CHAPTER -1

INTRODUCTION

The basic design concept of the modern lower limb prosthesis is the result of excellent work done by University of California group of Bio-Engineers who made an in depth study of critical features of human locomotion. Detailed observations of kinematics and kinetics of lower limbs during the act of walking helped them introduce many new ideas in terms of socket designs, stance phase stability, swing phase controls and some radical restructuring of foot piece.

Instead of traditional plug fit sockets which permitted considerable piston action of the stump during stance and swing phases, deliberate distortions in the shape of sockets were advocated so that adequate pressure could be exerted on the tissues where they were tolerant and relief provided where they were not. A close match at the stump-socket interface allowed for more effective weight transmission and also more efficient transfer of stump movements to the prosthesis with minimal energy loss. These developments explain the distortions which so bewilder a novice when he witnesses the modern PTB socket for below knee amputees and quadrilateral sockets for above knee amputees.

The problem of terminal oedema of the unsupported end of the stump in open ended sockets was overcome by introducing the concept of total contact sockets, which incidentally provided a much better sensory feed back to the skin of the stump to enable the amputee to know the position of the stump in space in spite of its distance from the ground.

In short the modern socket designs now provide a bio-mechanically efficient system which allows an amputee to walk faster over a longer distance with an almost imperceptible limp.

Lower limb is not merely a device for bipedal locomotion, but also has many other functional attributes than those envisaged by the sophisticated studies in a highly artificial situation of level walkways in gait analysis laboratories. In real life the demands on the lower limb are very diverse. The life style of an average Indian demands long times spent in position of squatting, sitting cross legged on floor etc. While squatting the ankles have to dorsiflex fully, the knees have to flex till the soft tissues of the thighs and calf can flatten against each other. It is this which allows our center of gravity to fall within our point of support to provide a stable equilibrium so that we do not fall backwards.

To fulfil the unique and diverse requirements of the amputees world over who needed a foot piece which was cosmetically acceptable in bare foot walking, was waterproof, would allow comfortable squatting and sitting cross legged on the floor and would not transmit constantly varying ground reaction to the stump while walking on uneven ground, the 'JAIPUR FOOT' was developed. It was an indigenous marvel.

This obliterated the need to use shoes, which are expensive and wear out quickly in the rough terrain of fields, water ditches, mud etc. where the amputees work. An average Indian would also disapprove of using the street shoes inside the house. Hence a conventional lower limb prosthesis has tobe removed on entering the home.

The makers of the ‘Jaipur Foot” kept the following points in mind while designing it.

(a) It should not require a shoe and should also have a degree of cosmetic acceptance by the amputee.

(b) The exterior should be made of a water-proof durable material.

(c) It should permit an amputee to squat (at least for short periods) by allowing for dorsiflexion.

(d) It should permit a certain amount of transverse rotation of the foot on the leg to facilitate the act of walking as well as to allow cross legged sitting.

(e) It should have sufficient range of inversion and eversion to allow the foot to adapt itself while walking on uneven surfaces.

(f) It should be inexpensive.

(g) It should be fabricated out of readily available materials.

To start with, an attempt was made to modify the standard SACH foot by the addition of a mid tarsal break to allow for some dorsiflexion so that the amputee could squat and sit cross-legged.

Then it was decided to cover this SACH foot with hard rubber moulded to the shape of a normal foot. Technical problems were encountered which were gradually overcome in stages till a satisfactory rubber foot could be made which was indistinguishable from a normal foot.

Amputees provided with such feet could move barefoot in any terrain. But they found it heavy. To make it more acceptable alterations and modifications were made till a model completely satisfactory in all aspects was evolved.

Till date the Jaipur foot has been made as a handicraft, but recently efforts are on to have it machine made. An endeavour is being made by the research team of MVSS to use polyurethane (instead of vulcanised rubber) as a material which is lighter and more durable and which can be made available in rigid forms resembling wood, solid elastomer and as foam of various densities. A variable density polyurethane foot can be cast in one piece using the RIM technique and above all it can be manufactured by automatic machines with excellent quality control with no variables in the quality of products.

Till about 1980’s the above knee prosthesis which were being offered by Dept. of PMR-RRC-Jaipur & Bhagwan Mahaveer Viklang Sahayata Samiti, Jaipur, were basically of conventional exoskeletal variety. In this type of prosthesis the shank and socket were made up of aluminium or HDPE, ‘Jaipur foot’ was used instead of SACH foot and was suspended either with a pelvic belt with hip joint or silasian band. Certain problems were encountered with this design.

(1) The amputee could not squat. The major obstacle to squatting was the rigid crustacean type of thigh and leg piece coming into contact when the knee was flexed beyond 100^{o}.

(2) The weight of the prosthesis was considerable. Elderly or frail individuals could not walk long distances without getting tired.

(3) Most amputees had to stabilize the knee joint manually while walking. This inevitably increased the energy consumption because of the necessity for hip hiking during swing phase.

(4) The time for fabrication of the prosthesis was considerable.

It was for these reasons that a decision for evolving a simple endoskeletal design was taken. It may be emphasized that this was not primarily based on labour saving considerations, as has been the case in the west. The basic thrust was to enable the amputee to squat and to provide a lighter limb for the comparatively light built and frail Indian amputee.

Thus a new design of knee joint was evolved made up of aluminium alloy, its main feature is the offset knee axis, which causes the weight line to pass anterior to it, causing the body weight to act as a force to lock the knee (alignment stability). A locking device with remote control can be added in selected cases.

Before incorporating this design as a standard fitment for the amputees, it was subjected to structural integrity tests at the structural engineering lab at MREC, Jaipur. Several static compression and torsion tests, as per specifications laid down by the bio-engineering unit - University of Strathclyde, DGHS were performed successfully without any structural failure.

A large field trial of 150 amputees was conducted over a period of 1 year, their objective impressions were recorded and subjective analysis of their gait was made, functional capacity tested by getting the amputees to perform activities like squatting, sitting cross legged, walking with different speeds on different grades and inclines without locking the knee and finally the prosthesis was scrutinized for any wear and tear.

The results of these field trials were extremely gratifying. Most of the amputees could squat and sit cross legged on the floor comfortably. The prosthesis was very light, imparted fairly good gait characteristics to the amputees, had greater patient acceptability, ease of production, considerable reduction in fabrication time and substantially reduced total cost of the prosthesis with the possibility of alignment and adjustments throughout the effective life of the prosthesis with inter-changability of the components.

The average weight of this prosthesis is just 3.11 kg whereas, average weight of the whole leg + foot in living human weighing 55 kg. is 3.36 kg so this artificial limb replaces what is lost in an above knee amputation.

Work motion studies conducted during the field trials revealed that it takes just 6 hours and 48 min to completely fabricate this prosthesis, while average fabrication time of conventional prosthesis was 24 hrs. and 6 min. Although the basic idea to develop endoskeletal prosthesis was to enable the amputee to squat and to provide limbs, but the quicker fabrication time and reduction in cost were however welcome spin off.

With the availability of new low weight high strength plastics in India, now the endoskeletal prosthesis is made out of a ilon joint and nylon rods, it has further reduced the weight of the prosthesis and improved its cosmesis.

Since its inception the Jaipur limb technology is upgraded on day to day basis by incorporating all the new technological advancements into it. Gone are the days when all the artificial limbs were made out of aluminium, as soon as high strength low weight ratio thermoplastics were made available in India. An endeavour was made by the research team of Bhagwan Mahaveer Viklang Sahayata Samiti to incorporate them in their limb designs. Now all the limbs are made out of High Density Polyethylene, an excellent bio-inert thermoplastic.

With inclusion of thermoplastics as a material for making limbs, total contact socket concept was also incorporated in the prosthesis made from Jaipur limb technology providing the ultimate stump socket interface. The open ended sockets are a thing of past, now all the limbs provided to amputees are of highly advanced material HDPE and are of total contact variety, enhancing the level of comfort considerably, providing extremely natural gait characteristics to the amputees.

CHAPTER - 2

NORMAL & AMPUTEE LOCOMOTION

Human Locomotion, is a difficult subject to understand; still it is essential that at least some basic concepts of it are understood by all those who are interested in fabricating limbs. Only then would they be able to critically evaluate their handiwork against an analytical framework with a view to making an amputee, whole again.

The present day understanding of this subject stems from the outstanding work done at the University of California at Berkely during World War II under the leadership of Prof. V.T. Inman. This project was sponsored by the advisory committee on Artificial Limbs, National Research Council of U.S.A. and the team consisted of Electrical and Mechanical engineers, physicians, physiologists, orthotists and prosthetists. One cannot avoid leaning heavily on the enormous amount of basic quantitative data made available by them.

Basic subdivisions of Gait Cycle

It is convenient to confine the analysis of the gait cycle to the movements of the body below the umbilicus, though we must recognize that trunk sways, arm swing and head motion play an extremely important role in normal gait. Viewed from the side, one can see that the limb repeats its movements for each step, progressing through a sequence of standing on the ground followed by swinging through the air. By convention, the start of a complete gait cycle is the instant at which the swing-limb heel strikes the ground. Following a progression of events, the cycle ends when that particular heel-strike indicates both 0 and 100% of the gait cycle.

The gait cycle is thus seen to consist of two phases. STANCE, which comprises 60% of the entire cycle, is followed by SWING, the remaining 40%. Since the stance phase is longer, it follows that there is an overlap of phases, when both lower limbs are bearing weight. This is called period of double support. As we walk faster, the period of double support becomes shorter; while running, the period of double support disappears and is replaced actually by a period of double float, with both lower limbs being simultaneously in the air. In competitive long distance walks, the judges are keenly watching for this double float to disqualify a candidate. This amounts to cheating, a walk being converted into a run.

Fig. 2.1

These two phases of support and swing are further subdivided into periods of events known as critical incidents. These incidents are heel strike, foot flat, heel off, knee bend, toe off; they are well illustrated in Fig. 2.1. After the toe leaves the ground, the limb gets into the swing phase. This is subdivided into initial swing, mid-swing and deceleration.

Energy Consumption in Walking

It is not enough that a person should be able to stand and walk, he should be able to walk as efficiently as possible so that energy consumption levels are reduced to minimum.

To be able to understand this, it is necessary to introduce the concept of the Center of Gravity of the body. By reducing the complex human shape to a single point, the subject is simplified and we can then apply the simple laws of physics to understand some of the peculiarities of human gait.

The Center of Gravity (C.G.) of the upright human body lies at level just anterior to the second sacral vertebra within the pelvis; seen from the front it lies just above the pubic symphysis and from the side, just above the tip of the greater trochanter.

If the pathway of Center of Gravity moving in space is followed, a fairly accurate comprehension of energy consumption can be realized. In normal walking pattern, the Center of Gravity undergoes a rhythmic upward and downward motion as it moves forward, describing a sine wave rising and falling a total of about 2 inches. The summit of rise appears when appearing limb is in midstance, and the lowest point occurs at the time of double support when both the lower limbs are separated apart.

In other words there would inevitably be an alternate rise and fall of the Center of Gravity during forward motion. Every time the body is required to be raised against gravity, work is done and an input of energy would be required. Obviously the greater rise and fall of Centre of Gravity, the greater would be the energy requirement.

In absence of a straight line progression, which is going to consume minimum energy, the next most efficient pathway along which the Center of Gravity should move is in the form of sine wave i.e. there should be an equal rise and fall with a smooth and gradual transition from the crest to the trough of this wave form.

It may be pertinent to point out another interesting fact. Walking height of a person is always lower than his standing height. If a person is made to stand in a tunnel with a roof just touching his head, he can continue to walk fearlessly without the risk of bumping his head against the roof. But the moment he stops, his head would strike against the roof.

With the conviction that man, for all his complexity, is a structure capable of undergoing mechanical analysis, an attempt was made to devise a mechanical model for more exact engineering studies of gait. A simple pylon of average limb length was fitted with a non-articulate foot. Instead of the sine wave pattern of human locomotion, the tracing of C.G. path was a series of connected arcs with sharp reversal points. They are described by the moving center of gravity at the tip of the artificial greater trochanter, given an average stride length, was found to produce a 3 inch vertical displacement from heel strike to mid stance. The 3 inch C.G. shift of the model would produce a 50% greater expenditure of the energy in

Fig. 2.2

elevating the body weight with each step than normal, and to this will be added additional energy expenditure due to sharp up and down movement of Center of gravity as there would be a complete halt and then a restart of the movement at the end of each step.

How is this remarkable sine wave progression of C.G. brought about? There exist six mechanisms in human body which convert these connected arcs of the movements of C.G. of mechanical model into smooth undulating sine wave, and these are so important and crucial that Inaman and Saunden called them " The Major Determinants of Gait".

To understand this mechanism, look at fig. 2.2. It shows two triangles. In triangle A the length of the sides is X inches, of base is Y inches, and the height is h inches. If somehow Z inches could be added to the length of sides of triangle A, situation would become as shown in triangle B, where the height of triangle has become H inches, which is more than the height (h inches) of the former triangle A.

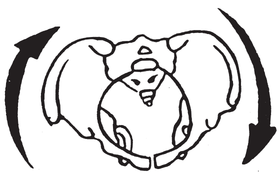


Fig. 2.3

FIRST DETERMINANT OF GAIT - PELVIC ROTATION

In human locomotion at the start of double support, the swing limb is at the heel strike and the stance limb is at the heel off, thus forming a triangle, the apex of which establishes the C.G. height from the ground, which is at its lowest point of undulating path: this situation is something shown in figure 2.2 A. The pelvis at this time rotates 4º forward with the swing limb and 4º backwards with the stance limb. This actually increases the length of the lower limbs, creating a situation like figure 2.2 B, where Z inches have been added to X inches, increasing the height of the triangle consequently elevating the C.G. at the lowest point of its excursion.

By horizontal pelvic rotation alone, the theoretical 3 inches up and down excursion in a series of arcs, the lower most point of arcs is raised by 3/8 inches. The curve thus becomes flatter (Fig. 2.3).

Second Determinant of Gait - Pelvic tilt

It is generally assumed that when a person stands on one leg, the pelvis on the unsupported side rises. This is the basis of the classical Trendelenburg Test.

This is not true, however, when we are walking. An elevation of the pelvis on the unsupported side would raise the level of C.G. and this would require extra energy expenditure. Actually a person always walks with a mildly positive Trendelenburg sign. The pelvis always tilts down on the unsupported side. Thus when the lower limb becomes vertical in the midstance phase, the resulting rise in C.G. is reduced by a 5^0 drop of the pelvis on the unsupported side. This is a controlled drop and the gluteus medius muscle carefully allows this by undergoing a lengthening or eccentric contraction. This controlled drop of the pelvis is an energy saving device; an uncontrolled drop, however, is energy consuming because such an excessive drop leads to an unstable equilibrium and to save oneself from falling, the excessive suprapelvic trunk deviation becomes essential.

Fig. 2.4

The lowering of C.G. at the crest of the summit has been found to be about 3/6 inch, due to this controlled pelvic tilt (Fig. 2.4).

Third Determinant of Gait - knee Flexion at Heel Strike

At the time of heel strike, the lower limb has to reach out by nearly fully extending the knee. As the foot is lowered to the ground, there commences a flexion of the knee which reaches a figure of 15^0 at foot flat, so during midstance phase, the knee is never fully extended. It is this which prevents a walking person from reaching his full standing height. This initial knee flexion is actually a diminution in rise of the C.G. summit by 7/16 inch

This knee flexion after heel strike serves another very useful purpose. It dampens the impact of ground reaction much as a shock absorber.

If the individual contributions of the first three basic determinants viz. pelvic rotation, pelvic tilt and knee flexion after heel strike are added up, the 3 inch vertical excursion of the C.G. of the mechanical model gets reduced by 1 inch i.e. up and down movement of C.G. is now only 2 inches (Fig. 2.5). However, the pathway still remains a series of arcs with abrupt reversal at the

Fig. 2.5

low point, instead of the efficient, smooth, undulating sinewave path.

These abrupt reversal arcs are smoothened out by the fourth and fifth determinants of gait, which are best considered together as they are intimately related.

Fourth Determinant of Gait - Foot and Ankle Motion

The axis of movement at the ankle rises and falls along an interesting pathway. Its distance from the ground depends on the verticality of the calcaneum. At heel strike the calcaneum is relatively vertical but as the forefoot drops the calcaneum becomes more horizontal. Thus the ankle axis which is high initially gradually falls at foot flat, where it remains at a fixed level till, after mid stance, the heel rises from the ground, causing the center of rotation at the ankle to rise again (Fig.2.6).

Fig. 2.6

Fifth Determinant of Gait - Knee Motion

As already mentioned the knee starts to flex immediately after heel strike, simultaneously as the ankle axis is also falling during foot flat. Then the knee reverses its action to one of extension while the ankle remains level. This concurrent knee and ankle action serves to smoothen out the C.G. pathway which otherwise would have included an abrupt reversal point.

Fig. 2.7

As the heel rises, the knee simultaneously flexes. These cancel out each other and the pathway assumes a smooth, undulation character (Fig.2.7).

Sixth Determinant of Gait - Lateral Pelvic Motion

The C.G. lies in the midline of the pelvis, just anterior to second sacral vertebra, and is located about 4 inches from the hip joints; when the weight is shifted over one foot, the C.G. has to be brought over the point of support to establish equilibrium. In other words a person has to shift his body from side to side at each step. One can appreciate this when two people are walking side by side. If they walk out of step, they keep on bumping against each other.

If the lower limbs were suspended down in a vertical line from the hips, the width of our walking base would be about 8 inches. This would lead to a very marked lateral shift of our C.G. from step to step.

Two important anatomical features, however, narrow our base of support. One is the relative adduction of the femoral shaft in varus in relation to the hip joint, and the other is the tibio-femoral angle which allows the tibial shafts to drop vertically in valgus. This leads to the width of the walking base which is only 4 inches or so. This allows the shifting of the C.G. only 1 inch laterally towards the stance foot, resulting in a total C.G. displacement of 2 inches per gait cycle.

The total excursion of the C.G. occurs within a square box of 2 inches. It would of course be appreciated that the up and down movement occurs twice during each gait cycle while lateral movement occurs only once (i.e. from heel strike to heel strike). This composite movement of C.G. projected in a coronal plane describes an almost perfect figure of eight. A three dimensional picture of the pathway of C.G. is that of a spiral.

Axial Rotation of Limb Segments

During walking not only the pelvis rotates, tilts and sways, there is considerable rotation of various limb segments about their long axis. The thigh rotates on the pelvis, leg rotates on the thigh; this rotation is transmitted to the foot. At the time of heel strike the lower limb is in internal rotation; it reaches its maximum of 4^0 at foot flat; this is followed by an abrupt reversal and the lower limb goes into external rotation reaching its maximum of 5^0 at the toe off. In swing phase there starts a progressive serial internal rotation, so that when the same limb reaches for heel strike again it is in internal rotation.

This fact of axial rotation is very important in the design of prosthetic foot piece. Most conventional foot pieces (e.g. SACH foot) have no provision for allowing a rotation of the shank on the foot piece. Therefore this rotation takes place at the stump socket interface. If the stump is scarred or tender, this causes a lot of discomfort. Herein lies the superiority of the Jaipur foot. Its design permits considerable transverse rotation of the shank on the foot piece. This absorbs a lot of ground reactions at the shank level and thus protects the stump.

Foot and the Gait Cycle

The behaviour of the foot has to be altered considerably during the different phases of gait cycle. At heel strike, the foot has to be gently lowered till it gets fully grounded and here it must be supple and mobile to be able to adapt to the contours of the ground. As it gets loaded, it has to become increasingly rigid, so that when the heel is lifted off the ground, foot is braced to provide a rigid lever for an effective push off.

There is a locking and unlocking mechanism provided at the level of the mid-tarsal joint and this, in turn, is related to whether the subtalar joint is inverted or everted. If the heel is everted, the forefoot can be moved up and down very considerably - the foot is unlocked. But if the heel is inverted, this excursion becomes markedly restricted.

The axes of talonavicular and calcaneo-cuboid joints are parallel to each other when the foot is everted and so the foot is mobile. During inversion, however, these axes are no longer congruent and midtarsal joint gets locked.

Inversion and eversion, in turn, are related to the rotation of legs; here the subtalar joint acts as a metered hinge joint. External rotation of the leg inverts the foot, while internal rotation everts it.

When a person walks, he has to reckon with two major forces: first, the pull of gravity and second, the forces generated by the muscular contractions. Analysis of both these forces makes it possible to measure the magnitude and direction of the external forces acting on the limb during the different phases of gait (Kinetics).

AMPUTEE LOCOMOTION

The appearance of normal gait is the sum total of various characteristic determinants of human locomotion. The gait of an amputee will depend upon the condition of the determinants he has remaining e.g. joints, skeletal links and muscles, the extent to which the prosthetic replacements mimic the original body parts, and the interface between body and prosthesis.

In below knee amputees, the knee and hip are intact; thus, provided there are no contractures, they can be expected to walk as normal persons. The patellar tendon bearing (P.T.B.) prosthesis with cuff suspension permits the amputee to flex his knee from heel strike through a foot and extend it from foot flat to midstance. The swing phase is controlled by muscles which are intact but a little abnormality may be observed as hyperflexion at knee and hip to allow swing through.

However, after good alignment of a well fitting prosthesis, the below knee amputee can be regarded as having a minimum of disability. The success of the prosthesis depends upon an intimate fit of socket and prosthetic foot designed to minimize the loss of ankle function.

To obtain an intimate fit of the socket, the present H.D.P.E. design was developed, and it has very successfully achieved it. The superiority in the present design lies in its foot piece - the JAIPUR FOOT.

An amputee using SACH foot has to vault because of long keel; in the Mahaveer prosthesis, the foot piece is fixed in plantigrade position thus obliviating any need to vault.

Conventional prosthesis does not accommodate for the axial rotation of the limb segments. The force generated by these rotations must either be absorbed in the superficial layers of the skin at the socket stump interface or at the ground. Shearing forces within the socket may seriously irritate stump tissue. Rotational forces between the foot and the ground may create instability by forcing the foot to rotate on the ground. The Jaipur foot permits considerable transverse rotation and all the movements in this plane are completely absorbed by it. No forces are created either at the socket stump interface or at the ground.

In prosthetic feet, plantar flexion bumpers which are too soft produce an apparent “foot slap” and those that are too hard do not simulate plantar flexion. Dorsiflexion bumpers which are too soft tend to produce an apparent “drop off”.

Resilient bumpers or springs have a reasonably characteristic load versus deflection curve and therefore do not respond adequately to the changing moment generated in walking The Jaipur foot is a complete unit and does not have adjustable bumpers. It has an excellent range of dorsiflexion (40^0) and is fixed in plantigrade position, thus mimicking normal action of the foot from heel strike to toe off.

In the SACH foot, the ankle or center of rotation in the sagittal plane has effectively been relocated somewhere in the heel, the resiliency of which determines both the range and rate of ankle plantar flexion under force applied. The SACH foot provides no dorsiflexion in the range of motion about the ankle and tends to shift the center of pressure under the foot rapidly to the “ball” represented by the end of keel. Whereas in Jaipur foot, the center of rotation is at the ankle level only and as described has excellent range of dorsiflexion, thus providing natural characteristics to gait, and so much mimics a normal foot that most of the time the onlooker is at a loss to recognise the artificial limb.

