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Jaipur Foot: Challenging Convention

At age 14, Sudha Chandran, an aspiring dancer, lost her right limb in a car accident. Devastated and convinced she would never walk, let alone dance again, she spent several months on crutches. Then one day in 1984, she read about Jaipur Foot.

There are five and a half million amputees in India just like Sudha Chandran. In addition, each year, according to one estimate an additional 25,000 people lose their limbs due to diseases, accidents or other hazards. The majority of these people are well below the poverty line and cannot afford healthcare or medical services.[1] In a world where prosthesis is a complicated and expensive industry, there is hope for these patients. However, nestled in the desert of Rajasthan is an operation of impressive scope that offers hope to the some of the most impoverished citizens of India and maybe even the world. It offers these handicapped citizens a chance to return to their livelihoods and pursue their dreams. This operation is called Jaipur Foot.

THE INNOVATION. . .

A prosthetic foot in the U.S. averages $8,000. The Jaipur Foot is tailored to the active life styles of the poor and costs only about $30 - and it is given away free to the many handicapped poor who have lost a limb.

Developed in 1968, Jaipur Foot is a hand-made artificial foot and lower limb prosthesis.[2] It has revolutionized life for tens of thousands of amputees around the world. This foot was originally designed to meet the needs of a developing country lifestyle such as squatting, barefoot walking and cross-legged sitting. Primarily fabricated and fitted by Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS), a non-governmental, non-religious and nonprofit organization, Jaipur Foot is fitted on approximately

This report was written by Scott Macke, Ruchi Misra and Ajay Sharma under the supervision of Professor C.K.Prahalad. The reports are intended to be catalysts for discussion and are not intended to illustrate effective or ineffective Strategies.

16,000 patients annually, while BMVSS services approximately 60,000 patients by providing Jaipur foot, calipers and other aids and appliances. There are seven centers throughout India and a number of mobile camps held every year in various parts of the country. Jaipur Foot camps also have been found in 19 countries, including Afghanistan, Bangladesh, Dominican Republic, Honduras, Indonesia, Malawi, Nigeria, Nepal, Nairobi, Panama, Philippines, Papua New Guinea, Rwanda, Somalia, Trinidad, Vietnam, Zimbabwe and Sudan.

With innovations in technology and management, as well as understanding the needs of its patients, BMVSS developed a unique business model. This model spreads the Jaipur Foot technology that allows rickshaw-wallah (pedicab operators) amputees to be rickshaw-wallaws, farmer amputees to be farmers and in the case of Sudha Chandran, classical Indian dancer amputees still to be classical Indian dancers.

THE NATURE AND SCOPE OF THE PROBLEM:

Global Amputees

There are anywhere from 10 million to 25 million amputees in the world, with an additional 250,000 added each year. The causes of amputation vary greatly. In countries with a recent history of warfare and civil unrest, amputation is due to trauma and landmine accidents.3 In places like the United States, the causes are more related to accidents, circulatory diseases and cancer. Regardless, prosthesis in both developing and developed nations is expensive and complicated, leaving a sizable number of amputees unable to afford adequate prosthetic care.4

Developed World

According to a 1996 National Center for Health Statistics study, there are more than 4 million amputees in the United States and approximately 200,000 new amputees every year, of which approximately 70% are lower limb amputees5 (October 1999). According to the World Health Report in 1998, amputation resulting from diabetes will more than double globally from 143 million cases in 1997 to 300 million by 2025.6 The most common causes of amputation of lower extremities are disease (70%), trauma (22%), congenital or birth defects (4%) and tumors (4%). Upper extremity amputation usually is due to trauma or birth defect. The cost of prosthesis is very high in the United States, leaving many without appropriate care. According to Mark Taylor, from the University of Michigan Prosthetics Department, due to insurance company policies and high costs, only 50% of patients in the U.S. receive the prosthetic medical care they require.

Developing World

In the developing countries of Asia and Africa, land mines have left millions of people limbless. According to the U.S. Centers for Disease Control, approximately 300,000 children are severely disabled because of land mines, with an additional 15,000 to 20,000 new victims each year.7 Moreover, most victims are not soldiers, but women and children who happen to live in areas that were once war zones. By some estimates, there are more than 100 million land mines buried all over the planet. In many poor nations, most amputees have to settle for a lifetime on crutches. In Vietnam alone, land mines injure more than 2,000 people each year.8 It costs approximately $300 to provide a high-quality artificial leg in Vietnam.9

Countries with the Most Number of Landmines

COUNTRY	# OF LANDMINES
Afghanistan	9,500,000
Angola	9,000,000
Iraq	7,500,000
Kuwait	5,000,000
Cambodia	5,500,000
Western Sahara	1,500,000
Mozambique	1,500,000
Somalia	1,000,000
Bosnia-Herzegovina	1,000,000
Croatia	1,000,000

Source: United Nations Data

In Afghanistan, there are approximately 10 million landmines and at least 50,000 amputees.10 In Cambodia, there are 25,000 to 40,000 amputees, or one amputee per 300 inhabitants. There are nearly as many land mines in Cambodia as people. Government hospitals are so severely under-resourced that patients, including the very poor, are forced to pay for services or drugs, leaving many without care.11 In Kosovo, the World Health Organization (WHO) estimated the 1999 land mine injury rate at 10 in 100,000, exceeding the rates of both Afghanistan and Mozambique. In India, there are 5.5 million people suffering from locomotor disabilities in India. Of these, about one million have lost their limbs and four million suffer from polio. Due to the increase in road accidents, diseases and other hazards, 25,000 new cases add to the population of amputees every year.

Treatment Costs

Developed World

PROSTHETIC COSTS IN THE UNITED STATES

BELOW THE KNEE LIMB				
Legs	$4,000– $5,000 (Low End)	$7,000 – $9,000 (Middle End)	$10,000 – $25,000 (High End)	
Prosthetic Sockets	$3450 (Replacement Socket)	$650 (Replacement Cover)		
Prosthetic Feet	$250 – $12,000			
Prosthetic Socks	$19 (Sheath)	$80 (Sheath w/Gel)	$25 (Wool Socks)	$9 (Single Ply); $50 (Shrinker)

Above the Knee Legs				
Legs	$8,765 (Low End)	$12,265 (High End without Knees and Feet)		
Prosthetic Sockets	$4300 (Replacement Socket)	$900 (Replacement Cover)		
Prosthetic Knee	$700 – $5400			
Prosthetic Socks	$25(Sheath)	$80 (Sheath w/Gel)	$25 (Wool Socks)	$10(Single Ply), $80 (Shrinker)

Developing World

OpenRoads, a U.S.-based NGO, will be shipping 100 prosthetics every year to each site. Below is a table of their estimated costs of providing limbs. It is based on the assumption that buying in bulk will reduce overall costs. With prosthetic care as expensive as it is today, it leaves many patients, in both the developing and developed world, without the care they need. A fast, dependable solution, at a cost people can afford (in the developing world, this cost is $0.00), is not only necessary but also imminent. Innovative business models, such as Jaipur Foot, already have started to accomplish this successfully.

