University of Surrey
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Pressure Casting Technique for Construction of Below Knee Total Contact Socket

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Chapter I introduces in brief the current problems of Below-Knee socket fitting, and aims of the author in overcoming these by developing a new casting technique.

Chapter II gives a brief account of the historical developments of lower extremity amputations and prostheses. The modern concepts of amputations and prostheses is presented.

Chapter III deals with the various anatomical and physiological factors to be taken into account in designing a successful below knee socket.

Chapter IV deals with the surgical considerations in the management of a below knee amputee. The commonly used surgical techniques for performing a below knee amputation are discussed. The critical assessment of the advantages and disadvantages of each surgical technique in terms of socket fit are described.

In Chapter V, the biomechanical principles to provide comfort, stability and functional connection between the stump and the socket of a patellar-tendon-bearing prosthesis are dealt with.

In Chapter VI, a critical review of the existing casting techniques for the production of a Patellar-Tendon-Bearing socket is presented.

Chapter VII introduces the authors concept of obtaining a total contact cast by the use of air pressure of controlled magnitude and uniform distribution, as an alternative to hand wrap casting technique. A method to implement the concept in clinical situation is proposed to achieve uniform pressure distribution at the time of casting and incorporation of other biomechanical features in the cast itself.

Chapter VIII discusses in detail the method of producing the stump casts by the air pressure casting technique for making below knee sockets.

In Chapter IX, criteria for selection of patients for the clinical trials and indications in routine practice for the new socket are discussed.

Chapter X describes the organisation of the clinical trials and the results obtained.

In Chapter XI, the work done is reviewed to determine how far it has achieved its objectives. The further work still to be undertaken, and the other applicabilities of the concept of air pressure casting are suggested.
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# INDEX

| CHAPTER I | INTRODUCTION AND OBJECTIVES | 1 |
| CHAPTER I | INTRODUCTION | 1 |
| CHAPTER I | OBJECTIVES | 2 |
| CHAPTER II | HISTORY OF AMPUTATIONS AND PROSTHESSES | 3 |
| CHAPTER II | HISTORY OF AMPUTATION | 3 |
| CHAPTER II | HISTORY OF PROSTHESSES | 4 |
| CHAPTER II | MODERN CONCEPTS OF AMPUTATIONS AND PROSTHESSES | 5 |
| CHAPTER III | ANATOMICAL AND PHYSIOLOGICAL CONSIDERATIONS | 7 |
| CHAPTER III | IN BELOW-KNEE PROSTHESES | 7 |
| CHAPTER III | FUNCTION OF BELOW KNEE STUMP | 7 |
| CHAPTER III | WEIGHT BEARING AREAS | 7 |
| CHAPTER III | THE KNEE JOINT | 8 |
| CHAPTER III | EDEMA | 9 |
| CHAPTER III | SOCKET DESIGN | 9 |
| CHAPTER IV | BELOW-KNEE AMPUTATION SURGERY | 11 |
| CHAPTER IV | GENERAL CONSIDERATIONS | 11 |
| CHAPTER IV | GENERAL SURGICAL PRINCIPLES | 13 |
| CHAPTER IV | SURGICAL TECHNIQUES | 17 |
| CHAPTER V | BIOENGINEERING OF BELOW-KNEE PROSTHESES | 20 |
| CHAPTER V | STUMP-SOCKET PRESSURES | 20 |
| CHAPTER V | ALIGNMENT AND PRESSURE DISTRIBUTION | 27 |
| CHAPTER V | SUSPENSION METHODS AND STUMP-SOCKET PRESSURES | 29 |
| CHAPTER VI | BELOW-KNEE SOCKETS | 32 |
| CHAPTER VI | "CONVENTIONAL" BELOW-KNEE SOCKET | 32 |
| CHAPTER VI | PATELLAR-TENDON-BEARING SOCKET | 33 |
| CHAPTER VI | SOME OTHER METHODS OF CASTING FOR P.T.B. SOCKETS | 35 |
| CHAPTER VII | THE PRINCIPLES OF PRESSURE CASTING TECHNIQUE | 41 |
| CHAPTER VII | OBJECTIVES | 41 |
| CHAPTER VII | CONCEPT OF AIR PRESSURE CASTING | 41 |
| CHAPTER VII | PRESSURE CASTING IN CLINICAL SITUATION | 44 |
| CHAPTER VII | CONCLUSIONS | 47 |
CHAPTER VIII  EXPERIMENTAL TECHNIQUE FOR PRESSURE CASTING

MATERIALS NEEDED ................. 49
PROSTHETIC MEASUREMENTS .......... 53
PREPARATION BEFORE CASTING ......... 53
PRESSURE CASTING .................. 57
MANAGEMENT OF THE POSITIVE MOLD ... 66

CHAPTER IX  CRITERIA FOR SELECTION OF PATIENTS FOR PRESSURE CAST SOCKETS .... 75
SELECTION OF PATIENTS FOR THE PROJECT .... 75
SELECTION OF PATIENTS IN ROUTINE PRACTICE .... 75

CHAPTER X  THE CLINICAL TRIALS OF THE SOCKET .......... 79
TRIALS WITH EXPERIMENTAL SOCKETS .......... 80
TRIALS WITH DEFINITIVE SOCKETS .......... 87
CONCLUSIONS ...................... 108

CHAPTER XI  THE CONCLUSIONS ...................... 109
REVIEW OF THE PROJECT .................. 109
FUTURE WORK ....................... 111
OTHER APPLICABILITIES .................. 111

Bibliography ............................ 113

Appendices

A to D. ................................. 119

Erratum

. Page 1, Para 2, Line 1 - For Redcliffe read Radcliffe (also elsewhere).
. Page 26, Para 5, Line 6 - For -(MM,dM)=0 read -(MM,dM)=0.
. Page 51, Para 4, Line 4 - For lb/sec read lt/sec.
. Page 61, Para 5, Line 2 - For (Fig.20a) read (Fig.20)
. Page 109, Para 2, Line 3 - For Wull read Will.
CHAPTER - I

INTRODUCTION AND OBJECTIVES

1. INTRODUCTION

The replacement of an extremity by an artificial device for restoration of the function has been in practice since pre-historic times. The nature and type of the prosthesis in use at a particular time depended on the state of art and science prevalent then, as is evident from the use of the ancient peg legs to the use of most advanced limbs of the modern times.

The first significant advance in replacement of the lost limb at the below knee level is attributed to Verudin, a Dutch surgeon who invented the "Conventional" Below-Knee prosthesis in 1696. This limb even today is used quite extensively. However during modern times, in the light of current knowledge of anatomical and physiological considerations of the stump and biomechanical principles of limb fitting, it is no more considered an ideal limb. The socket in this prosthesis is so designed that it utilises only the proximal pressure tolerant areas of the below knee stump for weight bearing. Because of the limited area in contact with the stump, it is usually necessary to provide additional weight bearing capability through the suspension mechanism, by the thigh or the ischial tuberosity. Since it is not a total contact socket oedema of the stump may develop due to the constricting effect of the thigh corset. Further, due to the presence of a single axis mechanical knee joint in the prosthesis, friction and piston action cannot be avoided resulting in excoriation of skin, and abnormal pressures over the stump. The movement is also not so natural and graceful, due to restrictions imposed by the mechanical knee joint. Furthermore comfort and effectiveness are often sacrificed because of a lack of understanding of the force actions to be transmitted in relation to the role of the corset, side joints and socket.

With these problems in mind, Redcliffe and Foort at the University of California, after several years of detailed work in testing and evaluating principles and procedures, developed a limb in 1959, known as "Patella-Tendon-Bearing" prosthesis. In this prosthesis there is no thigh corset, side steels or mechanical knee joint and thus the amputee is able to make full use of the knee joint whose function remains unaffected following below knee amputation surgery. The Below-Knee stump alone is utilised as a weight bearing and dynamic force transmitting organ by making use of all the
pressure tolerant areas of the stump. The introduction of the Patella-Tendon-Bearing (PTB) prosthesis was acclaimed as a major advance in prosthetics and soon was adopted all over the world.

2. OBJECTIVE
The successful fitting of a below-knee amputee with a comfortable and functional Patella-Tendon-Bearing socket depends entirely on the plaster wrap cast of the stump and subsequent rectifications of the positive plaster mould made from the wrap cast. A proper wrap cast should be considered as an accurate three dimensional measurement of the stump which, after appropriate rectifications will become the mould for a functional socket. Casting by hand and subsequent modifications requires a high degree of skill on the part of an experienced prosthetist, and even then a considerable amount of error can occur. The fit of a finished socket therefore depends upon the skill of the prosthetist taking the cast, certain inherent drawbacks of hand casting technique, and the amount of rectifications that the prosthetist considers necessary.

Keeping in mind the above limiting factors in successful construction of a socket, the author has devised a technique in which hand wrap casting and its associated drawbacks are eliminated by the use of Air Pressure casting technique. In this technique controlled uniform air pressure is used for the plaster cast to set. The other important feature of this technique is that in the cast itself all the positive rectifications are incorporated, and thus the positive mould made out of the cast by this technique requires only bare minimum modifications prior to socket fabrication.

The procedure is easy to learn and can be easily carried out by a prosthetist with average knowledge and skill of the art, as the factors of human error are eliminated to a great extent. The details of the concept and the technique of pressure casting are described in chapters VII and VIII respectively.
1. HISTORY OF AMPUTATION

Kirk in his monograph on the development of amputation, indicates that there is archaeological evidence that amputations were done during the Neolithic age. Amputations among these primitive people were done for punishment or magic rituals rather than with surgical intent. There is no record of amputations in the Old Testament or the Egyptian medical papyri. The artificial limbs found on mummies are considered embalmers art rather than evidence of their ever being used. There is a reference to artificial limbs in the Rig Veda of 1500 – 800 BC.

The earliest existing scientific account of amputation is in the Hippocratic treatise on joints during the later half of the Fifteenth Century. He described vascular gangrene as an indication for amputation, and advocated either waiting for separation to occur naturally or to amputate at the joint "below the boundaries of blackening" as soon as it was "fairly dead and had lost its sensibility". He advised "not to wound the living part lest the patient swooned away and died from pain". Hippocrates also refers to the use of cautery for haemostasis. Celsus advocated amputation at the line of demarcation between healthy and gangrenous tissue, and was the first to advise ligation of blood vessels to control haemorrhage. From Hippocrates through Celsus amputation for vascular gangrene was advocated as a last resort but by about 100 AD during Archigenes and Helidorus, it had become a recognised procedure for ulcers, growths, injuries and deformities.

Celsus in the First Century and Yperman in the Thirteenth used ligatures. It appears that during the middle ages much of the earlier teachings of Celsus were forgotten, and it was not until the Sixteenth Century, that Pare - father of modern amputation practice, reintroduced the ligation of blood vessels and abandoned the use of cautery or burning hot oil to control haemorrhage. He also introduced the concept of sites of election for amputation. His ideas on prosthetic design and prosthetic management of his patients stand comparison with present day limbs.

The use of tourniquet made ligation easier. The credit for its invention goes to Morel (1674), but many earlier surgeons such as Botallus (1560) and Fabricus Von Hilden used one or more tight bands round the limb. Petit
(1718) used a compressive tourniquet and Esmarch (1873) introduced a rubber bandage.

Post operative management of wounds has changed with the Centuries. Hippocrates practiced amputating through devitalised tissue and left wound open to heal by granulation. Celsus operated through viable tissue, divided the bone at a higher level than soft tissues, allowing the soft tissue to fall together over the bone. Ambroise Pare approximated the edges of the wound with adhesive strips. Von Gersdorff later in addition to adhesive strips used animals bladder to cover the wound. Brunsewig used combination of sutures and bandages. Yonge and Lowdham (1679) introduced flap amputation which made closure easier than in earlier method of circular amputation.

The operative mortality rate was very high and was due to shock produced by amputation due to lack of anaesthesia, haemorrhage and sepsis. Against such odds, speed was essential to lessen shock. Ferguson (1845) could amputate within 30 seconds and completed the procedure in three minutes. Surgeons worked without skilled help. While two assistants restrained the patient, a third administered pain relieving drugs and a fourth handed him the instruments. The sepsis rate was very high due to lack of knowledge of antiseptics and asepsis. The description of Dupuytren operating is that "he wore a dirty white apron, superfluously protecting a dirtier pair of trousers, a greasy threadbare coat and well worn carpet shoes". Pirogoff (1864) operated without wearing gloves. Bigelow's assistants at Massachusetts General Hospital carried sutures in button holes of their operating coats in the 1870's and as late as 1880's would hold the sutures in their mouths.

2. HISTORY OF PROSTHESIS

The history of prosthesis is as old as that of amputation itself. There is mention of artificial limbs in the Rig Veda. The earliest known record of a prosthesis used by man was made by a Greek historian, Herodotus (424 BC), who tells of Hegistratus of Elis, a seer who was condemned to death by the Spartans. He was chained by his leg awaiting execution but escaped by amputating his foot himself, later replacing it with a wooden foot. Amputees are depicted in the art of ancient times. In one of the ancient Peruvian potteries a figure is shown with a leg amputated at the ankle, and holding a painted 'cap' in the right hand, to be fitted to the stump. Illustrations such as the mosaic in the Cathedral of Lescar in France, show a prosthesis
for disarticulation at the knee, and resembles the one described and illustrated by Pare as well as the "Chelsea" peg used to the present day. The earliest surviving example of a prosthesis was Roman, found in a tomb in Capua in 1858, and was thought to have been made about 300 BC during the period of Samnite Wars. It was made of bronze and wood, and was shaped to resemble the thigh, knee and calf. This limb was destroyed during an air raid on London's Royal College of Surgeon's museum during World War II. A fragment of an antique vase unearthed near Paris in 1862, shows a figure with a Below Knee amputation of the right leg wearing a pylon with a forked end in place of the foot.

The wooden peg was commonly used by the poor, but it did not satisfy the aesthetic needs of the rich, therefore the armourers started making limbs. Many of these were functional as well as decorative but were heavier as they were made of iron. In Florence among the Stilbert Collection is a limb with rigid knee in semiflexed position suitable for neither standing or sitting but adequate for riding astride a charger. Pare made legs of iron very complex in construction. Verudin (1696) produced the first artificial limb for below-knee amputees which had a leather socket and thigh corset with articulated side steels.

It is not known where wooden artificial limbs other than simple pegs were first introduced, but the simple wood "clapper" limb was probably introduced by makers such as Grossmith who was working in London in 1750. James Potts of London is said to have introduced the wooden leg in 1800. The limb has co-ordinated ankle and knee movements, produced by artificial tendons, and the great craftsmanship is its essential feature. The limb is known as the Anglesey leg after Pott's most famous patron, the Marquis of Anglesey, who lost his leg at Waterloo.

3. MODERN CONCEPT OF AMPUTATION AND PROSTHESIS

Before the First World War surgical techniques very similar to present day techniques were introduced wherein muscle flaps are used. Unfortunately however due to lack of prosthetic advancement, these operations were not considered satisfactory. These stumps were thus revised or abandoned to meet the requirements of the limb maker, that is a conical stump. Similarly, Symes and Through-Knee stumps were not considered satisfactory due to difficulties in prosthetic fitting. It was after World War II that once again interest was created in the study of amputations and prosthesis.
The introduction of safe anaesthetics and knowledge of antiseptics and asepsis had a profound effect on the results of amputation.

Amputation is no longer considered just a mere transection of the limb. In modern times it has come to be considered as a plastic reconstructive procedure. The stump is fashioned in such a way that it acts as a dynamic and sensory motor end organ. For fitting of a good modern prosthesis, a good stump with adequate stump strength is needed, for which muscle stabilising procedures such as myoplasty or myodesis or a combination of both are routinely done these days. Pre-operative assessment of tissue viability studies at proposed site of amputation and myoplastic surgical procedures have now made it possible to get away with lower levels of amputation especially in ischaemic limbs. Surgical techniques of Symes and Through-knee amputations have been modified to provide better cosmetic limbs, yet retaining their basic characteristics of end bearing. Constant research work goes on to improve further the existing surgical procedures. Immediate post-surgical prosthetic fitting has made a great contribution towards early and better management of the amputated stump. The Endo-skeletal permanent prosthetic attachment still in experimental stage is hoped to become a reality in the near future.