CHAPTER - 3

FABRICATION OF JAIPUR FOOT

BASIC REQUIREMENTS OF A FOOT ANKLE ASSEMBLY

FUNCTIONAL STRUCTURE AND BIOMECHANICS OF THE ANKLE AND FOOT

The ankle and foot possess exceptional importance, since they constitute the terminal portion of the limb. The ankle joint is the strategic location for application of the muscle movements which initiate the forward swing of the limb and of those which cushion the application of the foot to the ground. Freedom of body movement requires an ankle joint which is flexible in more than one direction. Irregularities of terrain imperil security unless the foot and ankle are able to adapt themselves properly. To accomplish these functions there are three joints in the ankle region and numerous additional ones in the rest of the foot. Since the intricacies of the normal foot are beyond the possibility of prosthetic imitation, it will suffice to indicate the salient characteristics of the normal ankle and foot, so that the limitations imposed by their prosthetic counterparts may be well understood.

The two chief joints of the ankle region are separated by a single bone, the talus. Since this bone receives no muscle insertions, the same muscles pass over both joint. It is consequently appropriate to refer to them as the upper and lower ankle joints, although the technical designation is “talo-crural” for the upper and “sub-talar” for the lower. Movement is taking place simultaneously in both joints; the resultant axis combining both movements will be within a thin disk of tissue which is parallel to both axis. The two axis almost intersect, but not quite, so that an accessory translation does not take place along the resultant axis.

The normal foot is provided additional flexibility by the presence of the midtarsal joints. It has one part in common with the sub-talar joint, namely, the contact of the condyloid head of the talus with the concavity of the navicular. The other part is located more laterally and involves the saddle-shaped joint between the calcaneus and the cuboid. Because half of the midtarsal joint is also a part of the sub-talar, it is possible for inversion in the sub-talar joint to affect the mid-tarsal so as to make it more rigid when the foot is engaged in propulsion. Normal feet vary widely in the extent to which they allow mid-tarsal movement, the more flexible feet exhibiting a flattened longitudinal arch when they sustain the weight of the body.

The metatarsal bones extend forward to form five rays capable of exerting force on the ground through their heads, which form the skeletal elements in the foot. Each of the metatarsals participates in this function, not the first and fifth alone, so the foot in no sense resembles a tripod. The variables are formed by the metatarsal heads.

In each of these joints the chief movement is a simple rotation about a single axis, the location of which is shown in the figure (3.1). The movement in the upper ankle joint, which brings the toes closer to the knee is known as “dorsiflexion”, the opposite movement being “plantar flexion”. The axis of the lower or sub-talar joint is obliquely placed, allowing the foot to swing inward during “inversion”, the opposite during “eversion”; subsidiary movements, such as slight rotation about a vertical axis in the upper joint and translation along the axis in the lower, may be of critical importance in the solution of special problems.

The range of dorsiflexion is about 25^0 and that of plantar flexion is 35^0. Inversion and Eversion occur at sub-talar joint and adduction and abduction at metatarsal joint. The normal range is about 20^0 from neutral position (Fig. 3.1).

Of major importance for normal gait is the orientation of the axis of ankle movement. The axis of the normal upper ankle joint is horizontal, as is its prosthetic replacement, but it differs from the latter in not being perpendicular to the plane of progression. It pursues an inward and forward course, varying the angle from individual to individual. The lower ankle joint axis pierces the tibialis anterior tendon in front and the lateral face of the calcaneus in back. It influences the manner in which the foot rolls forward on its ball and is reflected in the toe break of footwear.

WEIGHT DISTRIBUTION

In the foot at rest or standing i.e. static foot, the total body weight is distributed more or less equally on the two soles. In each sole, pressure is equally distributed all over the pressure bearing area.

Half of the total body pressure is equally divided over forefoot and heel (Mortan and Napier 1935). The body weight of a person weighing say 120 pounds and “standing relaxed in a naturally held position” is distributed through the feet as follows : 60 pounds is distributed through each foot; of this, 30 pounds is through the hind-part (calcaneus) and 30 pounds through the fore-part, as might be expected, since the line of gravity passes slightly in front of the ankle joint. Now, the forefoot has six points of contact with the ground, namely, the two sesamoids under the head of the first metatarsal

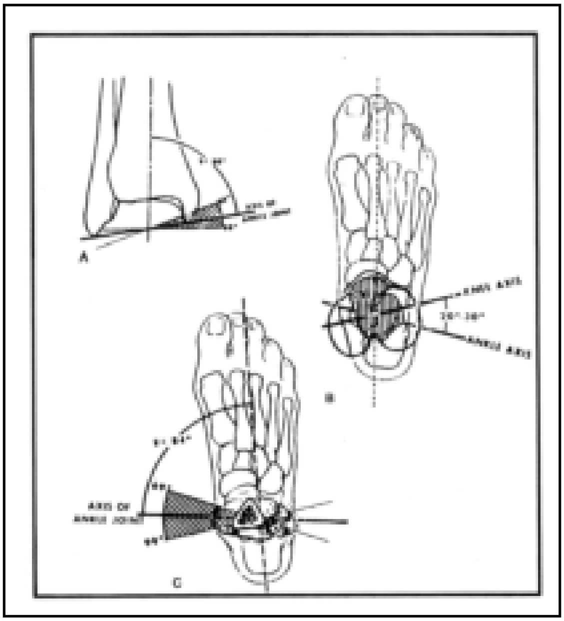


Fig. 3.1

and the heads of the lateral four metatarsals each supporting approximately 5 pounds ; the first metatarsal through its sesamoids supports a double load. Thus each head or a sesamoid bone bears one sixth of the pressure on the forefoot which is one twelfth of the total pressure on that sole or one twenty fourth of the total body weight.

WEIGHT DISTRIBUTION DURING WALKING

Each step or walking involves a roll of the body across the sole of the foot in succession from heel to toe-tips. The line of the roll begins at the point of heel contact and passes forward rapidly under the surface of the heel, up along lateral border of the sole to the region of the head of fifth metatarsal bone. It then passes across the metatarsal heads to the first and finally turns forwards along the big toe to its tip. All toes assist in final push-off.

PHASES OF GAIT

The gait cycle, one stride, encompasses the events from the moment one heel strikes the floor until the same heel contacts again. This cycle consists of two phases, stance and swing (Fig. 3.2).

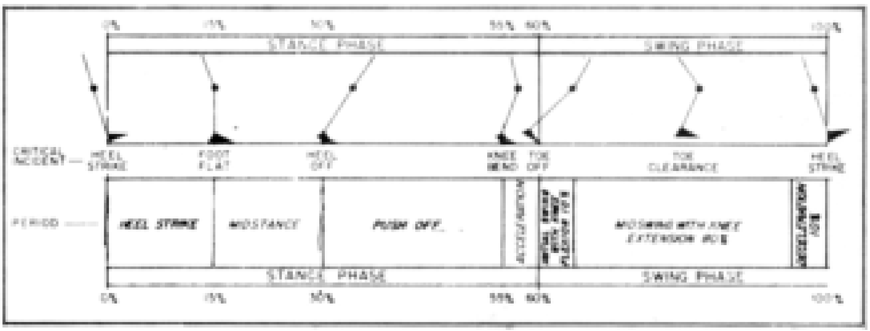


Fig. 3.2

Stance phase is composed of several parts, beginning with heel-strike, processing to foot-flat, than to mid-stance (when the trunk is vertically atop the extremity) followed by heel-off and concluding with toe-off. The interval between heel-off and toe-off is known as push-off. During stance, there is a period of restraint, from heel strike to mid-stance when the forward motion of the body is retarded until the trunk balances over toes supporting the extremity, and stage of propulsion, from heel-off to toe-off, as the leg gets ready for the forward swing.

Once the foot has lost contact with the floor, the swing phase ensues. Swing consists of three sections, acceleration (as the leg advances rapidly from its position posterior to the trunk), mid-swing (when it is directly under the trunk), and deceleration (when the speed of swing is reduced, preparatory to the next heel-strike)

About sixty percent of the time of each cycle is spent in stance, swing accounts for the remainder. Considering the interplay of two legs, alternately swinging and bearing weight, there is a time when portions of both feet touch the floor, called double support (double stance) for about twenty five percent of the cycle. One leg has begun stance, the other is pushing off. At slower walking speeds, the relative time spent in stance is prolonged. In faster gait, stance time diminishes, as does double support. Ultimately, in running, double support disappears, replaced by double float (double swing).

ANKLE KINETICS

At heel-strike, the resultant of the floor reaction is momentarily anterior to the ankle joint. As more weight shifts to the leg, the resultant moves posteriorly.

The dorsiflexors contract eccentrically to prevent the relatively long foot from slapping the floor. Unlike most muscles, the dorsiflexors contract throughout the cycle. At foot-flat, the shank rotates forward over the foot; this action advances the resultant and begins to generate a dorsiflexion movement of force, necessitating eccentric contraction of the dorsiflexion torque enlarged; this is because the support point of the body has shifted from the mid foot to the fore foot, increasing the distance from the floor reaction to the shank. Were this extremely generated movement uncontrolled, one might fall face first. Therefore, the calf muscles, facilitated by stretch imparted by ankle dorsiflexion, increase activity. At push-off the dorsiflexion movement reaches its peak, about eighty foot pound, synchronous with maximum plantar flexor activity. About this time, the other extremity has contacted the floor. Transfer of weight reduces the dorsiflexion torque on the side in question. Consequently, as the push-off period progresses, less plantar flexor force is required; the more anteriorly attached plantar flexors come into play, particularly the tibialis posterior and the peroneus longus. Finally, the intrinsic toe flexors participate to send the stance leg swinging. At toe-off, the dorsiflexion torque is low, as is muscular contraction.

Swing phase requires much less effort. Slight contraction of the dorsiflexors counteracts the plantar flexion movement developed by the weight of the foot and thereby retains the neutral ankle position to prevent the leg from dragging.

ANKLE KINEMATICS OR RANGE OF MOVEMENTS AT ANKLE JOINT IN NORMAL GAIT

At heel-strike, the foot is perpendicular to the shank, and moves to nearly 20^0 plantar flexion obtained at foot flat. Then the shank dorsiflexes over the foot, returning the ankle to the neutral position by mid-stance. The shank rotates forward until heel-off, when 15^0 dorsiflexion is recorded, as the individual rises on the ball of his foot, a uniquely human accomplishment. By toe-off the ankle has changed its direction suddenly, and is plantar flexed 10^0. During early swing, plantar flexion increases to 20^0, from mid-swing to deceleration, the ankle returns to the neutral position.

FREEDOM OF MOVEMENT AND FACILITY OF RESTORATION AND RESISTANCE

To duplicate the functional characteristics of a normal foot and ankle reasonably well, the prosthetic foot and ankle should provide the same freedom of motion, with the same facility of restoration to normal position within the required limits of flexion, extension, and rotation as a normal foot and ankle. To accomplish this, means must be provided for plantar flexion and dorsiflexion, inversion and eversion of the forefoot, active toe lift during the swing phase, possibly coordinated motion between knee and ankle at the start of the stance phase, and between push-off and knee flexion at the end of the stance phase. All these motions must be restrained and means must be provided for flexion, extension, and rotation about the different axis followed by restoration to normal position. The characteristics desired in restraining and restoring means to limit motion about each axis of the ankle and to return the foot to its normal position when the load is removed, and the fact that best performance requires they be independent for each axis, have made the design of these more difficult. There must be stiffness enough to provide sensual and actual stability, but enough motion must be allowed so that the purpose of the particular axis is not defeated by undue limitation of motion. Consideration must also be given to the fact that, when motion opposed by a restoring force is permitted, there must be in every instance a reaction to this restoring force located where the prosthesis is fitted to the stump. The greater the motion and therefore the greater the restoring force, the greater the resistance force required at the stump. In the human ankle, the equilibrium position is shifted immediately and unconsciously as occasion demands, some muscles tightening and some relaxing so that the magnitudes of the resisting and restoring forces remain nearly constant irrespective of position. In the artificial ankle, the equilibrium position cannot be shifted readily, nor can resisting and restoring forces whose magnitude is independent of the motion be provided, so that larger and larger forces are transmitted to the stump as motion about the various axis increases.

One of the most important functions of the ankle is to absorb some of the shock incident to contact of the heel at the start of the stance phase. This is usually accomplished by providing plantar flexion opposed by a movement which increases with amount of deflection generally; the same device which provides the restraining force in plantar flexion provides for shock absorption.

Because of the much shorter lever arm of the heel, resistance to plantar flexion is too high unless there is a hollow space in the heel sufficient to provide a soft air cushion.

RELATIONSHIP OF ANKLE JOINT PROSTHETIC FOOT

The location of the ankle joint in the foot is an important factor in knee stability. If it is too far to the rear, it causes an unstabilizing effect on the foot ankle action and shortens the stride length. If it is too far forward, the movement on the lever between the ankle joint and the point of contact of the foot on the floor will be too small to force the shin back with enough force to maintain knee stability.

A reasonably good compromise is to locate the ankle joint at a point forward of the heel equal to approximately one fourth the total length of the foot.

The location of the toe-break is also important, as placing it too far forward will cause the amputee to have the feeling he is “climbing a hill”, causing excess expenditure of energy and an unnatural gait. Placing it too far back will weaken the movement of force around the ankle, resulting in lessened knee stability.

The shape of the bottom of the foot must not be too flat. A curved “rocker” contour is desirable, somewhat like a ball of the normal foot.

MATERIALS USED FOR MAKING JAIPUR FOOT

The foot and ankle assembly is made of uncured rubber compound which is used for retreading automobile tyres. The rubber compound has to be packed inside an aluminium die and then heated to vulcanize it. The aluminium die is made to produce a foot of normal appearance. The appearance is so true to life that it is not easy to make out from a little distance that this foot is artificial. All the details of a foot with its veins, tendons etc. are reproduced.

The aluminium die has to be made in four sections which can be bolted together and fit each other perfectly. This is necessary so that after the rubber is vulcanised, the die can be easily removed. The facing of individual sections has to be perfect so that when bolted together, no rubber can escape from any crevice.

In order to make the die, a plaster mould of a foot has to be taken. This mould cannot be made in the conventional manner by wrapping plaster bandages around the foot or even by pouring a cream of plaster around the foot. The plaster bandages can never allow the accuracy of reproduction of toes etc, to be brought out. If the die is made in one piece, it is not possible to put strips of rubber compound into its depths. Even if made in two halves, it is not possible to remove each half easily after vulcanising since the entire surface is full of complex contours or with elevations and depressions. It was soon apparent, when the matter was discussed with professional aluminium die makers, that the mould of the foot will have to be taken in atleast four sections to allow ease of removal of individual components of the device. Since these sections have to fit each other accurately, it became necessary to take the mould of the foot in several stages. A plaster mould of the sole of the foot in a weight bearing position was taken and a die made. Then the foot was placed in this die and a mould of the forefoot taken. It would be appreciated that this mould would now be accurately matching the first die. Then a die would be cast to this mould again; the foot would now be placed in the two sections of the die and another plaster mould be taken of the lateral half of hind foot & ankle and a die made for this. Finally, the medial half would be completed.

It would thus be seen that the process is not carried out in two stages of making a plaster mould and then casting a die but in several stages with serial sequences of plaster mould- die in four sections.

Another point worthy of note is the position and attitude of the under surface of foot and toes when the mould is taken. If the foot is placed flat on the ground, a desirable degree of roll of the foot in the stance phase of walking cannot be obtained. To achieve a good rolling action, a slightly rocketed under surface of the foot is needed with the toes slightly off the ground, otherwise they are likely to hinder a proper take off. Also, a provision for using a footwear with a heel can be made by having the heel of the rubber foot slightly off the ground. In other words, the heel is kept at a slightly higher level than the balls of toes. This incidentally adds to the rocker action of the foot. To enable the foot to be kept in such a position, and at the same time bearing weight when the plaster mould is made, a sample device was worked out. A rectangular plate of plaster of Paris about 1 inch thick and of a size larger than the foot was made. The main relevant points of reference were marked on its side viz., the posterior limit of the heel and the highest point of the medial longitudonal arch, the ball of great toe was about 5/8'' below the surface.

METHOD OF MAKING PLASTER OF PARIS MOULDS

This process consists of making plaster of Paris moulds in four different pieces as compared to the conventional method. Such a procedure is adopted to reproduce moulds of complex contours of the foot having irregular and intricate shape. The four pieces are:

(a) Mould for imprint of plantar surface of foot (in normal weight bearing position).

(b) Mould of dorsum of fore foot from toes to mid-tarsal joint.

(c) Medial aspect of ankle joint and hind foot.

(d) Lateral aspect of ankle joint and hind foot.

(a) Method of making of mould for imprint of plantar surface of foot:

The mould for imprint of sole of foot and toes should fulfill the following requisites :-

i) Rocker effect in the sole and provision for a clear toe-off and adequate support at push-off.

Rocker effect in the sole is provided so that the amputee rolls off on the foot. For this, the toe and heel are kept raised from the ground. Moreover if the toes are not raised from the ground, these will hinder proper toe-off and patient will fall because of tripping of foot. In case the toe portion is too high, it will result in an inadequate support at push-off. Hence the height has to be adequate at optimum level.

The toe portion is curved upto a height of 4/8" (about 6^0) and the heel 3/8" (5^0) from the ground.

ii) The sole should have all the points of contact during normal weight bearing.

iii) Impressions of plantar half of the toes should be clearly delineated.

In order to provide these functional characteristics in the sole of the artificial foot, the following method is adopted for better results and convenience.

A plaster of Paris rectangular slab, about 1½’’ to 2" thick and 2" longer and 2" broader than the actual size of the foot (whose mould is to be taken), is made.

The main relevant points of reference were marked on its side viz., the posterior limit of the heel, the highest point of the medial longitudinal arch, the ball of great toe. The plate was hand carved in such a manner that the heel depression was 3/8" and the ball of great toe was about 4/8" below the surface.

The foot whose mould is to be taken is smeared with vaseline. Plaster of Paris cream is poured over the prefabricated plate and the individual is asked to place his foot over the plate and bear weight. The foot is kept in position till the plaster sets. This is done to obtain the mould of the plantar surface of the foot and toes to provide for the normal points of contact in the rubber foot ultimately.

The plaster of Paris is to be thick and absolutely smooth before the individual is asked to place his foot over it and bear weight as it breaks otherwise. The plate is also provided with additional plaster of Paris brackets, two on either side of the front portion of the plate, to provide for the holes for bolts separately.

This mould is then subjected to cleaning and designing processes needed for aluminum casting as described in text later. Such a mould designed to suit the casting procedure is known as “pattern”. This pattern is then casted with aluminium. The aluminium mould is then subjected to turning procedure by a lathe. By this procedure the walls of the mould are made flat and even, for purpose of proper facing of the different die segments. Then this is scraped, rubbed and polished.

This completed aluminium mould acts as a guide for construction of plaster of Paris moulds from other sizes of the normal foot. These plaster of Paris moulds are subjected to same procedures of designing, cleaning, casting and finishing as the previous moulds.

(b) Mould from dorsal aspect of foot with dorsal half of toes:

Next, the mould from the dorsal aspect of the foot with the dorsal half of the toes is taken, the foot is again smeared with vaseline and is placed in the cast aluminium mould for the sole of the foot. Plaster of Paris paste is now poured over the dorsal aspect of the foot from the toes to the mid-tarsal joint (approximately). When the plaster gets set, the mould is lifted up from the foot having clear impressions of the dorsal half of the toes and contours of the fore foot. This mould is again subjected to designing for making. Additional brackets, two on each side in the front part of the plaster of Paris mould are made at the level of the brackets of the mould for plantar surface of the foot. The patterns are casted by aluminium, and the aluminium casting is subjected to same procedure as described for the mould for plantar surface of the foot.

Likewise the moulds for the medial and lateral half of the ankle are prepared keeping the previously constructed moulds as the guide for their thickness and extent.

The plaster of Paris pieces for both the medial and lateral sides of the ankle are constructed to provide for the impressions of the malleolar region and the part of the lower end of the leg about 2" from the malleoli.

These moulds are also provided with thick walls, and additional bolts and screws are used through the wall of the different segments for a well fitting assembly.

To test the accuracy of the die, a plaster of Paris foot is constructed by pouring plaster of Paris cream in the mould cavity and allowing it to solidify. This foot is then checked for the points of contact and shape. Correction is done by scraping and deepening the part where the point of contact is not obtained. This plaster of Paris foot is preserved for construction of wood and sponge rubber frame as described later in the text.

DETAILS OF DESIGNING PLSTER OF PARIS MOULDS AND CASTING

The plaster of Paris moulds taken from different parts of the normal foot need designing for purposes of casting. The various allowances made in the plaster of Paris moulds for preparation of aluminium die are as follows :

Draft Allowance

During the process of sand casting, the mould from the sand has to be removed to leave a mould cavity into which molten metal is poured. The mould must be of such a shape that it can be withdrawn with little effort and without injury to the mould cavity. To lend facility in this operation, a taper is allowed on all vertical faces of the mould which comes in contact with the mould cavity.

Shrinkage Allowance

All metal casts in the foundry will shrink in size when they change from a liquid to a solid state, and a certain amount of reduction in size will occur as a result of cooling in the solid state from fairly high temperature to that of the surrounding air. Because of this, the pattern must be constructed somewhat larger than the anticipated casting. This allowance for natural shrinkage of the metal is called the pattern maker’s shrinkage allowance, and it will be found to vary with the type of metal used. For aluminium a shrinkage rule having added length of 3/32" per foot is used.

The moulds designed in this way are called “patterns”.

CHOICE OF PLASTER OF PARIS FOR PATTERN DESIGN

Many materials have been used by different makers for pattern making. Here plaster of Paris has been used because of many advantages.

The advantages offered by plaster of Paris over wood and other materials are:-

(1) Accuracy: Original patterns, models and moulds can be

made to extremely close tolerance.

(2) Dimensional stability:	Moulds are unaffected by normal change in temperature and humidity and therefore will not shrink and warp.
(3) Economy:	It is characterized by substantial savings in time because of its simplicity.
(4) Adaptability :	Plaster of Paris patterns are adaptable to complex contours and intersections of both original patterns and models and also in the reproduction of moulds having irregular and intricate shapes.

From the plaster of Paris patterns thus obtained, an aluminium die is made.

FABRICATION OF WOODEN AND POP REPLICA OF JAIPUR FOOT

The inputs for fabrication of 'Jaipur Foot' are-

(1) Tread rubber compound.

(2) Rubber cushion compound.

(3) Cosmetic rubber cushion compound (skin colour)

(4) Nylon cord impregnated in rubber.

(5) Rubber cement (vulcanizing).

(6) Sponge (MCR) rubber heel, metatarsal and toe blocks.

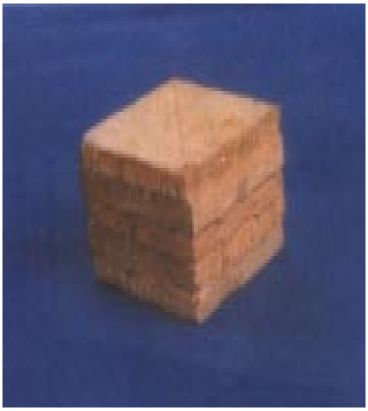
(Rubber used for the sole of Hawaii chappals).

