

Prosthetics in Developing Countries

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ABSTRACT

Throughout the world, the major objective of prosthetics is to restore, as close as possible, the functional capacity formerly held by a limb deficient person, while attaining the best cosmetic result afforded to, and deemed necessary by the patient. On the surface, it would appear that there would be very little difference in the design and manufacture of prosthetic solutions with respect to the approaches taken by Western and third world countries. However, availability of materials, resources and skilled personnel, together with a variety of cultural differences make third world prosthetics a subject in itself. This paper reviews the literature available on the subject, examines some different approaches to prosthetics in the third world, gives an overview of some materials and designs used for both upper and lower prosthetics, and considers adaptation for cultural differences. It concludes that, while direct transfer of Western prosthetics technology is useful in the short term, for long term benefit to the poorer amputees in the third world, culture-specific designs and materials are more appropriate.

INTRODUCTION

The most common cause of amputation in the United States is vascular disease, while in war-torn countries of the world such as Cambodia, Iran, and Afghanistan, 80 to 85 percent of amputees are land mine survivors. These mines are responsible for 26,000 amputations per year and have produced 300,000 amputees worldwide. Land mines have claimed more lives and caused more injury in the second half of the 20th century than both nuclear devices exploded in Hiroshima and Nagasaki combined (Berry, 2001). Other causes of amputation in these war-torn countries include industrial or environmental accidents, terrorist attacks, and the lack of basic public health which often leads to diabetes, gangrene, and infection. All of these causes are adding to the number of amputations at an alarming rate.

A prosthetic limb consists of three basic components: the socket, which is the interface between the limb and the mechanical support system, the extension (or pylon) which replaces the length of the lost limb and may also incorporate a knee/elbow joint if the amputation is above the knee/elbow, and lastly, an artificial foot/hand. Due to the increasing rate of amputations, there is an ever-growing demand for prosthetic limbs. Not only is there an immediate need for a person's initial prosthetic limb, but also multiple replacement limbs and repairs are necessary over a lifetime. Children between the ages of four and sixteen grow at an average rate of 0.75" annually. A prosthetic replacement is needed typically every 6-12 months for children, and every 3-5 years for adults. For example, if a child becomes limb deficient at the age of 10, he will need approximately 25 limbs throughout the course of his or her lifetime. However, if a person becomes limb deficient while they are adults, they

typically will go through about 15-20 limbs during their lifetime (Prosthetics Outreach Foundation, 2005). Numerous limbs are essential to support the basic needs of amputees.

One of the main problems in providing prosthetic limbs to developing countries is the lack of trained personnel within these countries. Properly constructing, fitting, aligning, and adjusting a prosthetic limb requires a high level of skill and despite the high demand for this expertise, there are very few training programs in low-income countries. Studies by the World Health Organization (WHO) indicate that while the current supply of technicians falls short by approximately 40,000, it will take about 50 years to train just 18,000 more skilled professionals (Walsh 2003).

Another problem is that importing components from industrialized countries to build prosthetic limbs are not only costly, but these parts are designed for very different lifestyles and usually do not hold up to the challenges which nature presents in rural environments. These countries have a farm-based economy and a tropical climate. In these harsh environments, conventional limbs made of wood and resin only have a lifespan of about 18 months. The costs of prosthetic limbs vary substantially by country, but a typical prosthetic limb made in a developing country costs approximately \$125 to \$1,875 USD, depending upon the region in which they are made. When the costs to make a limb in a developing country can be cut to as little as \$41 USD (well below the \$5,000-\$15,000 USD average cost for a prosthesis in the United States), the costs over a lifetime of replacements and maintenance can still amount to thousands of dollars. This presents a major problem since the average family income in rural areas is typically around \$300 USD annually. Bartering for goods is a natural aspect of their lives, but getting a prosthetic limb requires cash. It can take victims a decade or more to earn the money for an initial prosthesis (Walsh, 2003).

Having affordable and readily available prosthetic limbs is vital for everyone that needs them. In third world countries, many limb deficient people are farmers, herdsman, nomads or refugees and rely on physical labor for survival. In some cases, they become beggars on the streets in order to survive. Not only does the loss of a limb have a grave impact on a person's physical ability and appearance, it causes profound psychological damage and often contributes to the degradation of their social status.

How well limbs perform and how cosmetically appealing they are depend on many variables including cost, the skills that technicians have to make the limbs, and the materials that are available to fabricate the limb. A properly fit limb is the result of a close working relationship between the prosthetist and the patient. Ultimately, the design and fit of the socket is what determines the patient's acceptance, comfort, suspension, and energy expenditure.

HISTORY OF PROSTHETICS

The history of prosthetics and amputation surgery began at the very dawning of human medical thought. Its historical twists and turns paralleled the development of medical science, culture, and civilization itself. Prostheses were developed for function, cosmetic appearance, and to provide a psychological sense of wholeness. These patient needs have existed from the dawn of time to the present. The earliest evidence of humankind's recognition of deformity and concern for rehabilitation is difficult to determine. Many

ancient civilizations had no written records and history was recorded orally in poems, sagas, and songs.

The prosthesis of ancient cultures began as simple crutches or wooden and leather cups as depicted in some of the earliest recovered pottery. This grew into a type of modified crutch or peg to free the hands for functioning. An open socket peg leg had cloth rags to soften the distal tibia and fibula and allow a wide range of motion. These prostheses were very functional and incorporated many basic prosthetic principles. Prosthetic limbs made of fiber have been found in the wrappings of Egyptian mummies which were probably the creation of the burial priests rather than a functional device. In fact, a drawing dating back to 500 BC was found in France showing a man working in a field with a wooden support under his knee (International Rehabilitation News, 2000). This information shows that not unlike the countries of today, the ability to be mobile was a necessity, and not an option.

In the three great western civilizations of Egypt, Greece, and Rome, the first true rehabilitation aids recognized as prostheses were made. With the birth of these three great civilizations, came the development of the scientific approach toward medicine and subsequently prosthetic science. The Dark Ages produced prostheses for battle and hiding deformity. The Renaissance later emerged and revitalized the scientific development begun by the ancients. Subsequent refinements in medicine, surgery, and prosthetic science greatly improved amputation surgery and the function of prostheses.