OpenRoad Cost Estimates For Providing Prosthetic Care Globally Year and Number of People Served per Site			
Year	**Location**	**Number of People Served**	**Cost per Site**
1	Kosovo	50	$15,000
	Rwanda	50	$15,000
2	Kosovo	100	$30,000
	Rwanda	50	$15,000
3	Kosovo	100	$20,000
	Rwanda	100	$20,000
	Afghanistan	50	$10,000
4	Kosovo	100	$15,000
	Rwanda	100	$15,000
	Afghanistan	100	$15,000
	Mozambique	50	$7,500
5	Kosovo	100	$15,000
	Rwanda	100	$15,000
	Mozambique	100	$15,000
	Afghanistan	100	$15,000
	Total:	1250	$237,500

History of Prosthesis

The history of prosthetics begins at the very dawning of human medical thought. Its historical twists and turns parallel the development of medical science, culture and civilization itself.

The prostheses of ancient cultures began as simple crutches or wooden and leather cups depicted in Moche pottery. 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.

An artificial leg invented by Pare in 1561 for individuals amputated above the knee was constructed of iron and was the first artificial leg known to employ articulated joints. Major advances have been made in the field of prosthetic rehabilitation, stimulated in part by wars that increased the number of individuals who lost limbs. During the American Civil War (1861-1865), interest in artificial limbs and amputation surgery increased in the U.S., with the government paying for artificial limbs for veterans. In 1862, the U.S. government enacted the first law providing free prostheses to people who lost limbs in warfare. In 1870, Congress passed a law that entitled war amputees to receive prostheses every five years.

World War II spurred further developments. Dissatisfaction with heavy, uncomfortable artificial limbs gave impetus to prosthetic research. The American Orthotic and Prosthetic Association was established in 1949 and developed educational criteria and examinations to certify prosthetists and orthotists. In 1945, the National Academy of Sciences set up a Committee on Artificial Limbs (CAL) to develop design criteria that would improve their functions. CAL influenced development of modern prosthetics from 1947 to 1976. During this period, plastic replaced wood as the material of choice, socket designs followed physiological principles of function, lighter-weight components were developed and more cosmetic alternatives were fabricated.

In 1956, the biomechanics laboratory at University of California (Berkeley) introduced the solid ankle cushion heel (SACH) foot, which became the most popular prosthetic foot. In the 1960s, hydraulic knee mechanisms became more prevalent; and 1970 marked the inaugural year for the international Society for Prosthetics and Orthotics. In 1971, Otto Bock introduced endoskeletal prostheses.

Modern times are characterized by the emergence of prosthetics as a science as well as an art. Research into human movement, new materials and new technology has led to creation of very light and functional components. Gel liners provide shock-absorbing interface between residual limb and hard socket. Research is attempting to find a method to bring sensation into the prosthetic limb.12

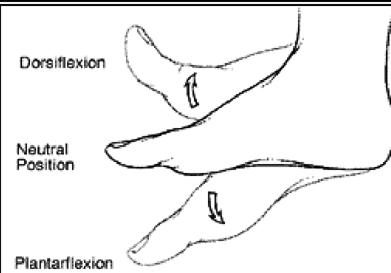
Lower Limb Anatomy

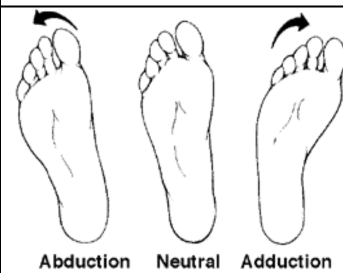
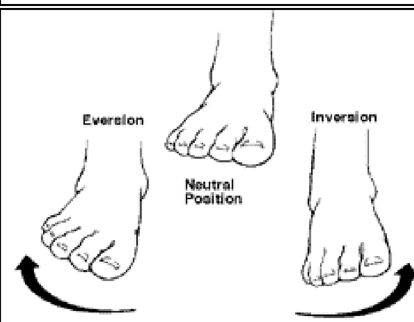
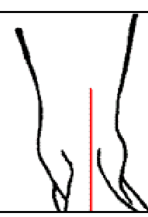
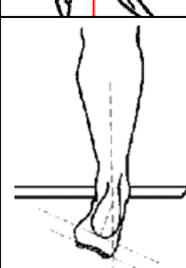
To understand fully the innovation behind Jaipur Foot, it is important to know something about the lower limb anatomy. The limbs must bear weight, provide a means for locomotion and maintain equilibrium. Bipedalism is the process by which we are able to stand upright and to move about on two limbs. It imparts three unique functions on the lower limbs.

The ankle joint is a hinge-type joint that participates in movement and is involved in lower limb stability. Dorsiflexion and plantar flexion (Please refer to basic foot movements below) movements take place at the ankle. Dorsiflexion is necessary in order to have the foot contact the ground heel first and to allow the foot to clear the ground during the swing phase of gait (please refer to gate cycle below). Plantar flexion provides the propulsive force necessary to lift the limb off the ground and start it swinging forward during the toe-off portion of gait. The foot plays an important role in supporting the weight of the entire body and in locomotion. The bones of the foot are arched longitudinally to help facilitate the support function. The transverse arch helps with movements of the foot. These movements help keep the sole in contact with the ground despite the unevenness of the ground surface. They also work in concert with the ankle joint to help propel the foot off the ground during the toe-off portion of gait.