Before actual fabrication of the Jaipur Foot starts, following components and patterns are prepared :

(A) Wooden Malleolar block :

It is shaped like a frustrum of cone with parallel bases; the lower base is broader than the upper base and resembles the lower part of the leg and malleolar region. It is made from any light wood. In order to construct a light and strong wooden block, built up technique is used. In this technique rectangular pieces of desired size are placed over each other to a required height in a ply fashion and glued together by fevicol glue. The grains of different blocks are kept in opposite directions. These blocks are then subjected to compression on a press for few hours. By doing so the opposite grains coalesce together to form a compact mass and hence impart strength to the wooden block. Following shape is then carried out of this block (for die size 7) (Fig. 3.3 & 3.4).

Upper Base :	Lower Base :	
Major axis	2"Major axis	2-3/8""
Minor axis	1" Minor axis	1½”
	Height of the Block	2½”


(Fig. 3.3)


(Fig. 3.4)

(B) Pattern for Matatarsal Block and Heel Block :

A plaster of Paris replica of the foot is obtained by filling the cavity of the aluminium die with plaster of Paris. As soon as the plaster of Paris sets, it is removed from it by opening the die. The toe portion of this plaster of Paris mould is cut at the level of metatarso-phalangeal joints.

With a guarded scalpel which can cut only 2/8" deep, squares of 1/ 4" x1/4" are carved out all over this plaster mould. With a chisel, cubes of 1/4"x1/2" x1/8" are scrapped off this mould. The mould thus obtained is 2/8" less than the inner dimension of the die. It is then divided into three pieces by cutting it at the level of midtarsal joint and at the level of lower end of the lateral malleolus. These blocks are used as patterns for metatarsal sponge rubber block and heel sponge rubber (Fig. 3.5 & 3.6).

(Fig. 3.5)

(Fig. 3.6)

Four to five layers of sponge rubber sheets are glued together; the metatarsal and heel blocks are carved out from it in such a way as to correspond exactly with the plaster patterns.

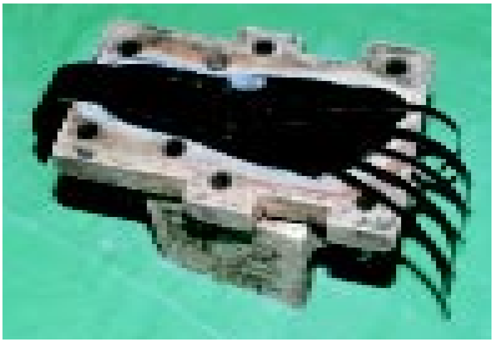
METHOD OF PREPARING A RUBBER FOOT

The fabrication of Jaipur foot can be described in 5 steps.

Step I : Fabrication of sole

1. Two patterns of the shape of sole are cut from the tread rubber compound sheet (It is a tough material which is used on the external facing of an automobile tyre). This tread compound has great resistance to abrasion, tears and cuts but is stiff and heavy. It's use is therefore restricted to the sole of the foot and can be compared to the thick planter skin of normal foot.

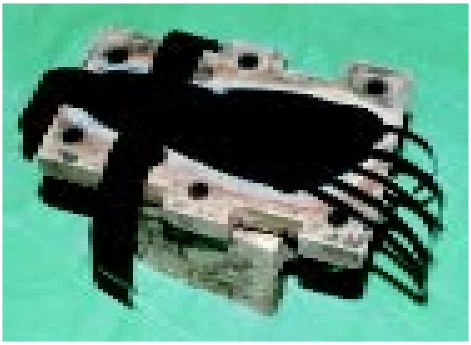
2. The first pattern is placed on the sole portion of the dye. A piece of nylon cord 2" (W) x 14" (L) is now placed on this 1st pattern in such a way that 4" of it protrudes out anteriorly, middle part of it covers the sole pattern and remaining posterior portion protrudes posteriorly (Fig. 3.7)**.**



(Fig. 3.7)

The second sheet of sole pattern is placed over this nylon cord piece.

3. Now a strip of another 2" x 6" of nylon cord is placed across (perpendicular to the) first nylon cord across the heel part of the tread rubber compound pattern (Fig. 3.8).



(Fig. 3.8)

4. These cords will later work for re-enforcement and strengthening of the foot piece.

Step II : Fabrication of Lower Part of Leg - Malleolar Region

1. As described previously the lower part of leg, which comprises of the malleolar region is made up of a wooden block. It is made up of light wood and has a laminated structure. In this technique wooden pieces of desired size are glued together with their grains in different directions as in plywood (Earlier when a single piece of wood was used for this purpose, the movement of the carriage bolt often led to splitting of wood along its grains). The plywood type of arrangement provides greater strength combined with light weight and splitting of wood is not encountered. The edges of the block are rounded off (sharp corners cause stress concentration).

Step III : Fabrication of MCR Block in the hind foot Region

1. The hind foot block is made up of several layers of sponge rubber glued together to form this large block. (This block works as universal joint in the Jaipur foot and represents the mobile section of the ankle, sub-talar and mid tarsal joint complex) This universal joint provides freedom of movement in all directions namely dorsiflexion /plantar flexion, inversion / eversion or abduction / adduction. Because of this block, the foot as a whole can now rotate on the leg and walking on uneven surface and squatting is also possible. This block is preferred to be softer to dampen the ground reaction at heel strike and to simulate plantar flexion in achieving the foot flat position.

2. This entire block is enclosed securely in a closed shell hard rubber so that it is completely separated above from the malleolar block and anteriorly from the mid foot block.

Step IV : Fabrication of the fore foot block

1. It is also made up of MCR rubber (1 piece) and is stiffer in its hardness as compared to the heel (hind foot) block. This is further stiffened by the re-enforcing layers of the tie cord.

   Previously it used to be made up of wooden block which caused a lot of Jaipur foots to crack around the perimeter of the ankle. It was because the rubberized hind foot block was squeezed between 2 wooden blocks (in malleolar and fore foot region). Because of these findings it was decided to replace the wooden forefoot block with an MCR block. This stiffened fore-foot block not only provides rocker action during push off phase, but its suppleness distributes the stress evenly over a much larger area of the foot and provides an extra bonus in the form of pronation and supination of the forefoot.

Step V : Assembly of various Segments of Foot

1. The blocks of the toe are placed in the dye in the spaces provided.
2. The fore foot block and the hind foot block are also placed over the tread compound pattern which is lying over the sole pattern of the dye (Fig. 3.9).

(Fig. 3.9)

3. The wooden malleolar block, the heel block, the fore foot block and the blocks for toes are then covered with cuation compound and painted with rubber cement. (Fig. 3.10)

(Fig. 3.10)

4. A strip of 2" x 6" of nylon cord is placed between the forefoot block and the heel block and a second strip of 2" x 6" of nylon cord is placed between the malleolar block and heel block, and are placed on pattern of sole kept on the sole plate.
5. The portion of the strip of the first nylon cord (2" x 14") which is protruding anteriorly is now divided into 5 tails. These tails are folded back over each of the toe block.
6. The strip of the cord which is protruding between the forefoot block and heel block is stuck to the superior surface of the forefoot block.
7. The strip of the cord which is protruding forward from in between the

malleolar block and heel block is divided into 2 tails and stuck to the superior surface of the forefoot block.

8. The strip of the first nylon cord which is protruding posteriorly is folded over the malleolar block.

9. The strip of the nylon cord protruding from the sides is folded over the malleolar block, 3 strips (1" x 6") are stuck to these blocks in a ‘Figure of eight’ pattern (Fig. 3.11).

(Fig. 3.11)

10. This unit is now covered with skin colored cosmetic rubber compound in such a way that it completely fills the cavity of the die (Fig. 3.12).

(Fig. 3.12)

11. The dye is now articulated and tightened with the help of bolts. After 2 hours the dye is opened and the foot is inspected for any filling defects. If present they are filled with cosmetic rubber.

12. The dye is again closed and tightened completely and placed in an autoclaving machine (vulcaniser) and is subjected to 23 PSI pressure of steam at 125^{0}C for 20 min. The die is removed from the autoclave. (Fig. 3.13, 3.14 &3.15).


(Fig. 3.13)


(Fig. 3.14)


(Fig. 3.15)

13. After the dye has cooled off, the foot is removed from the dye.

14. The redundant edges are removed and, after finishing, the foot is ready to be fitted in Jaipur prosthesis (Fig. 3.16).


(Fig. 3.16)

Advantages of Jaipur Foot over SACH Foot

	SACH-FOOT	JAIPUR-FOOT
APPEARANCE		
1.	SACH Foot doesn't look like a normal foot and has very poor cosmesis.	It looks like a normal foot. Cosmetically highly appreciated.
2.	SACH foot requires a closed shoe to protect as well to hide it.	No such need or requirement with Jaipur Foot. But in case someone has to wear a shoe, he can do it comfortably with a flat heel shoe.
MOVEMENTS & ACTIVITIES OF DAILY LIVING		
3.	Wooden Keel is long enough to restrict/limit movements. If at all the movements take place they occur at unnatural sites.	Metallic Keel (carriage bolt) is confined to ankle only. So no restriction of movements and all movements take place at natural sites.
4.	Squatting is not possible with SACH foot as it requires dorsiflexion at ankle joint, which due to rigid keel is not possible.	Squatting is easily achieved; as sufficient range of dorsiflexion is attainable.
5.	No cross-legged sitting is possible because it requires adduction at forefoot & transverse rotation of foot in relation to shank.	Cross - legged sitting is possible because of sufficient forefoot adduction & rotation of foot.
6.	As there is almost no movement at sub-tarsal joint, inversion or eversion is not possible; so SACH foot is suitable only for walking on level ground while walking on uneven ground & rough terrain is very uncomfortable.	As there is adequate inversion & eversion at sub-tarsal level, so walking on uneven grounds and rough terrain is comfortable.
7.	Bare-foot walking is not possible.	Bare-foot walking is possible.
8.	As no transverse rotation of foot in relation to leg is possible, the amplified ground reaction while walking on uneven ground & rough terrain is transmitted over the stump, so great discomfort is complained by	As transverese rotation of foot in relation to leg is possible, no complaint of discomfort while walking on uneven ground.

amputees.

AVAILABILITY OF MATRIEIAL & COST

9.	Stern training & skills are required to fabricate SACH foot.	Requires very little training to fabricate Jaipur Foot.
10.	Raw Material for fabrications is not locally available (in many parts of world).	Raw Material for fabrication is locally available.
11.	It is costly and unavailability of the raw material further adds to the cost.	It is very economical.

CHAPTER - 4

FABRICATION OF BELOW KNEE HDPE PROSTHESIS WITH POLYPROPYLENE TOTAL CONTACT SOCKET

Step 1 : Positive mould by “wrap-casting” method.

Materials :

1) Cotton stockinette 6" x 1.5 m.
2) Pre-formed POP (Plaster of Paris) Bandages - 6".
3) Indelible Pencil (to mark modification points).
4) POP Paste : to make positive mould of stump.
5) Inch-tape : to measure stump length.
6) Measuring caliper - to note A-P & M-L diameters of stump at various sites.
7) Pipe mandrel : to hold positive mould.
8) Surgical blade / knife : to cut negative mould.
9) Sand Paper : to smoothen the marks.
10) Condom : The advantage of condom over cast sock / stockinette is that it is only 1/3rd as thick and a rubber band at one end helps to keep it in position. A much more exact replica can be obtained.

Measurements :

Various measurements of stump and sound limb are noted :

a) SOUND LIMB :

(1) Length of sound limb from medial tibial plateau to medial malleolus.

(2) The patient is made to stand and a plumb line is dropped from the tip of head of fibula. The distance of anterior and posterior surface of the leg at the level of medial malleolus is measured and recorded(Fig. 5.2; Page 48).

(3) The plumb line is again dropped from tibial tubercle to the center point b/w medial and lateral malleolus. The distance from the plumb line to medial and lateral malleolus is recorded (Fig. 5.3; Page 48).

b) STUMP

(1) The length of the stump-from medial tibial plateau (MTP) to the distal end of the stump

Fig. 4.1

with the help of measuring tape **(Fig. 4.1).**

(2) A-P (Antero-Posterior) diameter of the stump-from just below the lower end of patella anteriorly, to popliteal area parallel to the anterior area posteriorly. It is taken with the help of measuring cal-lipers keeping knee in full extension **(Fig. 4.2).**

Fig. 4.2

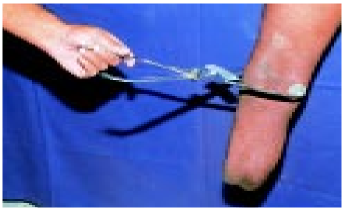


Fig. 4.3

(3) Medio-lateral diameter- from the widest area medio-laterally of the amputated knee joint, again with the help of measuring callipers **(Fig. 4.3).** It is considered as first mediolateral diameter. Then the same procedure is repeated at the distance of 1" downwards from this area till the distal end of the stump. The procedure helps a great deal in making a positive mould with accurate dimensions (simulating the stump).

Method :

Amputee is seated on a firm bench with his/her thigh supported and back of knee approximately 100 mm in front of the anterior edge of the chair.

(1) A moistened cast sock / condom is slipped over the stump which is placed in an attitude of slight flexion (approximately 5-10 degrees at knee) **(Fig. 4.4,4.5 & 4.6).** A snug fit is maintained by applying tension on the top of the cast sock from a strap around the waist clamped on each side of the cast sock. This can also be done by using a rubber-band to maintain cast sock in the desired place and preventing it from slipping. These problems (of slipping) are not encountered if a condom is used which has at its one

Fig. 4.4

Fig. 4.5

Fig. 4.6

end a rubber band that prevents it from slipping.

(2) Marking of certain prominences which will be important in modification procedure (Fig. 5.5 & 5.6 ; page 49), are made with indelible pencil on the following areas :

(i) Outline of the patella.

(ii) Mid patellar tendon - 2 horizontal lines, one at lower end of patella and the other at tibial tubercle. These indicate an important weight bearing area in the finished socket.

(iii) The tubercle of tibia.

(iv) Head of fibula - it requires a relief area in the socket to prevent skin abrasions and pinching of the peroneal nerve between the head of fibula and the socket.

(v) Anterior crest of Tibia.

(vi) Distal end of fibula.

(vii) Anterior distal end of tibia.

(viii) Medial flare of tibia.

(ix) Medial border of tibia.

(x) Any other sensitive area which may indicate the presence of bone spurs, adherent scar tissues, neuromas, or other conditions.

The following areas are outlined on the stump only if they require special treatment because of prominence, sensitivity to pressure or other reasons.

(xi) Anterior prominences of the lateral and medial tibial condyles.

(xii) The lateral border of tibia.

(3) Two 6" POP bandages (either pre-formed or prepared by simply smearing POP powder on plain 6" bandage) are submerged in water and when adequately soaked, are taken out and excessive water is squeezed prior to use.

(4) Begin the wrap by laying one or two layers of these bandages lengthwise, starting in front slightly above the patella and passing down and around the end & up the back of the stump to the posterior crease of the knee.

Fig. 4.7

Fig. 4.8

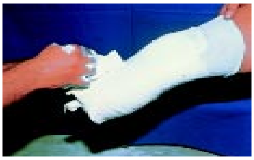


Fig. 4.9

Begin a series of circumferential warps starting at the upper border of patella and spiralling down and up the stump, overlapping one half the width of the plaster bandage with each layer, smooth each layer as it is applied. Apply bandage until the cast has maximum thickness of approximately 1/8" (3mm) in the proximal (top) third. Add additional layers over the distal end to build up a thickness of approximately 6 layers of bandage. Be sure to cover the femoral condyles. This requires that the wrap extend approximately 3" above mid patellar tendon area **(Fig. 4.7,4.8 & 4.9).**


Fig. 4.10

(5) Instruct the amputee to keep his / her stump muscles relaxed and to hold a fixed angle of knee flexion. Smooth the plaster over the surface of the stump by moving the hands around the stump and working towards the knee **(Fig. 4.10).** Work the plaster around bony prominences so that they are clearly defined in the cast, and continue to work the cast until it begins to harden.

(6) As the plaster begins to harden, the ends of the thumb and fingers are used to outline patellar tendon and compressing the popliteal tissues. Thumbs are placed at a 30-45^0 angle to the long axis of the tibia, on either


Fig. 4.11

side of the patellar tendon and pressed inwards, midway between the lower edge of the patella and the tubercles of the tibia **(Fig. 4.11).** Be careful not to push up on the inferior edge of the patella or on the anterior prominences of the tibial condyles. (One can also use first web space of the hand for the same). Firm pressure is applied with the fingers. The depth of the finger tip impression in the popliteal area serves as a measure of tissue firmness and an indication of how much modification of the model is required. When the plaster has hardened, release finger pressure but allow the wrap to remain on the stump for additional 1-2 minutes. Reflect the cast sock down over the cast. Place the fingers in the previous position, have the amputee flex and extend his/her stump against resistance, and carefully remove the cast from the stump by pulling down with an antero-posterior rocking action - Do not remove the cast sock from inside the cast.

(7) The wrap cast is filled with POP paste. An 18" long iron pipe is inserted in

the mould to a depth of not more than 6". This will serve as a mandrel for future bench vise operation and also helps in removing the air bubbles

Fig. 4.12

Fig. 4.13

present in POP paste **(Fig. 4.12 & 4.13).** So a solid positive mould is obtained with no air/gap left in it.

(8) After the plaster has set (20-30 min.), strip off the wrap by cutting it length-

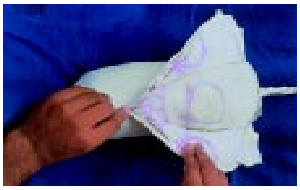


Fig. 4.14

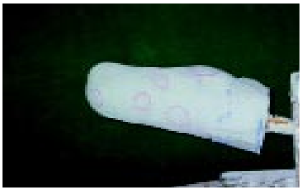


Fig. 4.16

Fig. 4.15

wise down the posterior surface **(Fig. 4.14).** The areas marked by indelible pencil are transferred to the positive mould and are rechecked **(Fig. 4.15 & 4.16).**

The model is now ready for modification.

Step II : Modification of the mould.

The second step involves modification of the stump mould so that it will serve as a model for the inside contours of the socket.

Material :

(1) Knife

(2) Metal files

(3) Wire mesh

(4) POP paste

(5) Sand paper

(6) Wire screen

Objects :

(a) To increase stump socket contact pressure where the forces between stump and socket must be developed and to decrease contact pressure in sensitive areas. Where greater pressures are required more plaster is removed from the corresponding areas in the model and to provide relief of pressure in the final socket, the model is built up with patches of leather or POP paste shaped to fit the sensitive areas.

(b) To recheck whether all the measurements taken of the stump (including length and various A-P & M-L diameters) are exactly same on the modified positive mould of the stump.

Method :

(1) Modify the patellar tendon area by cutting away the model midway between the lower edge of the patella and the tubercle of the tibia to a minimum depth of ½". The channel thus formed (which will become a protuberance in the socket) should have a height of approximately 1" as seen from the side. The modified area should extend on either side to the center of the thumb prints and as seen from the front should have a width of approximately 1½.".

(2) Modification at the medial tibial flare by shaving off at least 1/8" to 3/8" of plaster at the deepest point, tapering out to the edges.

(3) On the lateral side of the stump model, a minimum of approximately 1/8" to 3/8" of plaster should be removed starting 3/4" or finger width below the distal border of the head of fibula and continuing to within 1" from the end of the fibula.

(4) Shave off a minimum of 1/8" of plaster all along the anteromedial surface of the tibia, extending from below the medial flare to within 1" of the distal end of tibia.

(5) Shave off 1/8" to 1/4" of the plaster from the anterolateral surface of the stump model, blending in with any modification of the lateral surface, to within 1" of the distal end of the fibula.

(6) Modification of the popliteal area - shave away plaster to the depth of finger prints from the crease of the knee extending ¼" upwards and 2¼" downwards. Precautions must be taken not to touch hamstring area. Maximum depth is to be shaven off in popliteal region at the center point in the knee

crease, then as proceeding towards the peripheral area the depth of shaven off area is reduced with minimum depth at peripheral area.

(7) Relief or build ups with the help of POP paste (¼" thickness) or leather patches are applied over pressure sensitive areas like :

(a) Fibular head

(b) Distal end of tibia

(c) Distal end of fibula

(d) Any other bony prominence or sensitive area requiring pressure relief.

Fig. 4.17

Fig. 4.18

Finally the length of the stump model is increased by ¼" (to accommodate shrinkage of poly propylene socket) at the lower end **(Fig. 4.17 & 4.18).**

Step III : Fabrication of Soft insert.

Material :

(1) 6 mm thick EVA Rubber Sheet (which is a thermoplastic).

(2) Solution

(3) Scissors - for trimming.

(4) Brush

(5) Oven (preheated 180°C)

(6) Wooden stick

(7) Measuring tape

Method :

The procedure for Fabrication of soft insert is as follows :

(a) Place the mandrel of the stump model in the bench vise with the model held in a vertical position **(Fig. 4.19).**

Fig. 4.19

(b) The length of the stump mould and its width at the upper and lower end in measured and marked on the EVA rubber sheet which is cut accordingly and both the ends are glued together using the solution. This is placed on a stick and inserted into the pre-heated oven for 3-5 min. to make it more malleable **(Fig. 4.20).**

Fig. 4.20

(c) This is then taken out of the oven and sleeved over the stump model and allowed to cool **(Fig. 4.21 & 4.22).**

Fig. 4.21

Fig. 4.22

(d) A further covering of nylon sock / stockinette is applied over it to obtain final negative mould.

(e) Application of soft insert is needed in cases where local or systemic disease causing sensory deficit or hypoasthesia / hyperasthesia in the stump. Most commonly encountered diseases are - Diabetes Mellitus, Leprosy, Peroneal Nerve palsy, sciatic nerve injury etc.

Unique Characteristics of EVA

EVA or Ethylene Vinyl acetate, one of the vinyl compounds is a poly - vinyl chloride thermoplastic. Previously it was more popular in fabrication of orthosis as the densities available range from 30-360 kg/m^3, indicating the range over which a particular compound can be prepared so that a low density EVA can be used for cushioning. EVA is a polyethylene co-polymer. It is light weight, has shock absorbing characteristics, that is why in our center we use it for fabrication of soft insert.

Step IV : Development of HDPE / PP Total Contact Socket by Vacum moulding technique.

Material :

(1) 15" x 15" HDPE (10 mm thick).

(2) 2 metal frames of 15" x 15" (square).

(3) 4 metal clamps.

(4) Soap stone powder.

(5) Pre-heated oven with max. temp of 180^0 C to heat HDPE sheet.

(6) Suction machine.

(7) Metal or wooden platform built on an iron pipe is fixed on to the suction machine.

(8) Asbestos gloves.

(9) Scalpel with surgical blade attached to it to cut the excessive HDPE/PP sheet.

(10) Metal file to trim off the HDPE/PP socket.

(11) Cutting machine.

(12) De-burring knife for finishing off the HDPE/PP socket (A piece of glass may be used instead).

Method :

(a) A 15" x 15" piece of HDPE/PP sheet (10 mm thick) is cut from the larger sheet.

(b) It is fixed between 2 metal frames of the same dimension (15" x 15") with the help of metal clamps.

(c) It is placed on a stockinette (unfolded) and soap stone powder is sprinkled between sheet and stockinette so that the HDPE/PP sheet does not stick to it.