In the 15th century, there was not very many prosthetic alternatives available to the amputee except basic peg legs and hand hooks. Only the rich could afford to have prostheses made. During this era, there was a heightened use of metal for the fabrication of armor. Knights had prostheses made by their blacksmiths for use in battle. Some of these devices

were fairly advanced but were usually heavy, cumbersome, and functioned only in battle. Arms were set to hold shields at all times and legs set to ride in stirrups, but not for daily function such as walking. When knights returned home, they usually wore peg legs or hand hooks for daily function. Prostheses were more cosmetic than functional; they were meant to hide the disgrace and weakness of defeat from other battles. Armor makers made the prostheses appear as extensions of the knight's original armor. Although they had a great knowledge of the human body, they knew little about creating a functional prosthesis. Eventually, these skilled craftsmen came up with the first metal knee joint for the above-knee amputee.

Many of the prostheses developed during the 1600's were merely refinements of earlier armor type devices. They were bulky and heavy, but gradually gained more function. Some of these devices show contributions of other artisans such as watchmakers who integrated more intricate internal functions by incorporating springs and gears. These prosthetics exhibited more function and the focus shifted away from the earlier aesthetics-only approach.

From the 1600's to the late 1700's, we see great improvements of the prosthetic and surgical principles put forth in the Renaissance. The invention of the tourniquet, anesthesia, and disease fighting drugs brought medicine to the modern era, but also made amputation an accepted curative measure rather than a last ditch effort to save life. The surgeon had time to make residual limbs more functional, and therefore allowed the prosthetist to make better prostheses.

The industrial revolution brought about prosthetic advancement fueled by money available to amputees following the American Civil War. After WWII, many soldiers

returned with missing limbs and people became more aware of the problems these soldiers faced while trying to return to a normal lifestyle. With an escalated number of amputees and increased awareness, this forced the development of functional prosthetics for the masses. These functional prostheses were still by no means comfortable to wear, but the user was much more mobile and independent with the use of such a device. From heavy, immovable limbs to lighter, more functional limbs, prosthetics has come a long way. Today, modern materials such as plastics, carbon fiber, and strong but lightweight metals like titanium and aluminum, are water resistant and better able to withstand harsh environments. These materials are now widely used along with advanced designs, both of which allow the patient to expend less energy.

Fundamental proven prosthetic principles are never outdated, only the methods to accomplish them are refined. Ideas are endlessly being recycled from the past. Concepts that may have been impractical at the time of their inception, become possible with developments in materials and technology.

LOWER LIMB PROSTHETICS IN DEVELOPING COUNTRIES

When amputees cannot access a village or a mobile clinic that makes prosthetic limbs, they resort to anything they can make at home in an attempt to continue functioning and engaging in activities in their day to day lives. Crude and primitive home-made limbs can be made from anything ranging from the simplest hand-held pole/leg support, to a more sophisticated, self-adjusting leather socket. However, when amputees can access a village or

mobile clinic, then there are many other options available to them. These options range from limbs made with bicycle parts to limbs made with the latest computer software. This section will describe a variety of limbs in all of the aforementioned categories.

Pole and Crutch Limbs

The simplest lower limb prosthesis is a hand-held pole with either a leather strap or a platform to hold the leg in place. It can also be made with a crutch leg that has been cut away from the top half of a crutch and secured to the leg with several straps (Figure 1). These types of limbs are good for a short period of time when nothing else is available, but can lead to long term fitting problems. Contractures can easily form very rapidly in the knee or the elbow if the limb is not taken through a series of range-of-motion sets to stretch the muscles in the limb daily.

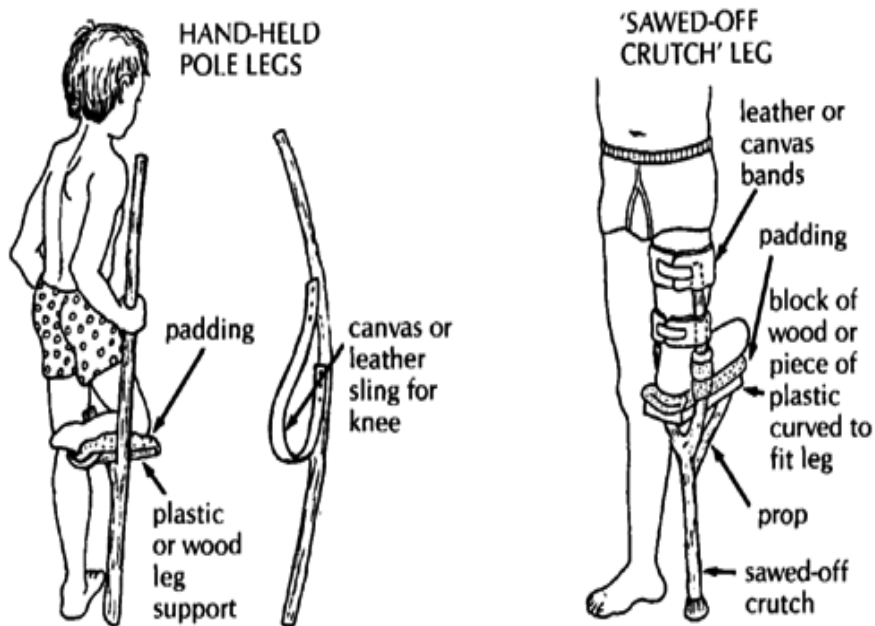


Figure 1

Bamboo/Plaster, PVC/Plaster Limbs

The bamboo/plaster leg and the pvc/plaster leg with an attached foot are both a step above the “pole legs” as the limb is held in a more natural, in-line position with the socket (Figure 2). This prevents the formation of contractures while the patient is walking because the knee has full range of motion. These limbs are constructed by first adding padding to the bottom of the residual limb. Socks are then pulled over the entire limb to hold the padding in place. The limb is then ready to be circumferentially wrapped in plaster bandages. Afterwards, a piece of bamboo is cut into many long narrow pieces and attached to the socket with a thin wire. A foot is then made by fashioning a wood block into the shape of a foot and then attaching a section of rubber, typically cut from a tire, to the bottom of the wood block for traction purposes. Both of these limbs are suspended by using a cuff-strap configuration. The only differences between the bamboo/plaster limb and the pvc/plaster limb are the materials that are used for the pylon and the receptacle in which the socket rests.

