2007) to determine whether they could have been used in life. Armorers in the 15th and 16th centuries made artificial limbs out of iron for soldiers who lost limbs. Over the next several centuries, craftsmen began to develop artificial limbs from wood instead of metal because of the lighter weight of the material.



The iron prosthetic hand worn by Götz von Berlichingen from 1508

In the 19th century, limbs became more widespread due to the large number of amputees from wars such as the Napoleonic Wars in Europe and the American Civil War. An artificial leg designed by London's James Potts in 1800 and patented in 1805 became known as the **Anglesey Leg**. The prosthetic was named after the Marquess of Anglesey who had lost his leg at Waterloo. James Potts fitted his prosthetic leg consisting of a wooden shaft and socket, steel knee joint, and an articulated foot with artificial cords or catgut tendons that connected knee flexion with foot flexion. The Anglesey Leg technology was brought to the United States in 1839 and became known as the American Leg. During the American Civil War, a Confederate soldier, J.E. Hanger, who had himself suffered the war's first amputation founded what was for a time the world's largest artificial limb factory.

Wooden leg of Gen. Józef Sowiński; from early 19th century

In England, Marcel Desoutter who was fitted with a wooden leg after an aviation accident, and his brother Charles, designed the first light metal limb to be manufactured. Their jointed Duralumin alloy leg was half the weight of the standard wooden leg. Developments included a frictional knee control, which allowed the wearer to control the speed and length of step, and the Desoutter cushion-joint foot, which imitated the natural action of the human foot. Desoutter Brothers, manufacturers of artificial limbs, was established in 1914 in London.

Technology improved primarily for two reasons: the availability of government funding and the discovery of anesthetics. After World War II, the **Artificial Limb Program** was started in 1945 by the National Academy of Sciences. This program helped improve artificial limbs by promoting and coordinating scientific research on prosthetic devices.

In recent years, a great deal of emphasis has been placed on developing artificial limbs that look and move more like actual human limbs. Advances in biomechanical understanding, through the combined work of doctors and engineers, the development of new plastics, and the use of computer aided design and computer aided manufacturing have all contributed in the development of more realistic artificial limbs.

Types

There are four main types of artificial limbs. These include the transtibial, transfemoral, transradial, and transhumeral prostheses. The type of prosthesis depends on what part of the limb is missing.

- A **transtibial prosthesis** is an artificial limb that replaces a leg missing below the knee. Transtibial amputees are usually able to regain normal movement more readily than someone with a transfemoral amputation, due in large part to retaining the knee, which allows for easier movement.

- A **transfemoral prosthesis** is an artificial limb that replaces a leg missing above the knee. Transfemoral amputees can have a very difficult time regaining normal movement. In general, a transfemoral amputee must use approximately 80% more energy to walk than a person with two whole legs. This is due to the complexities in movement associated with the knee. In newer and more improved designs, after employing hydraulics, carbon fibre, mechanical linkages, motors, computer microprocessors, and innovative combinations of these technologies to give more control to the user.

- A **transradial prosthesis** is an artificial limb that replaces an arm missing below the elbow. Two main types of prosthetics are available. Cable operated limbs work by attaching a harness and cable around the opposite shoulder of the damaged arm. The other form of prosthetics available are myoelectric arms. These work by sensing,

A US soldier demonstrates table football with two transradial prosthetic limbs.

via electrodes, when the muscles in the upper arm moves, causing an artificial hand to open or close.

- A **transhumeral prosthesis** is an artificial limb that replaces an arm missing above the elbow. Transhumeral amputees experience some of the same problems as transfemoral amputees, due to the similar complexities associated with the movement of the elbow. This makes mimicking the correct motion with an artificial limb very difficult.

Current Technology/Manufacturing

In recent years there have been significant advancements in artificial limbs. New plastics and other materials, such as carbon fiber, have allowed artificial limbs to be stronger and lighter, limiting the amount of extra energy necessary to operate the limb. This is especially important for transfemoral amputees. Additional materials have allowed artificial limbs to look much more realistic, which is important to transradial and transhumeral amputees because they are more likely to have the artificial limb exposed.

In addition to new materials, the use of electronics has become very common in artificial limbs. Myoelectric limbs, which control the limbs by converting muscle movements to electrical signals, have become much more common than cable operated limbs. Myoelectric limbs allow the amputees to more directly control the artificial limb. Computers are also used extensively in the manufacturing of limbs. Computer Aided Design and Computer Aided Manufacturing are often used to assist in the design and manufacture of artificial limbs.