(d) Now this assembly is placed in the preheated oven (at 180^0) for 20 min. At this temperature HDPE/PP sheet is molten (melting point of HDPE/PP thermoplastic is $160\text{-}168^0$C) **(Fig. 4.23).**

Fig. 4.23

(e) At its melting point HDPE/PP sheet becomes transparent. This property is of great help in recognizing that the sheet is ready for further use.

(f) The mould with mandrel covered with soft insert is placed over the metallic / wooden platform which is a part of suction apparatus. The mould should be kept in inverted position i.e. distal end of the mould facing the ceiling **(Fig. 4.24).**

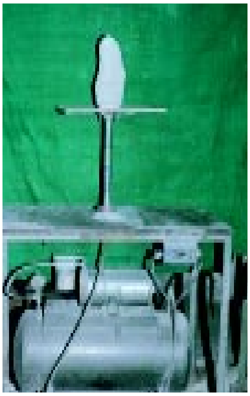


Fig. 4.24

(g) A nylon sock or stockinette is placed over the stump model so that a smooth inside of the socket can be attained later.

(h) The oven is switched off as the sheet becomes transparent.

(i) Two people wearing asbestos gloves, take out this heated sheet with each person holding 2 ends. This sheet is held over the mould.

(j) Great care is taken that the sheet falls by itself on the mould rather than “pulled down” by the people. Otherwise the socket obtained will be of unequal thickness **(Fig. 4.25 & 4.26).**

Fig. 4.25

Fig. 4.26

(k) The suction apparatus needs to be handled carefully. Instead of switching it on totally at once it should be switched on & off in rapid bursts. This method helps a great deal in preventing any wrinkling in the heated sheet and in getting perfect approximation of the sheet over the mould **(Fig. 4.27).**

Fig. 4.27

Fig. 4.28

Fig. 4.29

(l) The sheet takes the shape of the stump model by creating vacuum with the help of suction apparatus **(Fig. 4.28 & 4.29).** (Now the excessive area of the socket which is to be trimmed off is marked with the help of pencil).

(1) Anteriorly the wall of the socket extends upto lower 1/3rd to 1/2 of the patella.

(2) Medio-laterally the socket walls cover the medial and lateral femoral condyles respectively.

(3) Posterior wall is of such height at medial and lateral ends so as to accommodate medial and lateral hamstring tendons. As the medial hamstring tendon is inserted at a lower level on the tibia as compared to the lateral hamstring tendon so the medial side of the posterior wall is lower in height as compared to the lateral side.

(m) Now the stump mould (inside the HDPE/PP socket) is broken off with the help of hammer and nail **(Fig. 4.30 & 4.31).**

Fig. 4.30

Fig. 4.31

(n) The socket is shaped properly by trimming it with the help of cutter, chisel, file and de-burring knife **(Fig. 4.32 & 4.33).**

Fig. 4.32

Fig. 4.33

(o) After trimming off the socket patient is made to wear the socket for trial. For the convenience of donning the socket a 1" diameter hole is made at the lower end of the socket so that the patient can pull up the socket with the help of stockinette (pulling downwards).

Step V : Fitting the socket in 'Jaipur' prosthesis.

Material :

(1) HDPE pipe (PVC pipe)

(2) Heating oven

(3) Rivets

(4) POP paste

(5) Jaipur foot

(6) Threaded screws and bolts

(7) Cuff suspension

(8) Plastic emulsion paint

(9) Cotton stockinette

Method :

(1) A posterior reference line is drawn on the external surface of the socket, after the brim has been trimmed, by connecting center points at the posterior socket brim and near the posterior distal end of the shell.

(2) Another reference line is drawn on the lateral surface of the socket by finding the mid point of the distance from the center of the patellar tendon protuberance to the posterior brim. A line is drawn from this point on the lateral side of the socket shell, to a center point near the distal-lateral edge.

(3) The socket is held in vise in inverted position and aligned with the vertical line on the wall of the room at the level of posterior reference line of the socket. The vertical line acts as a reference plumb line.

(4) Now this socket is adjusted in such a way that the posterior reference line is titled approximately 5^0 laterally and the lateral reference line is titled 5^0 anteriorly in relation to vertical plumb line on the wall.

(5) An HDPE tube of the diameter of calf is selected from the stock of pre-formed tubes available. The tube is then placed over the socket in such a way that the area corsponding lateral and medial malleoli of the tube are at the same distance from the vertical plumb line on the wall as they were from the plumb line of the sound limb (Fig. 5.13; Page 52).

(6) The whole assembly is now rotated in the lateral plane and vertical line on the wall is now aligned with the lateral reference line on the socket. The tube is adjusted by moving it in such a way that the distance of the anterior and posterior surface of the tube at the medial malleolus level; from the vertical line on the wall is same as it was from the plumb line in the sound limb (Fig. 5.14; Page 52).

(7) Thus after obtaining the correct position of the preformed HDPE tube on the socket it is attached to the socket and filled with POP cream **(Fig. 4.34).**

Fig. 4.34

(8) When the cream sufficiently sets and dries, the tube is gently removed and this lengthened mould is left to dry.

(9) After drying it is again smoothened with a wire mesh and an attempt is made to make it an exact replica of the sound limb, which is not at all difficult as the dimensions are exactly similar **(Fig. 4.35 & 4.36).**

Fig. 4.35

Fig. 4.36

(10) Now a piece of HDPE pipe 7.5 cm longer than the sound limb is selected and covered both inside and outside with a cotton stockinette. A wooden rod is inserted in the pipe and it is placed in a preheated electric oven at 180^0C for 20 minutes. This makes the pipe fairly malleable.

(11) This heated pipe is now sleeved over the socket and worked with hands. This is well moulded over the socket and shank by applying sufficient pressure over the scooped out areas in the infrapatellar area in popliteal region, over the shin area and over medial and lateral malleoli **(Fig. 4.37,4.38 & 4.39).**

Fig. 4.37

Fig. 4.38

Fig. 4.39

(12) After the pipe is sufficiently cold and hard and has taken the exact shape of the mould, the POP mould is hammered out and excessive pipe at the lower end is cut off.

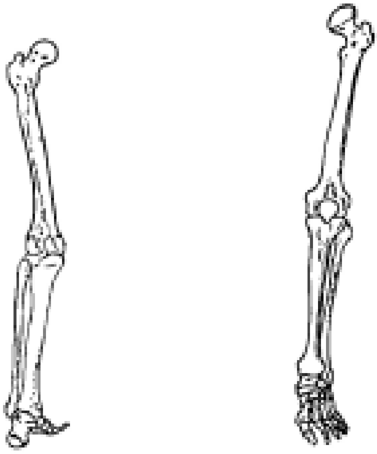
(13) The lower end of this prosthesis is heated again and the Jaipur foot of the matching size of the sound foot is attached to it by shrink fitting method with the foot in plantigrade position. 4 threaded screws are fixed to provide extra grip to the foot in the shank.

(14) A cuff suspension is attached at the upper end of the prosthesis for suspension.

(15) The prosthesis is now ready for dynamic alignment.

CHAPTER 5

FABRICATION TECHNIQUE OF HDPE PTB PROSTHESIS WITH OPEN ENDED SOCKET



Osteology of Lower Limbs (Fig 5.1)

MATERIALS

1. High density polyethylene pipe of appropriate diameter and length 7.5cm more than the length of sound limb.
2. Cotton stockinette
3. Plaster of Paris impregnated bandages (width 15cm).
4. Plaster of Paris powder
5. Soap stone powder
6. Metal Mandrel
7. Indelible pencil

TOOLS

1. Knife
2. Wire Mesh
3. Vice
4. Plumb line
5. Metal files : round and surform
6. Hand saw

7. Assorted Basins for water
8. Oven with maximum temperature 300ºC
9. Hammer
10. Heat Gun or heater

MEASUREMENTS

a) Sound limb

1. Length of sound limb from tibial tuberosity to a point between the medial and lateral malleolus.
2. The patient is made to stand and a plumb line is dropped from the tip of the head of fibula. The distance of anterior and posterior surface of the leg at the level of medial malleolus is measured and recorded (Fig.5.2).

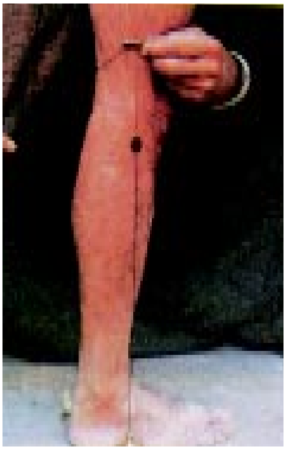


Fig. 5.2

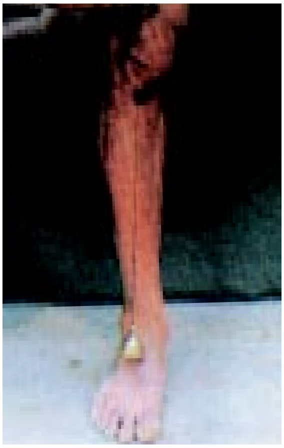


Fig. 5.3

3. The plumb line is again dropped from tibial tubercle and the distance of medial and lateral malleolus from the plumb line are measured and recorded (Fig. 5.3).

b) Stump

After taking measurements, the amputee is seated on a firm bench or table with his thigh supported and the back of knee approximately 100mm from the edge of chair.

Fig. 5.4

The prosthetist then pulls moistened stockinette over the stump. The stump is placed in an attitude of 15º - 20º flexion, which is maintained throughout the casting procedure (Fig.5.4).

With an indelible pencil following areas are marked:- (Fig. 5.5 & 5.6)

a) Outline of patella

b) a horizontal line at mid patellar tendon

c) the tubercle of the tibia

d) the head and distal end of fibula

e) the medial flare and border of the tibia

f) end of tibia

Fig. 5.5

Fig. 5.6

The stump is then wrapped with the plaster impregnated bandages. This is done carefully with a firm, even tension so that the triangular shape of the anterior part of the stump remains, and loose flesh is not pulled round with the bandages. The plaster is worked with the hands, clearly defining bony prominences and features such as the medial tibial flare. As the plaster begins to harden, the tips of the thumbs locate the patellar tendon, gauging the depth of tissue on either side of the tendon, and posteriorly the pads of the fingers are pressed into the popliteal area, the depth of the impression leaving a measure of the firmness of the tissue (Fig. 5.7 & 5.8).

Fig. 5.7

Fig. 5.8

When the wrap has hardened, it is gently pulled off the stump and filled with plaster of paris cream around an iron mandrel kept in the center of the mould. When the plaster of paris cream has hardened sufficiently, the P.O.P. bandages are slit open and removed. The positive mould thus obtained has indelible pencil markings. After the positive mould has sufficiently dried it is held in a vice by the mandrel. The mould is then thoroughly smoothened using a wire mesh. During this process more plaster of paris is removed from the areas of medial tibial flare, the lateral surface of the mould and popliteal area (fig. 5.9 & 5.10), and little or no plaster of paris is removed from the medial tibial area, head of fibula and hamstrings area. With a draw knife the infra pateller area at the mid patellar tendon levels is scooped out, taking care that this scooping is straight and does not curve along the inferior border of patella (fig. 5.11). The breadth of the scoop should be around 25mm and depth should be around 13mm (Fig. 5.12).

Fig. 5.9

Fig. 5.10

Fig. 5.11

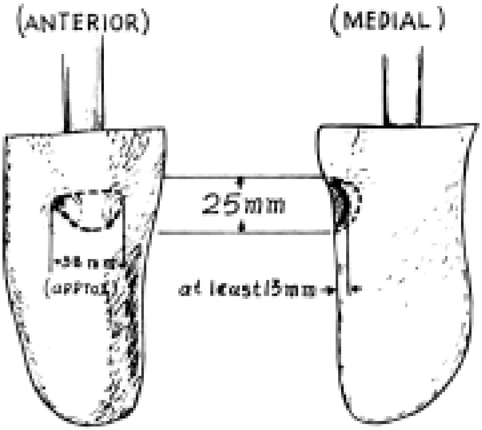


Fig. 5.12

Following this a thick layer of P.O.P. paste is applied over the following areas to build them up :-

a) The head of fibula
b) Tibial tuberosity and the shin
c) Hamstring tendons and
d) Ends of the amputated bones and any other bony prominences noted previously.

When this modified mould is dry the second stage of completing the mould starts. An HDPE tube of the Diameter of calf and ankle of the sound limb is selected from the stock of preformed tubes available.

The mould held in A.P. plane in the vice is first aligned with a vertical line on the wall of the room at the level of tibial tubercle (fig. 5.13). This vertical line on the wall of the room acts as a reference plumb line. The selected tube is then placed over the mould in such a way that the lateral and medial malleolus of the tube are at the same distance from the vertical line as they were from the plumb line of the sound limb.

Fig. 5.13

This whole assembly is now rotated in lateral plane and the vertical line on the wall is now aligned with the top of the head of fibula (fig. 5.14**)**. The tube is adjusted by moving it laterally or medially in such a way that the distance of the anterior and posterior surface of tube at the medial malleolus level, from the vertical line on the wall is same as it was from the plumb line in the sound limb.

Fig. 5.14

After thus obtaining the correct position of the preformed HDPE tube on the mould, it is attached to the mould by filling it with plaster of paris cream. When the cream sufficiently sets, the tube is gently removed and this lengthened mould is left to dry. When it is sufficiently dry, it is again smoothened with a wire mesh and an attempt is made to make this mould an exact replica of the sound limb, which is not at all difficult as the dimensions are exactly similar (fig. 5.15).

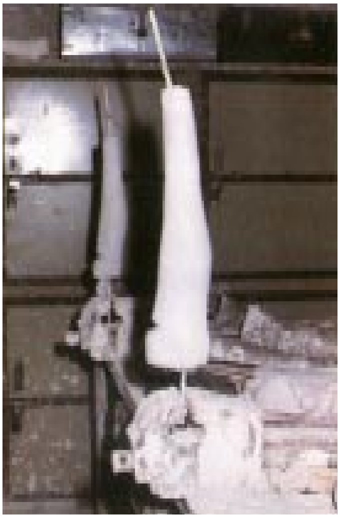


Fig. 5.15

Now a piece of HDPE pipe 7.5 cm more than the length of sound limb is selected and covered both inside and outside with a cotton stockinette. A wooden rod is inserted in the pipe, and it is placed in a preheated electric oven at 180ºC for 20 minutes (Fig. 5.16). This makes the pipe fairly malleable and this is then sleeved over the positive mould. With hands this is well moulded over the mould by applying sufficient pressure over the scooped out area in the infra pateller region, in popliteal region, over the shin area, and over medial and lateral malleoli (fig. 5.17). After the pipe is sufficiently cool and has taken the exact shape of the mould, the plaster of paris mould is hammered out and redundant edges are cut off with a hand saw.

Fig. 5.16

Fig. 5.17

The upper end of the prosthesis is cut as follows : anteriorly the cut is applied at mid patellar region upto the middle of the condyles (fig. 5.18) ; at this level it curves sharply downwards leaving sufficient space for the hamstrings, more space is left for medial hamstrings than for lateral hamstrings (fig. 5.19); the cut line then rises again upto the mid popliteal region **(fig. 5.20)**.

Fig. 5.18

Fig. 5.19

Fig. 5.20

The cut edges are then rounded, with the help of a file, and no sharp angles are left. The lower end of this prosthesis is again heated and the “Jaipur foot” of the matching size of the sound foot is attached to it by shrink fitting method. Care must be taken that foot is attached in plantigrade position. Although there is no need for a suspension system as the socket is well fitting, still to boost the confidence of the amputees a modified suspension system is glued to it. The prosthesis is now ready for static and dynamic alignment.

CHATPER 6

FABRICATION TECHNIQUE OF JAIPUR BELOW - KNEE ALUMINIUM PROSTHESIS

Since the introduction of total contact HDPE Prosthesis, this model has been phased out. But still few amputees who are using this model and insist on getting this prosthesis, this design is being provided.

For fabrication of the below-knee aluminium prosthesis the measurements are taken as follows. The patient is made sit comfortably on a chair. (A) The length of the sound leg is measured from tibial tuberosity to a point between medial and lateral malleolus. (B) The circumference of the knee on the amputated side is recorded at the level of the upper pole of patella. (C) The circumference of the sound limb is measured at an interval of 3" starting from 1" below the knee joint to the ankle joint **(Fig. 6.1 & 6.2).**

Fig. 6.1

Fig. 6.2

A rectangular piece of 16 swg. aluminium sheet is taken with the length equal to the length of the sound limb and breadth little more than the circumference of the knee on the amputated side. A central line is marked in the middle of this sheet **(Fig. 6.3).**

Fig. 6.3

The dimension (B) is marked on the top edge of this sheet, keeping the center line in middle. Dimension (C) is marked starting from 1" below the top edge on either side of the central line. These newly marked points are joined on either side of the central line.

The sheet is now cut on either side of central line along these newly joined points and pattern is obtained **(Fig. 6.4)**.

Fig. 6.4

This pattern is hammered on the side bars of an anvil and folded in such a way as to bring both the edges together. This provides a fairly good replica of the sound limb. The edges are then welded together **(Fig. 6.5).**

Fig. 6.5

The top edge of this socket is now deformed and cut to provide it with a P.T.B. shape. The patellar tendon is marked and an indentation is made over it just below the lower pole of patella, parallel to the floor. The depth of this indentation is kept about 13 mm and breadth about 25mm. The top edge of this socket is cut as follows. Anteriorly the cut is applied at mid patellar region up to the anterior 3/4 of condyles on either side; at this level is curves sharply downwards leaving sufficient space for the hamstring tendons; more space is left for medial hamstrings than for lateral hamstrings; the cut line then rises again up to the mid popliteal region **(Fig. 6.6).**

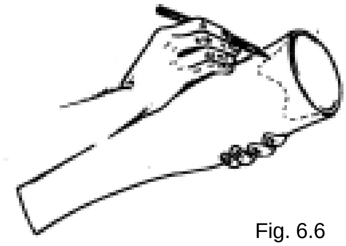


Fig. 6.6

With a hammer, a fairly good depression is made posteriorly between the hamstring areas for a good fit in the popliteal area. Mild depression is made in the area of medial tibial flare, and the area over the lateral side of the stump is flattened. The area over the head of fibula is lifted up to provide relief over it. Varus is produced in the shin area of the prosthesis, equal to the normal amount of varus present on the sound side.

A mild steel wire of 5mm diameter is then placed along these cut edges and the edges are folded over it. Same is done for the lower edges.

A round piece of wooden block is taken, its outer diameters little more than the circumference at the level of ankle with a hole of 2/8" diameter in its center. It is placed in this socket near its lower end, the carriage bolt of “Jaipur Foot” is passed through its central hole and tightened with the help of a nut. The foot is aligned in slight plantar flexion.

The socket is now smoothened for any rough areas, and a modified Jaipur suspension system is fixed to it **(Fig 6.7)**. The patient is asked to put it on and bear weight on both the limbs equally. Height of the prosthesis and fit of the socket over the stump is checked. The socket is then lined with corduroy and cotton blanket, and is given to the patient for gait training. After sufficient gait training, the prosthesis is painted with plastic emulsion paint having skin colour tones.

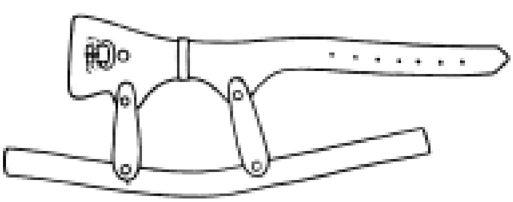


Fig. 6.7

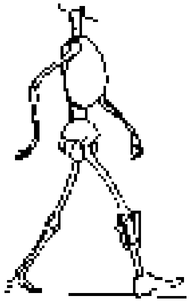
CHAPTER 7

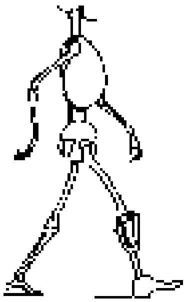
GAIT ANALYSIS AND FUNCTIONAL ATTRIBUTES OF B-K PROSTHESIS

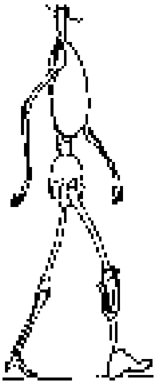
The major purpose of gait analysis is to identify gait deviations and to determine the cause associated with each deviation. This procedure requires a detailed knowledge of the principles of normal human locomotion, biochemical, prosthetic fitting and alignment.

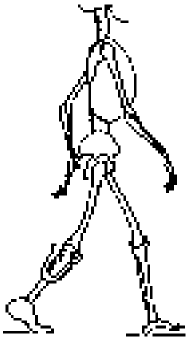
Some of the more commonly seen deviations in the gait of B-K amputees are discussed in this chapter and corrections are also suggested. It is helpful to identify the phase of the walking cycle during which each gait deviation occurs. So, the gait deviations are observed during following phases of Gait Cycle:-

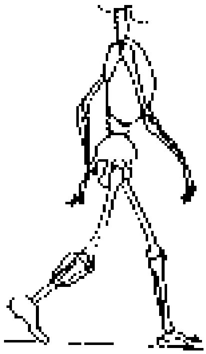
1) heel strike
2) Between heel strike and mid-stance
3) At mid stance
4) Between mid-stance and toe off

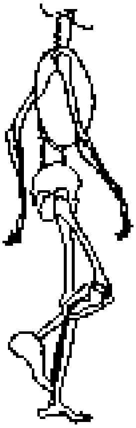
OPTIMUM GAIT BK-PTB	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
HEEL CONTACT VIEWED LATERALLY	1. Ball of foot dorsiflexed more than 1-1½”	a. Stride length too long. Gait training problem. b. Faulty suspension does not maintain knee in 5º - 10º flexion. c. Excessive socket flexion.	a. Train patient to walk correct stride length.
	2. Knee fully extended	a. Faulty suspension does not maintain knee in 5º - 10º flexion. b. Heel lever arm too short. c. Heel cushion too soft.	
	3. Unequal stride.	a. Faulty suspension does not maintain knee in 5º - 10º flexion. b. Gait habit.	b. Train for proper gait.
1. Ball of the foot not over 1-½” from the floor. 2. Knee flexed 5º - 10º, viewed thigh to shank or pylon. 3. Stride length same as normal.			

OPTIMUM GAIT BK-PTB	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
HEEL CONTACT TO FOOT FLAT VIEWED LATERALLY	1. Knee flexes jerkily.	Weak knee musculature.	Therapist gives treatment to build up strength of knee, Train amputee.
	2. Excessive knee extension, “Rides heel” through to mid-stance.	Bad gait habit carried over from use of conventional B/K prosthesis.	“Hamstring” flexed knee joint.
	3. Knee “Jack knifes” abruptly	Heel lever arm too long.	
	4. Piston action of stump in socket.	Suspension system incorrect.	
	5. Continual anterior distal tibia pressure.	Excessive use of knee extensors.	Teach amputee “Hamstring” type gait.
1. Knee flexes smoothly and quickly to approx. 25° or same number of degrees as the normal side. 2. Stump is down in socket. No Piston Action.			