After World War II prosthetic engineering and design improved considerably due to advances in technology and awareness of bio-engineering implications incident to the surgery itself. The recognition of biomechanics involved in fitting and alignment has resulted in improved types of prostheses at all levels. New and better types of materials are being introduced every day. Total contact self suspending sockets are becoming the practice of the day. The loss of anatomical knee joint by knee mechanisms which provide stance and swing phase controls are now freely available. Various types of prosthetic hip and foot mechanisms are being designed for better function. Standard methods of fitting and alignment of prosthesis are laid down and the necessary tools are being developed to achieve this goal. Highly skilled professionals in medicine, engineering and allied disciplines are now taking keen interest in this challenging field and are producing gratifying results.
Proper Below-knee fitting is complicated by the unique anatomy of the stump and knee. The skin covering a Below-knee stump is quite different from that of the heel or other areas anatomically suitable for load bearing. The bones are not clothed all around by muscles as in other situations, and thus only few areas which could tolerate loading are available. The complex human knee joint is difficult to match mechanically and thus the problems in fitting and aligning the jointed side bars and corset of a conventional Below-knee prosthesis.

1. FUNCTION OF THE BELOW-KNEE STUMP
Function of the knee is rarely affected, because insertions of muscles and ligaments that control the knee are located close to the knee joint. Flexion and extension is the principal action of the knee, and the muscles that perform these movements take origin higher up at the femur and the pelvis and are inserted at the upper ends of the Tibia and Fibula. Gastrocnemius muscle which also helps in flexion at the knee, though is divided, its distal end gets re-attached to the tibia and the remaining musculature assists in flexion. Those muscles which have origins on the tibia and fibula for control of ankle and foot lose their action and get atrophied. The amount of atrophy of these muscles is dependent upon surgical technique and post-operative care.

2. WEIGHT BEARING AREAS
In a Below-knee stump there are certain pressure sensitive areas over which no pressure could be tolerated. The tibial crest which forms the anterior portion of the leg is very sensitive to weight bearing, because of high unit pressures that would develop over the sharp knife-like ridge. For similar reasons, compressive stresses cannot be tolerated at the lateral and anterior distal ends of the fibula and tibia respectively. Pressure over the head of the fibula also cannot be tolerated because the lateral popliteal nerve passes on the lateral side just below it. Very little pressure could be tolerated at the end of the stump because of the shearing stresses developed between soft tissues and the cut end of the bone.

Knee bearing is commonly assumed human posture. The front of the knee consists of relatively insensitive bony prominences, tough ligamentous and tendinous structures, and a strategically located fat pad which contains
dense supporting structures.

Patellar ligament is that part of the quadriceps tendon which is between the lower end of the patella and at its insertion on to the Tibial tubercle. It is composed of extremely tough, inextensible fibres, and is particularly suited for compressive loads antero-posteriorly. Because of its extensible qualities there is little or relatively no motion between the patella and the tibia when the quadriceps develops tension, a condition which permits compressive loads over the quadriceps tendon, perpendicular to the fibres, up to the proximal edge of the patella. The sharp lower edge of the patella however is not suited for weight bearing.

Flares of the tibial condyles are wedge-like in shape covered with thin, tough overlying tissues. The medial and lateral flares of the tibial condyles can assume part of the weight bearing load. Most of the weight bearing surface is provided by the medial flare, because part of the lateral flare is obscured by the head of the fibula. Further, due to proximity of sensitive zones like head of fibula and rough tibial tubercle the useful weight bearing area of lateral flare is considerably reduced. Thus the medial flare, though smaller provides more surface area for load bearing.

The shaft of the tibia is roughly triangular. Its antero-medial wall though covered with thin layer of tissues is suitable for assuming some of the weight bearing stresses. The antero-lateral wall on the contrary is covered by Tibialis anterior muscle. Though this muscle gets atrophied after amputation, it can still transmit without discomfort considerable load to the antero-lateral wall of the tibial shaft of the stump.

3. THE KNEE JOINT

The human knee joint is formed by the condyles of the femur and tibia, and allows about 160 degrees of flexion. The joint surfaces, ligaments and muscular attachments provide considerable stability. The femoral condyles rides on a concave pad of cartilage which rests on the surface of the medial and lateral condyles of the Tibia. The articulating surfaces of the Tibia and Femur are encapsulated by a synovial membrane which secretes the lubricant for the joint.

The human knee joint is not a simple hinge joint with a single axis of rotation. Because of the shape of the articulating surfaces, movement of Tibia in respect to Femur is a combination of gliding and rolling action and some degree of rotation. The centre of instantaneous centre of rotation of
the knee thus varies with each degree of flexion. The exact course of the
centres for different individuals cannot be determined degree by degree
during knee motion. Even an average anatomic centre is estimated roughly
to be in the posterior portion of the femoral condyles.

In the conventional below-knee prosthesis, it is a common practice to
distribute the weight bearing between the stump and thigh by using a simple
hinge joint connected to the thigh corset. The thigh corset supports some
of the superincumbent weight, with a consequent reduction of load applied to
the stump. Since the centre of rotation of anatomic knee moves constantly
with flexion or extension, it is not possible to maintain exact congruency
of the mechanical and anatomic knee axes, even if a polycentric mechanical
knee joint is incorporated. It results in relative motion between the body
parts and the prosthesis causing chaffing, irritation and abnormal pressures
over the stump.

4. OEDEMA
In the normal intact limb, the pumping actions of the muscles is an important
factor for the return of venous blood back towards the heart. In a stump
there is a tendency for oedema to develop in the dependent portion unless
pressure is applied to the entire stump. Further, concentrated pressures in
one area can cause oedema in a distal area either by inhibiting muscle action
or by restricting the low pressure venous or lymphatic return. Tight fitting
of the socket proximally and loose fit distally is another contributing factor
in the development of stump oedema. In addition, terminal oedema of the stump
may develop due to the constricting effect of thigh corset.

5. SOCKET DESIGN
Taking into account the various anatomical and physiological factors, a
socket should be designed which should have as far as possible the following
characteristics:

Suspension of the prosthesis should not be achieved by side joints and
thigh corset.

The weight-bearing loads must be transmitted through the stump to the
skeletal system in such a way that it does not exceed the varying
tolerance of the different tissues.

The greater area of the stump should be in contact with the inner
socket-wall. A total contact socket provides better sensory feed-back
to the wearer. It also decreases to some extent the load that must be borne by the other areas of the stump. In addition, it helps to prevent oedema and aids venous return.

In a prosthesis the most important part is the socket. In the absence of a socket design based on various anatomical and physiological factors, comfort, stability and function would be seriously affected. Application of biomechanical principles as a whole in the construction of a prosthesis is essential for successful rehabilitation of the amputee.
CHAPTER IV

BELOW KNEE AMPUTATION SURGERY

1. GENERAL CONSIDERATIONS

Advance in medical science has increased the life span of man by at least 22 years during the past 50 years, as quoted by Tosberg in 1959. Therefore there is an increased trend in the rate of amputation among elderly people. Hanson (1965) of Sweden has reported that the amputation rate among people over 60 years of age has gone up from 34 per 100,000 in 1947 to 120 per 100,000 in 1962. Authors from other countries have also reported a similar upward trend in the rate of amputation of the lower extremity in older age groups due to increase in life span (Record 1963, Vitali 1964, Pederson 1968).

Though trauma, chronic infection, tumours, deformities, congenital limb deficiencies, paralysis, etc, are among several indications for amputation, vascular insufficiency today has become one of the most common indications for lower limb amputations. In a recent statistical report published by The Department of Health and Social Security, it has been brought out that there had been 5014 amputations in England during the year 1975, out of which 3638 were performed on patients over the age of 60 years. Vascular insufficiency was the cause of amputation in 3049 cases, out of which 2553 were among patients over 60 years of age. Such a high percentage of lower limb loss due to vascular insufficiency has been reported by a large number of authors (Vitali 1964 - 58.4%, Hanson 1965 - 85%, Burgess 1969 - 80%, Kihn 1972 - 91.3%, Robinson 1976 - 73%). It is obvious that the necessity to perform lower limb amputations for advanced vascular disease is primarily because of increased longevity.

An elderly patient is becoming an increasingly important segment of the surgical practice today. In the past, surgical practice was rarely extended beyond the barriers commonly thought to be imposed by old age. An elderly person, in addition to normal declining physiological processes, suffers from many coexisting diseases, which in turn seriously impairs wound healing and affects his general physical health.

Surgery in the past resulted in high mortality rates amongst the older age group. Silbert (1948) reported a mortality rate of 44 per cent. However, at present the mortality rate has gradually come down, because of ability to control infection, improved methods of anaesthesia and surgical techniques, and improved management of co-existing diabetes, cardio-vascular, pulmonary and renal diseases.
The mortality of operation now varies from 10-25 per cent (Little, 1975).

Not too long ago for gangrene of lower extremity due to ischaemia, amputation at mid-thigh level was performed to ensure primary healing. There are still many who advocate it for reasons of quick healing and shorter hospital stay, even if the prosthetic rehabilitation status is doubtful. However, there has been a recent trend to obtain amputations at more distal levels, with a view to retaining the knee joint, a factor of immense value for the future functional status of the amputee. Absence of the knee joint increases considerably the demand for energy output in walking with the prosthesis, even in a healthy adult, and this adversely affects the already low physical status of the vascular amputee. It is advisable to conserve the knee joint for the following reasons:

- The operative mortality is lower than it is for above knee procedures.
- Better chances of prosthetic rehabilitation.
- Energy expenditure during ambulation is less.
- Less strain is imposed on the other intact limb which may also be involved, atherosclerosis being a generalised disease.
- Patella Tendon Bearing prosthesis for this level of amputation is lighter and easy to put on.
- Preservation of knee joint allows a more normal gait and avoids the need for mechanical devices such as knee locks.
- Walking up hills or down the slopes is easier because of better balance and security.
- There is better sensory feedback due to a larger stump area being in contact with the socket.
- Turning in bed is facilitated.
- Even if the elderly patient becomes a bi-lateral below knee amputee, he would be able to walk due to preservation of the knee joints.

To assess the level of amputation no single criteria is entirely reliable. The level of amputation is determined by assessing the level of vascular sufficiency in the extremity by careful clinical examination, objective clinical tests and finally by assessment of state of circulation at operation. However clinical judgement concerning the state of circulation and nutrition of the skin and muscles at the time of operation is the most important factor.
in predicting the healing of the stump. Kihn, Warren and Beebe (1972) have pointed out in a study that the lowest palpable pulse does not significantly influence the primary or secondary healing rate of below knee amputations. However the amount of bleeding noted at operation did show some correlation, eventual healing occurring in 69% of those showing 'non or little' bleeding, 77% in the presence of 'somewhat diminished' bleeding and 93% in the presence of 'normal' bleeding.

In the light of above findings there is no justification in performing above knee amputations as a routine, unless there are definite contra-indications for a below knee level. If however there is evidence of trophic changes above the proposed level of amputation or joint disorders in the form of severe contractures, painful arthritis and grossly unstable joint, below knee amputation is contra-indicated.

Arteriography, thermography, skin mapping with inter-arterial fluorescein, radioactive Xenon and transcutaneous doppler recordings are useful adjuncts in determining the level of amputation.

Today a large number of vascular patients are getting away with distal amputations due to improved surgical techniques. Kihn, Warren and Beebe (1972) have pointed out that during a three year period they noticed a change in ratio of below knee to above knee amputations from 0.42 to 0.74. Little (1973) reported that while in 1967 only one in six amputations performed was at below knee level, by 1971, two in every three were at below knee level. Wray, Still and Moretz (1972) performed below knee amputations in 93% cases.

2. **GENERAL SURGICAL PRINCIPLES**
   
   A. **SITE OF ELECTION**

   The middle third of the leg is considered the best site for below knee amputation. This gives a stump length of 5" - 7" below the knee joint level; sufficient to control the artificial limb effectively. Longer stumps are not effective from the point of view of power or control and are subject to circulatory disturbances and prosthetic objections.

   In cases of peripheral vascular disease this ideal length may not be feasible to obtain. The surgeon under these circumstances must try to save all lengths down to the optimum level, keeping in view the importance of saving the knee joint. Today, with advances in the construction of prostheses, a bone lever as short as 2½" can be made use of for effective limb fitting. Very short below knee stumps are preferable to higher amputation, provided the insertion
of the patellar ligament is retained.

Blair and Morris (1946) advocate sectioning of the hamstring muscles at the level of knee joint to increase the functional length of a short below-knee stump. About 2" of usable stump length is achieved by this procedure. Though there is loss of power in flexion it is compensated for by the weight of the prosthesis.

In children while performing a below knee amputation the stump should be kept as long as possible. If overgrowth of the bone occurs in relation to the soft tissues, the projecting bone can be trimmed as required.

B. TREATMENT OF TISSUES
The tissues during the surgical procedure should be handled with utmost care, especially in an ischaemic limb where the tissue viability is already in a state of critical balance.

a. SKIN
The cause of skin breakdown of the stump is poor circulation. During amputation to close the stump skin flaps are fashioned, and this results in impairment of blood vessels. Impairment of blood vessels serving the skin cannot be avoided, but certainly can be minimised by certain procedures:- (i) the skin mobilisation from deeper tissues should be avoided. The flaps should be fashioned in such a way that they contain skin, fascia and muscle as one mass. No dissection between various planes should be done to avoid impairment of the vascularity of the flap. (ii) Sharp instruments should not be used in handling skin edges, instead gloved fingers or swabs should be used. (iii) The skin flaps should be placed over well functioning muscles. (iv) The sutures should not be tied too tightly. Preferably only a few stay sutures should be applied and the rest of the suture line approximated by Steristrips.

It has been well recognised for many years that the skin over the posterior aspect of leg has a better blood supply than that over anterior or anterolateral aspect. Fulford (1967) by doing skin dye studies has brought out that there is evidence of deficient blood supply in the region of Tibial tubercle, resulting in necrosis of the anterior flap. In the light of the above knowledge, current practice is to fashion a long posterior flap containing muscles while performing a below-knee amputation.
b. FASCIA
The fascia should be kept attached in its whole length. If part of it gets separated from underlying muscles, it should be excised, as otherwise it becomes fibrotic and acts as barrier for the blood vessels for the skin.

c. MUSCLES
Following below-knee amputation, the function of the knee joint is not affected as most of the muscles acting on it do not lose their attachment, except for the gastrocnemius muscle. In the conventional below-knee amputation procedure, the gastrocnemius muscle along with other muscle groups acting on the ankle joint and foot, having lost their distal attachments, retract upwards and slowly become atrophied. Since venous return is no longer aided by the muscle pump, stasis and oedema may result.

The strength of the stump is dependent upon its musculature and its length-tension relationship under which they normally act to best advantage. In a stump, stump strength can be created by muscle stabilisation procedures, in the form of myodesis or myoplasty or a combination of both. Myodesis is not recommended in an ischaemic limb; instead myoplastic procedure is carried out. The gastrocnemius muscle though no longer concerned with its major role of co-ordinator of knee and ankle movements, can be utilised by doing a myoplastic procedure to provide (1) a small additional measure of knee control, (2) a large firm area on the posterior aspect of the stump with the capacity to transfer comfortably the force actions produced by the socket, (3) an active venous pump and (4) an increased area of contact with the socket with benefits in proprioception, suspension and like (Murdoch 1969).

The gastrocnemius muscle by nature and level of its blood supply entering as it does at the level of Tibial epicondyles, deep to the medial borders of the two heads of the muscle, may survive when other muscles die due to gangrene of arteriosclerosis. It is due to this fact that very long posterior flaps with adequate chances of skin survival and wound healing can be fashioned. It is due to this fact that even in the presence of frank gangrene of anterior tibial, peroneal and soleal group of muscles, a below amputation can still be performed after excising the dead muscles, provided the gastrocnemius retains its vascularity and skin bleeds on cutting. (Murdoch - 1969, McCollough - 1972). Excision of muscles should be carried out if liquefaction has taken place, but if they are only brownish or pale, they should be left behind to proceed to fibrosis.
d. **BONE**

It is of the utmost importance that the cut ends of the bones should be filed carefully to remove all sharp edges to avoid pressure zones. The anteromedial angle of the Tibia should always be rounded off and the Fibula cut 1/2" higher up. The fibula should be cut at the same level as that of the tibia in the osteo-periosteal technique. In children, fibular growth in a below-knee stump always exceeds that of the tibia producing sharp bony projections under the skin requiring repeated excision till the bone growth ceases. It is therefore recommended to excise the fibula higher than usual. However procedures to arrest fibular epiphyseal growth are not recommended.