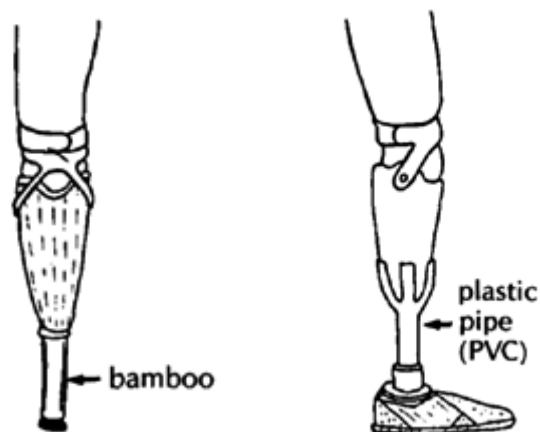


Figure 2

Wood/Metal, Leather/Metal Limbs

Wooden and leather sockets used to be very popular, but are time-consuming and require a lot of skill to make. The wooden socket is carved from a block of wood and attached to the pylon by traditional methods. On the other hand, the metal/leather limb is made of metal bars, a wooden pole for the pylon, and a thick piece of leather for the socket (Figure 3). The socket is formed around a positive model of the residual limb by stretching wet leather over a positive cast. Leather is self-relieving and correcting and can be adjusted for volume changes. The socket is then attached to the fashioned metal infrastructure, which itself is attached to the wooden pole. The foot is constructed in the same manner and using the same materials as the bamboo/plaster and the pvc/plaster limbs.

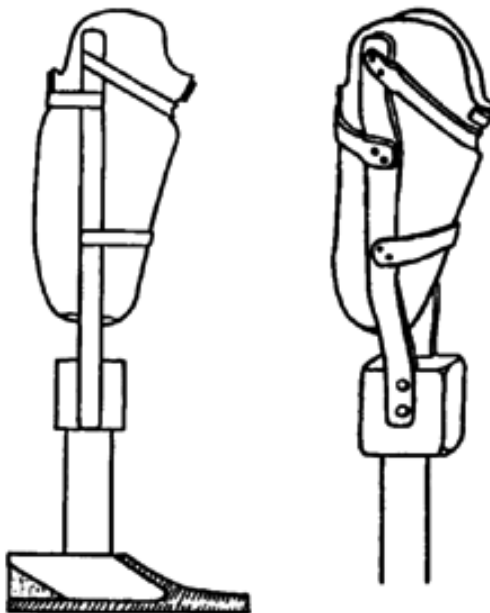


Figure 3

Residual Limb Protectors

Amputees with bilateral amputations above the knees are initially fit with short artificial limbs called residual limb protectors. These protectors are very useful in the initial phases of rehabilitation since they can help to prevent contractures, promote healing, and provide protection to the limbs. A set of residual limb protectors consists of custom-fit sockets with no knee joints, pylons, or feet.

These types of prostheses are used to achieve a lower center of gravity, and to attain better balance and stability. Although easy to use for the amputee, it restricts their range of motion, but allows for easy ambulation and less energy cost. Although typically used as training devices, these protectors are used daily in developing countries across the world. In these countries, the residual limb protectors are made using old tires (Figure 4). A piece of tire is cut to resemble the shape of an X and scored where the extensions connect with the body of the X to allow the tire to bend and conform to the shape of the limb. A thick sock is worn against the skin and the tire is attached to the limb with broad adjustable straps.

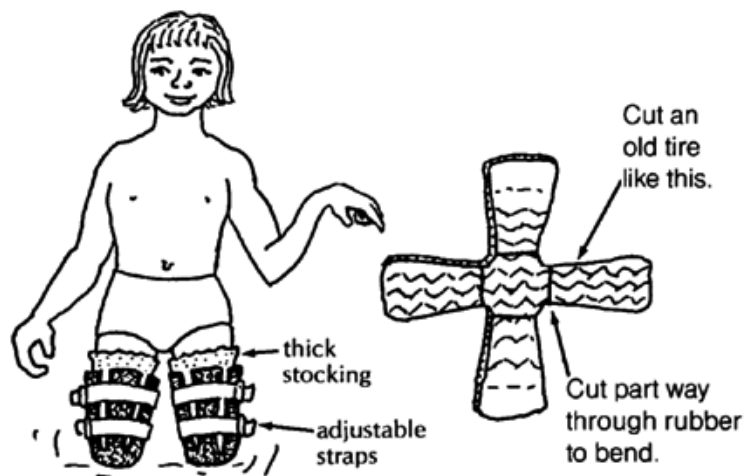


Figure 4

Adjustable Bicycle Limb

The bicycle-based limb is inexpensive and uses the materials and knowledge available in most developing countries. The components of this leg are adjustable for the growth of children, are inexpensive to repair or replace, and all parts of the limb can be adjusted with the use of a wrench. Initially the weight of this prosthesis was an issue, but it was understood by the users of the limb that the slightly increased weight gave the users an improved sense of stability.

The leg is built from the foot up by first removing the seat of the bike from the frame and separating the seat post from the seat by loosening and using the bolts and washers. The seat post is the base upside down and forms the lower shin and foot. A 1” thick piece of wood is cut to resemble a foot and lined with rubber on the undersurface for traction. The seat post is attached to the foot. The seat support frame and rear wheel supports are separated from the bike, and the rear wheel supports are bent to form the calf support for the socket. The shin and foot are attached to the socket holder and the length can be adjusted at this juncture. The socket is made directly over the residual limb and covered with foam to reduce bony pressure sites. A wooden disc is placed at the bottom of the limb to rest on top of the stump support. The socket is attached to the socket holder by plastering around the arms of the socket holder (Figure 5) and the prosthesis is held on with a suspension strap connecting the prosthesis to a belt worn around the waist.



Figure 5

If the bike is unusable, the cost is free. The cost of buying parts needed to repair an existing bicycle limb, or for the assembly of a new bicycle limb if no salvaged bicycles are available, would vary depending upon the region and the accessibility they had to parts in these countries. A used seat and frame could range in cost from \$3-15 USD. No further components are needed except what you can gain from the bicycle. The cost of the wood for the foot would be greatly diminished if bought in large quantities, but the average cost would be no more than \$1 USD. The cost per roll of plaster bandage is \$5 USD, and depending upon the size of the residual limb, you may use up to two rolls. To considerably decrease costs, local resins from trees and cellulose-rich plants such as grasses and cornhusks are used to make a mixture to imitate modern techniques (Cheng, 2004).