OPTIMUM GAIT BK-PTB	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
MID-STANCE VIEWED FROM ANTERIOR POSTERIOR	1. Lateral trunk bending exceeds 1" at the head.-	a. Prosthetic foot outset too far laterally. b. Prosthesis too short.	
	2. Gait base exceeds 2" “Wide base gait”.	a. Bad gait habit. b. Prosthetic foot outset too far laterally. c. Possibly hip abductor pathology. d. Prosthesis 1" or more too long.	a. Train to walk with narrow base. b. Physician diagnoses and treats.
	3. Inversion or eversion of foot walking on lateral or medial border of shoe.	a. Improper adduction or abduction of the socket. b. Loose socket.	
	4. Lateral displacement of socket exceeds ½”	a. Loose socket M.L, excessively inset. b. Prosthetic foot loose.	
	5. No lateral displacement or any displacement medially.	a. Prosthetic foot outset too far laterally. b. Pain in peroneal nerve. c. Very short stump. d. Knee joint Pathology.	c. Clinic orders side joints and lacer. d. Physician diagnoses and treat pathology.
1. Lateral bending of the trunk 1" at the head. 2. Width of gait base upto 2" between medial borders of the hell - noted as swing foot passes stance foot.			

OPTIMUM GAIT BK-PTB	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
3. Foot is flat on floor. 4. Socket is displaced laterally but not more than ½”.			
HEEL RISE VIEWED LATERALLY	1. Knee goes into extension. a. Pressure at the anterior knee reported by amputee. b. Amputee may also report “ unable to go over the toe.”	a. Toe lever arm too long. Sach foot too tight in shoe. b. Amputee changed shoe to lower heel height.	
		c. Bad gait habit.	Gait training indicated.
		d. Insufficient socket flexion (so called hyperextension).	
1. As the amputee passes over the prosthesis, knee flexion increases smoothly to equal that of the normal leg.			

OPTIMUM GAIT BK-PTB	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
WEIGHT TRANSFER TO TOE-OFF VIEWED LATERALLY  1. Weight is shifted to the sound side without perceptible drop or rise of the head and torso accompanied by increase in knee flexion on the prosthetic side equal to the sound side.	1. "Drop Off" (Weight bearing period shortened and knee flexion accentuated) 2. Prosthesis drops away from stump (shown by anterior socket brim gapping). 3. Knee flexes jerkily.	Toe Lever Arm too Short. Cuff Suspension. Weak musculature.	 Therapist trains.

OPTIMUM GAIT BK-PTB	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
SWING PHASE VIEWED LATERALLY  1. Shank and foot swing thru on line of progression. 2. Socket remains securely on stump.	<u>WHIP</u> 1. (Foot rotates during swing)	Improper placement of suspension studs for cuff suspension	
	2. Piston Action	Cuff suspension	
	3. Circumduction	Prosthesis too long.	
	4. Drags toe on floor	Prosthesis too long; foot not in dorsiflexion.	

FUNCTIONAL ATTRIBUTES WITH PTB PROSTHESIS

The Jaipur limb not only mimics the normal limb cosmetically, it mimics it functionally in such a way that it becomes difficult, even for trained observer, to point out which limb is artificial and which one is not, at first look. It is highly versatile artificial limb, comfortably providing all the postures required during the activities of daily living of amputee population world over.

Squatting is a posture, which has to be adopted so many times during the day for varying periods. While squatting the ankles have to dorsiflex fully, the knees have to flex till the soft tissues of the thigh and calf can flatten against each other. It is this, which allows our center of gravity to fall within our point of support to provide a stable equilibrium, so that we do not fall backwards.

For a below knee amputee to achieve this, the socket has to move forward

Fig. 7.1

and create a space in front to avoid unbearable pressure on the sensitive anterior tibial crest.

The working surface in this part of the world is the floor; a person on an

Fig. 7.2

Fig. 7.3

average has to sit cross - legged for four to eight hours every day. We not only work in this posture, but dine, relax and pray as well. While sitting cross - legged, the foot adopts a very awkward position; as the outer border of it is pressed against the floor, it inverts and twists medially. If a rigid foot piece like SACH foot is provided to the amputee, it will force the shank and socket to rotate medially, putting unbearable pressure on the stump. The Jaipur foot, provided with the Mahaveer limb, adapts easily to this awkward position, and does not transmit any of the medial rotational forces to the stump, thus allowing a very comfortable cross - legged sitting posture to an amputee for very long period.

Fig. 7.4

Our farmers can now do a full days work, without fear of getting the stump bruised due to accentuated and constantly varying ground reactions being transmitted to the stump-socket interface, while walking on uneven ground and rough terrain. This has been made possible by the Jaipur foot, as it has the requisite range of supination and pronation, and adapts superbly to uneven surfaces, thus precluding any transmission of uneven ground reactions to the stump - socket interface. Minor amount of uneven ground reactions reaching the stump-socket interface are efficiently absorbed by the socket itself, being fairly resilient.

Fig. 7.5

The prosthesis is totally waterproof, allowing the farmers to work in the irrigation channels without fear of spoiling the prosthesis, and at the end of day they can wash both the limbs and feel neat and tidy. In fact they can continue to swim, if they were swimmers before amputation; this attribute is welcome even to urban amputees.

Fig. 7.6

Fig. 7.7

Fig. 7.8

They have no difficulty in working on traditional open wells for irrigating their fields.

Fig. 7.9

Climbing trees to collect fodder for the livestock is an essential feature in the life of farmers. The foot piece grips and adapts itself to the convex contours of the trunk of the tree, providing good stability to the climber. The resilience of the socket acts as an efficient shock absorber while jumping from the height.

Fig. 7.10

Mechanization of farming is the call of the day; amputees using this prosthesis are not at all at a loss, and can drive heavy farm machinery efficiently.

Fig. 7.11

Fig. 7.12

Fig. 7.13

Fig. 7.14

Heavy manual work can be done with ease; the resilience of socket is in fact a great help here. Many of the amputees earn their bread as rickshaw pullers.

A large number of urban amputees using this prosthesis regularly go to their place of work on cycles and scooters.

With this prosthesis, amputees can even run; in fact they can achieve very high speed. Some of the amputees even clock one kilometer in just 4 min. and 20 seconds, a feat in itself. Running is made possible because the socket is fairly resilient, and the prosthesis is very light. Under the conditions of quick loading and unloading, the socket expands and comes back to its original shape in no time, thus acting as an efficient shock absorber. The quality of returning to its original shape in no time, when unloaded, prevents prosthesis from slipping off during running and precludes any piston action.

Fig. 7.15

CHAPTER - 8

FABRICATION OF ABOVE KNEE ENDOSKELETAL HDPE PROSTHESIS

The High Density Polyethylene Endoskeletal prosthesis is fabricated from the following components. All the components are pre-fabricated, and are stocked in the workshop, except the socket, which has to be fabricated individually.

1. **H.D.P.E. Socket:** For fabrication of the socket, the measurements of the stump are recorded. The amputee is made to stand as comfortably as possible with support of a parallel bar or a chair. Stump length is measured from the perineum to the end of the stump, along the long axis of the femur. With the measuring tape still held from the perineum to the end of the stump, the medial side of the stump is marke at 2" intervals (Fig. 8.1).

Circumference of the stump is measured at the level of perineum. Care should be taken not to apply too much tension on the measuring tape and to keep it horizontal, as viewed from the front, and perpendicular to the long axis of the stump, as viewed from the side. Subsequent to this, measurements are taken at 2" interval.

Fig. 8.1

Following this a negative plaster mound of the stump is taken. To ensure that the socket will be of correct size, there should be no oedema of the stump. For this reason, it is best to take the measurements early in the morning as soon as patient arises. If the amputee is already using a prosthesis he should take it off just before the procedure of taking plaster mould starts. If he is not using any prosthesis, then he should come with the stump correctly wrapped. For taking the plaster impression of the stump, three six-inches wide plaster of Paris impregnated bandages are required. The technician who is taking the negative mould sits on a stool in front and slightly lateral to the amputee and an assistant stands behind the amputee. The height of the stool should be adjusted so that the technician may support his arm by resting his elbows on his thigh when desired (Fig. 8.2).

Fig. 8.2

Cover the stump with a 4/6" stockinette. Proximally, it should extend upto 2" above the greater trochanter laterally, 2"- 3" above the level of ischial tuberosity posteriorly and upto the level of anterior superior iliac spine anterioly. It is held in position by two lengths of twine, it should be held firmly but not pulled upwards tightly since this may cause distortion of the stump shape.

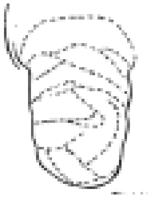


Fig. 8.3

Put 2 to 3 plaster impregnated bandages in a bucket of water and when they are thoroughly wet, wrap them around the stump laterally going upto 2" above the greater trochanter, anteriorly going upto 1" below the anterior superior iliac spine, posteriorly going upto 1" above the gluteal folds, medially going upto the perineum and to cover the protruding stump completely. Wrap snugly and evenly, avoiding formation of constrictive bands (Fig. 8.3).

As the plaster starts to harden, the assistant technician, who is standing behind the amputee, applies firm pressure with the help of 1½" diameter rod, just below the ischial tuberosity, so as to create a good indentation in the plaster cast for the weight bearing shelf. This rod is not held horizontal but its lateral end is 10^{o}- 15^{o} higher than its medial end. The technician who is sitting in front of the amputee presses gently against the lateral side to keep the stump in desired position of adduction with one hand. The lowest part of the hand, pressing against the lateral surface of the stump, should be atleast 1" above the end of the femur in order to protect the end of the stump from painful contact with the lateral wall of the socket when the femur abducts and simultaneously moves downwards with

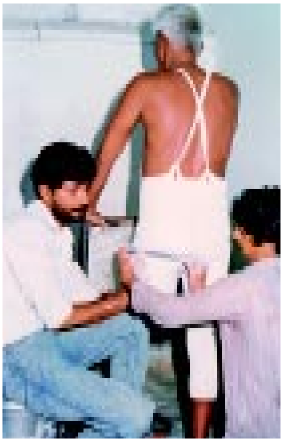


Fig. 8.4

Fig. 8.5

weight bearing, the hand should be positioned so that the fingers point upward, without greatly distorting the contour of the lateral socket. With the other hand the technician moulds the medial wall as vertical as possible. An indentation is also made in the scarpa's triangle area: it is made is such a manner that its deepest position is just opposite the indentation which has been made for the weight bearing shelf. Smoothen the plaster cast all over, particularly over the distal end .

When the cast has set, snip the two lengths of twine holding the stockinette in place and remove this cast from the stump with stockinette. Stockinette is then removed from inside the cast (Fig.8.4 & 8.5).

This negative mould is coated inside with a thin layer of Vaseline or other parting agents. The technician holds this negative mould in vertical position; the assistant then inserts a section of 1½" diameter rod in it, and fills it up to the brim with plaster of Paris paste: when this paste is set, the plaster of Paris bandages are removed. The negative mould thus obtained, is held in a vice with the help of the iron rod protruding out of it. The distal end of this positive mould is build-up by adding 1"-2" layers of the plaster of Paris paste on it (Fig. 8.6, 8.7, 8.8 & 8.9).

Fig. 8.6

Fig. 8.7

Fig. 8.8

Fig. 8.9

7 For modification of the positive mould, following dimensions are used as guidelines:

A. $$\left(\frac{X - 1\tfrac{1}{2}''}{4}\right) - 1\tfrac{1}{2}''$$

where x denotes the upper circumference of the stump.

This dimension should be the medial anteroposterior breadth of the positive mould, at the level of the brim.

B. $$\left(\frac{X - 1\tfrac{1}{2}''}{4}\right) - 1\tfrac{1}{2}''$$

Where x denotes the upper circumference of the stump.

This dimension should be the posterior mediolateral breadth of the positive mould, at the level of the brim. (The weight bearing shelf).

This build-ups of overhanging excess plaster above anticipated socket level must be reduced and shaped. This process ensures that sufficient material will be provided in the H.D.P.E. socket for adequate width and flare of the socket brim.

Reduce the build-up above the medial brim to approximately 3/4" from the perineum. It is very important to remove plaster in sagittal plane, so that it is parallel to the perineum.

Reduce the build-up above the posterior brim to approximately 5/8" from the posterior wall at the level of Gluteus maximus thus providing an ischial gluteal shelf of sufficient width. It is important to remove the plaster in a frontal plane, that is perpendicular to the medial wall.

Reduce the build-up above the anterior brim to the apex of the rectus femoris bulge. It is important to remove the plaster in frontal plane, that is perpendicular to the medial wall. Round off the corners posteromedially and anteromedially.

On the lateral side, the curve imposed on the positive mould by the flexible segment should be confined proximally to the top of the cast. Smooth out irregularities over the entire positive mould, except on the lateral distal end.

With a measuring tape, measure the length of the positive mould from the perineal level to the distal end. The length of the mould should be 1"-2" more than the length of the stump.

Use the tape to measure parameters of the mould at the perineal level and at each of the 2" interval mark, keeping the tape parallel to the perineum and ischial shelf. They should be equal to the parameters of the stump measured at same levels. The breadth of the medial wall at the perineal level should be equal to dimension A and breadth of the posterior medio-lateral wall at ischial gluteal level should be equal to dimension B. If the parameters and measurements of the mould are not equal make them so by adding the plaster of Paris to the mould. Care must be taken, when the parameter is being reduced at the perineal and proximal 2" levels, that most of the plaster removal should be done from the lateral side of the mould. If the parameter is being increased at these levels only fill in any existing irregularities. Reduce the mould parameters evenly by ½" in the distal half of the mould. Sand the mould for smoothness.

The modified positive mould is now held vertical keeping its distal end at the top and its proximal end towards the bottom. It is dusted with parting agents.

A piece of H.D.P.E. Pipe 2" longer than the length of the modified positive mould is selected and covered both inside and outside with cotton stockinette. A wooden rod is inserted in the pipe; the purpose of the rod is that the pipe can be hung freely in the oven by placing the ends of the wooden rod in the shelf made for this purpose. This pipe is then placed in a preheated oven at 200°C for twenty minutes. This makes the pipe fairly malleable; it is then sleeved over the positive

Fig. 8.10

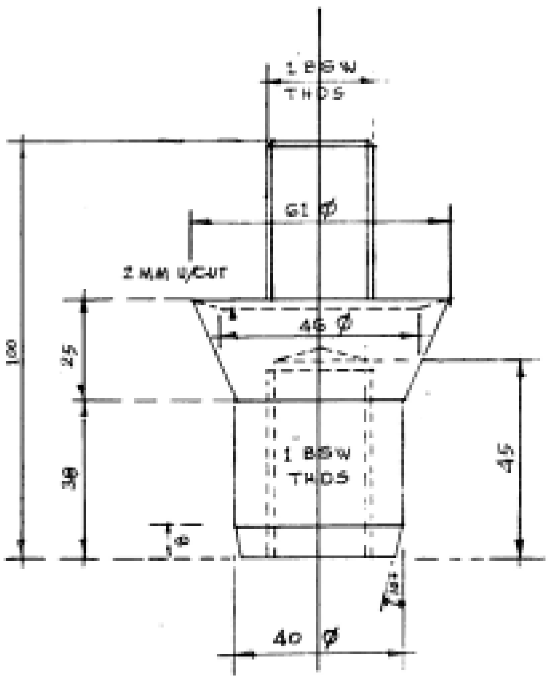
Fig. 8.11

mould. The edges of the pipe are folded over each other at the top in such a manner that they completely cover it, and the pipe is then well moulded with hands over the positive mould (Fig.8.10 & 8.11).

After the pipe is sufficiently cool and has taken the exact shape of the positive mould, it is removed from the vice. The plaster of paris mould is hammered out and the redundant edges are cut off.

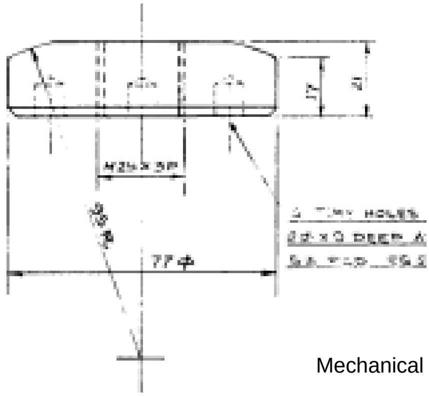
2. **Frusta of Cone Male female Connectors** - This piece connects the socket with the knee joint. The typical shape provides a fairly good seat for the socket, permitting change of alignment throughout the functional life of the prosthesis, and serves as spacer between the socket and the knee joint.

   It is machined from a single piece of nylon rod on a lathe machine. The male piece and female piece are provided with 1" B.S.W. threads. For specification please consult mechanical drawing No.1. These connectors of different length are stocked in the workshop.



Mechanical Drawing No.1

3. **Round Nylon Nut** - It is machined from a nylon rod on a lathe machine. It is a round nut with outside diameter of 75 mm. and inside diameter of 25mm. with 1" B.S.W. threads. For specifications please consult mechanical drawing No.2.



Mechanical Drawing No.2

4. **Knee Joint** - The joint which has been developed for this endoskeletal prosthesis is an offset knee joint. This joint is fabricated on a Lathe & milling machine in two pieces. The upper piece which is attached to the socket has a projecting eye piece at the distal end; the lower piece which is attached to the shin piece has a projecting female fork at the proximal end. Both the pieces are joined together by a pin, in such a way that the projecting male eye piece fits snugly in the forked female piece. The gudgeon pin provides an axis of movement for the joint. The main feature of this knee joint is the offset knee axis, which causes the weight line to pass anterior to the joint axis. The body weight thus acts as a force to lock the knee (alignment stability)

(I) **THE PROJECTING MALE PIECE -** The male piece is fabricated in a single piece, but for descriptive purpose it can be divided into three segments (Fig.8.12&8.13),for specification please consult mechanical drawing No.3.

Mechanical Drawing No.3

Fig. 8.12

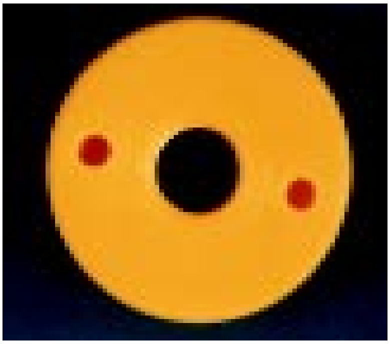


Fig. 8.13

A. **Cylindrical Threaded Rod -** This rod is 25 mm. in diameter and 33mm. long, placed in such away that it covers anterior three fourth of the superior surface of the body block, leaving a flat surface of about 10mm. on each side and 5 mm. posteriorly. It is provided with 1" B.S.W. threads.

B. **The Body Block -**The superior, inferior and anterior surfaces of this body block are rectangular in shape. The superior surface is perpendicular to the long axis of the prosthesis, but inferior surface is at an angle of 60^{o} to the long axis of the prosthesis, imparting this block a wedge shaped appearance in side elevation.

C. **Projecting Eye Piece-** This segment projects posteriorly and downwards at an angle of 120^{o} to the long axis of the prosthesis, is located in the centre of the inferior surface, is 15mm. thick and 50mm. long, leaving flat surfaces of 12.5mm. On each side, its posterior border is curved in half circle (30mm. diameter).

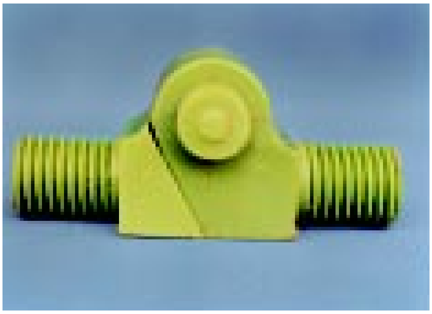


Fig. 8.14

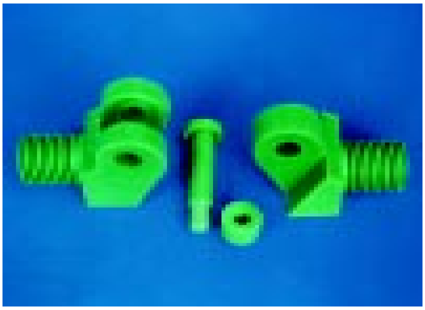
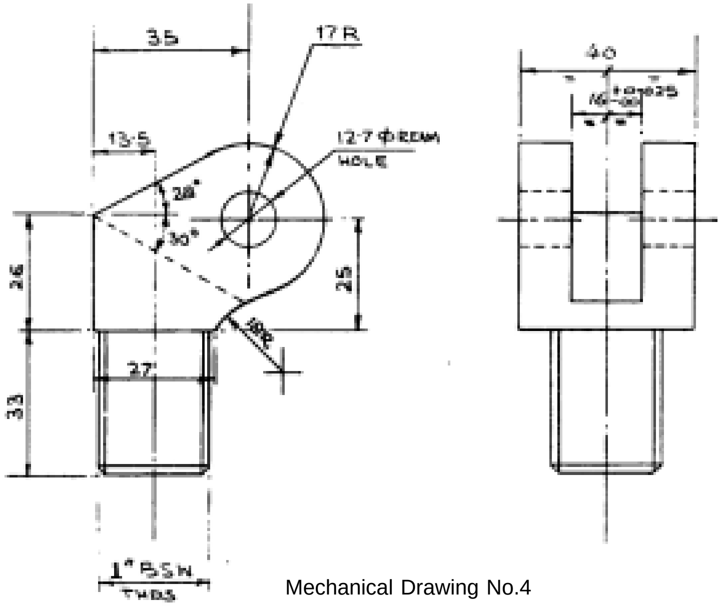


Fig. 8.15

(II) THE FORK FEMALE PIECE - Can also the divided into three segments



Mechanical Drawing No.4

(Fig.8.14,8.15 & 8.16), for description and specifications please consult mechanical drawing No. 4.

A. Projecting Forked Female Piece - This segment consists of two eye pieces projecting posteriorly and upwards at an angle 60^{o} to the long axis of the prosthesis, each one is about 12.5 mm. thick and 50mm. long. These projections originate from either side of the superior surface of the body block, leaving a clear space of about 15 mm. between them. The projecting eye piece of the Male

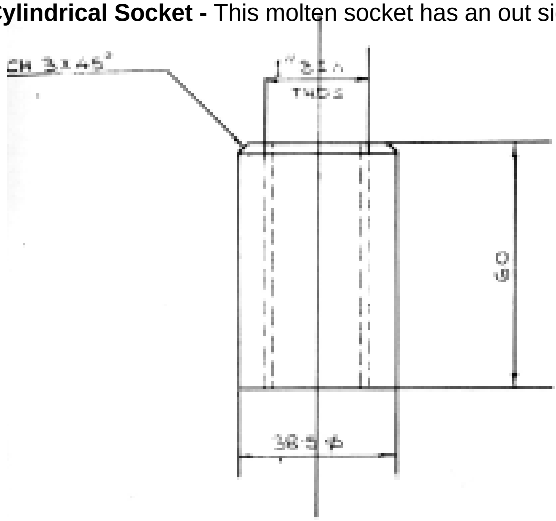
Fig. 8.16

piece fits snugly in this space. The posterior borders of each fork is half circle (30 mm. dia).

B. Body Block - The superior, anterior and inferior surfaces of this segment are rectangular in shape. The superior surface is at an angle of 120^0 to the long axis of the prosthesis. The inferior surface is perpendicular to the long axis of the prosthesis, acting as a base plate for the cylindrical threaded rod.

C. **Cylindrical Threaded Rod -** This Rod is 25 mm. in diameter and 33 mm. long, placed in such a way that it covers anterior three fourth of the inferior surface, leaving a flat surface of about 10 mm. on each side and 5 mm. posteriorly. It is provided with 1" B.S.W. threads.