In very short stumps below the level of the tibial tubercle, the bone section is done through the cancellous bone, which has some weight-bearing properties. Sockets for such short stumps if made properly could have some and bearing properties. The fibula in very short stumps due to the pull of Biceps femoris tendon gets abducted, leading to painful friction and subsequent development of an adventitious bursa. This bursa due to repeated friction is liable to episodes of frequent bursitis. Further, due to movement at the superior tibio-fibular joint, and pinching of the lateral popliteal nerve, often there is severe disabling pain in the stump. Due to above disabling features produced by a fibula in a very short stump, it is advisable to excise the fibula in toto. This procedure has the additional advantage of making available the lateral tibial flare to accommodate some of the forces of weight-bearing.

e. **NERVES**

The nerves should be gently pulled down, excised cleanly with a sharp knife, then allowed to retract within muscle mass. Too much traction before cutting the nerves leads to traction neuritis. Various surgical techniques for the treatment of the cut ends of the nerves for prevention of neuroma formation have been advocated. Alcohol injection, cauterisation of the cut ends; suturing of sheath over the cut end of the nerve, implantation of the cut end within the medullary cavity and Lenggenhager's method of three progressive weaker compressions at about 1cm from the cut end of the nerve, are some of the techniques which have been tried without successful results.

f. **BLOOD VESSELS**

The arteries and veins should be ligated separately, to prevent slipping of the ligature during post-operative phase and to avoid the remote chances for the development of an arterio-venous shunt.
3. SURGICAL TECHNIQUES

There are many techniques of performing the below-knee amputation. At present the consensus of opinion is in favour of techniques in which myoplasty or myodesis is performed. It is proposed to discuss the three commonly used methods, without going into the detailed operative techniques.

A. LONG POSTERIOR FLAP AMPUTATION

The improved results of below-knee amputation surgery are largely attributable to this more recent technique, especially in vascular patients. It is now universally recognised that in the vast majority of ischaemic cases amputation at this level can be successfully performed by this technique (Pederson 1964, Moore 1968, Warren 1968, Burgess 1969, Condon 1970, Robinson 1976). This has been possible because of the better understanding of the vascular pattern of the skin and muscles, already discussed earlier in the chapter.

The technique of using a long posterior flap was first described by Kendrick (1956) and he obtained 63% primary healing. Burgess (1969) utilised this technique in conjunction with immediate prosthetic fitting and obtained primary wound healing in 82% cases. The success is due to forming a short anterior flap thereby eliminating anterior tibial skin deficient in blood supply, and forming a long posterior myo-fascial flap with good vascularity. The long posterior flap containing the gastrocnemius muscle after soleus and posterior tibial group of muscles have been cut at the level of the bone section, is slightly bevelled distally and sewn anteriorly to the anterolateral deep fascia and the tibial periosteum. This myoplastic procedure helps in creating adequate stump strength, and provides soft tissue coverage of the bone ends, which are the pressure sensitive areas. The myoplasty of the gastrocnemius muscle encourages venous and lymphatic return which in turn prevents the development of the stump oedema. It further helps in augmenting the force of knee flexion and provides good musculature for the stump for transfer of force actions produced by the posterior wall of the socket. It is a reconstructive and plastic procedure, therefore the tissues should be carefully treated according to the principles of its management in plastic surgery. The surgical result of such an exercise is the production of a dynamic, sensory end organ - "a foot-like organ" at below-knee level. The cylindrical stump so produced is ideal for fitting of a total contact socket - the socket being the "shoe of the foot" (Burgess 1969).
B. THE OSTEOMYOPLASTY AMPUTATION

The essential feature of this technique is the creation of an osteo-periosteal bridge between the cut ends of the tibia and fibula, which in due course gets converted into a bony bridge capable of bearing some weight at its end. When the bones are transected in below-knee amputation they no longer transmit weight in the longitudinal direction, leading to some osteoporosis due to disturbances in mineral metabolism. Further open-end medullary cavities lead to alteration in normal conditions of pressure and circulation within the bone. However these ill effects could be prevented if some weight could be transmitted along the long axis of the bones. The lower cut ends of the bones are sensitive to pressure and unless made insensitive are incapable of load bearing. Creation of a firm bony bridge between the cut ends of tibia and fibula could achieve the above goals.

Bier (1893) is reported to be the first surgeon who attempted making the distal end of the stump less sensitive and capable of more weight bearing by an osteoplastic procedure in which the cut ends of the bones were covered with a flap of cortical bone attached by a periosteal hinge. Ertl (1949) developed a technique in which pliable osteo-periosteal flaps were made by making three periosteal flaps with small flakes of cortical bone attached to them, two from tibia and one from fibula. These three flaps are fashioned into a tube, bridging the distal cut ends of tibia and fibula. Mondry (1952) added the myoplastic procedure to this osteo-periosteal technique, wherein the anterior tibial and fibular muscle groups are sutured under moderate tension to the gastrocnemius-soleus group over the osteo-periosteal bridge. The detailed techniques of the operation have been well described by Loon (1962) and Murdoch (1969).

This procedure is indicated in all cases other than in ischaemic disease, as it is more elaborate, requiring extensive dissection and is time consuming. In an ischaemic limb where the state of circulation at proposed site of amputation is itself a matter of guess, it is not worth subjecting it to the added risks with the above technique.

This method has several advantages: (i) creation of an insensitive bony bridge at cut ends of the bones capable of partial end bearing; (ii) restoration of normal intramedullary pressure; (iii) prevention of abduction and abnormal mobility of the fibula especially in very short stumps and (iv) improved sensory feedback experienced by the amputee.
C. THE CONVENTIONAL BELOW-KNEE AMPUTATION

There are many methods described for performing this type of amputation. In all the procedures the muscles are cut at the level of bone section and allowed to retract. As the function of knee joint remains unaffected because the distal attachments of the muscles acting on it are retained, loss of only gastrocnemius muscle action of the knee joint is not considered of much significance. It was generally considered a satisfactory amputation, and is still performed by a large number of surgeons not familiar with the modern concepts of amputation surgery.

Due to the atrophy of the muscles and loss of vascular bed, these conical bony stumps have a tendency to develop terminal stump oedema. In the absence of muscular covering at their ends, the cut ends of the bone being subcutaneous are tender on pressure and thus incapable of being fitted with a total contact socket. Such stumps can be fitted up only with proximal weight-bearing sockets in which the stump hangs loosely. The weight bearing and constriction at proximal end of the stump if present may further aggravate stump oedema.
BIOMECHANICS OF BELOW-KNEE PROSTHESES

The Socket of the Below-Knee prosthesis is one of the most important components. It is not merely a simple female duplication of the stump shape. Its contours are designed to provide comfort, stability and functional connection between the stump and the prosthesis by application of certain biomechanical principles.

In the past, application of these principles were based upon clinical experience and trial and error. However, in more recent years contributions by research workers at the University of California (Redcliffe & Foort, 1961), and other investigators (New York University, Postgraduate Medical School, 1975), a clearer understanding of these biomechanical principles have emerged.

The aim in providing a prosthesis to a below-knee amputee is to make the full and unrestricted use of the amputee's knee joint. Therefore, it implies that the weight bearing and dynamic forces are to be transmitted to the stump alone, below the knee level.

It is proposed to discuss the related biomechanical principles to socket shape and alignment of the below-knee prosthesis with special reference to Patellar-Tendon-Bearing prosthesis. The illustrations and the biomechanical principles involved are reproduced from the manuals - Patella-Tendon-Bearing Below-Knee Prosthesis by Redcliffe and Foort (1961) and Lower Limb Prosthetics - New York University, Post-Graduate Medical School (1975 revision).

1. STUMP SOCKET PRESSURES
   (a) Pressure Versus Comfort. The magnitude of pressure between the stump and sockets is one of the major determinants of comfort in a prosthesis. To minimise discomfort, it is necessary to avoid excessive pressure on the stump. It is well known that pressure is directly proportional to the force applied and thus to reduce pressure it is essential to increase the area over which force is applied. To achieve this aim it is necessary to increase the contact area between the stump and the socket. In practice however, it is not so simple because tissues of the below-knee stump are not uniform
(b) **Socket Contours and Shape Related to Pressure Distribution**

The basic principle in prosthetic fitting is to utilise as much area of the stump as possible to distribute the forces applied by the socket to the stump. Since the degree of firmness and tolerance to pressure differs in various areas of the stump, the socket contour has to be modified with respect to stump.

The objective is to design a socket in such a way that it produces selective loading of the tissues, so that more of the weight is supported by pressure tolerant areas and less by the pressure sensitive areas. This aim is achieved by creating reliefs in the socket over the pressure sensitive areas of the stump and inward contours over the pressure tolerant areas. The inward bulges in the socket over the pressure tolerant tissues of the stump transmit a large portion of the load, whereas allowing only a smaller part of the load to be borne by the pressure sensitive areas, over which reliefs have been incorporated.

By applying these biomechanical principles to the below-knee socket, that is, incorporating reliefs and contours, the stump with varying degrees of firmness and tolerances to pressure, can be comfortably accommodated.

(c) **Effect of Relative Inclination of Supporting Surfaces**

Pressures on the stump are greatly influenced by the relative inclination of the supporting surfaces that are in contact with the stump. The more closely the supporting surface approaches the vertical, the greater will be the counterforces that must be applied to support a given weight. Conversely, the more the supporting surface approaches the horizontal, the less will be the counterforce that must be applied to support a given amount of weight.

In the case of a below-knee socket, a horizontal surface on which a major part of the load can be covered is not readily available. Although the end of the below-knee stump is horizontal, it cannot tolerate heavy loading. The problem is overcome by fitting the stump in slight initial flexion and making an inward bulge in the socket to fit under the area of patellar tendon, as shown in Fig. 1. Although this area
FIGURE 1

FIGURE 2

(a) Forces on the Amputee  (b) Forces on the Prosthesis
Although the supporting area of the Patella Tendon is less steeply inclined than other supporting areas, it has a downward and backward slope. The stump supported on this area, tends to slide downwards and backwards. To prevent this, an anteriorly directed counter-force is required, and is provided by the posterior wall of the prosthesis. Therefore the posterior wall should be relatively high, but not so high that it interferes with sitting comfort. The posterior wall should have an inward bulge, so that the tissues in contact are under some initial compression, otherwise the stump would slide downwards and backwards until the tissues on the posterior aspect of the stump are compressed sufficiently to provide a counterforce to arrest motion.

(d) Stump Socket Force Analysis
As the prosthesis is meant to support the body, it must be able to provide both vertical support and medio-lateral balance. Fig 2a illustrates the forces exerted by the socket on the amputee and Fig 2b, the corresponding forces on the prosthesis. The Vertical Components of pressure are applied against many surfaces of the stump, but for simplification are represented as a single support point S. Forces M and L represent force actions in medial and lateral directions respectively. \( W \) is the force due to the gravitational pull on the patient's body. \( R \) is the reaction force from the ground to the prosthesis and is inclined medially upwards resulting in a lateral inertia force \( I \), equal to the horizontal component of \( R \).

Summation of medial and lateral forces must act in the general position indicated by \( M \) and \( L \) respectively in order to counterbalance the toppling effect of force \( W \) about the support point. Keeping in view, and including the inertia effect and which is not negligible, summing the moments about the support point gives the relationship

\[
L = \frac{Wa - Ic}{b}
\]

The lateral stabilising force \( L \) can be reduced by either increasing the horizontal inertia force by moving the foot laterally so as to increase the medial inclination of the total floor reaction or by
as discussed later under medio-lateral alignment.

The prosthesis is subjected to forces applied by the stump from above and the counterforces applied by the ground from below. If these two forces are Collinear there would be no tendency for the socket to change its angular relationship with respect to the stump. However since the resultants of the opposing forces are not in line, there is a tendency for the socket to change its angular relationship. This tendency is resisted because of intimate fit of the stump in the socket. With an intimate fit, the tissues on the opposite aspects of the stump are compressed as the angular change begins to take place. The counterforces developed by the compression of tissues establish dynamic equilibrium and arrest the incipient motion.

When the prosthetic fore-foot of an amputee wearing PTB limb approaches the ground, the downward and forward forces applied by the stump to the prosthesis cause the socket to change its angular relationship with the stump in the direction as shown by the curved arrow in Fig 3. However this tendency is resisted by the counterforces that are developed as the socket increases its pressure on the anterior-distal and posterior-proximal aspects of the stump. If the amputee is to control the rate and amount of knee flexion by action of his knee extensors, the contours of the socket must accommodate the stump socket pressures that are built up in these areas. This indicates the need for a high posterior socket wall that presses firmly against the tissues on the posterior aspect of the stump, and for suitable relief on the antero-distal aspect of the stump.

At the end of mid-stance phase, the thigh is inclined downwards and backwards with respect to the ground. The counterforce applied to the prosthetic foot by the ground, prevents forward inclination of the prosthetic shank, and causes a change in angular relationship between the socket and stump as shown in Fig. 4. As a consequence increased pressures on the antero-superior and postero-distal aspects of the stump develop. The cuff suspension strap of the prosthesis however helps to limit these pressures on the stump, since the incipient relative motion in the direction indicated in Fig. 4 is resisted by the counterforces developed as the knee strap compresses the tissues above the patella.
towards the end of push-off phase of the Walking Cycle the ground reaction force produce change in angular relationship between the stump and the socket in the direction indicated by the curved arrow in Fig. 5. As a consequence of this, the tissues on the postero-proximal and antero-distal aspects of the stump are subjected to increased pressure. Once again, a high posterior wall and relief over antero-distal aspect of the socket help in preventing excessive pressures.

(e) **Stump Length Related to Pressure on the Stump**

The length of the stump has a marked bearing on the magnitude of the pressures that are developed as a consequence of change in angular relationship between the socket and stump.

Fig. 6. depicts the resultants of the forces applied to the prosthesis from above and by the ground from below. These opposing forces which are not collinear, constitute a force couple that tends to rotate the prosthesis in a counterclockwise direction. Assuming that the rotation is taking place around the axis designated by "0", the moment of forces generated by the forces represented by AB and CD is indicated by the Formula: $M_1 = (AB \cdot d_1) + (CD \cdot d_2)$, $M_1$ being the moment of force due to AB and CD.

Fig. 7. represents the counterforces applied to the proximal-medial and distal-lateral aspects of the socket as the tissues in the corresponding areas are compressed because of incipient motion of the socket. The incipient motion is arrested when the resisting clockwise moment developed by the forces represented by LL and MM is equal to the counterclockwise moment developed by forces AB and CD. The clockwise moment due to LL and MM is represented by the Formula: $M_2 = (LL \cdot dL) + (MM \cdot dM)$, $M_2$ being the resultant clockwise moment.

At a given time, if no change in angular relationship between socket and stump is taking place, then either the resultants of AB and CD are collinear or that there is dynamic equilibrium between moments developed by forces represented by AB, CD, LL and MM. In the later case, the relationship is represented by the Formula: $(AB \cdot d_1) + (CD \cdot d_2) - (LL \cdot dL) - (MM \cdot dM) = 0$.

Fig. 8. is similar to Fig. 7, except that the stump is shorter, and thus the distance from the axis of rotation to the line of action of
For a condition of dynamic equilibrium in Fig. 8, the combined value of LL and MM must increase proportionately to compensate for decrease in length of the moment arms. For this reason shorter stumps are subjected to greater pressures than would a longer one under the same circumstances consequent to change in angular relationship of the socket in respect of the stump.

2. ALIGNMENT AND PRESSURE DISTRIBUTION

Alignment refers to the relative position of the component parts of the prosthesis with respect to each other, particularly the socket and foot in the case of below-knee prostheses. The magnitude and distribution of the forces applied to the stump by the socket is largely dependent upon the alignment. By proper alignment it is possible to control the forces acting upon the stump, so that relatively higher pressures could be applied where they are best accommodated and most effective, whereas correspondingly reduced pressures to the pressure sensitive areas.