Basic Foot Movements

<table>
<tr><td>DORSIFLEXION: Flexion of forefoot away from ground

PLANTARFLEXION: Flexion of forefoot toward ground</td><td>
</td></tr>
<tr><td>ABDUCTION: Movement away from axial line (second toe position)

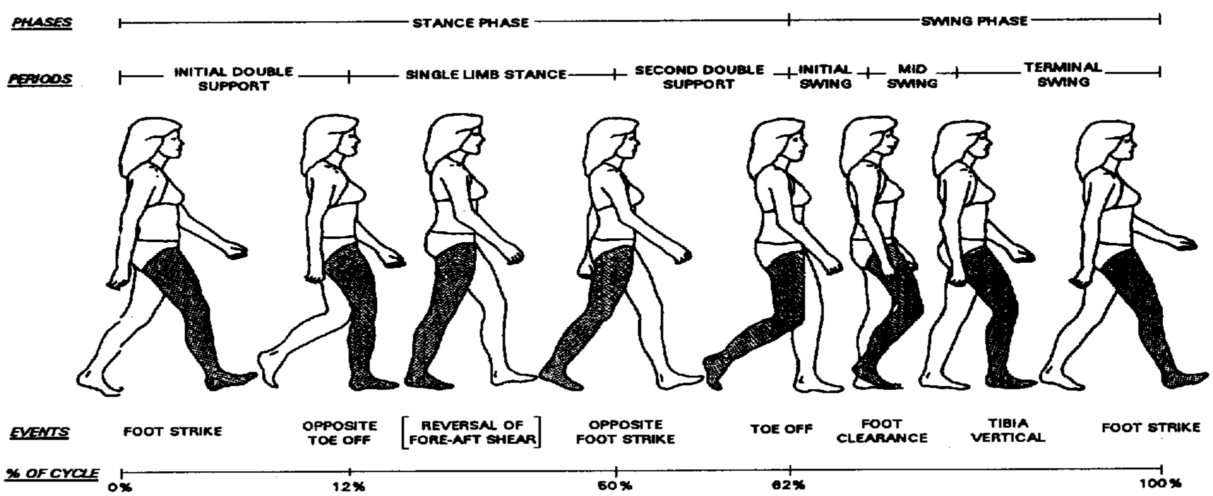
ADDUCTION: Movement toward the axial line</td><td>
</td></tr>
<tr><td>EVERSION: Turning sole of foot outward away from midline
INVERSION: Turning sole of foot inward toward the midline</td><td>
</td></tr>
<tr><td>PRONATION: Triplane motion consisting of simultaneous movements of eversion, abduction, dorsiflexion</td><td></td></tr>
<tr><td>SUPINATION: Triplane motion, which combines the movements of inversion, adduction and plantar flexion</td><td></td></tr>
</table>

Gait Cycle

The rhythmic alternating movements of the two lower extremities are the gait cycle, which results in forward movement of the body. Simply stated, it is the manner in which we walk. Gait cycle is the activity that occurs between heel strike of one limb and the subsequent heel strike of that same limb and consists of the following phases:

Stance: It begins when heel of the forward limb makes contact with the ground and ends when the toe of the same limb leaves the ground. It consists of:

Heel Strike:	Heel of foot touches the ground.
Mid Stance:	Foot is flat on the ground and the weight of the body is directly over the limb.
Toe Off:	Only the big toe of the limb is in contact with the ground.
Swing:	It begins when the foot is no longer in contact with the ground. The limb is free to move.
Acceleration	Swinging limb catches up to and passes the torso.
Deceleration:	Forward movement of the limb is slowed down to position the foot for heel strike.
Double Support:	Both limbs are in contact with the ground simultaneously.



Typical gait cycles illustrating the phases and events during the cycle.
(From Human Walking, 2nd Edition, Rose and Gamble editors, Williams and Wilkins, Baltimore, 1994, p. 26.)

Lower Limb Prosthesis: An Attempt to Simulate Natural Limb's Functions

People with limb loss (acquired amputation) or limb absence (congenital deficiency) use prosthetic limbs to restore or imbue some of the function and/or cosmetics of an anatomical limb. Solutions differ in the way they 'mimic' the natural foot's functionality (or a part thereof).

DEVELOPMENT OF JAIPUR FOOT

Ram Chandra, born into a family of master artisans, is commonly recognized as one of Jaipur city's finest sculptors. Growing up, Chandra saw that local people who were amputated were fitted with artificial limbs, either imported from abroad or locally made, that were not flexible enough and did not allow for a normal range of motion. The prosthesis did not facilitate postures common in India such as squatting or sitting cross-legged. Further, the shoes attached to the limb were made of heavy sponge, which made the prosthesis useless for farmers working in the rain or irrigated fields. This led to a high rejection rate of the prosthesis by the local amputee population.

While watching these patients, Chandra came up with an idea of creating an artificial limb that more closely resembled a natural foot, was lighter and was tailored for local conditions. He took his ideas to doctors at the city hospital and learned about human foot anatomy. Equipped with this knowledge, Chandra experimented with locally available materials such as willow, sponges and aluminum molds to create an artificial limb.[13]

One of many defining moments came one day when Chandra suffered a flat tire while riding his bicycle. According to Chandra, he went to a roadside stall whose owner was retreading a tire with vulcanized rubber. Once his bicycle was fixed, Chandra rushed to doctors to determine if this material could be used for a limb. Later he returned to the tire shop accompanied by an amputee and a foot cast, and asked the owner to make a rubber foot. The foot had the mobility and durability that Chandra sought, although it had to undergo numerous refinements. Working further with Dr. P.K. Sethi, an orthopedic surgeon.and Dr. S.C.Kasliwal and Dr. Mahesh Udawat, Chandra refined and improved the design to eventually create what is now known as the Jaipur Foot. To facilitate the spread of the foot, its creators decided not to patent the Jaipur Foot.

Step 1: Design Considerations

The Jaipur Foot was designed to simulate normal foot movements and provide a quality solution for the masses. For those poor in India who had lost their limbs, continuing to earn their livelihood was the biggest concern. In absence of an efficient social security system, being able to work was essential for their survival. It necessitated a prosthesis, which supported their work and lifestyles. Jaipur Foot's design process emphasized the following activities, which are commonly enjoyed by India's working poor:

ACTIVITY	MECHANICAL REQUIREMENT [14]
Squatting	Need for dorsiflexion
Sitting Cross Legged	Need for transverse rotation of the foot
Walking on Uneven Ground	Need for inversion and eversion in the foot so that varying terrain is not transmitted to stump
Barefoot walking	Cosmetically similar to natural foot

Step 2: Overcoming Constraints

However, the technical demands were not the only demands forced by the creators of Jaipur Foot. In addition, they faced the following constraints.