Sathi Limb

The Sathi limb, also called the Trans-Tibial Plastic Modular Component (TTPMC), can be used with any socket design and any foot including the bare foot models. This is a modern endoskeletal design in which accurate alignment and adjustments are possible. The use of thermoplastic components in prosthetics enables technicians to utilize the inherent characteristics of plastics in that they are lightweight, inexpensive, non-corrosive, and water resistant. The lighter the prosthesis, the less energy the amputee has to use to walk. A light prosthesis also reduces shear forces on the limb and decreases the pistoning action on the limb.



Figure 6

The Sathi limb is made out of lightweight, high-density polyethylene water pipes with four ribs to give the pipe strength (Figure 6). The Sathi limb is made up of a polypropylene pylon, chosen from 20 different sizes. Each pylon is made in 1 cm increments to suit almost all lengths of residual limbs below the knee, a socket adapter and 2 discs, one placed below the socket and the other above the foot piece for alignment in the anterior-posterior, medial-lateral and able to tilt in all directions. These components can be assembled rapidly and are available at a mere \$50 USD. Pulling a thin plastic cone made of Ethaflex over the pre-shaped shank can make this limb cosmetically appealing (Sathi, Mobility India).

Mukti Limb

The Mukti limb is very lightweight and is custom-made for amputees in just 5 hours. The Mukti limb can be made in remote villages. These quality legs can be made quickly and are provided free of cost by the Mukti organization to all amputees. With little skill or training needed on the part of the technicians to make these legs, the Mukti limb has grown in popularity. The Mukti limb is normally made by a mobile outreach program equipped with tools needed to produce these limbs. Small vans travel to remote villages for 5-6 day workshops. A team of 5 technicians can make up to 60 limbs in 5 days and send the patients back to their families within one day.

A high-density polyethylene (HDPE) irrigation pipe (3" in diameter) is used to make the socket and the shank of the limb. The pipe is skin-colored and molds easily once it has been heated. Once a plaster mold is made of the residual limb, a cardboard cone is adhered

to the bottom of the mold and the cone is filled with plaster to make a positive mold for the shank of the limb. The HDPE pipe is cut to the desired length and then put over a wooden stick and heated in the oven until pliable. It is then stretched over the cast of the leg. The plaster is removed from the inside of the mold and a pre-made foot is attached. Leather straps for suspension hold the prosthesis on the residual limb. The toughness and durability of these limbs and the mobility of the vans that travel to make these limbs accessible to many people has made the Mukti limb a success. The Mukti Limb Foundation has set up camps around India and presently have 350 camps internationally (Werner, 1998). The pictures shown are of a 14-year-old boy wearing a finished above-the-knee Mukti limb (Figure 7).



Figure 7

CAD/CAM Monolimb

In order to meet the needs of amputees worldwide, research into computer-aided design and computer-aided manufacture (CAD/CAM) are essential. New technology in the design and fabrication of prostheses for amputees has been widespread. In evaluating the amputee, the ability to fabricate prosthetics from a remote location has endless possibilities. A prosthetist can complete a prosthesis in less than 4 hours. This is a significant improvement considering that a prosthetist in a developing country usually needs weeks to produce a finished prosthesis (Prosthetic Outreach Foundation).

The process starts with a simple casting of the residual limb on-site in the developing country. The cast is digitized at a remote location using the computer to perform the usual socket modifications (Figure 8). The socket is then manufactured out of a thermoplastic sheet, either with the computer directly connected, or remotely. Then the prosthesis is completed by attaching the components and fit to the patient. If changes are needed, the revisions can be made by returning to the socket shape on the computer.

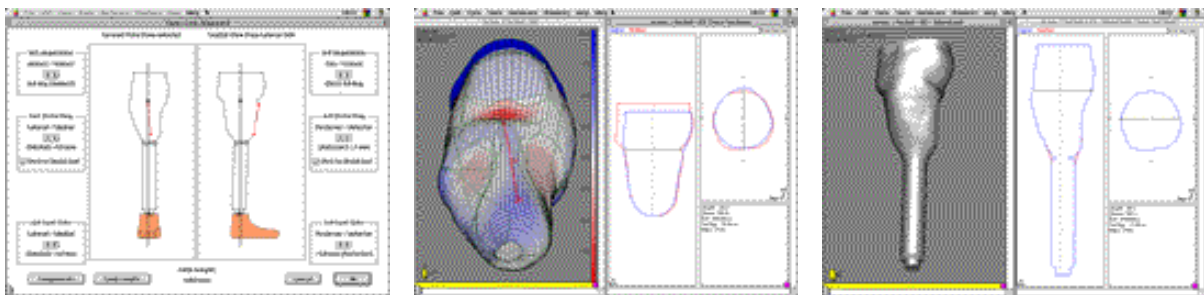


Figure 8

There have been thousands of limbs fit using the automated techniques of the CAD/CAM and many have been the Monolimb design. The Monolimb is lightweight, durable, and fairly inexpensive. The Monolimb grew out of a need to fit long transtibial amputees which limits the use of conventional alignable components. Now the limb is also used for higher levels of transtibial amputees. The cost of a Monolimb is \$35 USD per leg and the raw materials that go into making a Monolimb are half the cost of those materials used in a traditional lamination. Thermoplastic production is a fast, odorless process using softened sheets of thermoplastic that are drape-molded over a positive cast. Lamination, on the other hand, is a toxic, time-consuming routine and makes for a fairly heavy prosthesis (Clear Path International, 2005). A Patellar tendon bar is used for suspension of the Monolimb as well as a cuff strap occasionally for below the knee amputees. If it is necessary to increase height of the limb, plastic spacer discs are placed in between the foot and the socket. An adjustable cosmetic shell is made from 1/8" polyethylene material and riveted in place. Flesh-tone plastic or surface coloring is used to match various skin tones. A positive ankle block model was designed for both left and right feet and matches the ankle of most prosthetic feet. The process of making a Monolimb takes several hours and the prosthesis lasts at least three years.

PROSTHETIC FEET IN DEVELOPING COUNTRIES

In the last section, many of the primitive limbs used simple feet, such as wooden blocks. This section will describe some of the more developed feet which are better suited for the remainder of the more advanced limbs.