(a) Medio-Lateral Alignment

The placement of the prosthetic foot in relation to the socket during alignment of the prosthesis has a significant effect on the pressures applied to the stump as well as on the gait pattern.

The medial displacement of the foot, as shown in Fig. 9, tends to make the socket change its relationship to the stump in the direction shown by the curved arrow. It results in increased compression of the tissues on the lateral distal and medial-proximal aspects of the stump, with relatively decreased pressure on the lateral-proximal and medial-distal aspects. This type of alignment where the prosthesis is aligned with a narrow walking base is the correct procedure. It helps in distributing the medial force at the medial flare, the weight bearing area and the lateral stabilising force over the lateral distal half or third of the stump. At the same time the lateral proximal pressure sensitive area (fibular head) is relieved of pressure. The medial displacement in Fig. 9 is shown in exaggerated form to illustrate the effect on pressure distribution. In actual practice it is not so great.

Fig.10 shows exaggerated lateral displacement of the foot. With this alignment the socket rotates in the direction shown by curved
allow. It results in greater pressure at lateral-proximal and medial-distal aspects of the stump. This is not desirable as the lateral-proximal area of the stump is pressure sensitive. Further it results in a wide-based gait which is abnormal and unnecessary.

(b) Antero-Posterior Alignment
An optimum antero-posterior alignment of the socket with respect to the foot is essential. Displacement of the socket too far forwards causes excessive pressures over the antero-distal pressure sensitive area and postero-proximal area during heel strike and end of push off phase of the walking cycle. On the contrary if the socket is placed too far back, the knee is forced into hyperextension just before heel off position is reached.

3. SUSPENSION METHODS AND STUMP SOCKET PRESSURES
The role of Cuff Suspension Strap of a PTB prosthesis in helping to limit pressures on the stump has already been dealt with under Stump Socket Force Analysis (para 6).

Suspension mechanisms are designed primarily to hold the prosthesis to the stump. In special circumstances like short stumps which are prone to develop greater pressures, the suspension could be utilised to reduce stump socket pressures. For short below-knee stumps the two suspension variants of PTB prosthesis commonly employed are known as Supracondylar system and PTS system (Patellar Tendon Supracondylar). In both of these variants high medial and lateral walls encompassing Femoral Condyles is employed. In PTS system in addition to high medial and lateral walls, the anterior wall is also high. These high walls of the socket not only secure the prosthesis to the stump, but also constitute extended lever arms. Referring back to Fig. 7, it can be seen that upward extension of the walls of the socket increases the length of the lever arm extending upwards from the instantaneous centre of rotation "0". This in turn would result in reduced stump socket pressures when the socket tends to change its angular relationship with the stump. The pressures would reduce in proportion to the increase in length of the lever arm extending above point "0".

Another form of suspension mechanism in use, for reducing stump socket pressure, is when a Thigh Corset and side steels are used. The Thigh Corset supports some of the superincumbent weight, resulting in reduction
of load applied to the stump. When the socket changes its angular relationship with the stump, the side bars and thigh corset press against the thigh. The thigh corset thus, by applying stabilising counterforces at a relatively greater distance from the axis around which rotation takes place, substantially reduces the forces required to establish dynamic equilibrium and angular change.

However, thigh corset and mechanical knee joint of the suspension mechanism have certain biomechanical disadvantages. The Thigh Corset due to its constricting effect produces atrophy of the thigh and oedema of the stump. It also interferes with heat dissipation during hot weather, and adds to the bulk and weight of the prosthesis.

When a Thigh Corset is used alignment of the axis of the mechanical knee joint with the anatomical knee axis is an important factor in achieving satisfactory comfort and function. If two sets of joints have congruent axes as shown in Fig. 11, there will be no relative displacement as motion takes place in the joints. However if the joint axes are not congruent as shown in Fig. 12 relative displacement of the two sets of joint attachments does occur.

The human knee joint is not a simple hinge joint with a single axis of rotation, but a combination of gliding, rolling and some degree of rotation movements. The centre of rotation of the knee also varies with each degree of flexion, and the exact course for the centres for different individuals cannot be determined degree by degree during the movement of the knee. The prosthetic below-knee joint is of the hinge type with single axis of rotation. It is therefore not possible to maintain exact congruency of the mechanical and anatomical axes as the knee flexion and extension occurs. It therefore leads to the problems related to relative displacement between the amputee's limb and the socket and thigh corset, namely, piston action and friction leading to chaffing, irritation and pressures over the stump and thigh.

In order to minimise the problems mentioned above it is necessary to locate an optimal mechanical knee joint centre in relation to the anatomical knee centre, which would offer best function and eliminate discomfort resulting from this relative motion. It has been established that it is achieved by placing the mechanical axis slightly above the average anatomical joint axis. This arrangement provides sitting comfort by drawing the stump slightly out of the socket, and minimising piston action during walking.
The below knee sockets are constructed either by a trial and error fit from tracings and measurement of the stump as in conventional Below Knee prosthesis or from a cast or impression of the stump as in Patellar-Tendon Bearing (P.T.B.) prosthesis. The plaster of paris cast to obtain a model of the stump for construction of a below knee socket has been in use from time to time (Murphy 1954), but it was not until 1959 that it became a routine procedure with the introduction of PTB prosthesis by Redcliffe and Foort.

1. CONVENTIONAL BELOW-KNEE SOCKET

The conventional Below knee socket is so designed that it utilises only the proximal weight bearing areas of the stump for transmission of weight bearing and stability loads. It therefore becomes essential to provide additional weight bearing and stability at some other site. These are provided by the thigh or ischial tuberosity through the side steels and thigh corset.

The socket may be constructed as an integral part of the shank as in wooden limb or as a separate socket contained within the shank. The materials generally used for the construction of the socket are wood, leather and various plastics.

In many parts of the world the wooden socket is most popular. The socket is carved using measurements of stump, and usually a set of general shape patterns with measurements noted on the tracing or with a plaster cast for visual inspection. Successive trial fittings and necessary adjustments by carving and sanding are essential during fitting and early use of the prosthesis. The successful outcome therefore is dependent on the skill and artistic ability of the fitter. In England the leather socket is most often used in this type of limb.

The disadvantages of the conventional below knee socket are in its utilisation of only the proximal weight bearing areas of the stump, the loose fit over the rest of it and unsupported terminal tissues. Since it is not a total contact socket; its proximal ring fit and the constricting effect of the thigh corset may produce terminal oedema of the stump. The biomechanical disadvantages due to incorporation of the single axis mechanical knee joint has already been dealt with in the previous chapter. It is due to it that friction and piston action cannot be avoided which in turn results in
excoriation of the skin and painful adventitious bursae over the stump.

These shortcomings have been recognised by the clinicians and the prosthetist for many years, and in order to overcome them the concept of total contact with varying degrees of pressure and weight bearing over the entire stump surface, and elimination of the mechanical knee joint and thigh corset was originated.

2. PATELLAR TENDON BEARING (PTB) SOCKET

This socket was developed at the University of California by Redcliffe & Foort in 1959. This socket transmits all the weight bearing and stability loads below the knee joint. It is so designed that it produces selective loading of the tissues, so that more of the weight is supported by pressure tolerant areas and less by pressure sensitive areas. The vertical support load is borne largely by the patellar tendon, a tough area well suited to the function. Both tibial condyles and to some extent soft tissues of the stump share the weight. The socket design aims at achieving total contact with the stump.

Since the socket is able to transmit all the weight and stability loads to the stump below the knee joint, it has been possible to dispense with the cumbersome thigh corset and mechanical knee joint. Instead a cuff suspension in the form of a strap which encircles the thigh just above the patella is used.

This type of socket is made from a cast or impression of the stump. The wrap cast of the stump is obtained by wrapping plaster bandage over a cotton sock. As the plaster begins to set, it is moulded over the patellar tendon with counter pressure in the popliteal fossa to give the patellar tendon bearing characteristics to the cast. The negative cast incorporates only some of the features necessary for transmission of dynamic force actions. Further modification is necessary and this is accomplished by using the negative cast as a mould to produce a positive model of the socket. The positive mould is then rectified by removing plaster from areas that can tolerate weight bearing, and by adding plaster to relieve pressure in pressure sensitive areas. The rectified positive mould represents the inside shape of the socket.

The plastic socket is then laminated over this rectified positive mould. The socket so produced should be a total contact socket with variable degrees of pressure and weight bearing over the entire stump surface.
The fit of this socket is largely dependent upon the knowledge and skill of the prosthettist in correct evaluation of the characteristics of each individual stump and the application of the guiding principles in taking the negative cast and subsequent rectification of the positive mould. The procedure is by no means a difficult one, but since casting by hand requires a high degree of skill considerable amount of errors are encountered in the routine day to day practice. The usual drawbacks of the hand casting procedure resulting in failure of successful construction of the below knee socket are as follows.

While wrapping the plaster of paris bandages manually around the stump it is very difficult to apply it with a uniform pressure all around. Each turn of the plaster bandage applied circumferentially is likely to have a different tension. The tension in the bandage results in higher pressures over the areas of small radius of curvature such as bony prominences, and minimal or no pressure over flat or re-enterant areas of the stump. Further during the procedure if there is excessive tension in the plaster bandage on one side, it may displace the soft tissues of the stump from their normal anatomical position, thus altering the shape of the final socket in relation to the normal shape of the stump.

During rubbing of the plaster around the stump, to mould it and define the bony areas, if one is not very careful the important markings on the stump sock may get displaced due to sliding of the sock off the stump. It would result in turn, in rectifications of the positive mould at the wrong places.

The deformation of the cast done by hand to give the cast patellar tendon bearing characteristics results in increase in the medio-lateral and decrease in the antero-posterior diameters at its upper end. This in turn leads to distortion of the contours of the cast in the region of the medial tibial flare, an important weight bearing area of the stump. The amount of increase in the medio-lateral dimension and consequent loss of contact pressure in the region of the medial tibial flare would thus be dependent upon the force exerted by the prosthetists hands. The 'caving in' of the plaster along a \( \frac{3}{4} \)" strip on each side of the tibia to define the anterior crest is also subject to the same objections as above.

Rectifications of the positive mould requires a good deal of skill and knowledge of the application of the biomechanical principles on the part of the prosthettist. The amount of plaster to be removed from the pressure
tolerant areas varies with individual patients, depending upon muscle tone, degree of wasting of the muscles, and condition of the skin and subcutaneous tissues. It is therefore desirable that the prosthettst carries out these rectifications immediately, while the detailed features of the stump characteristics are still fresh in his mind, rather than postponing it for later rectifications, to prevent improper interpretation of the individual stump characteristics. In practice however it is seen that the prosthetist who in addition to taking a number of casts in a day has also to attend to the patients to fit the limbs, doesn't find time to do immediate rectifications. In England and Wales often the prosthetist himself doesn't carry out the necessary rectifications. Instead this work has been delegated to the staff in the plaster shop that may be far remote from the Limb Centre. The staff in the plaster shop, who have not seen the patients stump, carry out the rectifications according to standard procedure and so takes little account of the needs of the individual patient. It is obvious that the outcome following this regime of arbitrary rectifications is dubious. Both under and over rectifications would ultimately lead to an ill fitting socket.

Due to the above drawbacks, unsatisfactory sockets are produced, and this has led to a search for a method of stump casting which gives better results and removes the human factor.

3. **SOME OTHER METHODS OF CASTING FOR PTB SOCKETS**

Because of problems encountered in successful fitting of the socket by the casting technique of Redcliffe and Hoort, many workers have attempted to improve upon the existing casting technique. The various techniques described below however have not been widely accepted, and only remain in use at the Centres where originally invented.

(a) **Suspension Casting** This system was developed by Hampton in 1956 at The Northwestern University to permit casting of the below knee stump in an attitude simulating stance phase weight bearing in a prosthesis. This has been attempted by the application of the chinese finger trap principle, namely, when a cloth cylinder of a suitable weave is, stretched longitudinally, the circumference of the cylinder is decreased.

In this system a casting sock of a suitable weave is suspended from the metal ring attached to the casting stand. The amputee stands with his stump within the suspended casting sock with his weight evenly distributed between the two limbs. When the weight is borne, the casting sock stretches and helps
in containing the tissues firmly and emphasising the bony prominences. Pads of appropriate thickness are then applied over those areas of the stump which requires relief of pressure from the socket. The stump is then wrapped as per the technique of casting by Redcliffe & Poort. The resultant positive mould needs rectifications in all other areas except for pressure sensitive areas.

In order to further reduce the amount of positive mould rectifications, attempts have been made to create patellar tendon and popliteal impressions in the negative cast itself. This has been tried by making use of a clamp in one modification, whereas use of pads has been made in another variation.

The casting technique has the advantage that it results in production of a positive mould which needs fewer rectifications, but has certain drawbacks. Because of the tension in the suspended casting sock the tissues at distal end of the stump may get distorted, and be subjected to excessive end pressures. The end of the stump can withstand only partial weight bearing, but if the pressures generated becomes excessive, it may become intolerable.

(b) Hydrostatic Pressure Casting. Murdoch at Dundee in 1964 has described a technique in which he has employed hydrostatic pressure to cast a below knee stump, in weight bearing situation. He has tried to eliminate the ill effects of the circumferential hand wrap casting technique, by using plaster of paris impregnated casting socks and hydrostatic pressure. Use of hydrostatic pressure was aimed to control pressures and tightness of the cast around the stump.

The equipment employed by him for this technique consists of a tank with water inlet and outlet. The top of the tank is closed with a loose diaphragm of thin nylon sheet. The water is run into the tank and the patient stands with the stump invaginating the nylon sheet into the water. Water is added as required until the patient is evenly balanced with the amputated side immersed in the tank to a point 3" above the knee level.

The stump is withdrawn and a dry nylon sock is pulled over it, followed by three more socks impregnated with plaster of paris powder and water. The patient once again inserts the stump with plaster socks in position and his weight evenly balanced, until the plaster has hardened. The hydrostatic pressure employed for casting is around 2 p.s.i.

The stump during the whole procedure remains separated from water by a thin nylon membrane, and the cast is moulded by the reaction of water in a
closed system to the body weight passing through the stump.

The cast obtained by this method is then used as a check socket after an adjustable patellar tendon bar has been added to it. After satisfactory trial, a positive plaster mould is made out of the plaster check socket (negative cast). The only modification over the positive mould recommended by Murdoch is over the antero-distal part for relief of the antero-distal end of the tibia. A plastic socket is then laminated over it.

Though the system has the advantage that the ill effects of circumferential wrapping and hand moulding of the plaster cast have been eliminated in it, it has certain disadvantages.

The system suffers from the ill effects of a closed pressure system in which the pressures are transmitted over the stump via a membrane, which in turn modifies the intended pressures to be applied over the stump.

When a stump is introduced into the invaginated membrane, which separates the stump from the water pressure chamber, the membrane is stretched on weight-bearing. Stretching of the membrane is also produced as a result of bulging up of the membrane at its fixed upper end, when the water pressure is raised. The stretching of the membrane results in distortion of the terminal tissues, and development of pressures in excess of water pressure. The amount of pressures over the stump/cast interface at the time of casting therefore remains unpredictable. The effect of depth of immersion on pressures over the stump however may not be a significant factor, in view of the depth to which the stump is immersed, but it will still be present to some extent.

Though the cast has formed under pressure, in the absence of popliteal depression in the socket made by this method, the posterior socket wall may not provide adequate anteriorly directed counter force to support the stump on the patellar tendon bar. This in turn would lead to sliding downwards and backwards of the stump, subjecting it to excessive end pressures on hard contact with the bottom of the socket. The absence of adequate relief for pressure sensitive areas other than antero-distal tibia is also not a satisfactory feature in a socket.

c) Pneumatic Casting. Gardner in 1965 described this technique for casting below knee stumps. In order to overcome the drawbacks of hand wrap casting, use of air pressure has been made to cast a stump in this technique.