CONSTRAINTS	IMPLICATION
Poverty	The vast majority of local amputees were poor. Lower cost of prosthesis with the possibility of alignment and adjustments would facilitate specialized yet equally functional solution.
Closed Economy	Limited import of foreign materials in India meant the foot had to be fabricated from readily available local materials
Work Lifestyle	Most amputees worked hard and long hours. The ability to walk on uneven ground was essential for their work. India was largely an agricultural economy, and days spent without limbs threatened their livelihood and in many cases sustenance. This led to a need for accessible prosthesis that could be fitted quickly.
Limited Trained Manpower	Lack of skilled labor relative to the huge demand for prostheses necessitated a simplified manufacturing process, which could be performed with limited training.

Step 3: Deviation from Traditional Design

The design of Jaipur Foot was initially based on the SACH foot design.[15] However, the design divorced away from the SACH foot due to problems such as weight and non-suitability to local conditions. The endoskeletal design was pursued, and a new, knee joint design evolved. Distortions were introduced in the sockets so that adequate pressure was put only on those tissues, which could resist them. Total contact sockets also were introduced.

Jaipur Foot is made of three blocks simulating the anatomy of a normal foot. The forefoot and heel blocks are made of sponge rubber and the ankle block consists of light wood. The three components are bound together, enclosed in a rubber shell and vulcanized in a mould to give it the shape and cosmetic appearance of a natural foot.

Below-knee as well as above-knee prosthesis products are indigenously designed and fabricated from locally available and durable high-density polyethylene pipes and a Jaipur Foot. These are rapid-fit limbs with low fabrication times. Fitting and fabrication times vary from one hour for below-knee prostheses to about five to six hours for above-knee prosthesis. Functionality of the prosthesis mirrors that of a natural human limb, and it permits amputees to run, squat, sit cross-legged, climb trees and jump from heights. The Jaipur Foot is waterproof and does not require maintenance after it is fitted. Barefoot walking is possible, an amputee can work in wet and muddy fields and the foot is suitable for any type of terrain. The patient also can wear shoes. Bio-mechanically, it is based on the standard Patella-Tendon-Bearing prosthesis and scientifically fabricated to meet its weight distribution requirements for maximum comfort. Average weight of the prosthesis is 3.11 kg; the weight of a 55 kg person's lower limb is 3.36 kg.

Step 4: Materials Sourcing

The Society produces the prosthesis with readily available and inexpensive components in order to limit the cost of procurement as well as the cost of the prosthesis itself. A typical Jaipur Foot, shank and simulated knee joint is constructed with the following materials:

COST ANALYSIS OF ABOVE KNEE LIMBS WITH PLASTIC KNEE JOINT				
S. NO.	NAME OF MATERIAL	QUANTITY	RATE	AMOUNT
1.	Jaipur Foot	1 No.	120.25/No.	120.25
2.	HDPE Pipe 90 MM	0.60 RMT	146.16/Mtr.	87.70
3.	HDPE Pipe 110 MM	0.60 RMT	219.25/Mtr.	131.55
4.	Plastic Knee Joint	1 Set	100/Set	100.00
5.	Plaster of Paris	4 Kg.	4/Kg.	16.00
6.	Stockinatte 2"	150 Gms	115/Kg.	17.25
7.	Stockinatte 4"	200 Gms.	115/Kg.	23.00
8.	A.K. Belt	1 No.	39/No.	39.00
9.	Elastic belt	1 No.	10/No.	10.00
10.	Cotton Bandages	3 Nos.	4/No.	12.00
11.	Dunlop Solution	20 Gms.	90.8/Kg.	1.81
12.	Steel Screw	4 Nos.	0.13/No.	0.52
13.	Press Buttons	4 Nos.	0.06/No.	0.24
14.	Soap Stone Powder	50 Gms.	2/Kg.	0.10
15.	Loctite	1/4 Tube	0	5.00
	Total Material Cost			564.42

IUS$ =Rs.45

The estimated US$7.68 cost of materials outlined above includes the cost of the components of the Jaipur Foot itself as well as the simulated joints for a below-knee limb. Each material is locally sourced and does not require special procurement agreements. Most are virtual commodities. Furthermore, most of the materials can be sourced locally if necessary when the Jaipur Foot is manufactured in other developing nations.

Step 5: Production Equipment

The Jaipur foot, as well as the calipers and other portions of the prosthesis ultimately fitted on the patient, is constructed with very basic tools. Most of the fabrication process is completed with the tools of an ordinary artisan. The most specialized piece of equipment consists of the foot-shaped die used to mold the shape of the foot. However, its cost is not significant enough to even warrant listing on a fixed asset schedule. The most expensive piece of equipment is the vacuum-forming machine used to get exact replica of the mould and is used when heated HDPE sheet or pipe is draped over the mould of the patient's remaining limb (stump). The machine costs approximately 200,000 Rupees, or roughly US$4,000. For heating pipe and sheets a machine is used which resembles an ordinary oven. The machine is commonly found throughout India and the rest of the developing world. The Jaipur location of the Society requires two vacuum forming machines to serve an estimated 60 patients per day. Each machine lasts from five to seven years

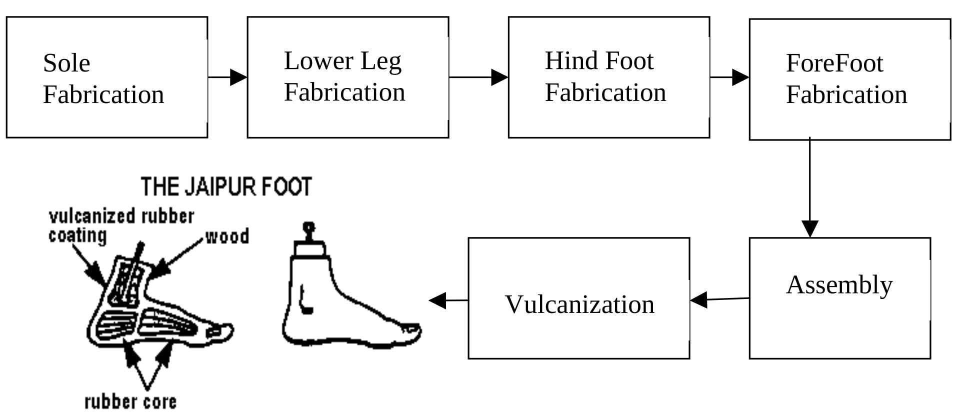
Step 6: Labor

Fabrication of the Jaipur Foot, as well as the process by which a patient is fitted, is a very labor-intensive process. This process capitalizes on the large supply of skilled artisans in India and their manageable labor rates. A Jaipur Foot artisan is a craftsman with several years of experience and is further trained for several more years to mold, sculpt and form the Jaipur Foot. The Society typically schedules 70 trained technicians and artisans each day to achieve a one-to-one patient-to-employee ratio. Artisans and technicians, who are more experienced artisans, operate in a supervisory capacity and are paid by the hour plus overtime. A typical artisan earns 5,000 Rupees per month, or roughly US$100 including benefits. The estimated US$1,200 annual income of an artisan is approximately twice that of the per capita income in India.