Jaipur Foot

The Jaipur foot was first developed in India and named after a city in India. The Jaipur foot was invented due to the lack of cultural sensitivity that the Western feet provided the third world countries in their everyday lives. Many people in India go barefoot, and squatting is common in India's culture. Neither mosque and temple visits nor working in the rice fields permits wearing shoes. This goes to say that a foot needed to be put into production that would accommodate the Indian environment and their culture.

The Jaipur foot looks like a real foot, has the ability to bend in all directions enough to allow a person to squat and walk on uneven terrain, and is a very low-cost alternative costing less than \$5 USD to make, and can be fabricated in less than 3 hours (Werner 1998). The foot is made out of wood and sponge rubber and then heat-molded using iron molds. The outer rubber gives the foot its realistic appearance and natural color as well as waterproofing the wooden block inside (Figure 9).



Figure 9

The original Jaipur limb was made out of sheet aluminum and required special equipment as well as a lot of skill to fabricate. Once a village is set up to make the Jaipur limb, it would be a matter of 1 hour from the time measurements are taken until the time the patient is walking. The cost for a Jaipur limb is less than \$20 USD. The only drawback to the Jaipur limb was that the height could not be adjusted. This caused many problems as patient follow-up was important, but difficult for the patient to reach a clinic due to the lack of transportation. The Jaipur foot is still popular and widely but normally is used in conjunction with other more versatile limbs, such as the Sathi limb, for example.

Prahba Foot

The word Prahba means “superior energy” and due to its outstanding qualities, allows much of the patient’s energy expenditure to be reduced. This foot looks very natural and can be worn barefoot or with shoes. The foot is durable, maintenance free, and cost-effective making it very affordable for low income patients.

The matching Prahba limb is an advanced endoskeletal, above-the-knee prosthetic limb, and much like the Jaipur limb/foot, it is lightweight, allows the patient to participate in religious and social functions, can be covered by a superficial foam cover, and can be produced in less than one hour. The patient is able to sit naturally or cross-legged on the ground without having to remove the limb with the constant friction knee joint.

EB1 Foot

Throughout history, in developing countries as well as the western world, if the foot becomes unusable on a prosthesis either from wear and tear or from the foot fracturing, the prosthesis is generally not used anymore. The EB1 foot is very similar to the Jaipur foot in the way it is constructed. It is made using locally-available materials as well as the machines. The EB1 foot is well-designed and can be cosmetically appealing. The foot is very resilient and has an expected lifespan of at least 3 years. The feet are made in Vietnam and are priced below \$5 USD (Pye).

The EB1 foot is highly functional, but due to the wooden keel, it has been known to crack and be heavier in weight. The EB1 foot is made with two cast aluminum halves, and seven different-sized molds are used to produce various-sized feet (Figure 10).



Figure 10

The EB1 foot has gone through many improvements after much patient feedback on the foot. After many complaints about the weight and the restrictive nature of patient activity levels, the EB1 foot was redesigned with a lightweight, flexible plastic keel and the amount of rubber used in each foot was decreased.

All Terrain Foot (ATF)

Most prosthetic feet perform poorly on uneven surfaces, walking over high obstacles, or in the water. An alternative rubber foot works very well for special applications. Despite the unique appearance of the ATF, many people use this foot near or in the water. In Vietnam, rice farmers use the ATF when planting their fields. This foot can pull out of 20 cm of mud easier than when using a typical prosthetic foot, and there are no harmful affects from prolonged exposure to water. The limb is constructed of stainless steel and high-density rubber. The bottom of the foot is convex rather than flat allowing for a more normal gait while still providing traction to the amputee. The foot can also be interchanged with more traditional feet for everyday tasks (Evans, Lemke, Renfrow).

Niagara Foot

The Niagara foot is a very simple yet inexpensive, practical, and sturdy. The foot is made from a single piece of Delrin plastic formed to imitate a normal human foot (Figure 11). The shape of the foot is to provide energy return much like many of the high-end feet we offer in the United States. Although weight and energy expenditure are not an issue, the

cosmetic appeal of the foot and the ability to wear shoes created a few hurdles for this foot. The foot appears to be less stable as it produces irregular motion throughout the gait cycle.

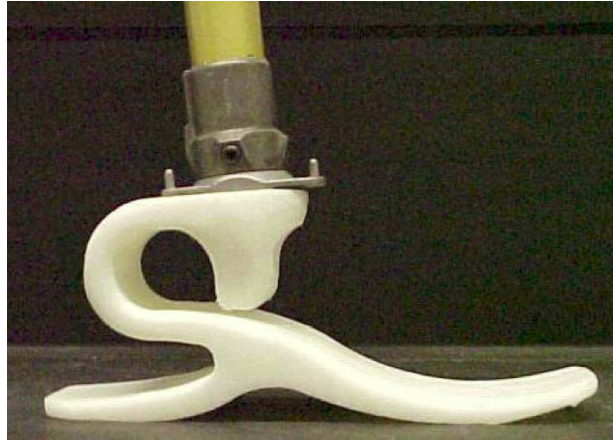


Figure 11

The mechanics of the foot were tested by 16 patients, and after 1 year on the Niagara foot, they showed only a limited amount of wear with no failures. The clinical testing is significant in that most feet at the time of the trial were only lasting up to 3 months. The Niagara foot can be attached to most prosthetic limbs except for setups with wooden components. This is due to the elevated strain that is placed on the bolt assembly during gait.

UPPER LIMB PROSTHETICS IN DEVELOPING COUNTRIES

The basic components of an upper-limb prosthesis are a socket, wrist unit, a forearm section or extension, a suspension system to secure the prosthesis and a terminal device or hand. Leather or nylon cords transmit forces to the terminal device, generated by movement

from the shoulder for example, allowing the terminal device to open and close. Above elbow prostheses also contain an elbow mechanism and an upper arm section. The terminal device is a centrally important part of the prosthesis, since it provides replacement of the limb's most important function, the ability to grasp objects. The hand is one of the most intricate organs of the human body. As such, it poses a serious challenge to the designing of prostheses meant to replace the function of hands. An artificial hand, which even comes remotely close to replicating a human hand, has yet to be developed. Upper-extremity prosthetics come in two types, functional and cosmetic, both of which are explained below.