In this technique after the stump sock has been pulled over the stump, the distal end of the stump is first manually wrapped with plaster of paris
and allowed to set before other areas of the stump are wrapped with plaster. After this plaster has set, the plaster of paris bandages are wrapped around the stump incorporating two latex forms in the patellar tendon and popliteal region to create patellar tendon and popliteal impression in the negative cast itself.

The stump is then subjected to air pressure by employing a double walled open end pneumatic pressure sleeve. The pressure sleeve is pulled over the stump and inflated to provide pressures of about 2 p.s.i. When the sleeve is inflated its inner wall exerts pressure over the stump to set the cast under pressure. After the cast has set, a positive mould is obtained from it and rectified over the antero-distal tibia alone, before a socket is fabricated over it.

The disadvantages of the system are that the inner membrane of the pressure sleeve is attached at both the upper and lower ends, and thus does not provide pressures over the entire surface of the terminal end of the stump when inflated. It is because of this that in the technique preliminary hand wrapping of the distal end of the stump to provide tightness of the cast becomes necessary. The stump thus requires casting in stages. Further, the interposing membrane of the pressure system may modify the intended pressures meant for casting the stump.

The absence of adequate relief for pressure sensitive areas other than antero-distal tibia is another objectionable feature of the casting system.

(d) Vacuum Casting. In this technique use of suction has been employed to apply a cast over the stump. This technique is advocated by Kuhn of University of Munster, Germany, and also employed by Maurer and Fajal.

In this technique after the stump has been wrapped with plaster of paris bandages, it is covered with a band of loose cloth or wadding. A P.V.C. bag closed distally over a vacuum connection is then pulled over the stump, and its proximal end sealed around the thigh above the plaster bandage by a string. A vacuum of approximately 0.6 atm. is then applied causing the P.V.C. bag to collapse over the cast. As the plaster is about to set pressures are applied by hand to mould the cast in the patellar tendon and popliteal areas to give it the patellar tendon bearing characteristics. The positive mould obtained is then rectified as per standard procedure.

This system doesn't produce entirely satisfactory results. When the vacuum is applied, the P.V.C. bag merely collapses over the cast without
exerting any positive pressures. The cast therefore doesn't set under pressure against the tissues. Further to apply a vacuum the seal around the thigh has to be applied under adequate tension, and if tied tightly may produce a tourniquet effect. Furthermore the moulding of the cast by hand and its subsequent management has the same inherent faults as a bandage wrap.

(e) Preamended Casting for PTB Socket. This is a modified version of the standard hand wrap casting procedure. Zettl and Traub (1971) of Seattle, Washinton have described this technique for casting a below knee stump. The technique is aimed at modifying the negative cast on the patient's stump itself, so that the positive mould doesn't require any rectifications at all.

In this method various pads are applied at the strategic areas of the stump during casting procedure. The pads employed are in the form of relief pads for bony sensitive areas and the hamstring tendons, and compression pads for the pressure tolerant areas. These suitably shaped pads are strategically placed and wrapped in various layers of the plaster wrap. When the cast is about to set the patellar tendon bar and popliteal impressions are created in it by a specially designed casting fixture. The positive mould obtained from such a cast doesn't require any rectifications, as all the necessary features have been transferred to it from the negative cast.

The technique essentially is like standard circumferential hand wrap casting, and thus is exposed to the same inherent drawbacks. The correct fashioning of the shape of the various pads in relation to the anatomical features of the individual stump is a critical step of the technique. The technique is a complicated one, and required a very high degree of skill to achieve satisfactory results.

(f) Two Part Casting Technique. This is another modification of the standard hand wrap casting procedure. Fillauer (1971) has described this technique. The technique aims at defining the anterior structures of the stump precisely, as they are of utmost importance in socket fitting. Once these features are established, the rest of the casting features are defined in the next stage of casting. This entails casting of the stump in stages.

In this technique, first a plaster splint is placed over the anterior half of the stump to define its features. When it is about to set patellar impressions are created on either side of the patellar tendon. After this pre tibial shell has formed, the rest of the stump is wrapped around to complete the casting procedure.
It is claimed that by this technique an improved definition of bony structures is obtained, and no gross reduction of plaster is required in the positive mould to obtain medio-lateral weight bearing and lateral support along the shaft of the fibula.

The casting system has a definite advantage in defining the critical areas of the stump. However, since its success is dependent upon the skill of the prosthetist in taking the cast, it has the same inherent drawbacks as that of standard wrap cast.

It is evident from the discussions so far that attempts to improve upon the circumferential hand wrap casting technique by employing other methods, have resulted in overcoming some of the factors but have led to the introduction of other objectionable features. The current state of the art of casting techniques seems to need further work. The author, therefore, decided to develop a technique in which the existing drawbacks could be eliminated as far as possible, by the application of a uniform air pressure directly over the stump while casting it. The remainder of this thesis will be devoted to a description of my work on this topic.
CHAPTER VII

THE PRINCIPLES OF PRESSURE CASTING TECHNIQUE

The successful fitting of the PTB prosthesis depends upon precise shaping of the socket in relation to the stump. The current method of hand wrap casting and rectifications of the positive mould to obtain a model for construction of PTB socket is largely dependent upon the skill of the prosthetist. The drawbacks of such a procedure have already been dealt with in the previous chapter.

While working at Biomechanical Research and Development Unit, Roehampton, London, it seemed to me that a new concept of casting a below knee stump could be developed which would overcome the various limiting factors of the hand wrap casting procedure.

1. OBJECTIVES

It was thought at the outset that if the following factors in the new system to be developed could be dealt with effectively, it might be possible to overcome most of the objectionable features of the existing casting technique.

(a) The system used to be such in which the ill effects of circumferential hoop stresses and hand moulding could be eliminated.

(b) The level and distribution of pressures at the stump/cast interface should be predictable, and the level of pressure should be capable of being varied.

(c) The system used to be such that it results in a closely applied cast, which in turn forms a basis for the formation of a total contact socket.

(d) To develop a system of stump casting that would result in a positive mould which would require the minimum of hand work on it prior to socket making.

(e) The system used should be capable of producing consistent results, defined upon being able to reproduce the casting conditions with accuracy.

(f) The system used must be simple to apply and need no complicated or expensive support equipment.

2. CONCEPT OF AIR PRESSURE CASTING

The below knee stump is triangular in cross section rather than circular. Circumferential wrapping of the stump by plaster bandages tend to round the usual triangular cross section of the stump, and also because the tension in
different turns of bandages applied cannot be controlled, there is no knowledge of the actual level of pressures or its distribution at the stump/cast interface. Such a procedure tends to produce higher pressures over areas of small radius of curvatures, such as bony prominences, and no pressure over flat or re-entrant areas, a situation exactly opposite to the one required at stump/cast interface. It is because of this fact that the positive mould requires reduction rectifications to increase contact in those areas where there was no pressure and build up rectifications where higher pressures were applied.

The author proposed to overcome the above drawbacks of undesirable pressure gradients at the stump/cast interface by employing some means to produce and control tightness of the cast while it is setting around the stump. It was felt that it might be possible to achieve this by use of raised air pressure. If this were possible to achieve in practice, it would ensure that tightness of cast was uniform in all areas.

For the application of uniform air pressure all around it was considered essential that the system should be such that the pressures are imparted directly over the stump without being modified if a membrane is interposed between the stump and the air chamber. This was suggested in order to avoid the possible adverse effects resulting from the use of the membrane in the Hydrostatic or Pneumatic casting systems described in previous chapter.

In a closed pressure system (Fig.13A), the separating membrane at its fixed upper end tends to rise up the conical section of the limb when the pressure is raised. This in turn produces a sling effect over the end of the stump which may distort the terminal tissues. The net result of this would be that the terminal tissues are subjected to pressures in excess of intended pressure.

It was thought that it might be possible to provide a single wall open bag with a self adjusting air seal at the open end that would fit to the patient's thigh (Fig.13B). When the below knee stump is placed in this bag it should be possible to raise the air pressure within the bag by means of a pump which would have the capacity to maintain the raised pressure in the presence of any air leak past the seal. The tissues of the stump would thus be compressed directly by the raised air pressure in the bag.

If the tissues of the stump were covered by a layer of fluid plaster of paris, which in turn was covered by an impervious membrane whose proximal end was not fixed in the pressure bag, and the space between this membrane and
**FIGURE 13A**

- Double Walled Pressure Container
- Outer Wall
- Flexible Inner Wall (membrane)
- Positive Pressure Within Pressure Container
- Membrane In Tension
- Stump

**FIGURE 13B**

- Single Wall Pressure Container
- Air Seal
- Air Leak
- Positive Pressure Within Pressure Container
- Stump
the skin was vented to atmosphere pressure, the raised air pressure within the bag would "squeeze" the wet plaster on the tissues. The use of the fluid layer of plaster at this stage of the casting would act as a pressure transfer medium. By this means the fluid plaster would be held against the tissues by the raised air pressure until it has set.

Because the tightness of the cast would be produced by air pressure, this can be controlled and would be uniform in all areas at the time of plaster setting, being independent of the shape of the tissues being cast. The resultant cast would therefore conform to the shape of the stump at the time of casting.

In this system since the level of delivered air pressure can be controlled and kept constant throughout the casting procedure by employing a suitable blower unit with a pressure gauge, the level and distribution of pressures at stump/cast interface can be predetermined at the time of casting.

Such a system would eliminate the non-uniform pressure distribution produced by hand moulding and deformation of the cast responsible for invoking a variety of tissue responses, varying from zones where pressures are locally excessive to areas where no support is available.

Having proposed a method of applying a uniformly applied total contact cast, it was decided to implement the philosophy in the clinical situation.

3. PRESSURE CASTING IN CLINICAL SITUATION

To give a practical shape to the principles considered necessary in the casting procedure, the author suggested a technique of putting it into practice.

First the stump would be covered by a sock extending well up the thigh. This sock would vent the cast to atmosphere when the plaster is wet, and line the cast when the cast has set.

In the proposed technique (Fig.14A), in order to eliminate the positive mould rectification procedures, it was planned to incorporate these features in the negative cast itself at the time of casting. This would be achieved by employing suitably shaped pads at suitable places among the layers of the cast itself.

In order to prevent the circumferential hoop stresses of plaster bandage wrapping, it was decided to lay the plaster slabs lengthwise over the stump without any tension.
Pressure Cast

FIGURE 14A

Relief Pad For Upper Tibial Flare

Relief Pad For Lower Tibial Flare

Relief Pad For Head of Fibula

Relief Pad For Lower Cut End of Fibula

2/3 Cast Sock

1/3 Cast Sock

PVC bag

Plaster Slab

Stump

Pressure Bag

Air Under Pressure

Vent to Atmosphere
Cross Section Leg

FIGURE 14B
A thin P.V.C. bag would be employed as an impervious membrane to cover the plaster slabs and pulled well up the thigh. It was decided to use as a pressure container for the new casting technique a special plastic bag developed in Biomechanical Research and Development Unit, Roehampton, as a wound dressing, and incorporating a self adapting air seal developed in the Hover Craft industry (Patent No.1329241). The stump with its sock, wet plaster and separating membrane on it, would be placed in this special bag and the air pressure raised to the desired level.

The plaster of paris while in a liquid state, will flow freely under pressure to adopt the shape of the stump before it sets (Fig.14B). During the procedure the air within the P.V.C. bag and among various layers of the casting socks and plaster slabs is expelled to the atmosphere, resulting in an intimately fitting cast.

The use of uniform air pressure therefore would ensure contact of the cast not only in the important support areas of the stump, but all around including the distal end of the stump. The pressure sensitive areas of the stump covered by relief pads though subjected to uniform pressure, would find adequate relief in the form of recesses left when the relief pads are removed.

The negative cast produced by this method will have, in addition to the recesses produced by relief pads for the pressure sensitive areas, contours for contact pressures in the pressure tolerant areas produced by air pressure. These features will get transferred to the positive mould when plaster is poured in the negative cast to obtain it. The positive mould therefore would require no major rectifications. The only work to be done on it would be to cut a patellar tendon groove and provide a flaring effect to the top posterior brim of the socket. The resulting positive plaster mould would resemble the stump contours accurately, thus providing the basis for the construction of a total contact, comfortable and functionally acceptable socket.

4. CONCLUSIONS

Implementation of the procedure proposed in this chapter should result in achieving the desired objectives. By this method it would be possible to eliminate the non-uniform pressure distribution over the stump at the time of casting. The technique of casting employed should result in a positive mould which doesn't require major rectifications.
Since the technique would dictate the physical dimensions of the socket necessary to produce the required condition at the stump/socket interface, the prosthetist with an average skill, should be able to carry out the technique to produce consistent results.
The intention of this chapter is to describe in detail the method of producing the stump casts for the clinical trial (previously illustrated in Fig.14-A).

1. MATERIALS NEEDED

The following materials and equipment are needed in the casting of a below knee stump in this technique.

Two, two-way stretch brushed nylon casting socks.
Stockinette sleeve.
Semi-compressed self adhesive surgical felt 5mm and 2mm thick.
Popliteal pad.
Double sided sticky tape.
Two, 2-ply 6" plaster slabs to measurements.
4" Plaster of Paris bandages.
A P.V.C. bag.
Indelible pencil.
Scissors.
Tape measure.
Combination square.
Knee measuring caliper with calibrated scale.
Basin with clean water.
Plaster trolley.
Pressure bag.
Controlled Pressure Casting (CPC) Machine.
Casting plinth.

Pressure Bag - This casting technique employed a pressure bag developed by BRADU, Roehampton (Fig.15a, b & c), because it being a single walled open bag with a self adjusting air seal at its open end met all the requirements considered essential in a pressure bag for the air pressure casting system.

These bags are made of clear flexible P.V.C., and are fabricated by high frequency welding. The bag incorporates a pleated type of air seal at its proximal end, similar to the one used in the Hovercraft industry. The seal is made up of pleats of flexible plastic and is thus self adapting to a wide range of sizes and shapes of the limb. The seal maintains the raised air pressure within the bag without exerting any tourniquet effect on the
limb. Because the flexible pleats of the seal itself cannot develop any force against the tissues, the pressures developed by the inflated bag against the tissues is uniform, and no higher pressure can develop under the seal. This is the only type of seal which doesn't exert any tourniquet effect.

**Controlled Pressure Casting Machine** - This is essentially a blower unit employed to maintain required raised air pressure within the pressure bag. Two types of blower units are in use at present. The prototype unit developed and constructed in BRADU, Roehampton, and the commercial unit marketed by Cape Engineering Ltd.

Both units are portable and require only the normal mains supply. The prototype unit has a multi-stage centrifugal blower, whereas the commercial unit (Fig. 15a, b & c) employs a two stage high speed centrifugal blower, as used in the cylinder type vacuum cleaners. The blower units are connected to the pressure bag by means of a flexible lightweight plastic hose, and thus there is no electrical connection to the patient.

The air output pressure of the prototype unit is controlled by allowing excess air to escape to atmosphere through a manually controlled oriﬁce, placed near it junction with the pressure bag. The Cape unit however incorporates a thyristor speed control, again manually operated.

The prototype unit delivers air pressures over a range of 5 to 40 m.m. of Hg., and the Cape unit from 5-60 m.m. of Hg. The air flow capacity of both units is in excess of the air leak rate from the pressure bag, which generally falls in the range of 1.5 to 5 lb/sec. The delivered air pressure is displayed on a pressure gauge of the range of 0-60 m.m. of Hg.

**The Popliteal Pad** - This pad is required to create the desired popliteal impression in the cast. To make this pad, a light thermoplastic material known as Pelite has been employed. This pad is prepared by shaping the Pelite material into a roughly triangular form, one side of which remains flat, whereas the other shaped into a convex surface (Fig. 16a & b). The length and width of the pad are kept to about 3½" and 2½" respectively. The maximum thickness measured at the centre of the pad should be approximately ½", tapering gradually towards its edges. The pad of this dimension with its convex surface towards the stump when placed in the popliteal region in between the hamstring tendons, produces the contour in the cast required for the necessary anteriorly directed counter force by the posterior socket wall.
Pelite Popliteal Pad

**FIGURE 16A**

**FIGURE 16B**
2. **PROSTHETIC MEASUREMENTS**

Before casting a stump, it is necessary to record certain data. For keeping such records, the form used by the author is shown on page 54. Careful record not only helps in making the socket and the prosthesis, but also helps in future references. Data for patients is tabulated in Appendix A (i) on pages 119-120.