An on-site doctor supervises the entire fabrication and fitting process. The Society has one doctor on the payroll full-time. In addition, other local doctors either volunteer their time or work on a part-time basis to ensure that a certified physician approves a patient's final prosthesis and fitting.

Step 7: Fabrication

Fabrication of Jaipur Foot is a fast and simple process. The foot incorporates locally available materials/equipment. These include a die, tread rubber compound, sponge rubber, cosmetic rubber, nylon cords, a vulcanizer, wood and scissors. Foot and ankle assembly is made of a vulcanized rubber compound. An aluminum die is used to cast a normal foot shape. The die consists of four sections, which can be bolted together. This allows for ease of setting up different material components. The process thus involves several stages with serial sequences of plaster mould-die in four sections. The position of under-surface of the foot and toes is slightly rocketed with the toes slightly off the ground to achieve the rolling action. The heel is kept slightly off the ground to accommodate the heel when worn in the shoe. This complements the 'rocker' action of the foot. Please refer to *Appendix D* for details of fabrication process.



Jaipur Foot Fabrication Process

Step 8: Fitting of the Jaipur Foot

Nearly 60 patients each day obtain prostheses from Jaipur Foot's main facility in Jaipur, India. Remarkably, unless other medical conditions intervene, each patient is custom fitted with a prosthesis in one day – usually within three hours. The goal is to return the patient to their profession and an independent life after the patient's first visit to the clinic.

However, the Society's desire to accommodate the social requirements of India's poor does not consist solely of the speed of service. The Society's operating process also attends to the psychological needs of its patients. The Society provides on-site meals and overnight accommodations to patients at no cost. These services are shared with other patients in order to provide an immediate support group for the patients and to develop a sense of community within the facility. Additionally, free meals and accommodations are provided to the patient's family members, again at no cost. This permits family members to affordably travel with patients and provide on-site support and comfort. A typical patient experience to receive a Jaipur Foot might proceed as follows:

Monday	**1:00 PM**	The patient catches a train from New Delhi to Jaipur, India. The patient's husband and child accompany her on the journey.
	6:00 PM	The family arrives at the front gate of the Society in the heart of Jaipur. A guard at the gate of the one-story facility admits the family inside.
	6:30 PM	The family joins other patients and family members at a communal dinner prepared by the Society's food service employee.
	9:00 PM	The family sleeps on mattresses in a large room within the facility's modest housing wing.
Tuesday	**8:00 AM**	The family shares breakfast with other patients and families at the facility.
	8:30 AM	The patient joins the line forming in the Society's inner courtyard and awaits registration.
	9:00 AM	A doctor checks the patient and outlines the prosthesis that is required. The patient will keep the card until it is given to a technician.
	9:10 AM	prepared for a cast.
	9:30 AM	A trained artisan wraps a cast around the limb, forms it tightly around the limb and removes it.
	9:45 AM	The patient is ushered back to the inner courtyard and waits. The artisan pours a mold into the cast, lets it dry, and then carves it to the limb's specifications under the supervision of a technician.
	10:15 AM	A common polyurethane pipe is heated in a vacuum forming machine, is removed, and is stretched over the mold of the patient's remaining limb.
	10:30 AM	polyurethane prosthesis.
	11:00 AM	A prefabricated Jaipur Foot is attached to the prosthesis.
	11:30 AM	The patient is ushered back into the medical wing of the facility and a technician fits the prosthesis to the patient.
	NOON	The on-site doctor supervises as the patient tests the new prosthesis in the inner courtyard. The patient describes some modest discomfort as she walks around a separate inner courtyard.
	12:15 PM	prosthesis.
	12:30 PM	The patient and her family share lunch at the facility.
	2:00 PM	The family catches a train back to New Delhi.
	7:30 PM	The family returns home to resume a life similar to their lives before the loss of the patient's limb.

Competitive Benchmarking

Jaipur Foot supports developing country lifestyles (such as squatting, sitting cross-legged, walking on uneven surfaces and barefoot walking) while a conventional SACH foot does not. Please refer to *Appendix B* for a comparison of Jaipur Foot with the conventional prosthesis (SACH foot).

The table below details comparison of Jaipur Foot with VariFlex (Ossur) and TrueStep (College Park Industries), two leading prostheses in the developed world. The table compares the prostheses for range of motion, general attributes such as cost, activities supported, and quality standards to which they adhere.

Jaipur Foot provides for an excellent range of dorsiflexion movement. As the table demonstrates, though not explicitly superior to the Western prosthesis shown, the Jaipur Foot possesses technical characteristics that make it a comparable product. The clear differentiating features are the respective prices and the years of introduction of the products. The Jaipur Foot presents an interesting comparison to the Western prosthesis at a price performance basis despite being introduced nearly two decades before its Western counterparts. Furthermore, the Jaipur Foot compares favorably on the activities for which it was designed, especially walking barefoot, working in wet fields, walking on uneven ground and climbing trees.