In general, the functional prosthesis is lighter and less expensive, but more difficult to fit, and requires that the amputee be trained to use the device to its maximum capacity. The socket must provide a total contact, intimate fit for the amputee to have maximum control and for the device to be comfortable. The cable system must be properly attached and the harnessing properly adjusted so that all motion translates to terminal device control. Most terminal devices simply open and close. Objects are held between two posts but cannot be manipulated. They are simply held in one position through a spring, rubber bands, or pressure exerted through a cable. Many attempts have been made over the years to improve the function of these prostheses through better terminal devices and/or control cables.

The functional prosthesis consists of a socket and a cable system connected to a terminal device. Functional hands are strong and sturdy. The terminal devices are designed so that one end of the terminal device fits easily into a small opening made in the end of the socket and locks into place. The terminal devices are usually made of steel. Artisans, farmers and agricultural laborers can use these functional hands effectively for both farm and non-farm work, including plowing the field, digging the ground, carpentry and welding.

Although functional hands are very useful, the most commonly used hands are rigid, cosmetic hands. Presently, the most successful arrangement has been to operate the first and second fingers along with some motion of the thumb, in a three-jaw-chuck type of prehension pattern. Mechanical hands with finger phalange movement, which improves prehension, are also available in Asian and Pacific developing countries.

The cosmetic prosthesis (Figure 12) is passive. It serves to mask the amputation and has no mechanical function with added weight and decreased durability. However, within a culture where amputees are traditionally perceived to be “incomplete” human beings, many amputees desire hands over hooks for cosmetic reasons. In the United States, approximately 70 percent of users wear hooks, whereas outside of the United States, especially in developing countries, there is a greater preference for hand-shaped prostheses.



Figure 12

Upper-extremity amputees are often times disappointed by the prostheses they receive, with regard to both cosmetic and functional features. The most frequently used cosmetic versions can neither open wide enough to hold many common objects nor flex

tightly enough to hold small objects in a firm grip. This limits their functional range. A manual worker will likely require a functional hand to replace even a non-dominant hand. For others, a cosmetic hand will likely be an adequate replacement, at least for a non-dominant hand. Unilateral amputees generally find it easier to learn to use their non-dominant hand than to use a functional prosthetic hand. Bilateral amputees are often best served by one functional hand with a hook as a terminal device and one cosmetic hand.

A hand prosthesis can be activated and operated either through body power or through an external power source (e.g., batteries). Myoelectric hands, are operated through contact with electrodes in the socket, but are rare in developing countries as they are very expensive and require frequent repairs and maintenance. They are used in a few countries such as China, but their long-term usefulness has yet to be established as their cost is often high. Currently, the only manufacturer of electronic hands in developing countries is the Nevedac Prosthetic Centre at Chandigarh, India

The world experience is that many of the upper-extremity amputees reject any prosthesis that is provided. This is particularly so if the amputation is unilateral (one limb). Bilateral (loss of both limbs) amputees do present a difficult problem, since they are dependent on others for their daily activities. Children are so adaptable and agile that they quickly find ways to cope without a prosthesis, by using their feet as they would hands, for example. Worldwide experience is that less than 1 percent of children provided with one or more upper-extremity prostheses will continue to wear, let alone use, such prostheses.

Who should be considered for fitting with a prosthesis? The decision should be based on available resources. Should all upper-limb amputees be fitted? Even in the most industrially developed countries, there is debate as to whether all upper-extremity amputees

should be fitted with a prosthesis. Health policy makers agree that unilateral upper-extremity amputees should be at the bottom of the priority list, especially in countries with limited resources. People with below-the-knee amputations are at the top of the priority list, since in most countries they comprise a majority of the amputees and are most likely to benefit from being fit with a prosthetic device.

Furthermore, there is a relatively short window of opportunity for fitting the upper-extremity amputee. Generally, adults who sustain an upper-extremity amputation find it more difficult to manage successfully with a prosthesis if more than one or two months elapse between amputation and fitting. The majority of professionals agree that the window should remain open for six months, but after that period of time, the potential for success is unlikely. There are always exceptions, but most of the time, by the time upper extremity amputees in developing countries are reached, their amputations happened more than one year ago.

Nevadac Electronic Arm

The demand for the Nevedac electronic arm arose as a result of the increasing number of amputations from accidents in the use of farm machinery such as threshers and harvesters, as well as persons affected by polio. The Nevedac electronic arm (Figure 13) is made from indigenous materials and components, which are easily available in many of the third world countries. Compared with conventional mechanical arms and hands, these prostheses are a great deal more comfortable, are easier to operate, and the fingers operate in a more fluid

motion. The hand on the Nevadac arm is cheaper than a myoelectric hand, but just as effective. The cost of this type of prosthesis is roughly \$300 USD.



Figure 13

The switch control system of the Nevadac electronic arm has been in use since 1994 with satisfactory results, especially for bilateral arm amputees. The Nevadac arm is powered by an on-board rechargeable battery. Recharged daily, the battery has a life expectancy of about two years. Each arm also comes with a battery charger, an extra battery, and a spare micro switch. This arm is very reliable, and only minor adjustments or replacements of the micro switches are required.

Within a period of about 15 to 20 days, a bilateral arm amputee can be fitted and trained in the use of the prostheses. The training initially given focuses on using the

prostheses to eat, drink, write, as well as undertake activities of daily living, including personal hygiene. Bilateral arm amputees cannot do heavy production work. Through vocational rehabilitation, amputees are trained to become painters, decorators, artists, office workers, and watchmen. About 35 percent of the Nevedac Corporation's employees are persons with disabilities.

Socketless Holder Prosthesis

It has long been recognized that the limiting factor in prosthetic construction is the socket, which provides the interface between the residual limb and the prosthesis. Requiring casting, molding and multiple fitting sessions, a socket is expensive in both time and financial resources. Any changes in the residual limb such as growth, weight gain or loss, limb maturation, etc., may render a prosthesis useless because the socket will no longer fit.

A socket often requires frequent follow-ups, an added difficulty for amputees who need to travel to a distant community for their prosthetic care. Assurance of a successful prosthetic outcome is extremely important. Weighing less than 50% of a standard socket system, socketless prosthetic technology preserves the wearer's energy for the desired task, not for moving the socket. This technology also allows for heat transfer reducing daily discomfort and secondary skin break down.

The Socketless Holder Prosthesis (Figure 14) uses a metal frame contoured to the remaining forearm. A reaction pad is placed over the distal radius, and the device is secured with a circumferential Velcro strap. The terminal device is bolted distally onto the metal frame and a triceps cuff is used along with standard harnessing.