Stump measurements are used to check the positive mould before a socket is laminated over it. The antero-posterior measurements at the patellar tendon level is used to ensure that the stump is properly supported by the patellar tendon bar and the posterior socket wall. The medio-lateral dimensions at the femoral epicondylar level again establishes its relationship with respect to socket measurements at this level. Stump length is taken into account for the purpose of alignment and fitting, and to decide upon the type of suspension to be provided.

Measurements of the normal leg and foot are necessary in making the prosthesis of correct length and shape. The other informations required are shown on the record sheet and are self explanatory.

3. **PREPARATION BEFORE CASTING**

Before casting of the stump is done, it is necessary to make the pressure relief pads and the plaster slabs to be used in the casting procedure.

(A) **Preparation of Relief Pads.** The relief pads are prepared by measuring the length and breadth of the bony areas of the stump which require relief from pressure within the socket. In this technique semi-compressed self adhesive surgical felt has been employed, because it is readily available from the hospital supply stores and comes in various thickness sizes, with a protective covering over its adhesive side. Other materials like kemblo, leather or ordinary felt could also be used for making these pads. However it will have to be ensured that they are of proper thickness, and that a suitable adhesive substance is applied to it and at the appropriate areas on the cast sock, where these pads will be located.

The semi-compressed self adhesive surgical felt is preferred over the soft variety, because the fibres of the soft surgical felt get stuck to the inner surface of the cast, when it is removed from it along with the sock over which it was stuck.
<table>
<thead>
<tr>
<th>Name</th>
<th>Age</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Amputation</td>
<td>Weight</td>
<td>Date of Cast</td>
</tr>
<tr>
<td>Cause of Amputation</td>
<td>Date of fitting</td>
<td></td>
</tr>
<tr>
<td>Amputation side</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### STUMP MEASUREMENTS

**STUMPS MEASUREMENTS**

- Tibial Plateau
- **A.P =**
- **M.L =**

**Shoe size:**

**Heel height:**

### SOUND SIDE MEASUREMENTS

- Tibial Plateau

### STUMP DESCRIPTION:

- **Type of amputation**
- **Shape of the stump**
- **Condition of skin**
- **Condition of subcutaneous tissue**
- **Condition of stump musculature**
- **Condition of the bones**
- **Condition of pressure tolerant areas**
- **Condition of pressure sensitive areas**
- **Condition of knee joint**
- **Other features if any**
Tibial Relief Pads. In the usual practice two relief pads are fashioned to provide relief to the bony sensitive areas of the tibia. However, in certain stumps in which the bony tubercle over the Lateral Tibial flare is too prominent, a third pad has also to be made.

A single large relief pad for the crest, antero-distal and lower cut end of the Tibia is first made out of 5 m.m. thick surgical felt (Fig.17-a). To fashion this pad, measurements are taken from the proximal border of the Tibial tubercle to the posterior cut edge of the Tibia (a-a1) to give the required length of the pad. The measurements at maximum width of the Tibial tubercle (b-b1), bevelled antero-distal (d-d1) and lower cut end of the Tibia (e-e1) are then recorded. The width of the pad in the Tibial crest region (c-c1) is kept to 1" so that ½" of felt covers the bone on either side of the crest. A pad is then cut from the surgical felt as per the dimensions taken above.

For the provision of the additional relief in the antero-distal and lower cut end of the Tibia, another small relief pad is fashioned. To make this small pad (Fig.17-b) measurements from the area from where the Tibia is bevelled, to the posterior cut edge of the bone (a-a1), gives the required length of the pad. Record of maximum width of the lower cut end (c-c1) and at the antero-distal bevelled area (b-b1) completes the measurements necessary for shaping this pad. The pad is then cut out of 2 m.m. thick surgical felt as per the dimensions taken. The pad is thereafter reduced in size by ¼" all around, to enable it to be neatly overlapped by the lower end of the single large Tibial relief pad, when both are stuck to the stump.

A third small oval pad (Fig.17-c) is occasionally needed to cover the too prominent bony tubercle over the lateral Tibial flare. This pad is fashioned out of 2 m.m. thick surgical felt by measuring the length (a-a1) and breadth (b-b1) of the tubercle.

Fibular Relief Pads. Two relief pads, one for the head of fibula and the other for the lower cut end of the bone are made. Relief pad for the Head of Fibula (Fig.17d) is made by taking measurements from the upper end of the head to ½" beyond its lower edge (a-a1), and the antero-posterior dimensions (b-b1). It is essential to extend the relief pad down to the neck of the fibula to protect the lateral popliteal nerve. The pad is then fashioned out of 5 m.m. thick surgical felt.

Similarly a small pad is made for the lower cut end of the fibula (Fig.17-c), by noting the length (a-a1) and breadth (b-b1) at its cut end.
Tibial Relief Pads

FIGURE 17A

FIGURE 17B

FIGURE 17C

Fibular Relief Pads

FIGURE 17D

FIGURE 17E
The relief pads prepared in the above manner are then neatly skived near their periphery, so that when stuck to the stump sock, there is smooth transition between the pads and the stump sock.

(B) Preparation of Plaster Slabs. Two plaster slabs are needed during the casting procedure. They are made to measurements from six inches wide Plaster of paris bandages, two layers thick. The slabs are required to cover the antero-posterior and medio-lateral aspects of the stump lengthwise to produce a cast of the stump.

To make the antero-posterior slab, measurements are taken from the upper edge of the patella, round the end of the stump to a point corresponding to the upper edge of the patella behind the knee. The medio-lateral slab is then made keeping it one inch longer than the antero-posterior slab, so that it covers the femoral condyles at a slightly higher level.

4. PRESSURE CASTING

The amputee is made to sit on the casting plinth and the adjustable seating board is adjusted so that it supports the thigh and the back of the knee is approximately 4" distal to its edge.

A length of stockinette sleeve is pulled over the thigh, extending from the groin downwards up to 2" above the patellas. Thereafter a two-way stretch brushed nylon casting sock is pulled over the stump. The two-way stretch casting sock fits snugly over the entire stump, and contains the soft tissues firmly under it. As the snug fit is maintained by the sock itself, tension on the top of the sock by a webbing belt is not necessary.

In this technique two-way stretch brushed nylon casting stump socks which come in various sizes have been used because of the above advantages, and that it comes off the stump along with the plaster cast easily without hairs getting stuck to it, thereby avoiding discomfort to the patient. However ordinary cotton cast socks employed routinely in prosthetic practice could also be used, but would need webbing elastic belt to maintain adequate tension at its top, to keep the tissues firmly under it.

The stump is then flexed to 20°, and held in that degree of flexion throughout the subsequent procedure by the amputee. The amputee is instructed to maintain this position in a relaxed manner. This amount of flexion at the knee helps in defining the patellar tendon and is necessary to emphasise the bony prominences around the knee.
The relief pads are then stuck to the pressure sensitive areas of the stump over the first casting sock (Fig. 18 a & b). These relief pads are tailored to individual stumps. The 5 mm. thick surgical felt has been found to provide adequate relief of pressure at most of the bony pressure sensitive areas. However, for the antero-distal and lower cut end of the Tibia this amount of relief is found to be inadequate, as these areas are specially sensitive to pressure. Therefore additional relief in this area is provided by shaping another pad of surgical felt 2 mm. thick. A total of 7 mm. thick relief in this area is found to be adequate in most of the myoplastic stumps in which the cut ends of the bones are well covered with adequate musculature. However, in those situations where the distal soft tissue is sparse, and the cut end of the bones are prominent or sharp, additional amount of relief will become essential depending upon the tenderness in the region. This may however result into loss of distal support, an undesirable feature.

Over the lateral tibial flare, occasionally the bony tubercle is found prominent, and thus needs some relief of pressure from the socket wall. The lateral tibial flare is a pressure tolerant area, but when such a situation arises, protection of the bony tubercle by an oval 2 mm. thick felt pad solves the problem.

These pads are stuck over the sock very carefully by palpating the bony structures, before sticking them. First the small pad (Fig. 17-b) is stuck over the antero-distal and lower cut end of the Tibia, after removing the protective covering to expose the adhesive surface of the pad. It is carefully checked that the pad is in the correct position. Thereafter the large Tibial relief pad (Fig. 17-a) is stuck covering the Tibial tubercle, crest of Tibia and the small 2 mm. thick pad already placed over the antero-distal and lower cut end of the Tibia. At its lower end, it may become necessary to cut darts in the felt pad at suitable places, to cover the end of the stump neatly. It is ensured that the pad is correctly placed. The relief pads for the Head of Fibula, lower cut end of fibula and the bony tubercle over the lateral Tibial flare are then stuck at their respective places.

The second two-way stretch casting sock is then gently rolled over the first casting sock with the pressure relief pads in place. While applying the second casting sock, care is taken to ensure that the pressure relief pads do not get displaced from their position. The position of the pads is verified before proceeding to the next stage. The outlines of the Patella, the level of the patellar tendon bar, the upper border of the posterior socket wall and the vertical line along the long axes of the stump, are then
These markings get transferred on to the positive mould and serve as important landmarks for exact location of the above reference points. A horizontal mark over the Patellar-tendon is made at mid-point between the lower edge of the Patella and the upper end of the Tibial tubercle. Another horizontal mark is then made behind the knee at the same level. This line represents the location of the top brim of the posterior socket wall. A vertical line at right angles to this horizontal mark represents the long axis of the stump, and facilitates the correct placement of the Popliteal pad.

These reference lines in the posterior aspect of the stump are drawn so that the popliteal pad could be correctly located before casting the stump. It was observed that if the pad was placed after the plaster was applied to the stump, or even within the layers of the plaster, it was difficult to orientate its correct placement.

Though it was found easier to correctly locate the pad before casting the stump, the pad made of heavy material due to its weight tended to fall away from the stump. It would have been easier to hold it in place if the stump was wrapped circumferentially but since in this casting technique plaster slabs are placed longitudinally to cover the stump, the cast had a tendency to sag with the weight of the popliteal pad leading to increase in the antero-posterior dimensions.

In order to overcome this problem, it was decided to employ some very light material to construct the popliteal pad. Pelite a light thermoplastic material was therefore chosen to make this pad.

The Pelite Popliteal pad with its convex surface towards the stump is then placed in the popliteal region (Fig. 20a). The upper border of the pad should be parallel to and at the level of the posterior horizontal mark, and its long axis coinciding with the long axis of the stump. The Popliteal pad is held in place by using double sided sticky tape over the convex surface of the pad.

The next step of the procedure is application of the plaster slabs to the stump, but before doing it once again the correct positioning of the relief pads, popliteal pad and the degree of knee flexion are ascertained. Patient is instructed to maintain $20^\circ$ flexion at the knee in a relaxed manner throughout the further casting procedure.
The popliteal pad is then held firmly in place by a two layer 4" wide plaster slab long enough to cover the posterior half of the stump along with the pad (Fig.21a). The slab is not placed around the whole circumference of the stump to avoid any hoop stresses on the stump. It is followed by the application of the Antero-posterior and Medio-lateral slabs (Fig.21b & c). The Antero-posterior slab is applied lengthwise, starting in front of the patella, passing down and around the end of the stump, up the back to the posterior point corresponding to the upper border of the Patella. The Medio-lateral slab is then applied starting from the medial side of the knee about ½" above the patella, passing down along the medial side and around the end of the stump, continuing up along the lateral side of the stump and knee to a point about ½" above the patellar level. The medio-lateral slab is applied at a higher level on either side of the knee, because the medial and lateral socket walls are required to be at a higher level.

The plaster slabs are applied dripping wet, using cold water, to allow more time for the plaster to set. It is ensured that the slabs are evenly spread over the stump all around. The slabs are not rubbed on the stump, to avoid shifting of the pads and the markings on the socket in relation to the underlying structures of the stump.

The thin P.V.C. bag long enough to extend well up the thigh is then pulled over the stump (Fig.21d). It is followed immediately by application of a suitable pressure bag on the limb (Fig.21e). The pressure bag is held in place by hands, and the air pressure is gradually raised to 40 m.m. of Hg. by means of the blower. During this procedure it must be ensured that the stump is maintained in 20° flexion, and it doesn't touch or rest against the walls of the pressure bag. The upper end of the P.V.C. bag should be well above the air seal of the pressure bag, to enable it to separate the stump compartment from that of pressure bag compartment, which have different pressures. Due to a pressure gradient the fluid plaster flows smoothly around the stump to adapt its shape when it sets. It has been found that a pressure around 40 m.m. of Hg. results in a cast which fits snugly around the stump. It takes approximately 5 minutes for the plaster to set. After the plaster has set the air blower is switched off, and the pressure bag and P.V.C. bag removed from the limb.

The cast at this stage is quite thin (Fig.22-a,b & c), and thus may get deformed during its removal from the stump. The cast shows that it has set, intimately in contact with the stump all around. The cast before it is removed, is therefore reinforced by applying a 4" plaster bandage, using
warm water for quick setting, (Figs. 22d, e & f). After the plaster has set, the upper ends of the casting socks are reflected over the cast (Fig. 22g) and the cast is then gently removed from the stump.

Keeping the second (outer) casting sock reflected over the cast, the first (inner) casting sock along with the relief pads attached to it is then carefully removed from within the cast (Fig. 22h). The second casting sock is left undisturbed, and the interior of the cast is inspected before pouring the plaster to obtain the positive mould. The inspection would reveal that the relief pads have left recesses for the pressure sensitive areas (Fig. 22i). The Popliteal pad lying between the second casting sock and the plaster cast, produces the desired inward bulge in this area (Fig. 22j). The inner wall at the rest of the places conforms to the shape of the stump, as it has set under air pressure.

5. MANAGEMENT OF THE POSITIVE MOULD

The positive mould is obtained by pouring plaster within the pressure cast. In the mould obtained from the pressure cast, most of the necessary rectifications are already there. The build up rectifications are produced by the recesses in the negative cast. The reduction rectifications in the pressure tolerant areas have been produced by the contours of the cast formed under air pressure (Fig. 23a & b). The Popliteal impression has been produced by the popliteal pad (Fig. 23c).

The only plaster work to be done on this mould is to cut a Patellar-tendon groove and construct a posterior flare for the back brim of the socket. The mark indicating the level for cutting this groove has already been transferred to the positive mould from the marking on the negative cast. This point represents the mid-patellar-tendon level (Fig. 23a). The level for construction of posterior flare and socket trim lines are then drawn over the positive mould by an indelible pencil as shown in Fig. 23a, b & c. The horizontal line over the posterior aspect of the mould drawn at mid-patellar tendon level represents the back brim of the socket. Next, lines drawn from the middle of the patella and upwards on either side gives the shape of the medial and lateral socket walls. These lines are then drawn towards the posterior brim line.

A horizontal groove is cut to a depth of about ½" over the horizontal mark indicating level for cutting the patellar groove. The groove should be about 1½" long and ¾" to 1" wide. The upper and lower edges of this groove should be curved smoothly towards the patella and the tibial tubercle.
FIG. 26-A.

5 MM PELITE LINER

1/4" PLASTAZOTE BUILD-UP

FIG. 26-B.
After the groove has been cut the antero-posterior dimensions at this level are checked with those recorded at the time of stump measurements, and the two should be within the same range.

To construct the posterior flare plaster is added above the posterior trim line. While the plaster is still slightly wet a flare is formed by smoothing the plaster with the fingers. The flaring of the posterior trim line is done so that the back brim of the socket should be formed into a broad, flared surface against which the hamstring tendons and the soft tissues in the popliteal region can rest comfortably in flexion.

Finally a smooth finish over the entire model is given with a wet sand paper. The stump measurements taken initially are checked with that of the model, before a socket is laminated over it. The finished mould with the patellar tendon groove and posterior flare are shown in Fig.24a, b & c.

The socket (Fig.25a, b & c) is then made over this mould as with the standard P.T.B. lay-up for fabricating a polyester socket, with a Pelite liner. It is not proposed to discuss the socket lamination procedure. However, it is felt that a mention should be made about the Pelite liner. The liner is made of 5 mm thick Pelite. At its distal end a \( \frac{1}{4} \)" build-up of Plastazote in the form of a cup (Fig.26a & b) is made to provide some resilience at the bottom of the socket on weight bearing.