FEATURE/ FUNCTION	VARIFLEX [16] (SINCE 1990)	COLLEGE PARK FOOT [17] (SINCE 1991)	JAIPUR FOOT [18] (SINCE 1968)
Range of Motion			
Dorsiflexion	Limited Dynamics	25^0	40^0
Plantar Flexion	Limited Dynamics	25^0	0^0
Inversion	12^0 (split toe version)	12^0	10^0
Eversion	12^0 (split toe version)	12^0	10^0
Supination	Not Applicable	20^0	7^0
Pronation	Not Applicable	20^0	5^0
Attributes			
Cost (Foot Piece)	$1,400	$1,059	$5 (240 Indian Rs.)
Average Cost (including Prosthesis & Fitting) *	$3,700	$2,700	$30 (1500 Indian Rs.)
Fitting/Fabrication time	1-2 hours.	1-2 hours	2 hours
Foot piece Weight	240g	510 g	850 g
Size/weight rating	Up to 166 kg	Up to 160 kg	Not rated
Adjust for heel height change	Low/high heel options	No	No
Warranty	30 months	36 months	None
Maintenance Requirements	None	Limited	None
Average Life	2-3 years	3 years	2.5 – 3.0 years
Activities Supported			
Work in wet fields	Yes	Not recommended	Yes
Walk barefoot	Special sole required	Yes	Yes
Sit on floor	Yes	Yes	Yes
Squat	Yes	Yes	Yes

FEATURE/ FUNCTION	VARIFLEX [16] (SINCE 1990)	COLLEGE PARK FOOT [17] (SINCE 1991)	JAIPUR FOOT [18] (SINCE 1968)
Drive a car	Yes	Yes	Yes
Ride a bike	Yes.	Yes	Yes
Walk on uneven ground	Yes (split toe version)	Yes	Yes
Climb trees	Yes (with Limitations)	Yes (with Limitations)	Yes
Hike	Yes	Yes	Yes
Swim	Yes	Not Recommended	Yes
Run	Yes	Yes	Yes
Quality Standards			
CE Marked	Yes	Yes	No
Additional	ISO 10328 standard		Internal Quality standards

*This is average cost for complete solution, which may involve multiple clinic visits. Actual costs will vary depending on options chosen.

Community Outreach: Providing Access

Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS)

The designers of Jaipur Foot quickly discovered that designing a prosthesis that could withstand the rigorous use of India's poor was only the beginning. The next challenge was to construct an organization and operating system, which could make the Jaipur Foot available to as many amputees as possible. The expectation was that nearly all prospective amputees would fall below the poverty line. Subsequently, Jaipur Foot's custodians focused their attention on the financial and social needs of India's working poor. Their efforts eventually took the form of the nonprofit society named Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS), generally referred to as "the Society."

The desiging of the prosthesis that could withstand use by India's poor was only the beginning. The next challange was to construct an organisation and operating system; which could make Jaipur Foot available to as many amputees as possible. The expectation was that nearly all of the prospective amputees would fall below the poverty line. To meet the financial and social needs of the amputees and also to promote further technical development, a non-profit society named Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS) was established in March 1975 by Mr. D.R. Mehta. In the first 7 year after the development of Jaipur Foot in 1968, hardly 50 limbs were fitted. In the first year sfter the formation of the society 59 limbs were fitted. Now, the number of limbs fitted every year is around 16,000. Between the March 1975, when BMVSS was established to March 2003, BMVSS has fitted 236,717 limbs in India and 14,070 around the world (Please refer to table below). But for the value system and patient centric management practices followed by BMVSS, Jaipur Foot might have remained on the shelf and in limbo. The BMVSS emphasizes a holistic approach to addressing the problems of amputees. The society focuses on not only the medical problems of the underprivileged, but also the financial and social problems as well.

The society has laid down extremely simple procedures for reception, admission, measurement taking, manufacturing, fitment and discharge of patients. Unlike in all other medical centers all over the word, patients are admitted as they arrive without regard to the time of day. Further patients are provided boarding and lodging facilities at the centers of BMVSS till they are provided with limbs, calipers or other aids. In most orthopaedic centers in the world, patients must come back several times for a custom fit. This process could take several weeks. Such a system would be unsuitable to the poor patients who find it extremely difficult, both in physical and financial terms, to come back a second time from long distances. Jaipur Foot is custom fitted on the same day; in fact in less than 4 hours. Most significantly the prosthetics orthotics and other aids and appliances are provided totally free of charge to the handicapped. But for this policy, virtually more than 90% of the patients would have remained deprived of artificial limbs, calipers and other aids and appliances. The setting up of patients oriented value and management system was an equally important innovation.

BMVSS has ten branches in India. In addition, there are approximately 60 workshops that fabricate or fit the Jaipur Foot in India. The Society also has aided the establishment of several centers abroad. Funded by the Indian government and philanthropic groups, BMVSS and similar organizations offer medical care, room, board, and a prosthetic at no cost to the patient. It also has helped launch free clinics in more than a dozen countries.

INDIA: NUMBER OF ARTIFICIAL LIMBS AND OTHER AIDS DISTRIBUTED BY BMVSS

Artificial Limbs	219,450
Calipers	152,165
Tricycles	36,941
Crutches & Other Aids	225,492
Hearing Aids	6,666
Polio Surgery	3,860

Source: Jaipur Foot (BMVSS)

World: Number of Artificial Limbs and other aids distributed By BMVSS

Afghanistan	1,355	Panama	400
Bangladesh	1,000	Philippines	3,000
Dominican Republic	500	Papua New Guinea	170
Honduras	400	Rwanda	500
Indonesia	600	Somalia	1,000
Malawi	250	Trinidad	200
Nigeria	500	Vietnam	600
Nepal	200	Zimbabwe	250
Nairobi	500	Sudan	1,800
		TOTAL	13,225

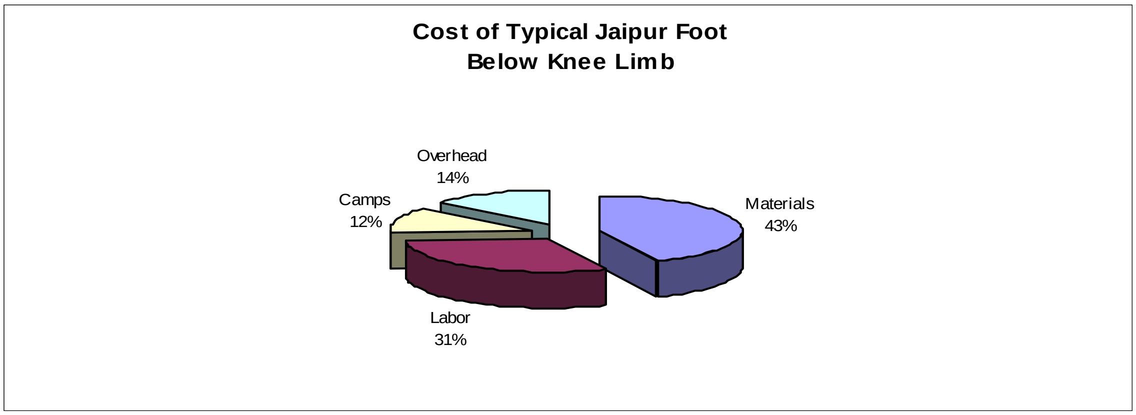
Source: Jaipur Foot (BMVSS)

Jaipur Foot: Filling a Social Need

The determination was made at the outset that the Jaipur Foot prosthesis would be provided free by means of a nonprofit framework. The prospect of no additional funds realized for additional prostheses fitted forced administrators to focus on containing costs. In particular, emphasis was placed on the cost of the materials used to construct the Jaipur Foot, the capital equipment required to fabricate the foot and the method by which the foot was fitted to a patient in order to make the prosthesis widely available.