5. **Cylindrical Socket -** This molten socket has an out side diameter



Mechanical Drawing No.5

Fig. 8.17

of 38.5 mm. and is 60 mm. long. This connects the knee joint with the nylon rod, used as shin piece in this prosthesis. For specifications please consult mechanical drawing No. 5; (Fig. 8.17).

6. **Nylon Rod -** This rod is used as shin piece in this prosthesis. It has an outside diameter of 38.5 mm. At one end it is provided with male 1" B.S.W. threads, and on other end it is provided with 5/16" B.S.W. female threads. These rods of various sizes are stocked in the store (Fig. 8.19).

7. **Jaipur Foot -** Prefabricated Jaipur Foot piece matching with the foot of normal side is selected.

8. **The suspension System -** A modified conventional suspension system is used. The metallic hinge connecting the pelvic belt to the thigh section is replaced by a flexible leather strap which allows the limb to move in all directions. A posterior elastic strap is being added which becomes tight while squatting or sitting cross legged allowing the socket to remain snugly pulled up against the stump, which other wise has a tendency to slip out in this posture, especially if the stump is short.

ASSEMBLY OF ABOVE KNEE H.D.P.E. PROSTHESES

Following measurements of sound limb are obtained (Fig.8.18)

A) From perineum to adductor tubercle

B) From adductor tubercle to the sole of foot.

The center of the base of the quadrilateral socket is marked. A second point 10 mm. medial and 10 mm. posterior to this center point is again marked, a hole of 25 mm. diameter is drilled through this second point.

Fig. 8.18

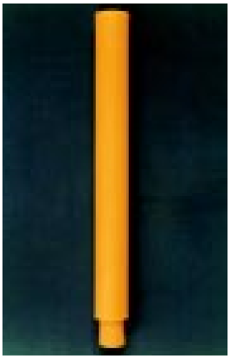


Fig. 8.19

The threaded male portion of the frusta of cone male female connector is passed through this hole and socket is tightened over it with the round nylon nut. As the hole drilled in the base of the quadrilateral socket is eccentric, it keeps the socket in 5^0-10^0 adduction in relation to the frusta of cone male female connector.

It is important to select this connector of correct length. Its length should be such that when the quadrilateral socket has been fixed on it, and the cylindrical threaded rod of the knee joint has been screwed into its female segment, the length from the ischial seat of the quadrilateral socket to gudgeon pin of the knee joint should be equal to dimension ‘A’.

The Jaipur foot is screwed into the female threads of the nylon rod. It is again important to select a nylon rod of correct length. Its length should be such that when this nylon rod is connected to the cylindrical threaded rod of the female piece of the knee joint with the help of cylindrical socket, the length from gudgeon pin of the knee joint to the sole of Jaipur foot should be equal to the dimension ‘B’.

The axis of the knee joint is kept at an angle of 10^0 to 15^0 of external rotation with respect to the coronal plane, to counteract any tendency of the prosthesis to whip during the swing phase.

The Jaipur foot is attached in 10^0 to 15^0 of external rotation with respect to coronal plane (toe out) for smooth transition from stance to swing phase and for better ground clearance during swing phase.

A pelvic suspension system is then fixed to the socket. The patient is then made to put on the prosthesis and asked to stand. The static alignment is checked. Following this the amputee is made to walk and dynamic alignment is checked, gait analysis of the amputee is done and accordingly corrections in the alignment are made (Chapter 10). Once a satisfactory alignment is achieved, sufficient gait training with special emphasis on walking without locking the knee, squatting and sitting crosslegged is provided.

Following satisfactory gait training the prosthesis is provided with a soft polyurethane foam stockinette cover to provide a natural shape and texture to this prosthesis. In situ foaming agents are still not available in India economically. So for this purpose 50 mm. thick U-foam sheets are used.

To prepare this cover, circumference of the sound limb is recorded at an interval of 3", starting from the level of the distal end of the stump to the level of the ankle. A U-foam sheet of 50 mm. thickness and length equivalent to the length of the prosthesis from the distal end of socket to the proximal end of the Jaipur foot is selected and a central line is marked. The dimensions equivalent to the circumference of the sound limb are marked on this sheet at the same interval of

3"' keeping the central line in middle. Now this sheet is cut along these marked points on both the sides of the central line. This pattern is then folded around the prosthesis, its lateral edges are glued together. This imparts the prosthesis with exact shape of the sound limb. This is then covered with cotton stockinette. This combination of stockinette and foam provides fairly normal texture to the prosthesis.

FABRICATION OF ABOVE KNEE ENDO-SKELETAL PROSTHESIS (Aluminium)

The endo-skeletal above knee prosthesis is fabricated from the following components. All the components are pre-fabricated, and are stocked in workshop, except the socket which has to be fabricated individually.

1. QUADRILATERAL SOCKET

(a) The circumference and length of the stump are recorded; upper circumference of stump is measured at the level of perineum. Care is taken to ensure that too much tension is not applied on the measuring tape and that it is kept horizontal as viewed from front and perpendicular to

Fig. 8.20

Fig. 8.21

the long axis of the stump as viewed from the side. The lower circumference of the stump is similarly measured at the lower end of stump. Length of the stump is measured starting from the upper end of the greater trochanter along the long axis of the femur upto the lower end of stump (Fig. 8.20 & 8.21).

(b) A rectangular piece of 16 S.W.G. aluminium sheet is taken, having length equal to the length of the stump and having breadth a little more then upper circumference of the stump. A central line is drawn on the sheet. At the upper edge, a dimension equivalent to the upper circumference of the

Fig. 8.22

Fig. 8.23

thigh is marked and at lower edge, dimension equivalent to lower circumference of the thigh is marked, keeping the central line in middle. Now with the help of a scale and marker, upper and lower points on the left side of the central line are joined and same is done for the right side. The

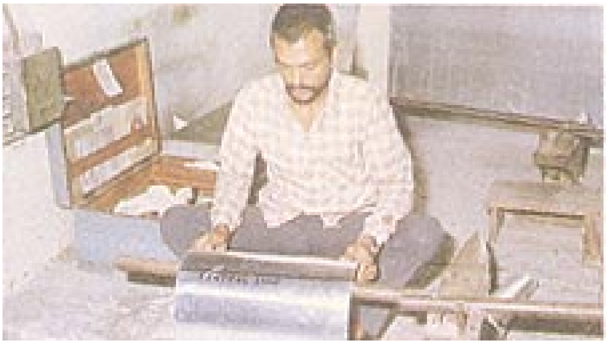


Fig. 8.24

sheet is cut along these newly marked lines (Fig. 8.22 & 8.23).

Then the sheet is hammered on the side bars of anvil in such a way that both left and right edges of sheet are brought together, giving it shape like a funnel; the edges are then welded together, forming primary socket which is now deformed to give it a quadrilateral shape as follows (Fig. 8.24).

(c) Socket Brim - The socket is held keeping the central line in front which was marked on the aluminium sheet before giving it a shape of funnel. Two points (a and b) are marked on either side of this line.

Point a — at a distance equivalent to (x - 1½"/4) is marked on the medial side of the central line. This dimension is equivalent to medial antero-posterior length of the socket brim (where x denotes the upper circumference of the stump).

Point b - at a distance equivalent to (x - 1½"/4) is marked on the lateral side of the central line. This dimension is equivalent to the posterior medio-lateral length of the socket brim, where x denotes the upper circumference of the stump.

Fig. 8.25

Fig. 8.26

Now a 2" to 2½” deep cut is made between points a and b. The socket is now deformed in such a manner that the postero-medial corner of the socket comes over to the central line, antero-medial corner comes over point ‘a’ and the postero-lateral corner comes over point b of the socket brim. The medial wall of the socket is shaped between point ‘a’ and the central line and the posterior wall of the socket is shaped between the central line and point ‘b’ (Fig.8.25 & 8.26).

(d) The medial wall - is shaped perpendicular to the floor. Comfort and function are best preserved by maintaining flat contour throughout upper third of socket wall. In the coronal plane approximately the first four inches are kept vertical, than the contour starts to move laterally in order to maintain contact with the distal stump. On very short stumps, this lateral curving may start much closer to the brim.

A wall constructed in such a manner, in combination with the inward sloping of the lateral wall, keeps the stump in adduction; as the ‘rest length theory’ of the muscle action has shown that the muscles of the body act most efficiently when they are approximately at their normal length, it increases the efficiency of hip abductors in addition to the relaxation of the adductor muscles. As a result of this relaxation, the pressure in the crotch or medial area is then predominantly lateral rather than vertical and no longer causes painful pressure on stretched adductor tendons in the region of the ramus.

(e) The posterior wall - is shaped at 90^0 to the medial wall and is slightly concave in contour and forms a horizontal angle of 97^0 to 100º with the medial wall. An ischial seat of fairly good size is formed from its upper edge; in coronal plane the ischial seat should be horizontal to the floor. Medially, anterior edge of the ischial seat has a radius of about ½” so as not to produce too sharp a pressure on the hamstring tendons. It must at the same time maintain a fairly level support for the ischium.

(f) The lateral wall - of the socket is shaped in such a manner that if fits snugly over the entire length of the stump, slopes inwards and is flattened over its entire length. This prevents abduction of the stump in the socket, when the patient lifts the normal limb, and abductors of the hip are contracting to prevent the pelvis from dipping on the unsupported side. The lateral wall never proceeds downwards to meet the posterior wall but it rather flows down and into the ischial seat level of the posterior wall with a sweeping smooth curve. The radius of joining the posterior wall is sharper at ischial seat level providing room for the gluteus maximus, yet no evidence of a corner is left deeper in the socket once this muscle is accommodated.

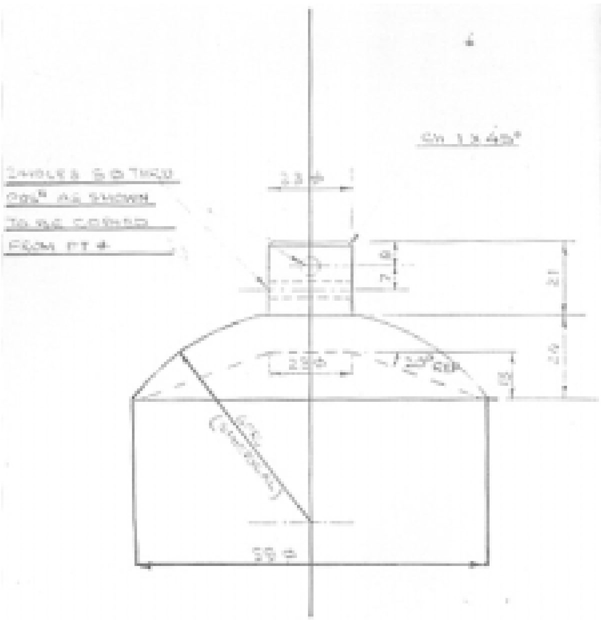
A slight pocket is left opposite the end of the amputated femur, thus providing relief from pressure when it is drawn forcefully against the lateral wall by the gluteus medius and minimums in stance phase.

(g) The anterior wall - is 2½" above the ischial seat level and on very short stumps can be even higher. This height provides a large surface over which to distribute the anterior forces and precludes as much as possible any soft tissue roll. Medially on this wall a bulge is made inwards to produce a firm but evenly distributed pressure over the entire scarpa's triangle. The portion of scarpa's bulge which is most posterior, is located in the medial one-third and is directly opposite the ischial seat, extending and tapering off upto 4" below the ischial seat level, below that no evidence of bulge is left.

The socket is flared at the antero-medial and postero-medial corners to provide channels for adductor longus and hamstring muscles.

2. ALIGNER DISC.

It is saucer shaped and a piece of conduit pipe of 30 cm. length is attached to it in the center of the inferior surface. It is made of aluminium alloy and is sand



Mechanical Drawing No.6

Fig. 8.27

casted with conduit pipe as a single piece. The diameter of the disc is 10 cm., the concavity of the discs - 20 D, and outer diameter of the conduit is 2.55 cm. The shape of alignment disc not only allows easy adjustability of the socket in planes perpendicular to the long axis of the prosthesis but also allows socket to be attached to it, at any angle of flexion and adduction; for specification please consult mechanical drawing No.6. (Fig. 8.27).

3. CONDUIT PIPES (ELECTRIC RESISTANCE WELDED)

Hot extrusion type of the mild steel seamless pipes are used as the supporting structure of the prosthesis. The pipe has an outer diameter of 2.55 cm. and wall thickness of .225 cm.

4. KNEE JOINT :

The knee joint which has been developed for this endo-skeletal prosthesis is an offset knee joint. It is made of an aluminium alloy by sand casting, in two pieces. The upper piece which is attached to the socket has a projecting female

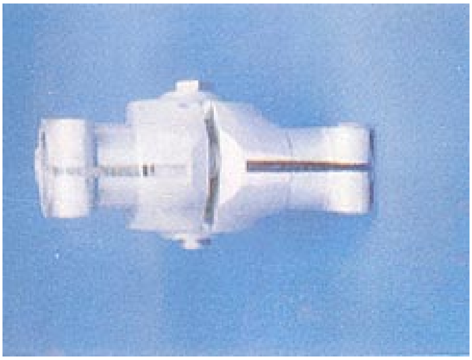
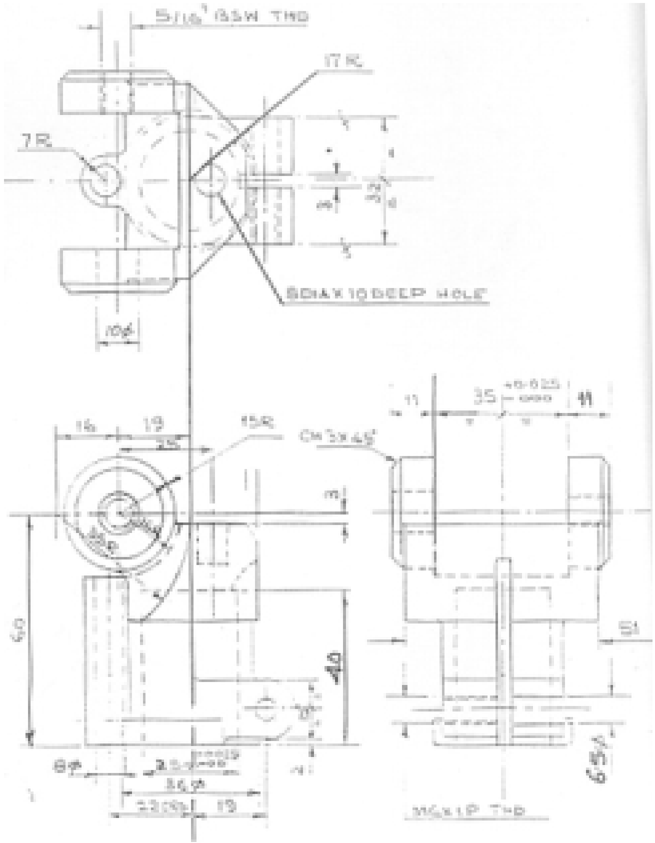


Fig. 8.28

Fig. 8.29

fork at distal end and the lower piece which is attached to the shin piece has a projecting male eye piece at the proximal end. Both the pieces are joined together by a mild steel case hardened gudgeon pin, in such a way that the projecting male eye piece fits snugly in the forked female piece. The gudgeon pin provides



Mechanical Drawing No.7

an axis of movement for the joint. The main feature is the offset knee axis. The body weight thus acts as a force to lock the knee (alignment stability) (Fig.8.28 & 8.29).

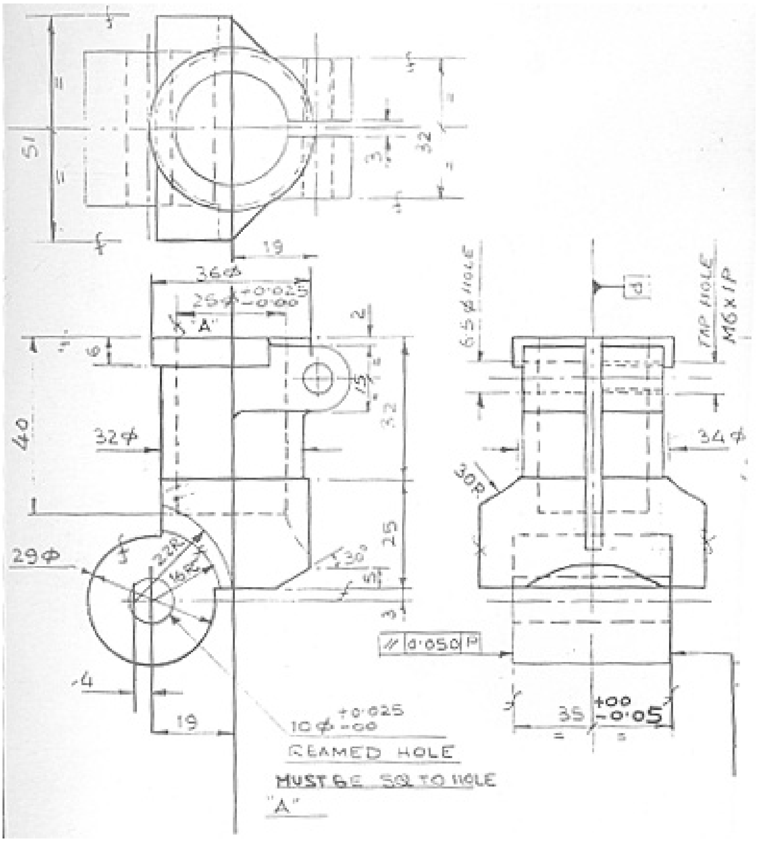
THE FEMALE FORKED PIECE :

This female fork piece is sand casted in one piece; for descriptive purpose it can be divided into three segments (For specifications please consult mechanical drawing No. 7).

(a) Hollow Slotted Rod - This rod is fabricated hollow so as to hold the conduit pipe of the aligner disc, and slotted to act as a clamp. Two projections are provided at the upper rim on either side. The 4 mm. wide slot on the anterior surface, each having a hole of 6.5 mm. diameter in the horizontal plane. When through these holes a bolt is passed and tightened, it allows this hollow slotted rod to firmly grip the conduit pipe of the aligner disc. This attribute of the hollow slotted rod, by which it can firmly grip the conduit pipe of aligner disc or loosen it completely just by tightening or loosening of the horizontal bolt at its upper rim, provides the facility for the change of alignment of the socket and knee joint throughout the functional life of the prosthesis and also allows the easy change of components.

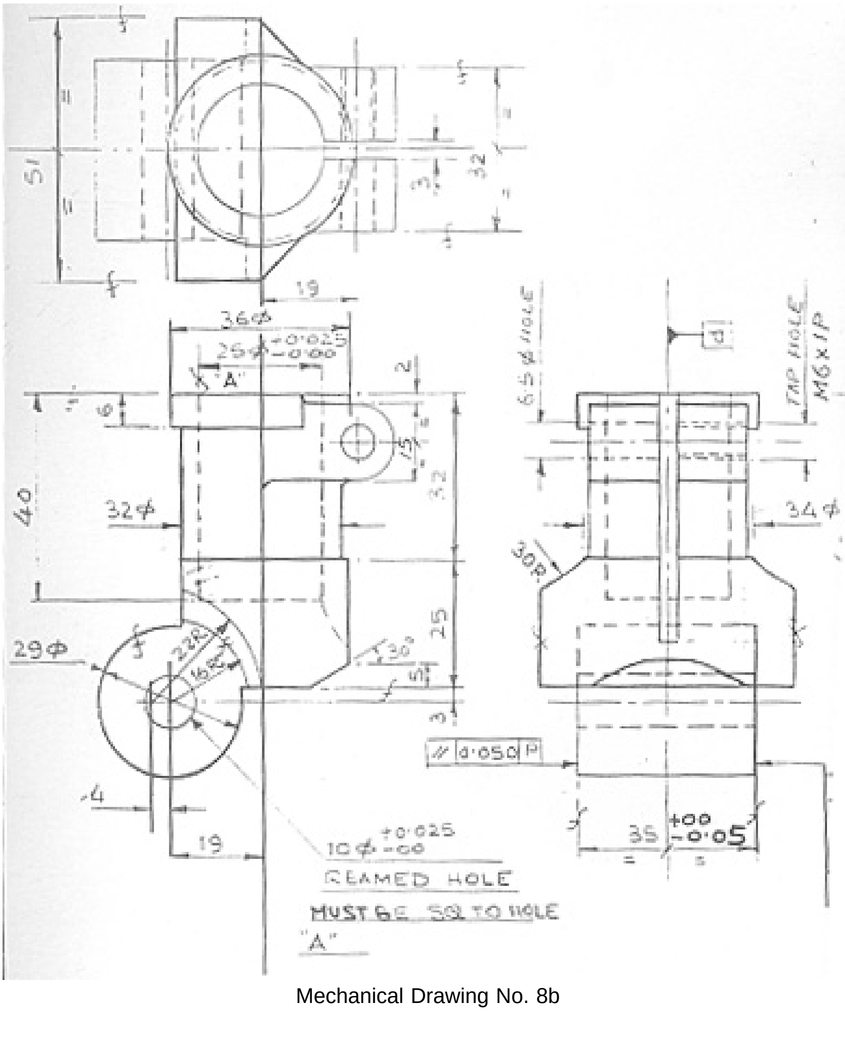
The out side diameter of this hollow slotted rod is 32 mm. and the inside diameter is 25 mm. It also has a longitudinal hole all along the posterior surface for remote control locking. The 4 mm. wide slot at the anterior surface is extended upto and into the superior surface of the body block to improve the gripping characteristics.

(b) Body Block - This body block has a parabolic shape anteriorly, and a flat



Mechanical Drawing No. 8a

surface posteriorly. The superior and inferior surfaces are perpendicular to the long axis of the prosthesis. The anterior surface is chamfered at the lower end. The inferior surface is provided with an H.D.P.E. button, which acts as a shock absorber.



Mechanical Drawing No. 8b

(c) Projecting Fork - This fork projects downwards and posteriorly at an angle of 120º from the longitudinal axis of the prosthesis. Each prong of the fork is placed on either side of the interior surface, leaving a clear space of 3.5 cm. thick & 5 cm. long. The posterior border of each prong is a half circle (30mm. diameter).

(B) THE MALE PIECE :

This male piece is sand casted in one piece; for descriptive purpose this can also be divided into three segments (For specifications please consult mechanical drawing No.8a & 8b).

(a) Projecting Eye Piece : The eye piece projects posteriorly and upwards at an angle of 60º to the long axis of the prosthesis. This is located in the center of the superior surface of the body block. It is 3.5 cm. wide and has an outer diameter of 3 cm. leaving a shoulder space of.85 cm. on each side. The shoulders on each side are machined in circular sector form having a radius of 2cm., they are also provided with under cuts for better performance.