The socket so formed would be a total contact socket with contours and shape designed on sound biomechanical principles.
CHAPTER IX

CRITERIA FOR SELECTION OF PATIENTS FOR PRESSURE CAST SOCKETS

The criteria for selection of patients for fitting with pressure cast sockets is discussed under two headings i.e. for the purpose of clinical trials and in routine practice.

1. SELECTION OF PATIENTS FOR THE PROJECT

For the purpose of conducting the clinical trials smoothly, it was decided that only active, well motivated, volunteer patients would be selected.

Before selecting the patients, they were briefed about the concept of the proposed project, the duration of the exercise, and the expected results to be achieved. It was made clear to them that their cooperation and help in making themselves readily available during the entire phase of the project would be an essential criterion for their selection for the project.

It was decided, that for the purpose of clinical trial only active Patellar-Tendon-Bearing limb wearers with good fitting would be selected. It was realised that a patient with an unsatisfactory limb would be readily satisfied with even a marginal improvement in any other limb. It was therefore considered essential to have good P.T.B. wearers in this trial to enable us to evaluate the results of the below-knee sockets produced by the pressure casting technique.

A decision was made to expose six patients to clinical trials initially, keeping in mind the other research commitments and the limited production capabilities of the unit. However, if time permitted more patients would be fitted with this type of socket.

2. SELECTION OF PATIENTS IN ROUTINE PRACTICE

It is now proposed to consider the criteria in general for selection of patients for Pressure Casted Total Contact Below-Knee Sockets.

(a) AGE OF THE PATIENT

Age is no bar for fitting of a limb with this type of socket. Besides young active limb wearers it is equally indicated for the children and elderly amputees.

It has in fact special applicability for elderly amputees. These ischaemic stumps are unsuitable for bearing localised high pressures at certain spots and less or no pressure at other sites. Localised pressures
besides causing discomfort and pain lead to formation of distal oedema, aggravation of ischaemic manifestations, and possible break-down of the stump.

The Pressure Casted Socket being a total contact socket, should help in distributing the pressures over the greatest possible stump surface, thereby providing a comfortable fit. The intermittent positive pressures applied to the stump during walking cycle helps in venous and lymphatic drainage, and return of blood flow. This again is a factor of great importance for keeping the stump in a healthy condition. Better sensory feedback provided by the socket is of immense value to an elderly amputee, whose power of balancing and co-ordination are as such impaired due to normal ageing process.

In children and adolescents the problem is of replacing the sockets to keep pace with the growth, at frequent intervals. This problem is common to any type of fitting.

(b) **SEX OF THE PATIENT**

The socket is suitable for both men and women.

(c) **AGE OF THE STUMP**

During the first few months after amputation, there is a tendency for the stump to shrink. Shrinkage takes place due to resolution of the post-operative oedema, and atrophy of the muscles. Though the shrinkage of the stump due to resolution of oedema is desirable, too much muscle atrophy is unwanted. In a stump the amount of shrinkage attributable to muscle atrophy is dependent upon the type of amputation done and the type of socket provided.

In a stump in which cut ends of the muscles have been allowed to retract, the muscle power is diminished. Muscles in such a stump having lost their distal attachments atrophy rapidly.

In a myoplastastic stump, where opposing group of muscles are re-attached under suitable tension, muscles contract isometrically and thus will not atrophy to the same extent. Further, a total contact socket, acts as a vascular pump, maintaining adequate vascular supply and in turn preventing the muscles from atrophy.

In a new amputee, the amount of stump shrinkage with Pressure Casted Socket would thus be largely due to resolution of the oedema, and would need change of the socket when it has taken place. The muscular atrophy would be minimized and the sockets would not need frequent changes once the stump had
stabilised.

(a) **LENGTH OF THE STUMP**

The ideal length of the stump for fitting such a socket is about 5½"-6" from the line of the knee joint. However as short as 3" - 3½" of stump length could be accommodated.

(e) **CONDITION OF THE PRESSURE SENSITIVE AREAS**

Small adherent painless scars over the lower cut and of the tibia are no contra-indication for fitting with such a socket. However, gross tender lesions are not suitable as the pressures exerted may not be tolerable to the patient.

Stumps with sharp bony spurs at the lower cut end of the bones are also not suitable for fitting with this type of socket for similar reasons.

Stumps in which the cut ends of the bones are not well covered with soft tissues and are prominent, provision of such a socket is possible only by compromising with some element of total contact philosophy. The relief in these areas has to be sufficient to prevent its coming into contact with the distal socket wall. Normally, the amount of relief provided is just sufficient for the pressure sensitive areas to be accommodated during weight bearing. In fact on full weight bearing these areas are just in contact with the socket wall, contributing some pressure distribution as mere touch down pressure.

(f) **CONDITION OF PRESSURE TOLERANT AREAS**

The skin and subcutaneous tissue should be healthy in order to tolerate pressures on the stump. Well healed scars, and healthy skin grafts over these areas are no contra-indication for fitting such a socket. However, if the skin is thin and unstable and likely to break-down, especially over important major weight bearing area like patellar-tendon, this socket is not indicated.

Small, localised areas of unstable skin or sensitive areas in less important weight bearing areas of the stump can be accommodated by providing relief to these areas.

A stump with manifestations of advanced ischaemic changes, however, is not suitable for this socket. Such a stump in all probability in future may need further surgery, possibly amputation at a higher level.
Mere presence of arthritic changes in the knee joint is not a contraindication. However, if movements at the knee joint are painful and un-tolerable it is not indicated. The best guide is the state of mobility on such a knee prior to amputation. If he could walk despite pain in the knee, he would probably be able to do it again with the prosthesis.

An unstable knee joint following trauma or disease process is also not suitable for this socket because the prosthesis with such a socket does not provide much knee stability.
CHAPTER X

THE CLINICAL TRIALS OF THE SOCKET

After having finalised the technique of air pressure casting procedure, a clinical trial was organised to determine whether or not the casting technique results in production of satisfactory sockets.

The provision of an accurately fitting socket is essential for comfort and function. To determine the adequacy of the socket fit, it is therefore essential to have means of evaluation of the stump-socket relationship. The assessment techniques commonly employed in routine day to day practice are:

- Observations made by the prosthetist of the socket design and subsequent fitting and check out procedures.
- Use of materials such as talcum, chalk, clay or lipstick in determining the contact fit.
- Patients comments regarding comfort and fit of the socket.

The above tests by the prosthetist and the feedback from the patient are usually the factors that aid the prosthetist in deciding about the adequacy of the socket fit. Since the patients acceptance of the prosthesis is a strong factor, it is usually considered a satisfactory fit, if he is comfortable and the prosthetist is satisfied with the accuracy of socket fit and design.

However, it is highly desirable that some positive method of evaluation of the critical relationship between the stump and socket should be available. Radiological examination has been found to be a simple, practical and most reliable method available for determining the socket fit.

The use of transparent check sockets for visual assessment of the socket fit during the developmental stages of a technique, plays a very important role. It is now extensively used all over the world in research work.

On fitting a socket, if the patient does not complain of pain or discomfort, and there is no evidence of signs of excessive pressures over the stump, it is presumed that the pressures encountered over the stump are tolerable. However, more recently in order to aid in improving the prosthetic fit, studies are being done to determine the levels of pressure distribution between the socket and the stump. To determine the pressures in the critical regions of the below-knee stump suitable transducers are being employed.
Use of thermography in studying the temperature fluctuations that occur for certain pressure intensities and duration are being investigated. Some workers are trying to study the effects of pressure and shearing forces by employing polyurethane foam sock impregnated with microcapsules of blue dye. These microcapsules get crushed when pressures and shearing forces are developed and stain the sock. By studying the degree of staining some rough idea is obtained about the intensity of the pressures.

These pressure studies are still under investigation, and would take some time before becoming established techniques in stump-socket evaluation.

In the clinical trials of the sockets made by air pressure casting procedure, it was decided to carry out transparent check socket and radiological evaluations in addition to the routine procedures. Pressure studies were not carried out due to lack of time and facilities.

The clinical trial was planned to be carried out in two phases. In the first phase the technique was to be tested under laboratory environments, making use of experimental check sockets. In the second phase field trials were to be carried out by making use of definitive plastic laminate sockets.

1. TRIALS WITH EXPERIMENTAL SOCKETS

To study the relationship between the amputation stump and socket of the prosthesis, if the socket could be made of a transparent material, it would be of immense help. It would enable visual assessment of the fit and pressure distribution of the stump in the socket through its transparent walls, and would prove a useful tool during the developmental stages of a particular stump casting technique.

It is necessary that the material used for making such experimental sockets besides being transparent, should have adequate strength to sustain the loads normally transmitted to it during weight bearing.

Since during the developmental stages of a technique, to evaluate the results, one has to do repeated experiments it is desirable that the method of making such sockets be reasonably simple and doesn't take much time.

It was therefore considered necessary to conduct the initial trials by employing some suitable transparent material for constructing a check socket.
(a) Polycarbonate check socket. To make transparent sockets for initial trials, it was decided to use Polycarbonate, a thermoplastic material, as it meets many of the requirements.

This thermoplastic material is readily available under the trade name Lexan. Polycarbonate sheets are available in a range of thicknesses suitable for vacuum forming. This material when heated to about 250°C becomes quite soft and can be rapidly vacuum formed over the plaster positive mould to produce a transparent socket.

This material has some drawbacks. Though it has adequate stiffness and good impact resistance, it has poor fatigue properties. Local stresses arising from bolts or rivets may give rise to serious stress cracking on prolonged usage of the socket. It is therefore not suitable for making permanent sockets.

However its use in making check sockets for socket evaluation has been found to be very beneficial because of its transparency. Their use in laboratory environments for limited periods doesn't result in any serious defect.

The initial trials with such sockets was started in August 1976, following a series of experimental casts and fittings. The check socket with cuff suspension strap was attached to the endo-skeletal shank and foot (Fig.27 a & b) to make a temporary limb, for evaluating the results of socket fit.

(b) Subjects for the trial. Six patients originally selected for the research project were fitted with the transparent check sockets to assess the characteristic features of the socket made from a pressure cast.

Relevant information on the subjects in the study are shown in the table below:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Subject</th>
<th>Age</th>
<th>Date of Amputation</th>
<th>Site of Amputation</th>
<th>Cause of Amputation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>J.A.</td>
<td>32yrs</td>
<td>22.1.76</td>
<td>BK(RT)</td>
<td>Trauma</td>
</tr>
<tr>
<td>2</td>
<td>R.T.</td>
<td>30yrs</td>
<td>13.11.65</td>
<td>BK(LT)</td>
<td>Trauma</td>
</tr>
<tr>
<td>3</td>
<td>A.F.</td>
<td>60yrs</td>
<td>20.10.42</td>
<td>BK(RT)</td>
<td>T.B. Ankle joint</td>
</tr>
<tr>
<td>4</td>
<td>S.J.S.</td>
<td>33yrs</td>
<td>Feb.'66</td>
<td>BK(RT)</td>
<td>Trauma</td>
</tr>
<tr>
<td>5</td>
<td>C.F.M.</td>
<td>47yrs</td>
<td>8.7.55</td>
<td>BK(RT)</td>
<td>Thrombo-angitis-obliterans.</td>
</tr>
<tr>
<td>6</td>
<td>F.D.</td>
<td>57yrs</td>
<td>21.11.63</td>
<td>BK(LT)</td>
<td>Trauma</td>
</tr>
</tbody>
</table>
Results of check socket evaluation. The comfort, stability and function of a socket are achieved primarily by the application of certain biomechanical principles. To accommodate different degrees of firmness of the stump and different tolerances to pressure the socket should have appropriate reliefs and contours. This helps in distributing relatively larger portions of the load over the pressure tolerant areas of the stump and a smaller part of the load over the sensitive areas. For comfort the socket should be designed to provide total contact with the stump, so as to make available a greater area over which to distribute weight bearing loads.

In order to determine whether the above parameters could be achieved by the air pressure casting technique it was decided to use transparent check sockets. Since a polycarbonate socket is made of a transparent material it is easy to look through it and establish the relationship of various parts of the socket in relation to the anatomical structures of the stump.

Before the socket was offered to the patient, it was tested for accuracy of the measurements. The antero-posterior and medio-lateral measurements taken initially should coincide with those of the socket brim. If the A.P. measurement of the socket is less, it would not allow the stump to be inserted fully in the socket. It in turn would lead to abnormal relationship at stump/socket interface. Increase in the A.P. measurements on the other hand, would cause the stump to sink further in the socket, subjecting it to excessive end pressures.

The accuracy of M-L dimensions is essential for stability and comfort. If the M-L dimensions are more, the medio-lateral stability of the socket is affected, whereas reduction would lead to discomfort and pain over the femoral condyles. The check sockets made by the air pressure casting technique were found to conform to the measurements taken before casting the stumps, thus the author proceeded with further evaluation procedures.

The patients were asked to wear a woollen stump sock normally worn by the amputees before fitting on the limb. The sock was well pulled up over the stump, so that it fitted intimately with the stump all around without any gaps or wrinkles. The position of the sock over the stump was thereafter maintained by elastic webbing straps attached to a waist belt. Over this stump sock markings were made over the important landmarks of the stump. The levels of the middle of the patella, femoral epicondyles, mid-patellar tendon point and corresponding level in the popliteal region were marked.
Thereafter the bony sensitive areas of the stump were carefully outlined. These markings could be easily seen through the transparent socket wall and helped in evaluating the socket fit.

Adequate height of the socket walls is essential for comfort and stability. The anterior brim in the PTB socket should extend to the level of the middle of the patella, and the medial and lateral walls up to the epicondyles. The medial and lateral walls should be in contact with the epicondyles, otherwise it may cause instability. Examination of the patients wearing check sockets with marked stump sock confirmed that the socket walls were of correct height. The contact of the medial and lateral walls with the epicondyles could be seen through the transparent walls.

The vertical support load in a below knee stump is borne largely by the patellar tendon, a tough area well suited for the function. It is therefore very important that the patellar tendon bar in the PTB socket is made at the correct place. It should be located at the mid-patellar tendon level, a point between the lower border of the patella and upper border of the tibial tubercle. Its position higher up or below in the vicinity of the bony structures would cause intolerable pain. In all the check sockets made by air pressure casting technique, it was confirmed by looking through the walls that they were correctly located at the mid-patellar tendon mark.

The top brim of the posterior socket wall in the check sockets coincided with the mark on the stump sock in the popliteal region, and had adequate flare. The inward contour of the posterior socket wall produced adequate initial compression of the tissues in the popliteal region. This anteriorly directed counterforce is essential to maintain the supporting area of the patellar tendon over the patellar tendon bar. In its absence the stump supported on this area tends to slide downwards and backwards into the socket. The patellar tendon was found well supported over the patellar tendon bar in all the cases. No excessive bulging of the soft tissues over the top brim of the socket walls was observed, and patients did not report feeling of discomfort or pain in this region.

The use of transparent check sockets proved of immense help in determining the location and amount of relief provided for the pressure sensitive areas. The exact location could be confirmed by comparing the outlines of the socket reliefs with those of underlying stump sock markings. In most of the cases it was found to be correctly located.

To determine the amount of relief over the pressure sensitive areas, besides patients reactions, examination of the underlying prosthetic sock is
of some help. If the relief provided is inadequate it is reflected as localised area of compression of the prosthetic sock, whereas excessive relief is seen as looseness and wrinkling of the prosthetic sock. Besides looking for the state of the underlying sock to further confirm the findings, drill holes in the socket in doubtful areas were made. This helped in obtaining much more positive information.

During the course of the developmental stages of the technique, the author found that to provide adequate relief in the socket walls use of 5 m.m. thick felt at most of the bony sensitive areas, except for lower antero-distal tibia which needed additional 2 m.m. thickness, resulted in adequate relief for the sensitive areas. The use of 2 m.m. or 7 m.m. thickness felt when tried resulted in lack of relief or excessive relief respectively. In one case, in which the lower cut end of the tibia was quite prominent and had a bony spur, 10 m.m. thickness build up resulted in excessive relief leading to loss of distal contact.