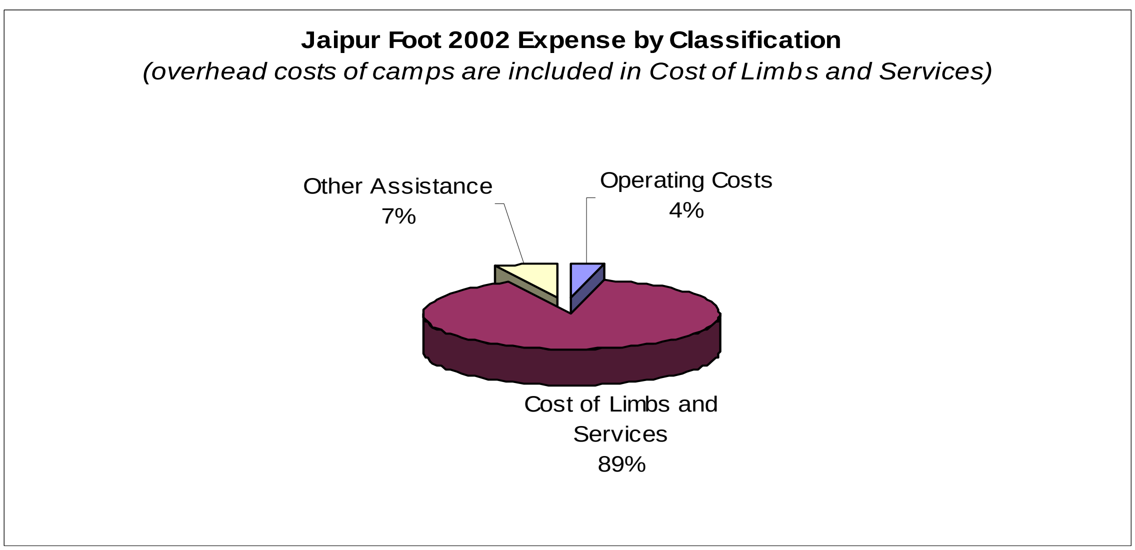
Jaipur Foot Operations

The result is an organization that spends nearly 74% of its cost on the materials, labor and services necessary to fit amputees with a prosthetic limb. The following diagram estimates the cost components of providing each Jaipur Foot:



Source: BMVSS Adjusted Cost Report

Only 14% of the cost of a typical Jaipur Foot goes toward meeting overhead and administrative costs. The remaining cost goes toward the materials used in the foot, the labor employed to manufacture and fit the limb and the cost of running camps, which reach the poor throughout India and beyond. This cost efficiency is also reflected in the Jaipur Foot's annual expenses:



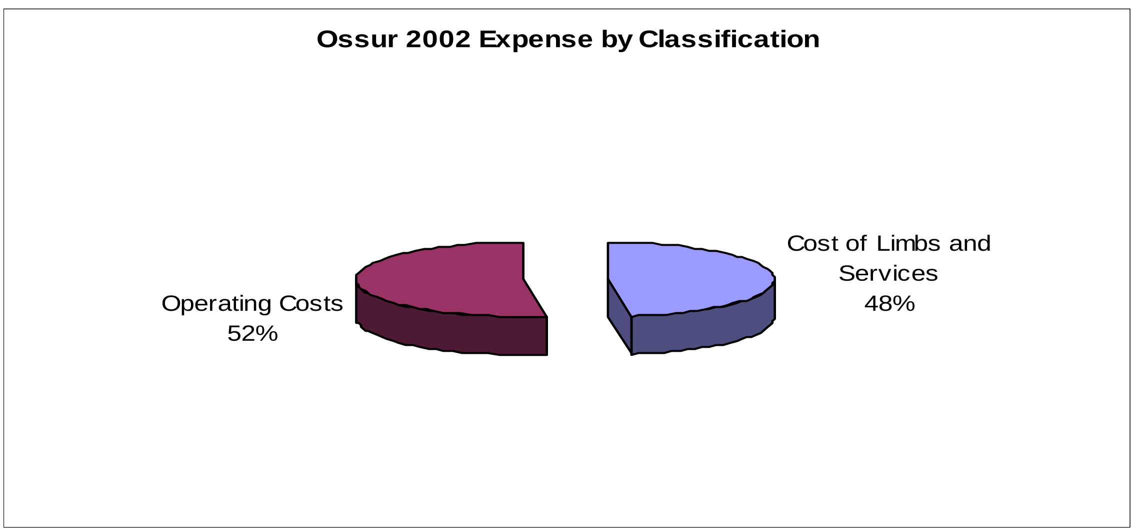
Source: BMVSS Adjusted Cost Report

Jaipur Foot's expense breakout for the 2002 fiscal year underscores the efficiency of expense and underpins the Society's effort to serve as many patients as possible given its financial resources. Nearly 90% of the company's expenses in the 2002 fiscal year were directly related to the cost of producing and fitting prostheses for the poor. Another 7% of the company's expenses went toward other forms of charitable assistance. Only 4% of its expenditures went toward administrative and overhead expenses.

Comparison with Ossur

The Society's cost structure differs significantly with that of Ossur, an Iceland-based publicly traded company that manufactures, markets and sells prostheses throughout Europe and North America. Ossur is the second-largest producer of prostheses in the world.

As the diagram demonstrates, just over half of Ossur's annual expense goes toward administrative and operating costs while half its expense goes toward the actual cost of producing prostheses. A more detailed examination of the annual financial statements of Jaipur Foot and Ossur reveals that a significant portion of Ossur's expenditures are related to sales and marketing (21%) and research and development (9%). Although this disparity in part underscores the different competitive environments, regulatory environments and organizational goals that separate the two organizations, it also provides a framework that underscores the Society's ability to funnel its resources directly to patients.