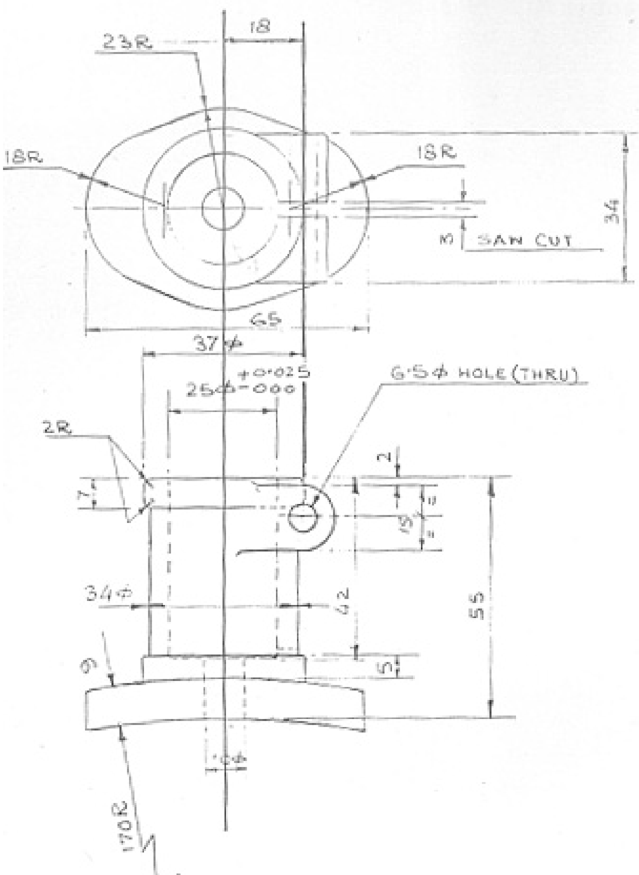
(b) The Body Block : Except the shoulder area which is machined in circular sector form, the superior and inferior surfaces are perpendicular to the long axis of the prosthesis. The body block has a parabolic shape anteriorly and a flat surface posteriorly. The anterior surface is chamfered near the superior surface.

(c) Hollow Slotted rod: This rod is again fabricated hollow so as to hold the conduit pipe which is used as shin piece in this prosthesis, and slotted to act as a clamp. Two projections are provided on this hollow slotted rod, over the inferior rim on either side of the 4 mm. wide slot, on the anterior surface. When a bolt is passed through these horizontal holes and tightened, it allows the hollow slotted rod to firmly grip the pipe. This attribute of hollow slotted rod by which it can firmly grip the conduit pipe (shin piece) or loosen it completely just by tightening or loosening of the horizontal bolt at lower rim, provides the facility for change of alignment of the knee and ankle throughout the functional life of prosthesis and also allows for easy change of components.

The outside diameter of this hollow slotted rod is 32 mm. and inside diameter is 25 mm. The 4 mm. wide slot in the centre of anterior surface is extended upto and into the inferior surface of the body block for improved gripping characteristic. The anterior surface is chamfered superiorly.

After sand casting, the male and Female piece are subjected to milling operation so that the surface of female projecting fork and male projecting eye piece can be made parallel to each other. This allows for free rotation of male piece in female piece during movement of joint.

After milling operation, the male piece is held in a special fixture. This fixture is especially designed for machining operation; It has two bolts, one to hold the male piece and another to hold the female piece of the joint, with a facility that either of the pieces can be removed or reinserted without disturbing position of either. First the male piece is held into it, and the fixture is then mounted on the chug of the lathe machine. The male piece is then centered in such a way that it



Mechanical Drawing No.9

cuts shoulder on the superior surface of the body block, in sector circular form of 2 cm. radius and depth of .85cm. with under cuts on both sides. Now it is centered at the half circle of the posterior surface of the fork (3cm. diameter). A case hardened gudgeon pin having shape of bolt, as it has a hexagonal head on one side and threads for nut on other side, is passed through this hole and nut is tightened. The articulated joint is now removed from the fixture and is ready for use.

5. FOOT PIECE GUIDE :

The foot piece guide is sand casted in one piece but for description it can be considered in two segments. A) Hollow slotted rod B) Flat plate. For specifications please consult mechanical drawing No.9.

(A) Hollow Slotted Rod : This is made hollow to hold the conduit pipe used as shin piece in this prosthesis, and slotted to act as a clamp to firmly grip this pipe. Two projections are provided at the superior rim on either side of the 4 mm. wide slot on the anterior surface, each having a hole in horizontal

Fig. 8.30

plane. When a bolt is passed through these horizontal holes and tightened, it firmly grips the said pipe.

This attribute of the hollow slotted rod, by which it can firmly grip or completely loosen the said pipe just by tightening or loosening of the horizontal bolt, allows for alignment adjustment of the knee joint and facility for change of components throughout the functional life of the prosthesis.

(B) Flat Plate : This is an oval flat plate; it is 6.5 cm.x 4.6 cm. in its long and short axis and 1 cm. thick; it acts as a base plate for the hollow slotted rod. There is a hole in the center of this plate to accommodate the carriage bolt of Jaipur Foot.

6. JAIPUR FOOT :

Prefabricated Jaipur Foot piece matching with the foot of normal side is selected.

7. THE SUSPENSION SYSTEM :

A modified conventional suspension system is used. The metallic hinge connecting the pelvic belt to the thigh section is replaced with a flexible leather strap, which allows the limb to move in all directions. A posterior elastic strap is being added which becomes tight when sitting cross legged or squatting, allowing the socket to remain snugly pulled up against the stump which otherwise has a tendency to slip out in this posture, especially if the stump is short.

ASSEMBLY OF ABOVE KNEE ENDO-SKELETAL PROSTHESIS

1. The assembly of the prosthesis begins from the knee joint. Measurements of amputee are taken on sound side in standing position A) from ischial tuberosity to the adductor tubercle of the femur and B) from adductor

tubercle to the sole of the foot.

2. The aligner disc is temporarily attached to the socket in 5º-10º of flexion by four welding tucks. The conduit pipe of the aligner disc is cut and shortened to such length that, when it is placed in the hollow slotted rod of the female forked piece of the knee joint the length from the ischial seat of the socket to the gudgeon pin of knee joint, should be equal to length A).

3. The horizontal bolt of the hollow slotted rod of the female forked piece of knee joint is tightened, keeping the axis of the knee at 10º-15º lateral rotation with respect to the coronal plane, to counteract any tendency of the prosthesis to whip during the swing phase.

4. A conduit pipe, of the measurement equivalent to B) minus the (height of foot piece+ body block of male piece of knee joint) plus 1 cm. is selected and placed in the hollow slotted rod of male piece. The horizontal bolt of this piece is tightened to firmly grip this conduit pipe.

5. The pre-selected 'Jaipur Foot' is attached to the foot piece guide by passing its carriage bolt through the hole at the center of the flat plate of foot piece guide and firmly tightened with the help of a nut.

6. The free end of the conduit pipe which is attached to the male piece of the knee joint at one end, is now placed in the hollow slotted rod of the foot piece guide. The Jaipur Foot is attached in slight plantar flexion and 10º-15º of external rotation with respect to coronal plane (toe out) for smooth transition from stance to swing phase and for better ground clearance during swing phase. The horizontal bolt is then tightened to firmly grip the said pipe.

7. A pelvic suspension system is then fixed to the socket. The patient is then made to put on the prosthesis and asked to stand. The static alignment is then checked. Following this the amputee is made to walk and dynamic alignment is checked, gait analysis of the amputee is done and accordingly corrections in the alignment are made . Once a satisfactory alignment of socket is achieved, the aligner disc is completely welded with the socket. All the horizontal bolts are firmly tightened.

8. Once sufficient gait training with special emphasis on walking without locking the knee, squatting and sitting cross-legged has been given, the prosthesis is provided with a polyurethane cover. Before providing cover, all the horizontal bolts are checked and finally tightened.

9. A soft polyurethane foam stockinette cover is prepared to provide a natural shape and texture to this prosthesis. In situ foaming agents are still not available in India, economically. So, for this purpose 50 mm thick U-foam sheets are used.

To prepare this cover, circumference of the sound limb is recorded at an interval of 3", starting from the level of the distal end of stump to the level of the ankle. A U-foam sheet of 50mm thickness and length equivalent to the length of the prosthesis from the distal end of socket to the proximal end of the foot is selected and a central line is marked. The dimensions equivalent to the

CHAPTER 9

FABRICATION OF JAIPUR CONVENTIONAL (ALUMINIUM) EXO-SKELETAL ABOVE - KNEE PROSTHESIS

Since the introduction of above knee endo-skeletal prosthesis and subsequent introduction of HDPE model, this prosthesis is gradually being phased out. But still in few cases where it is indicated, this design is being provided.

For fabrication of this prosthesis, the measurements of the amputee are taken as follows. The amputee is made to stand, taking support of a chair or parallel bars as comfortably as possible. With a measuring tape, following dismensions of the sound limb are recorded.

(A) From adductor tubercle to medial malleolus (Fig. 9.1).

Fig. 9.1

(B) From perineum to adductor tubercle.

Fig. 9.2

(C) Circumference of the limb is measured at an interval of 3", starting from the knee to medial malleolus.

(D) Circumference of the stump is measured at an interval of 3" from perineum to the end of the stump. Care should be taken to ensure that too much tension is not applied on the measuring tape and that it is kept horizontal as viewed from the front and prependicular to the long axis of the stump as viewed from the side (Fig. 9.2).

A rectangular piece of 16 S.W.G. aluminium sheet is taken; its length should be equal to dimension 'A' and breadth a little more than the upper circumference of the stump. A central line is drawn in the middle of the sheet. At the upper edge, a dimension equivalent to the upper circumference of the stump is marked, keeping the central line in middle. Similarly dimension 'D' is marked at 3" interval, at the lower edge circumference of the knee of the sound side. Now with the help of a scale and a marker, all the points on left side of the central line are joined and same is done for the right side. The sheet is then cut along this newly marked line (Fig. 9.3 & 9.4).

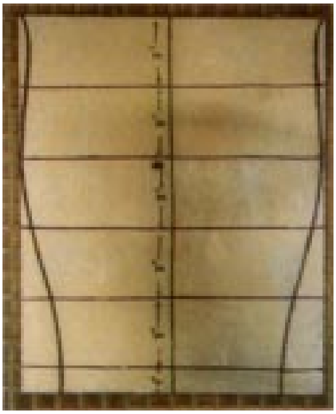


Fig. 9.3

Fig. 9.4

This pattern is then hammered on the side bars of an anvil in such a way that both left and right edges of it are brought together giving it a shape like a funnel. The edges are then welded together, forming a primary socket. This socket is now deformed to give it a quadrilateral shape.

The primary socket is held keeping the central line which was marked on the aluminium sheet before giving it a shape of funnel in the front. Two points (a & b) are marked on either side of this central line (Fig. 9.5).

Fig. 9.5

Point a-at a distance equivalent to $\left(\frac{X - 1\frac{1}{2}''}{4}\right) - 1\frac{1}{2}''$ where 'x' denotes the upper circumference of the thigh

Point b - at a distance equivalent to $\left(\frac{X - 1\frac{1}{2}''}{4}\right)$ where 'x' denotes the upper circumference of the thigh

A 2" to 2½" deep cut is made between points a & b. The socket is now deformed in such a manner that the posterio-medial corner comes over the central line, the antero-medial corner comes over point 'a' and the postero - lateral corner comes over point 'b' of the socket brim. The medial wall of the socket is shaped between the central line and point 'b'.

The medial wall is shaped perpendicular to the floor. Comfort and functions are best preserved by maintaining flat contour through the upper third of socket wall. In the coronal plane, approximately the first four inches are kept vertical, then the contour starts to move laterally in order to maintain contact with the distal stump. On very short stump this lateral curving may start much close to the brim.

A wall constructed in such a manner, in combination with the inward sloping of the lateral wall keeps the stump in adduction; as the 'rest length theory' of the muscle action has shown that the muscles of the body act most efficiently when they are at approximately their normal length. It increases the efficacy of hip abductors in addition to the relaxation of the adductor muscles. As a result of this relaxation, the pressure in the crotch or medial area is then predominantly lateral rather than vertical and no longer causes painful pressure on stretched adductor tendons in the region of the pubic ramus.

The posterior wall - is shaped perpendicular to the medial wall, is slightly concave in the contour and forms horizontal angle of 97º to 100º with the medial wall. An ischial seat of fairly good size is formed from its upper edge; in coronal plane the ischial seat should be horizontal to the floor. Medially anterior edge of the ischial seat has a radius of about ½" so as not to produce too sharp a pressure on the hamstring tendons. It must at the same time, maintain a fairly level support for the ischium.

The lateral wall - of the socket is shaped in such a manner that it fits snugly over the entire length of the stump, slope inwards and is flattened over its entire length. This prevents abduction of the stump in the socket when the patient lifts the normal limb, and abductors of the hip are contracting to prevent the pelvis from dipping on the unsupported side. The lateral wall never proceeds downwards to meet the posterior wall but it rather flows down and into the ischial seat level of the posterior wall with a sweeping smooth curve. The radius of joining the posterior wall is sharper at ischial seat level, providing room for the gluteus maximus, but no evidence of a corner is left deeper in the socket once this muscle is accommodated.

A slight pocket is left opposite the end of the femur, thus providing relief from pressure when it is drawn forcefully against the lateral wall by the gluteus medius and minimus in stance phase. Above ischial level, the lateral wall is curved inwards to retain contact with the stump.

The anterior wall - is 2½" above the ischial seat level and on very short stump, can be even higher. This height provides a large surface over which to distribute the anterior forces and precludes as much as possible any soft tissue roll. Medially in the socket, a bulge is made inwards to produce a firm but evenly distributed pressure over the entire scarpa's triangle. The portion of scarpa's bulge which is most posterior is located in the medial one-third and is directly opposite the ischial seat, extending the tapering off upto 4" below the ischial seat level; below that no evidence of bulge is left.

The socket is flared at the antero-medial and postero-medial corners to provide channels for adductor longus and hamstring muscles.

A saucer shaped aluminium sheet is welded at the lower end of the socket. This socket forms the thigh piece of the prosthesis.

A second rectangular 16 S.W.G. sheet is taken, its length equivalent to dimension (B) and breadth a little more than the circumference at the knee level of the sound side. A central line is marked in the middle of this sheet. Dimension 'C' is marked at 3" interval keeping the central line in middle, marking the circumference of the knee at the top edge and circumference at the malleolus level at the bottom edge. With a scale and marker, the newly marked points are joined together on the left side of the central line and the same is done on the right side. The sheet is then cut along these points, on either side of the central line.

This pattern is then hammered on the side bars of an anvil in such a way that the right and left edges are brought together. This provides a replica of the sound leg. The edges are then welded together.

The socket is now held keeping the central line in front, and the mid points between this central line and welding line is marked on both the sides. A 2" to 2½" deep cut is made between these mid points in the posterior half of the top circumference.

Two uniaxial knee joints are now fixed to this socket; the joint on the medial side is fixed 10mm. posterior to the medial mid point, and joint on the lateral side, anterior to the lateral mid point. This will keep the joint axis in 10º to 15º of external rotation with respect to the coronal plane to counter act any tendency of the prosthesis to whip during the swing phase.

A circular wooden block with a hole 5/16" in its center and outside diameter little more than the circumference at the malleolar level is then placed inside this socket. A prefabricated Jaipur foot of the matching size of the sound foot is fitted to

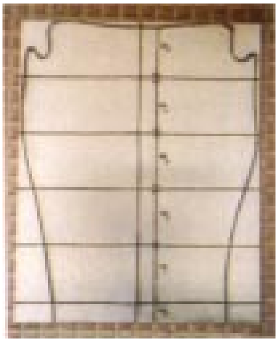


Fig. 9.6

Fig. 9.7

this socket. The bolt of Jaipur foot passes through the hole of the said wooden bolt and it tightened with help of a nut in slight plantar flexion and 5º to 10º external rotation (toe out) for smooth transition from stance phase to swing phase and better ground clearance during swing phase.

The quadrilateral socket is then fixed to the upper bars of the uniaxial knee joints in 5º - 10º of flexion and 5º - 10º adduction. A pelvic suspension system is then attached to the socket.

After putting on the prosthesis, the amputee is then made to stand and static alignment is checked out. Then the amputee is asked to walk and dynamic alignment is checked out by gait analysis and corrections in the alignment are made accordingly.

Once the performance is found satisfactory, sufficient gait training is provided. When the patient is satisfied with the performance of the prosthesis, it is padded with cotton blanket and corduroy, then it is painted with fevicol to make it weather proof. Natural colour dyes are added to the fevicol to impart matching colour to the prosthesis.

CHAPTER - 10

GAIT ANALYSIS AND CHECK OUT WITH THE ABOVE KNEE PROSTHESIS

As with the B-K Amputee gait, the purpose of gait analysis of A-K Amputee is to identify any gait deviation and determine the cause associated with each deviation. Considerable valuable information about the amputee and his/her prosthesis can be derived from careful observation of the gait pattern.

Some of the more common above knee deviations and their usual causes are presented in this chapter in chart form. It is helpful both to observe and to understand the particular phase of gait at which the deviation occurs, together with the preferred vantage point for observation.

The deviations are observed in the following phases of Gait :-

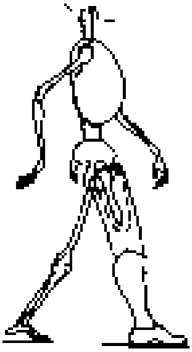
i) Heel contact

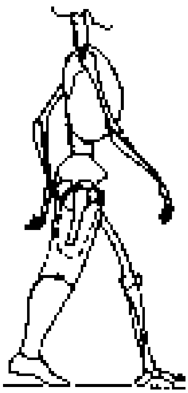
ii) Mid stance to heel rise

iii) Toe off-heel rise acceleration

iv) Swing through

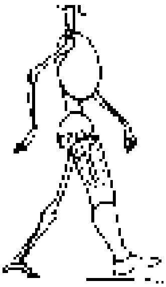
v) Deceleration

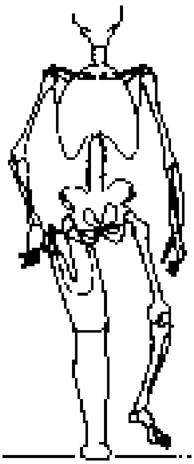
OPTIMUM GAIT-AK	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
HEEL STRIKE TO FOOT FLAT VIEWED LATERALLY 	1. Knee instability	1. a) Plantar bumper too stiff. b) SACH heel too stiff. c) Plantar flex, too limited -hydraced. d) Knee center too far anterior to troch-ankle line. e) Weak hip extensors	1. a) CP b) CP c) CP d) CP e) RPT
	2. Foot slap	2. a) Conv-plantar bump too weak. b) Hydracad-gait training prob. c) Never seen in SACH foot.	2. a) CP b) RPT&CP
1. Hydracadence only as shown. 2. Conventional- comes down fairly well. 3. SACH deforms- may resemble.	3. Terminal impact (will see again in deceleration)	3. a) Amp. insures full knee extension by forceful impact.	3. RPT

OPTIMUM GAIT-AK	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
MID-STANCE TO HEEL RISE VIEWED LATERALLY	1. Pelvic rise “hill climbing”. amp. rolls over ball of foot, pelvis rises excessively.	1. a) Toe lever arm too long. b) Hydracadence foot set in excessive plantar flex. c) Shoe change by amp. lower heel.	1. a)CP Realign b)CP Adjust c)PT Corrects
	2. Drop-off torso lowers excessively.	2. a) Toe lever arm too short (toe break SACH heel) b) Hydra foot in excessive dorsiflex. c) Dorsi stop weak. d) Stride length on sound side too long. e) Anterior placement of socket, re : foot.	2. a) CP b) CP c) CP d) RPT e) CP
1. CG follows smooth and uniterrupted path. 2. Hip extends to 10º by ant. pelvic rotation; no knee/ankle help. 3. Need 5º-10º initial flexion socket.	3. Excessive lumbar lordosis	3. a) Insufficient initial socket flexion. b) Hip flexion contracture in amp. c) Painful ischial seat or post. wall. d) Posterior displacement of shoulders for balance	3. a) CP b) MD & RPT c) MD d) RPT

OPTIMUM GAIT-AK	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
TOE OFF - HEEL RISE ACCELERATION (VIEWED LATERALLY) 	1. Excess heel rise.	1. a) Inadequate knee flexion damper action, friction - hydra-extension aid. b) Excess knee stability, amp. must force. c) Excessive hip flexion force by amputee. 1. Excess energy expend. 2. Excessive press- ure on the distal end of femur.	1. a) CP b) CP c) RPT
1. Smooth reversal rise of CG to start heel rise. 2. Smooth heel rise with quad control of knee flex. 3. Effortless start of hip flexion.	2. Early piston action	2. a) Inadequate fit and suspension. b) Amp. not seated in socket.	2. a) CP or team b) RPT

OPTIMUM GAIT-AK	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
SWING THROUGH (VIEWED LATERALLY)  1. Smooth CG summit ARC. 2. Slight drop of pelvis on swing side. 3. Smooth dorsiflexion of pros. foot (Hydra).	1. Excess knee flexion with acceleration. 2. Socket loose, stump with-drawing. 3. Vaulting on sound foot (Claudication of sound leg may be justification for short prosthesis)	1. a) Mech. or hydraul. friction too weak. b) Excess hip flexion on part of amp. 2. Poor fit stump shrinkage suspension 3. a) Prosthesis too long. b) Amp. not well seated. c) Improper dorsiflexion pros. foot-hydra. d) Bad gait habit e) Excess knee friction.	1. a) CP b) RPT 2. Tension Analysis CP 3. a) CP b) RPT c) CP d) RPT e) CP

OPTIMUM GAIT-AK	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
DECELERATION (VIEWED LATERALLY) 	1. Terminal impact may be seen at H.S., may be to end of swing" "goose step," at heel strike "dig in heel")	1. a) Excess shank velocity as knee reaches full extension - improper friction (mech or hyd). b) Bad gait habit (clue for full extension)	1. a) CP b) RPT
	2. Knee hyperextension	2.a) Worn extension stop. b) Knee bolt more than 3/8" behind T-A line. c) Lack of sufficient flexion, posterior socket wall as related to shank.	2. a) CP b) CP c) CP
Smooth noiseless deceleration of swing leg — no goose step	3. Unequal step length, Prosth. > normal.	3. a) Hip flexion contracture not accomodated for in the alignment of the prosthesis (Initial flexion) b) Bad gait habit	3. a) CP b) RPT

OPTIMUM GAIT-AK	DEVIATION FROM OPTIMUM GAIT	CAUSES OF DEVIATION	CORRECTIONS
HEEL STRIKE TO MID-STANCE VIEWED FROM (ANTERIOR - POSTERIOR)	1. Rotation of foot at heel strike.	1. a) Plantar flexion bumper, (SACH) heel, hydr. plant flex, too stiff. b) Ant. med. brim not flared enough, presses on pubis and med. inguinal area.	1. a) CP b) CP
	2. Lateral trunk bend.	2. a) Weak abductors b) Insufficient adduct, lat. wall. c) Painful lat. prox. femur. d) Foot outset too far. e) Prosthesis too short.	2. a) RPT b) CP c) CP d) CP e) CP
	3. Lat, Socket shift with gaping	3. a) Foot inset medial to ischial-med. heel line. b) Excess adductor pressure - post. brim slanted in c) Stump shrinkage	3. a) CP b) CP c) CP
1. Trunk erect, head sway <1" 2. Narrow base foot aligned like mate. 3. Pelvis level 4. Ischium over center of heel.	4. Abducted gait	4. a) Excess crotch pressure (ischium off seat). b) Hip flex, contr. - ant. tilt pelvis - brim pressure c) Prosthesis too long d) Poor gait habit e) Distal femur pain	4. a) CP b) CP-Team c) CP d) RPT e) CP

CHECK OUT WITH A-K-PROSTHESIS

Checking out of the above knee prosthesis is done when the amputee, after putting it on is standing, sitting on a chair, squatting, sitting cross-legged and finally while walking. As both the aluminium and HDPE sockets and prosthesis have facilities for correction throughout their functional life, it is important to understand the problems which may arise due to improper alignment and imperfect shape of the socket. These problems must be removed before the final delivery of the prosthesis.