Figure 14

This system appears to be adaptable for mid-level to long transradial amputations. Literature indicates that this type of a system is also available for transhumeral and lower-limb amputations. Prosthetic technicians who have received limited prosthetic instruction can fit this system. The transradial design appears to be an excellent method of rapidly fitting amputees. The life expectancy of such a system is 10-15 years. In that capacity it can fulfill several roles: helps to assess if the amputee will be a prosthetic user, the patient is able to experience a temporary device, permit prosthetic activity while awaiting more definitive care, plus saving time and the expense of providing conventional prosthetics to the patient who will reject prosthetic use can be avoided.

PROSTHETIC HANDS IN DEVELOPING COUNTRIES

Under-Actuated Prosthetic Hand (UAPH)

The UAPH is an inexpensive hand and was designed exclusively for users in developing countries. Both the structure and actuation of this hand are tightly integrated. The actuation is performed by the tendons, which are linked and supported by the shoulder of the patient. These tendons are embedded in an elastomeric matrix providing strength and rigidity. The palm is sustained by a suitably shaped wooden plate which regulates tendon spacing and contains low friction corridors through which the tendons pass.

High dexterity is an expensive characteristic that increases the complexity of the design and the cost of the final product. A simpler design was chosen that features basic dexterity, which is acceptable since its purpose is not to provide users with a prosthesis for fine manipulation, but rather a cheap tool to aid in farming and other raw tasks.

The shape of the prosthesis is based on a real human hand for a more natural look. The model wears a cotton glove which is immersed in a bucket of plaster (Figure 15). The cast is shaped by holding a cylinder with a suitable diameter, such as a plastic bottle. The cast is dried by hot air, then slipped off and cut in half. It is then marked with reference lines to facilitate placing the cast back together again at a later time.

The tendons are placed on the lower half, pieces of cork are attached along each finger to create the flexural hinges. Then elastomeric polymer is molded inside the halves to form the structural matrix of the hand. Once the wood palm has been incorporated, the two halves of the cast are then closed, properly aligning the reference lines.



Figure 15

The tip of each finger is connected to the triangular plate by a tendon (Figure 16). When the triangle plate is pulled by the user's shoulder, each tendon slides inside its sheath and closes the hand. The amount of movement of each tendon, with respect to its sheath, depends on the shape of the grasped object. The realized hand is able to grasp objects having different sizes.

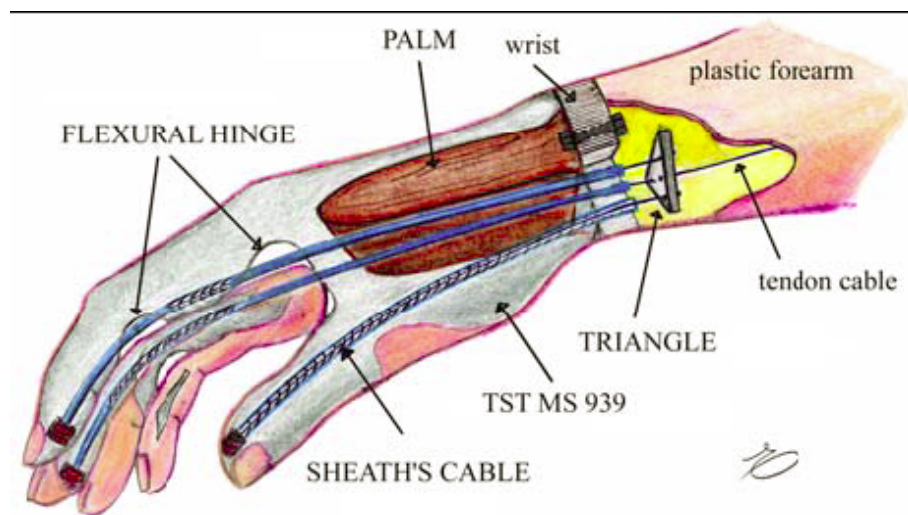


Figure 16

Gloveless Endoskeletal Prosthetic Hand

Current prosthetic hands, although functional, have the potential of being improved significantly. The Gloveless Endoskeletal Prosthetic hand (Figure 17) is a novel design that is lighter in weight, less expensive, and more functional than current hands. The new prosthesis features an endoskeleton embedded in self-skinning foam that provides a realistic look and feel and obviates the need for a separate cosmetic glove. This new prosthesis can securely grasp objects with various shapes and sizes. Compared to current hands, weight has been reduced by approximately 50%, and cable excursion required for full finger flexion by more than 50%. The new endoskeletal prosthesis requires approximately 12-24% less force input to grasp a variety of everyday objects, largely due to its adaptive grip. Production cost estimates reveal the new prosthesis to be significantly less expensive than current prosthetic hands. The goal in designing this particular prosthetic hand was to address these deficiencies by increasing function and appearance while decreasing cost and weight.



Figure 17

The design mimics the appearance and movement characteristics of the human hand, and the endoskeleton surrounded by self-skinning foam proved to be a viable solution. The endoskeleton is composed of four active fingers (Figure 18), each capable of bending at the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints. The endoskeleton contains a passive thumb that can be positioned by the user to provide different grips, power and precision. The fingers remain extended until the harness cable is displaced. Harness cable actuation causes flexion of all four fingers against the stationary thumb. Upon release of the cable, the fingers extend, opening the grip. This voluntary-closing mechanism offers the benefit of graded prehension, allowing the user to vary grip force depending on harness cable force.