Most modern artificial limbs are attached to the stump of the amputee by belts and cuffs or by suction. The stump usually fits into a socket on the prosthetic. The socket is custom made to create a better fit between the leg and the artificial limb, which helps reduce wear on the stump. The custom socket is created by taking a plaster cast of the stump and then making a mold from the plaster cast. Newer methods include laser guided measuring which can be input directly to a computer allowing for a more sophisticated design.

One of the biggest problems with the stump and socket attachment is that there is a large amount of rubbing between the stump and socket. This can be painful and can cause breakdown of tissue.

Artificial limbs are typically manufactured using the following steps:

1. Measurement of the stump
2. Measurement of the body to determine the size required for the artificial limb
3. Creation of a model of the stump
4. Formation of thermoplastic sheet around the model of the stump – This is then used to test the fit of the prosthetic
5. Formation of permanent socket
6. Formation of plastic parts of the artificial limb – Different methods are used, including vacuum forming and injection molding
7. Creation of metal parts of the artificial limb using die casting

8. Assembly of entire limb

Emerging Technology

There are several areas of technology that have advanced significantly in recent years and are showing considerable potential. Robotic limbs and direct bone attachment are two new technologies that have made tremendous gains recently.

Robotic Limbs

Advancements in the processors used in myoelectric arms has allowed for artificial limbs to make gains in fine tuned control of the prosthetic. The **Boston Digital Arm** is a recent artificial limb that has taken advantage of these more advanced processors. The arm allows movement in five axes and allows the arm to be programmed for a more customized feel.

Recently the **i-Limb** hand, invented in Edinburgh, Scotland, by David Gow has become the first commercially available hand prosthesis with five individually powered digits. The hand also possesses a manually rotatable thumb which is operated passively by the user and allows the hand to grip in precision, power and key grip modes. Raymond Edwards, Limbless Association Acting CEO, is the first amputee to be fitted with the i-LIMB by the National Health Service in the UK. The hand, manufactured by "Touch Bionics" of Scotland (a Livingston company), went on sale on 18 July 2007 in Britain for £8,500 (U.S. $17,454). It was named alongside the Super Hadron Collider in Time magazine's top 50 innovations.

Targeted muscle reinnervation (TMR) is a technique in which motor nerves which previously controlled muscles on an amputated limb are surgically rerouted such that they reinnervate a small region of a large, intact muscle, such as the pectoralis major. As a result, when a patient thinks about moving the thumb of his missing hand, a small area of muscle on his chest will contract instead. By placing sensors over the reinervated muscle, these contractions can be made to control movement of an appropriate part of the robotic prosthesis.

Photo from www.geekzor.net

An emerging variant of this technique is called targeted sensory reinnervation (TSR). This procedure is similar to TMR, except that sensory nerves are surgically rerouted to skin on the chest, rather than motor nerves rerouted to muscle. The patient then feels any sensory stimulus on that area of the chest, such as pressure or temperature, as if it were occurring on the area of the amputated limb which the nerve originally innervated. In the future, artificial limbs could be built with sensors on fingertips or other important areas. When a stimulus, such as pressure or temperature, activated these sensors, an electrical signal would be sent to an actuator, which would produce a similar stimulus on the "rewired" area of chest skin. The user would then feel that stimulus as if it were occurring on an appropriate part of the artificial limb.

Recently, robotic limbs have improved in their ability to take signals from the human brain and translate those signals into motion in the artificial limb. DARPA, the Pentagon's research division, is working to make even more advancements in this area. Their desire is to create an artificial limb that ties directly into the nervous system.

Direct Bone Attachment

Direct bone attachment is a new method of attaching the artificial limb to the body. The stump and socket method can cause significant pain in the amputee, which is why the direct bone attachment has been explored extensively. The method works by inserting a titanium bolt into the bone at the end of the stump. After several months the bone attaches itself to the titanium bolt and an abutment is attached to the titanium bolt. The abutment extends out of the stump and the artificial limb is then attached to the abutment. Some of the benefits of this method include:

- Better muscle control of the prosthetic.
- The ability to wear the prosthetic for an extended period of time; with the stump and socket method this is not possible.
- The ability for transfemoral amputees to drive a car.

The main disadvantage of this method is that amputees with the direct bone attachment cannot have large impacts on the limb, such as those experienced during jogging, because of the potential for the bone to break.