Source: Ossur 2002 Annual Report

Scalability

Camps

The Society's current method of expanding the reach of the Jaipur Foot to more remote areas of India and beyond is the camp system. Administrators, doctors, technicians and artisans from the Society's Jaipur location travel to a predetermined site and set up a temporary facility referred to as a camp. A camp is typically funded by another private organization or government that has invited the Society to the location. A camp can last from just a few days to several weeks depending on the number of amputees expected to be fitted with prostheses.

A BMVSS physician supervises camps. It takes about one day to set up and a half day to close. The sponsoring organization pays the Society's employees a travel allowance and a per diem while on site. In general, the camp requires one artisan for every two patients expected to be treated per day. Though most of the components of a typical Jaipur Foot and caliper can be locally sourced, the Society usually travels with the expected required materials. Likewise, employees travel with the equipment necessary to fabricate the prosthesis, including a vacuum-forming machine, the largest and most expensive piece of equipment required for fabrication. Any material shortages are usually covered with locally purchased goods with little incident. The sponsoring organization takes responsibility for promoting the camp and for any transportation of amputees.

New Locations

The Society also facilitates the establishment of new permanent locations to fabricate and fit the Jaipur Foot. Although the Society itself supports several locations in India, including New Delhi and Mumbai (Bombay), the Society encourages the establishment of other charitable organizations to run clinics. The Society is active in assisting the new organization in determining the feasibility of clinic location, training of employees and in making the Jaipur Foot available to the clinic.

The Society, in conjunction with a new organization, studies the number of amputees near the new location and estimates the ongoing need for the Jaipur Foot prosthesis. A new location requires a modest level of capital expenditure. The most significant piece of equipment is the vacuum-forming machine at an estimated cost of US$2,000. Additional equipment and tools generally cost another US$2,000. Artisans are trained at the Jaipur facility for up to six months. Virtually all this training takes place with patients and under the supervision of technicians and doctors. The Society maintains and updates a manual, which outlines the fabrication and fitting of the Jaipur Foot to assist in this process.

After the new location is staffed, its employees are trained and the new clinic is ready to fit patients, the Society sends a technician to supervise and support the clinic's initial operations. The number of artisans and technicians at the new facility depends on the expected patient load. Additionally, each clinic retains a doctor to supervise the treatment and fitting of patients. The Society makes the process to fabricate the Jaipur Foot available to the new clinic, or the Society simply produces the required number of prosthesis and supplies it to the new clinic free of charge.

Future of Jaipur Foot

Jaipur Foot Technical Improvements

BMVSS collaborates with hospitals, but is also involved in its own research & development to further improve the limb design. R&D at BMVSS is led by Ram Chandra while Dr. M.K. Mathur, a trained orthopedic surgeon and former head of physical medicine & rehabilitation at a leading hospital, heads the medical and technical effort. Its staff includes doctors, technicians and social workers.

BMVSS/Jaipur Foot has made several changes in the design and manufacture of lower-limb prostheses to keep pace with increases in human understanding of biomechanics and advances in material technology. High-strength plastics are now being used instead of aluminum. Total contact sockets also have been incorporated in the design. However, the custodians of BMVSS have targeted other areas for improvement. The Jaipur Foot currently is being hand designed, which raises the issues of inconsistency, its impacts on quality and reliability.

Furthermore, at 850 grams, the current foot piece is heavy compared to other solutions. Jaipur Foot has not been tested/certified for any well-known international standard. It also has not yet received regulatory approvals for usage in certain developed countries such as United States (such an approval has not yet been sought).

Collaboration with Space Research Organization

BMVSS has signed an agreement with the Indian Space Research Organization (ISRO) to receive ISRO's polyurethane technology.[19] ISRO, established in 1969, is one of the premier space research organizations in the world. Its activities include space research, design, development and launch of satellites and other space vehicles.

The polyurethane technology developed by ISRO is borne out of ISRO's pioneering research and development of various polymeric materials. The materials are to ensure the reliability and quality of launch vehicles and satellites. Polyurethane is a versatile polymer that can be produced in various forms like adhesives, coating materials and in flexible or rigid forms. ISRO has developed PU polymer and its advanced derivatives, which are being extensively used in propellants, cryogenic insulation, thermal insulation pads, structural damping, acoustic insulation and other lightweight structural materials for vibration control, shock absorption liners and adhesives.

This collaboration is expected to reduce the cost of manufacturing a Jaipur Foot. Cost of each foot will be reduced by about 40% to Rs. 140. The foot piece also will become lighter by approximately 60% to 350 grams.

The technology transferred to BMVSS will help produce a more durable and comfortable artificial foot in large numbers. Average foot fabrication time will be reduced from three hours to around 40 minutes. PU foot prostheses would be bio-mechanically advantageous from a comfort level perspective. The slip resistance of the PU foot is much higher than rubber and allied materials used in conventional artificial foot prostheses. Amputees using the PU foot prostheses could walk more safely on any surface since its abrasion resistance is higher. In addition, the PU foot lasts longer.

The polyurethane foam foot molded with cosmetically attractive skin covers has been found to be more acceptable to amputees. The new polyurethane foot has been subjected to accelerated flex fatigue tests, and several amputees have been successfully fitted with such prostheses produced under the technology transferred by ISRO. Field trials have been reported to be encouraging.

Endnotes

[1] www.jaipurfoot.org
[2] Please refer to Appendix A for a description of lower limb functionality and prosthesis
[3] http://www.mossresourcenet.org/amputa.htm
[4] http://www.limbsforlife.org/about.htm
[5] http://www.ottobockus.com/products/op_lower_cleg1.asp
[6] http://www.newbeginnings2000.org/facts.html
[7] http://www.openroads.org/
[8] http://www.pofsea.org/Outreach/Outreach.html
[9] http://www.pofsea.org/Help.html
[10] http://www.dpa.org.sg/DPA/publication/dpipub/spring97/dpi18.htm
[11] http://telebody.com/sihanouk/AboutTheHospital/about-the-Hospital.html
[12] www.nupoc.northwestern.edu/prosHistory.html
[13] Interview with Mr. Ramchandra Sharma (BMVSS)
[14] Please see Appendix for description of lower limb functionality
[15] Interview with Dr. MK Mathur (BMVSS)
[16] Based on inputs from Ossur
[17] Based on inputs from College Park
[18] Based on inputs from BMVSS
[19] The Hindu Business Line (30 July 2002 edition)