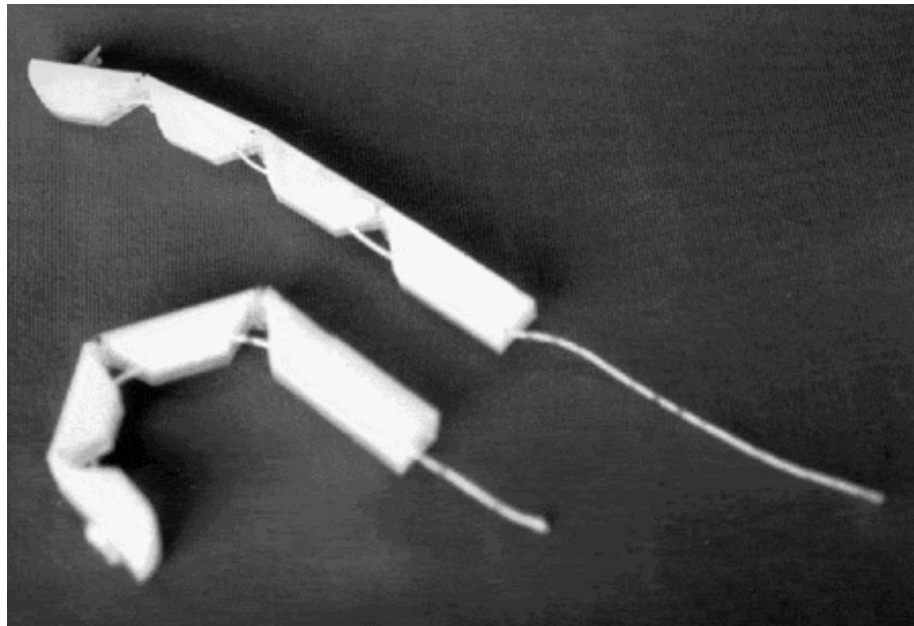


Figure 18

The self-skinning foam forms a skin on the surface during polymerization within the mold. The skin offers good detail, including palm wrinkles and fingerprints. The foam opposes finger motion less than traditional gloves, and is inert, nontoxic, resistant to abrasion, and treatable with flame retardant. Pigments can be added to achieve various skin shades. Since the foam is lightweight, prosthesis weight is reduced. A passive version of the endoskeletal hand has also been constructed. As in the active hand, significant detail can be achieved, including fine wrinkles and fingerprints. The weight of the passive version is approximately equal to that of the active hand.

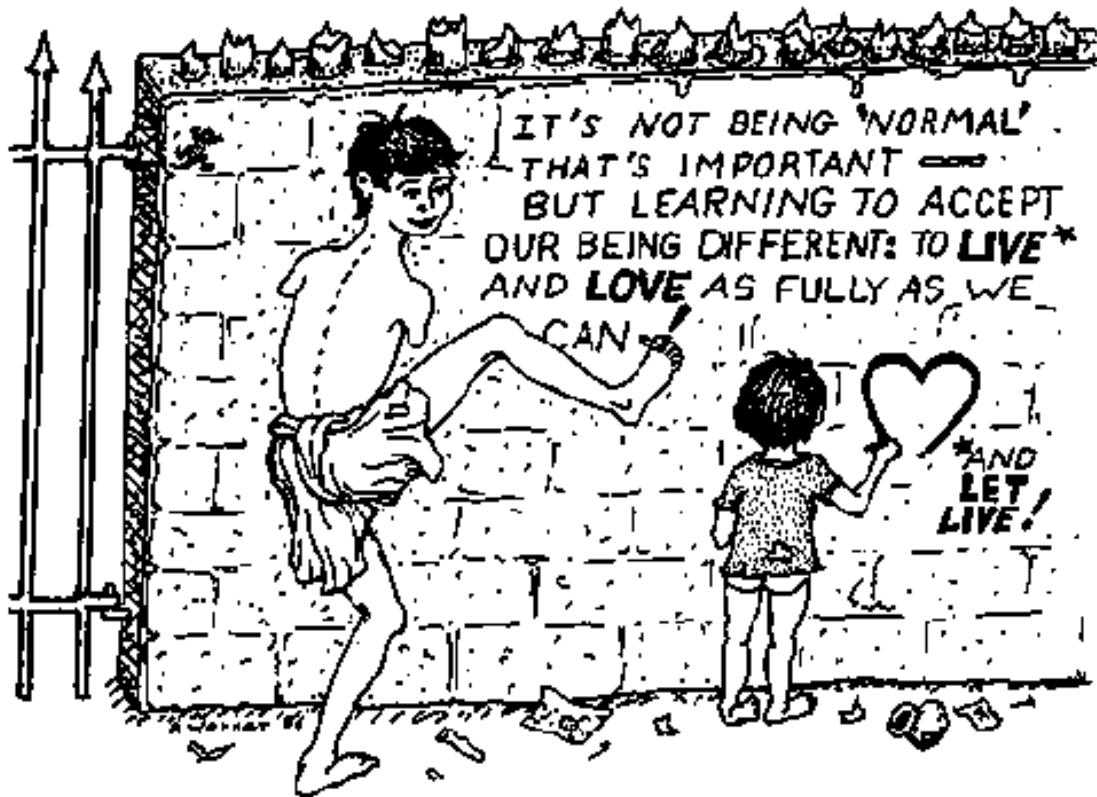
For a production run of 1,000 units, the estimated cost of production (material and labor) is \$50 USD per hand. Compared to current hands that cost several hundred dollars each to produce, the endoskeletal hand is much less expensive, mainly because less skilled labor is required. There are multiple potential applications for a low-cost endoskeletal hand prosthesis. This hand could be manufactured and distributed in developing countries, where limb deficient persons who could not otherwise afford a conventional prosthesis, could obtain this prosthetic device. Additionally, the prosthesis could be used by growing children who require a larger size every 6 months or so, as it can be cheaply replaced. Adults could also use this prosthesis as a disposable alternative if it is ever torn or stained.

SUMMARY

In developing countries, an overwhelming number of prostheses are necessary. The availability, accessibility and cost of prosthetics are significant concerns to limb deficient persons who, without the assistance of a prosthetic device may not be able to function, succeed or be accepted by society. Individuals who become candidates for prosthetics in developing countries find multiple replacement limbs necessary over their lifetime. Obtaining a single prosthesis, let alone subsequent replacement prosthesis, is resource- and cost-prohibitive. The initial rehabilitation, fitting and training process is a critical step towards the patient experiencing maximum benefit from the prosthesis and being fully compliant.

Several types of prosthetic limbs and terminal devices were described as well as the techniques used for their manufacture in developing countries. Fundamental proven prosthetic principles are never outdated, only the methods to accomplish them are refined. Ideas are endlessly being recycled from the past. Concepts that may have been impractical at the time of their inception, become possible with developments in materials and technology.

Although prosthetic components can be imported from other countries at a high cost, components that are multi-environmental tolerant, exhibit culturally-sensitive designs, can be manufactured with inexpensive, locally available materials, and require very little training to assemble are successful components of choice for third world countries.



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