I. IN STANDING

After putting on the prosthesis, ask the amputee to stand erect, as comfortably as possible, bearing weight equally on both the feet, keeping the heel centers not more than 150mm apart, and check the following :-

1. Does the patients suffer from excessive pressure in the antero- medial aspect of the socket ? The most important cause of this condition is insufficient relief for adductor longus tendon in the antero-medial corner of the socket. The fitting of the adductor longus tendon into its channel is important, as it determines whether or not the socket is positioned correctly on the stump. Unless the adductor longus tendon fits properly, the relief and contours of the socket are not likely to correspond to the areas of the stump for which they were intended. The prosthetist must ensure that a proper channel has been formed for the adductor longus tendon and the tendon is properly located in it, otherwise the amputee will continue to suffer from this condition. If there is a proper channel made for adductor longus muscle, then the following conditions can also produce the problem:
   - (a) Antero-posterior dimension of the medial wall is too small.
   - (b) Small medio-lateral dimension of the socket.
   - (c) Downward slant of the ischial seat may cause ischium to slide medially, which may compress the adductor longus tendon.

2. Does the patient suffer from burning sensation in hamstring and gluteal area ? This condition is produced when the ischial tuberosity is pushed too far posterior because of very small anteroposterior socket dimension. Normally the ischial tuberosity should rest approximately 12mm. behind the inner surface of the rear wall and 20-25mm. lateral to the inner surface of the medial wall.

   To check the position of the ischial tuberosity on the ischial seat, stand behind the amputee and ask him to bend forward and take most of his weight off his prosthesis. Provide suitable support while he is bending forward. Probe for ischial tuberosity with palmer surface of index and middle fingers. Then ask the amputee to straighten and bear weight on his prosthesis, and relax the muscle of his stump. The examiner's fingers should be squeezed between the ischial tuberosity and the ischial seat of the socket.

3. Does the patient suffer from vertical pressure or burning sensation in crotch area? This condition is caused by very large antero-posterior dimension of socket, too low an anterior wall or an insufficient bulge in scarpa's triangle area to provide adequate counter pressure. This condition can also be caused if the tuberosity is displaced medially either due to too small mediolateral dimension or downward slant of the ischial seat lateral to medial side. If the medial wall is too high it will again produce this condition.

4. Observe whether the patient has developed lumbar scoliosis. This is most frequently produced if the prosthesis is of incorrect length. If it is too short, there will be lumbar scoliosis with the convexity towards the prosthesis. If it is too long, the scoliosis will be reversed, with the convexity towards the sound limb.

   To check the length of the prosthesis, compare the heights of anterior superior iliac spine. They should be at the same level; an imaginary line across the anterior superior iliac spines or crests should be parallel to ground.

   Before arriving at a decision about the length of the prosthesis on the basis of this test, it should be checked that the prosthesis has been donned properly, the socket fit is not poor and Jaipur foot has not been placed in excessive plantar flexion. All these three conditions can lead to apparent limb-prosthesis length discrepancy. Sometimes asymmetrical pelvic development seen in congenital amputees may be the cause of uneven pelvis.

5. Is the amputee pressing the socket backwards with this stump to stabilize the knee? This condition is extremely rare with the present design, as the artificial knee joint is an offset joint, and the knee axis always remains posterior to the trochanter, knee and ankle line (TKA line).

To check stability of the knee, have the amputee stand near parallel bars or other support. His weight should be evenly distributed on both feet; strike the back of the knee with moderate force. It should give slightly, but should return immediately into full extension.

II. IN SITTING

Now ask the patient to sit on a chair, and check the following :

1. Does the socket remain securely on the stump? The socket should remain securely on the stump while the patient is seated. If the socket changes position, the posterior elastic strap of the suspension system should be checked and properly tightened. Sometimes pressure of socket against the abdomen or crotch may force the socket off the stump; also ascertain that the anterior brim does not come into contact with anterior superior iliac spine.

2. Whether the shank remains in good alignment? It is very important that the amputee should be able to sit comfortably with his foot flat on the floor, both the knees level and shank remaining vertical. If the shank does not remain

vertical, check the length of thigh piece and shank piece again and horizontal alignment of the knee gudgeon pin.

3. Does the patient have burning sensation in the hamstring area ? The most common causes for this condition is too thick ischial seat.

   Although the ischium rests on chair, the ischial seat will push the hamstring area and produce burning sensation.

III. IN SQUATTING

Now ask the amputee to squat and check the following :-

1. Whether the amputee can squat satisfactorily ? It should not be imagined, as is often is, that unless a design permits prolonged squatting without discomfort, the purpose has not been served. This is a fallacious assumption. Most activities require merely short spells of squatting and if even this is achieved it is very much worthwhile.

2. Does the socket remain securely on the stump? If the socket changes position, the posterior elastic strap should be checked. The height of the anterior socket brim is of utmost importance here. The high anterior brim digs into the iliac spine area when hip is flexed beyond 100^o. Some patients can tolerate this while others cannot. A lot depends on the prominence of the anterior superior iliac spine and the soft tissue yield of the anterior abdominal wall. In cases where anterior wall is high and the anterior superior iliac spine is very prominent it may even push the socket off the stump.

3. Does the shank remain in good alignment ? This is totally dependent upon how much dorsiflexion is permitted by prosthetic foot piece. The Jaipur foot has commendable range of dorsiflexion. A more mobile ankle would certainly facilitate this, but too free a dorsiflexion at the ankle can affect the stability at the knee joint by causing excessive knee flexion during stance phase. In the absence of stance phase control, the knee joint can buckle and so the patient would be inclined to use a knee lock while walking. This inevitably raises the energy requirement and so some compromise has to be made in the matter of allowing free dorsiflexion at the ankle,"except Jaipur Foot".

IV. IN SITTING CROSS-LEGGED

Now ask the amputee to sit cross-legged and check the following :-

1. Does the socket remain snugly on the stump? If the socket changes position, the posterior elastic strap should be checked and tightened properly.

V. IN WALKING

Now ask the amputee to walk at the normal speed and observe for any gait deviation from front, behind and side from behind.

GAIT DEVIATIONS TO BE NOTED

A. STANDING BEHIND

a) **Lateral bending of Trunk** - The trunk bends towards the amputated side when the prosthesis is in stance phase. It is most prominent during heel strike to midstance. Common causes for this condition are :

1. Short Prosthesis
2. Insufficient support by lateral wall. If the lateral wall is not snugly fitting, it fails to prevent the stump from abducting, when the abductors of the hip of the amputated side are contracting, to prevent the pelvis from dropping on the unsupported side, during the stance phase of the prosthesis. To prevent the pelvis from dropping on unsupported side the amputee shifts his center of gravity towards the prosthesis by bending his trunk.
3. Abducted socket : The alignment fault reduces the effectiveness of the hip abductors on the amputated side to prevent dropping of the pelvis on the unsupported side during the stance phase of the prosthesis. The resulting tendency of the pelvis to drop on sound side is counteracted by lateral bending of the trunk.
4. Weak Abductors : As above, lateral bending counteracts the tendency towards pelvic drop on sound side.

b) **Abducted Gait :** The width of walking base is significantly greater than the normal range 50-100mm. It is most pronounced during the period of double support. Most common causes for this condition are

1. Too long prosthesis - The amputee walks with abducted gait so that the prosthesis will clear the ground during swing phase.
2. Shank aligned in valgus position with respect to the socket.
3. Pain or discomfort in the crotch area. This may be due to pressure from the brim on medial wall or soft tissue roll.
4. Abducted stump.

c) **Circumduction :**The prosthesis follows a lateral curved line as it swings through. Most common causes for this condition are :

1. Too long prosthesis **-** It forces the amputee to swing the prosthesis out to clear the ground.

2. Loose suspension system allowing the prosthesis to slip from the stump, thus apparently increasing the length of the prosthesis during swing phase (Piston action). The amputee is thus forced to swing the prosthesis out to clear the ground.

3. If the ischial tuberosity is not well seated due to small socket.

4. Prosthetic “Jaipur foot” set in excessive plantar flexion.

d) **Vaulting :** The amputee bobs up and down excessively as he walks. He raises his entire body by excessive plantar flexion of the sound limb during swing phase of the prosthesis, for ground clearance. The most common causes for this condition are same as those of circumduction. The amputee can choose circumduction or vaulting for ground clearance due to long prosthesis, whichever is convenient to him. The basic problem for both the conditions is too long a prosthesis.

e) **Swing Phase Whips :** *Medial whip* at toe-off, the heel moves medially and knee moves laterally. *Lateral whip* at toe-off, the heel moves laterally and knee moves medially. The most common cause for these conditions is wrong alignment of the knee axis. Excessive internal rotation of the knee axis produces lateral whip and the excessive external rotation of the knee axis produces medial whip. If the socket is too tight, pressure from the contracting muscle can also sometimes produce rotation of the prosthesis around it long axis.

B. STANDING ON SIDE

Now stand on the side of the amputee and observe for the following gait deviations if present :

a) **Uneven Arm Swing :** The arm on the prosthetic side is held close to the body during locomotion. This deviation if present can be observed throughout the gait cycle. This defect may sometimes be due to habit pattern of the amputee and most of the time it may be due to fear, insecurity and lack of development of a good balance. An improperly fitted socket may sometimes cause stump discomfort and produce this gait deviation.

b) **Uneven Timing :** The steps are of unequal duration, usually a very short stance phase on the prosthesis. Mostly it is seen in the amputees who have not developed good balance ; fear and insecurity may be added contributory factors. In some cases improperly fitted socket may produce pain when the prosthetic limb is in stance, and may force the amputee to shorten the stance phase on the prosthetic side. The musculature of the amputee must be checked ; an amputee with weak stump will always demonstrate uneven timing.

c) **Uneven Heel Rise :** Usually the prosthetic heel rises higher than the sound heel. However, the reverse may also be seen, that is, the prosthetic heel shows a smaller rise than the sound heel. It is most pronounced during the first part of swing phase. Among the most common causes for too much heel rise is that the amputee wants to ensure by forceful stump flexion that prosthetic shank will be fully extended at heel strike. For insufficient heel rise the only cause is the feeling of fear and insecurity by the amputee forcing him to walk with little or no knee flexion.

d) **Terminal Swing Impact :** The prosthetic shank comes to a sudden stop with forcible impact as the knee goes into extension, at the end of swing phase. This deviation is seldom seen with this prosthesis as it has an offset joint. This deviation if seen is because of amputee's fear of buckling and causes him to sharply extend the stump as the knee approaches full extension. This manoeuvre snaps the shank forward into full extension and then 'digs' the heel into the ground. Sometimes if the nut of the gudgeon pin of the artificial knee is not properly tight it may cause this deviation.

e) **Drop off :** At the end of stance phase, as the body moves forward over the prosthesis, there is a characteristic downward movement of the trunk. This deviation is produced if the socket has been placed too far anterior in relation to the foot.

f) **Uneven Step Length :** The length of step taken with the prosthesis differs from the length of the step taken with the sound foot. Mostly pain or fear will cause the amputee to get his weight off the prosthesis and to his sound leg as quickly as possible. To do this he takes a short quick step with his sound limb. Any restriction of the extension range of the motion of the hips, which may be due to flexion contracture of the hip or insufficient flexion of the socket, will be reflected by a shorter step length on the sound side.

C. STANDING IN FRONT

Now stand in front of the amputee and observe for the following gait deviation :-

a) **Rotation of the foot on heel strike :** As the heel contacts the ground, the foot rotates laterally. This deviation will be produced if the prosthetic foot piece has been attached in too much dorsiflexion.

After observing the amputee from front, behind and side, while he is walking on level ground at normal speed, any gait deviation if present, should be noted. It should be analyzed and corrected. After correction, when the amputee has achieved near normal gait then he should be observed going down the grades and up the inclines. His performance should be checked going up and down the stairs.

Once the amputee has achieved satisfactory performance with the prosthesis, and is satisfied regarding comfort, stability, performance and appearance he can then be discharged from the workshop.

CHAPTER - 11

FABRICATION TECHNIQUE OF SYME'S PROSTHESIS

STEP-I

Negative mould of the patient's stump by wrap casting method

Measurements :

1. Patient is asked to stand with Pelvis squared. This can be done by making sure that both the anterior superior illiac spines are in the same (Horizontal) line. Now the distance between the inferior surface of the stump and the floor is measured. This gap is filled by placing ¼" thick square wooden blocks (Fig. 11.1). This measurement helps in making Syme's Prosthesis of same length as the normal lower limb.

Figure-11.1

Material

1. 6" Bandage - 1 (or preformed 6" bandage impregnated with POP powder.
2. Stockinette (Cotton)

Method

- Patient is seated on a chair or bench. Now a cotton stockinette is sleeved over the stump. It extends 6-8" above the lower end of the stump (Fig. 11.2 & 11.3). It is held in place with the help of a rubber band.

Figure-11.2

Figure-11.3

- Now a 6" bandage is submerged in water for 3-5min. When it is soaked completely the excessive water is squeezed out by compression at both ends.

- Now the bandage is wrapped around the stump of the patient from below upwards and then in reverse direction, maintaining moderate tension (Fig. 11.4 & 11.5). Make sure that this negative mould is at least 4-6 layers thick. The mould is smoothened by applying POP cream & then it is allowed to set (Fig. 11.6).

(Fig 11.4)

(Fig 11.5)

(Fig. 11.6)

- Just when it begins to harden it is slit open on the anterior surface from above downwards (Fig. 11.7).
- When it has dried completely, patient is asked to pull out his/her stump from this mould in the anterior direction.

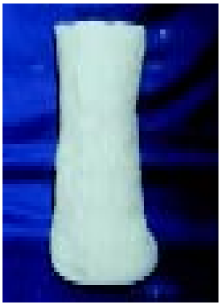
(Fig. 11.7)

- Now both the ends of the mould are approximated anteriorly & POP cream is applied and thread is tied around this negative mould to maintain the position (Fig. 11.8).

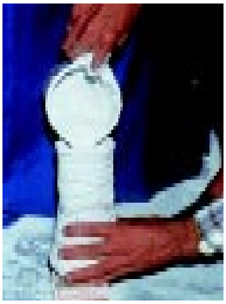
(Fig. 11.8)

STEP-II Fabrication of positive mould

- The negative mould is filled with POP cream (Fig. 11.9) & allowed to dry. When the POP cream has hardened the negative mould (wrapped around positive mould) is slit open anteriorly & is discarded. A positive mould is now obtained which is the exact replica of the stump of the patient (Fig. 11.10).



(Fig. 11.9)



(Fig. 11.10)

- 3 layers of felt lining are glued with the help of a solution around this positive mould. This makes the mould ¼”-½” thicker. This felt lining will later form the lining of socket of the prosthesis.
- Now divide this modified positive mould into 2 segments sagitally by drawing a line on the superior aspect, thus forming medial lateral segments.
- ½” thick layer of POP cream is now applied on medial & lateral sides. The 2 segments thus obtained are now allowed to dry (Fig. 11.11& 11.12).

(Fig. 11.11)

(Fig. 11.12)

Alternate method’ of making POP mould of the stump.

- To get a more accurate replica of the stump another method to obtain a positive mould is used. This can be done by asking the patient to lie supine. Now the stump of the patient is smeared with vaseline about 6-8" above the base of the stump.
- A sufficient quantity of POP cream is spread over the floor & the patient is asked to place the stump gently over this cream & remain still till the plaster sets. This is done to obtain the impression of the posterior half of the stump.
- This same process is repeated for the anterior half of the lower ¼ of the leg. Now the 2 segments obtained are kept to dry.
- Vaseline is then smeared on the inside of the 2 segments & the 2 halves are firmly secured.
- POP cream is poured in the cavity of the mould when the cream solidifies, the 2 segments are separated & an exact replica of the stump is thus obtained.

Step III. Fabrication of “Foot” for the Syme’s Prosthesis

- The four piece die used for making the Jaipur Rubber foot is firmly bolted & filled with POP cream & the cream is allowed to solidify (Fig. 11.13).

(Fig. 11.13)

- The bolts are then unscrewed & the "Plaster of Paris Foot" is taken out (Fig. 11.14).
- Now the ankle region of the this 'POP foot' is carefully chiselled out leaving the length at the sole portion equal to the height of the wooden blocks placed earlier (below the syme's stump of the patient while he/she was standing).
- The heel & the forefoot portion of this POP foot is left intact.

(Fig. 11.14)

- The stump mould is then placed in position in the 'Jaipur foot ankle prosthesis', where originally the malleolar wooden block is kept (Fig. 11.15).
- In other words the space for the malleolar wooden block in Jaipur foot is now more or less occupied by the stump mould.

(Fig. 11.15)

A. Fabrication of aluminium die

- The 2 moulds prepared earlier (medial & lateral segments) are subjected to cleaning & designing processes needed for aluminium casting.
- Such mould designed to suit casting procedure is known as the 'pattern'.

(Fig. 11.16)

-This pattern is then casted with aluminium. (Fig. 11.16 to 11.34).

-The aluminium mould thus made is then subjected to turning procedure by a lathe. By this procedure the walls of the mould are flattened & evened out for proper facing.

(Fig. 11.17)

- Then this is scraped, rubbed & finally polished.
- Medial & lateral segments of the 4 piece dye are ready.

(Fig. 11.18)

(Fig. 11.19)

(Fig. 11.20)

(Fig. 11.21)

(Fig. 11.22)

(Fig. 11.23)

(Fig. 11.24)

(Fig. 11.25)

(Fig. 11.26)

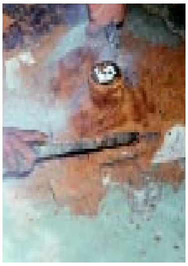
(Fig. 11.27)

(Fig. 11.28)

(Fig. 11. 29)

(Fig. 11.30)

(Fig.11.31)



(Fig.11.32)

(Fig.11.33)

(Fig. 11.34)

B. Fabrication of rubber foot for syme's amputee

a) Type of rubber used

For the sole, tread rubber compound is used. The rest of the foot is filled with cushion rubber compound which is lighter & has more resilience than the tread compound. The rubber is reinforced with rayon cord dipped in rubber gum. The foot is covered with skin coloured rubber compound.

b) Metatarsal Block

This block is made up of single piece of sponge rubber & placed in the metatarsal region. This provides stability & the shape of the forefoot. The length of this block corresponds to the length of the metatarsals from the base to just before the heads of the metatarsals i.e. upto the balls of the toes. It is higher medially & posteriorly and tapers down gradually laterally & anteriorly. The anterior end of the block has a curve simulating with the curvature of metatarso-phalangeal joint.

c) Sponge Rubber Block

Sponge rubber used in this process is from the sole of V strap chappals (thongs). Sponge rubber block extends from heel to posterior part of metatarsal block i.e. it fills the hind part of the foot. Pieces of sponge rubber sole are glued one over the other to a required height. The stump mould is placed over the top layer & the outline is carved out so that the lower portion of the stump mould snugly fits into the sponge rubber.

C. Moulding of rubber compound over metatarsal block, sponge rubber and Plaster of Paris stump mould

From the roll of the tread rubber compound a broad piece is cut to resemble the shape and size of the sole of the foot. This is placed in the mould cavity of the die for the plantar surface of the foot. Such two to three layers are used. Over this vulcanizing cement is painted and a cord piece is glued to the rubber for purposes of reinforcement. The hollows for the plantar half of the toes; in the die the planter surface of the foot is filled with the cushion rubber compound.

Next, the prepared Metatarsal foot block and sponge rubber hind foot block is glued in position by vulcanising cement to the rubber compound for the sole of the foot. The surface of this frame is also painted with the vulcanising cement for proper anchorage of the rubber strips. The sponge rubber pieces are also placed in the spaces for the toes after painting them with vulcanising cement.

Rubber strips from the roll of the cushion rubber compound are pasted over the frame. The thickness of the rubber required at different places is adjusted from time to time by placing the various components of the die in position and applying pressure with the clamps. If the rubber is less, more is added and if more, then it is cut. Compression with clamps helps in casting out details of the impressions of the die moulds over the rubber foot. After covering the sponge rubber of the hind part with cushion rubber, the plaster stump mould is placed in position and is covered by a glazed, transparent paper. This glazed paper prevents the rubber to stick to the plaster of Paris mould and it facilitates in the easy removal of the stump after vulcanising is over. Cord lining is applied at the ankle and around the plaster of Paris mould for reinforcement. The rubber strips of skin colour are pasted to the surface of the pre-vulcanised black foot and again compressed.

With the clamps or a press it is pressed and care is taken so as not to leave any space between the inner wall of the die and contents because at the time of vulcanisation rubber melts and flows, and on cooling retracts and sets. This would result into uneven bonding of rubber, leaving behind patches without rubber. All the component parts of the die are placed in position and assembled to a wall fitting unit by bolts and screws, enclosing the pre-vulcanised rubber foot (Fig. 11.35 ,11.36 & 11.37).

(Fig. 11.35)

(Fig. 11.36)

(Fig. 11.37)

D. Vulcanisation

By vulcanisation the uncured rubber compound is fixed and made rigid but resilient by application of heat. Unvulcanised rubber is weak, brittle in cold weather, softened by moderate heat and soluble in many liquids. Unvulcanised rubber consists of a very large number of long chain molecules which are considerably entangled but are not linked together in any way. When curatives like sulphur, accelerators and activators etc. are added with rubber and heat is applied vulcanisation reaction starts and it is believed that sulphur forms bridges or cross-links between different molecules at all points along their length thus developing snappiness or elasticity of cured rubber. This cured rubber has increased strength, increased resistance to oils and is less effected by change in temperature. Another important effect of vulcanisation is that plasticity of rubber is suppressed and elasticity is enhanced.

Heat can be applied by steam at pressure or dry heat. Rubber compounds of different companies have different curing time. Dry heat has been used because of convenience and simplicity.

Vulcanisation is done by placing the die containing the pre-vulcanised rubber foot in an electrically heated furnace. This furnace is used in the prosthetic workshop for moulding alkathene products used in orthopaedic practice. It provides uniform heat. Approximate temperature of the furnace is about 300-400°C. Heating is commenced. After 50 to 60 minutes the die is taken out of the furnace and allowed to cool. The die is opened and the hardness of the rubber checked by an instrument called the Durometer. If the hardness is above 40 durometer, the foot is taken out of the die for use, if it is less, more heat is given. Hardness between 40 to 60 durometer is sufficient to provide the required properties such as strength, resilience, wear resistance, cutting and abrasion resistance , resistance to water, chemicals and solvents.

Over-heated samples becomes brittle and tends to crack. After vulcanisation is over, the great toe is freed from the second toe by cutting the rubber layer between them. Excess of rubber at other places is scrapped off. With a sharp knife the foot is slit along the midline on the anterior aspect, from the top upto the base of the stump. The plaster of Paris mould is taken out. The inside cavity is lined with thin superior quality leather (mass). Three to four holes are made on both flaps and a lace is passed. Earlier a metal chain was fixed behind the flaps, but it broke away because of its poor quality. Two or three holes of ¼" diameter are made on the postero-medial border to provide a little ventilation.