In order to minimise discomfort, it is important to avoid excessive pressure on the stump; one way to reduce pressure is to increase the area over which force is applied. In this casting technique it has been attempted, by employing uniform air pressure, to set the cast. To confirm the contact between the socket and pressure tolerant areas, use of transparent check sockets has again played an important role. In most of the cases the features of total contact could be established by inspecting the contact of transparent socket walls in relationship with the stump all around. In doubtful areas, the spot inside the socket was marked with coloured chalk which in turn stained the stump sock on reintroducing the stump if it was in contact with the socket wall. Drill holes made in such areas also helped in assessing the contact fit.

To confirm whether weight bearing was distributed over the proper areas of the stump, the stump sock weave imprint on the skin of the stump was studied. The patients stumps were examined after they had used the prosthesis with the check sockets for some time. Due to compression of the tissues by the socket wall in the weight bearing areas, the overlying stump sock leaves its imprint on the skin.

The inspection of the stumps revealed well marked stump sock imprints in the weight bearing areas of the stump, indicating evidence of proper weight bearing. The pressure sensitive areas on the other hand either had no markings or at the most very faint impressions indicating adequate relief from pressure.
It is common to observe some reddening of the skin over the important weight bearing areas of the stump. It is not a cause of concern if there is no pain, discomfort or sensory deficit and that it disappears within a short time. If on the contrary the reddening persists and patient complains of pain or discomfort it indicates that the area is subjected to excessive pressures.

For comfort and stability it is essential that the socket fits snugly around the stump. If the socket is loose it leads to excessive piston action causing irritation, discoloration and abrasions over the stump. The check sockets made by air pressure casting technique were tested for it by marking the stump sock at the level of the posterior brim of the socket, and asking the patient to lift his pelvis on the amputated side without flexing the knee. The prosthesis did not slip more than $\frac{1}{2}$" from the marking on the sock, indicating adequate socket fit. Before doing this test it is important to check the suspension system, because if it is at fault there would also be piston action.

It was found that to achieve this snug fit of the socket, air pressure in the range of approximately 40 m.m. of Hg was essential at the time of stump casting. Pressures in the range of about 30 m.m. of Hg resulted in casts that produced loose sockets.

In order to make sure that the results could be reproduced by employing the technique meticulously, patients were cast repeatedly. The results of such an exercise were very encouraging, in that it resulted in nearly identical sockets in terms of fit and comfort.

(d) **Patients reactions.** Since these temporary limbs with polycarbonate check sockets are not strong enough to sustain loads normally experienced during full time wear, their use by the amputees was limited to laboratory environments only. It is therefore obvious that complete feedback of patients reactions would be lacking at this stage.

The amputees in this trial were intelligent volunteers, keen to help in the research work. They were made to realise the importance of providing accurate information, for arriving at logical conclusions. The author also took additional precautions by not putting leading questions to the patients. Some of the observations made by the patients about this type of socket are presented below.

The stump felt comfortable on wearing the check sockets, and they did not experience any abnormal pressure points over the stump on standing or walking. This was anticipated because in the casting technique it was
aimed to accommodate the differing degrees of firmness of the stump and different tolerances to pressure. Inspection of the check sockets had earlier also confirmed that there were adequate provisions to provide relief for the pressure sensitive areas of the stump, and contact with pressure tolerant areas.

The patients reported that the sockets fitted snugly all around. This was due to the fact that use of air pressure was made to achieve total contact cast. This fact was also established at the time of check socket evaluation earlier.

It was reported that the socket was retained more securely over the stump, and it didn't tend to fall off the stump when the limb was off the ground. This again had been possible due to intimate socket fit and was confirmed earlier by demonstrating minimal piston action.

All of them reported a different feel at the end of the stump due to contact with the socket. This unusual feeling was quite expected, firstly because of different sensations due to unaccustomed contact of socket at this place, and secondly, due to the absence of soft liner in the check sockets. Some even expressed doubts that if they persisted with such a socket for longer times it may lead to discomfort or pain at the end of the stump.

They however expressed that it would be a definite improvement from the existing sockets in use, if the experimental sockets were lined and some additional resilience was provided at the end of the stump.

(e) Conclusions. The encouraging results of check socket evaluation and patients favourable responses indicated that the pressure casting technique could be successfully transferred from the laboratory to clinical trials with definitive plastic laminate sockets with a soft liner. It was also decided to provide some extra resilience for the end of the stump.

2. TRIALS WITH DEFINITIVE SOCKETS

At the end of successful laboratory trials, clinical trials with Glass Reinforced Plastic (G.R.P.) laminate sockets were commenced in January 1977. The same patients who had participated in the trials earlier took part in the exercise. The GRP laminate socket was laminated over a cast with a soft 5 m.m. thick Pelite liner between the cast and the socket to produce comfortable loading for the below knee stump. At the distal end of the Pelite liner, a ¼" build up of Plastazote (Fig. 26, a & b) in the form of a cup was considered essential to provide some more resilience at the bottom of the socket.
Since the GRP socket is not transparent, it is difficult to evaluate the adequacy of socket fit precisely. Under the circumstances some check out procedures and feedback from the patient are essential factors that aid the prosthetist's decision concerning the adequacy of fit. However, in view of the experimental results achieved by this technique, it was hoped that these sockets would also have features based upon sound biomechanical principles.

In order to safeguard against false conclusions by the above methods alone, the author felt the need for a positive means of checking the GRP socket fit. A decision was therefore made to employ radiological means to determine it.

It is now proposed to discuss the results of evaluation of the socket fit under two major headings, i.e. findings at the time of initial fitting of the socket and, subsequently, at frequent follow up. The results of detailed check out procedure for each patient; reactions of the patients, the author and the prosthetist regarding adequacy of fit, and the summary of overall results are presented in a tabulated form in the Appendices B, C & D respectively on pages 121 to 132.

(a) Socket Evaluation at initial fitting

(i) Socket Evaluation. The sockets on inspection were found satisfactory as they had features considered necessary in a Total Contact Socket as per the principles of pressure casting technique. The initial measurements taken coincided with those of the socket, and the sockets had reliefs and contours to accommodate different degrees of firmness of the stump and different tolerances to pressures.

The socket had adequate height of its walls for comfort and stability. The top brim of the posterior socket wall had adequate height and flare. The inward contour of the posterior socket wall did not cause discomfort or pain. The soft tissues over the top brim were not found bulging out of the socket. It occurs if the tissues in the popliteal region are excessively compressed by the posterior socket wall.

Due to creation of a flare at top posterior brim, the tissues in the popliteal region felt comfortable on bending the knee while sitting. The patients could sit comfortably with their knees flexed to 90°, without any discomfort at the back of the knee, with minimal bunching of the soft tissues in the popliteal region. The amputee finds his socket uncomfortable while sitting, if the posterior brim is too high and without a proper flare to accommodate the soft tissues and hamstring tendons.

On lifting the prosthesis off the ground without bending the knee minimal piston action was noted.
The patients felt comfortable in their sockets during performance of activities such as standing, level walking, walking on soft or uneven ground and going up and down inclines and stairs.

Inspection of skin of the stump for stump sock imprints revealed that the weight bearing was distributed over the proper areas of the stump and that the sensitive areas were adequately protected. The stump markings on the skin overlying the mid-patellar tendon region showed evidence of correct location of the patellar tendon bar.

The stumps were found free from abrasions or discolorations immediately after the prostheses were removed. The transient areas of reddening usually noticed in the major weight bearing areas, faded away within a short time after removal of the prostheses.

To establish the distal contact of the stump with the socket wall, the bottom of the soft liner was smeared with lipstick. On reintroducing the stump, if there was distal contact the terminal end of the stump sock got marked with stains. In one case in which more relief at the terminal end had to be provided because of inadequate soft tissue cover and a bony spur, it showed lack of distal contact. However, it was not considered a failure of the technique, because the stump situation demanded this modification.

(ii) Patients Reactions. The author once again took the precaution not to ask any leading questions from the patients regarding fit of the socket. The patients were asked to use the prosthesis for about an hour before they were asked to give their views about the socket made from a pressure cast. The following observations were made by the patients.

The socket felt more comfortable to wear, as the entire stump remained well supported by the socket walls. They did not feel any areas of high pressures over the stump leading to discomfort or pain.

The snug fit of the socket was expressed as "Fits like a glove", or "feels part of the body."

They all reported a constant awareness of the feeling of touch at the lower end of the stump due to contact with socket wall. The feeling however was not described as discomfort or pain. It was expected, because in the sockets that had been in use there was no distal tissue support.

One of the patients, a case of thrombo-angitis-obliterans complained of pain in the stump on walking for about two furlongs. The pain in the
stump was the claudication pain due to the disease process rather than ill-fitting socket. On walking, besides pain in the stump, he felt pain in the sound leg too, and this forced him to rest for a while before he could walk a similar distance again. He experienced similar pain on walking with the limb that he had been using previously.

These were the initial reactions of the patients at the time of initial fitting. It was decided to get more feedback of the information at a later date when the amputees had given the limb a fairly extensive trial.

(iii) Radiological Evaluation of the Socket. This investigation is one of the most practical and reliable method of obtaining information regarding the critical relationship between the stump and the socket. By this method, in addition to evaluation of total contact of the stump with the socket, other parameters of socket fit can also be evaluated. The utilisation of suitable weight bearing areas of the stump such as patellar tendon, popliteal area and tibial flares, and provision of adequate relief for pressure sensitive bony areas can be determined. This investigation in addition gives an opportunity to diagnose any soft tissue, bony or joint abnormalities in the stump.

All the six patients in this series were subjected to this investigation, wearing the Pressure Cast socket and the old PTB socket. The radiological examination consisted of an antero-posterior and lateral films of the stump during weight bearing and non-weight bearing positions.

A soft tissue radiological technique was employed for taking the X-rays. With a 3 phase, 6 pulse, generator X-ray equipment, using Kodak rapid processing films, the optimum settings were arranged at 100 ma, 48 KVP, 0.08 secs., and 100 cms. F.F.D.

The above technique resulted in sharply outlining the periphery of the stump and the socket wall. The soft Pelite liner interposed between the stump and socket wall however threw a less distinct though well demarcated shadow. The Plastazote (Foamed Polyethylene) material used as a build up at the end of the Pelite liner does not throw any shadow, and thus appears as an air space between the bottom of the socket and the lower end of the liner. In all the sockets made from pressure cast Pelite was used as a liner.

The X-ray results of the amputees wearing pressure cast sockets are depicted in Figures 28 to 33. It is worth mentioning that in the
photograph of an X-ray film, sometimes, the detailed features seen in
the film are not reproduced. In the X-ray photographs of Case No. 2
(Fig. 29) the outlines of the Pelite liner are not visible, whereas in
Case 3 and 4 (Figs. 30 & 31) it is poorly defined. The Pelite liner as
such throws a less distinct outline in an X-ray film, and in the
photographs of the above cases it has become even less apparent. However,
in the photographs of the X-rays of Cases 1, 5 and 6 (Figs. 28, 32 & 33),
the outlines of the liner are clearly defined. The examination of the
original X-ray films however show these features quite distinctly in all
the cases.

Examination of the A.P. views of the X-ray films of the pressure
cast sockets showed that the relief for the head of fibula in the socket
walls were adequate and correctly located in all cases. There was evidence
of total contact on weight bearing films in all but for in Case No. 4
(Fig. 31, a & b), in which there is some gapping between the distal aspect
of the stump and the socket liner (marked by dotted lines). This stump
had poor soft tissue cover at its end, and in addition had a tender bony
spur. It was therefore considered essential to provide extra relief to
accommodate this sensitive spot. It is therefore not considered a failure
of the casting technique. On comparing the weight bearing films with the
non-weight bearing ones, minimal pistoning effect of the stump in the
socket was observed, indicating snug fit achieved by the pressure casting
technique.

Examination of the lateral views of the films again confirm the
presence of total contact, but for in Case No. 4 (Fig. 31, c & d) the
reasons for which have already been explained. In these views also
minimal pistoning effect is noticed. Patellar tendon bar, the important
weight bearing area of the socket over the patellar tendon was found to
be correctly located at the level of the knee joint line, which represents
the mid point of the patellar ligament.

The top brim of the posterior socket wall is found to have adequate
flare and located at the correct level, that is, at the level of the patellar
tendon bar. The posterior socket wall in all cases has adequate inward bulge
for the desired amount of compression of the soft tissues.

X-ray photographs of all the old FIB sockets are not included in
the thesis. However a typical example is shown in Fig. 34, A to D. None
of the X-ray films showed evidence of total contact fit. The most common
FIG. 28-A.
A.P.VIEW(W.B)

FIG. 28-B.
A.P.VIEW(N.W.B)
CASE-2

FIG. 29-A
A.P. VIEW(W.B)

FIG. 29-B
A.P. VIEW(N.W.B)
CASE-2

FIG. 29-C
LAT. VIEW (W.B)

FIG. 29-D
LAT. VIEW (N.W.B)
FIG. 31-A
A.P.VIEW(W.B)

FIG. 31-B
A.P.VIEW(N.W.B)
FIG. 32-A
A.P.VIEW(W.B)

FIG. 32-B
A.P.VIEW(N.W.B)
CASE-5

FIG. 32-C
LAT. VIEW (W.B)

FIG. 32-D
LAT. VIEW (N.W.B)
FIG. 33-C
LAT.VIEW(W.B)

FIG. 33-D
LAT.VIEW(N.W.B)
FIG. 34-A
A.P.VIEW(W.B)

FIG. 34-B
A.P.VIEW(N.W.B)
site of gapping was between the end of the stump and the socket liner. A gap of $\frac{1}{2}''$ to $1\frac{1}{2}''$ was recorded on the X-ray pictures. The patellar tendon bar was wrongly placed in three cases. In three cases the top brim of the posterior socket wall had no flare and caused bulging of the soft tissues above it. Significant pistoning effect was noted in four cases. Relief for the head of the fibula was either absent or wrongly placed in two cases.

It is evident from the above that how important this investigation is in evaluating the stump/socket relationship. It has further confirmed the philosophy of producing total contact fit and accuracy of other parameters in a below knee socket by the air pressure casting procedure.

(b) Socket Evaluation at follow up. With a view to assessing the prosthetic fit, after the patient had given it a fair trial, it was planned to examine the patients one month after the initial fitting and thereafter every two months. The patients were instructed to use the prosthesis with the new type of socket all the time, and to make notes of the points in favour or against it, in order to help in evaluating the socket fit at frequent follow ups.

(i) Follow Up One Month after Initial Fitting. This is the most important stage of follow up. During this initial period of socket wear, the amputees reactions towards any new subjective feelings are very sharp. He is usually able to make up his mind about the state of the fitting. In a nature of work like this, therefore, due consideration has to be given to their reactions too, in addition to ones own findings.

Socket evaluation. The check out procedure for the state of socket fit revealed that the limbs fitted well to the amputees. The prostheses were in a satisfactory state and the patients were comfortable.

The stumps were in healthy condition and the stump sock imprint on the skin showed evidence of proper distribution of weight over pressure tolerant areas and of relief over pressure sensitive areas.

The callosities and terminal pigmentation noted at the time of initial fitting in four cases showed evidence of regression.

All of them had got used to the feeling of constant touch at the distal end of their stumps.

One patient complained of discomfort at lower lateral side of the stump after prolonged use of the prosthesis. This was found to be due to slightly more lateral stabilising forces over the stump, and
Patients reactions. After having used the prosthesis for about a month, the following information was provided by the patients.

The socket feels comfortable, and they don't feel tired even on prolonged walking.

The walking distance has increased, as they can bear more weight on the stump by the new type of socket. Earlier they had to take more weight on the sound leg to avoid excessive weight bearing on the stump during walking, and thus got tired earlier.

Due to the snug fit of the socket, the limb feels as part of the body, and as a result they have developed a better control and improved gait.

It has been possible to lead a more active life with the new socket.

Two patients reported improvement in the state of their phantom pain. One of them had to take analgesics in the past to relieve it, but has now abandoned its use.

The patient suffering from thrombo-angitis reported improvement. He felt more comfortable to walk as the stump was well supported and weight bearing distributed over a larger stump surface. As he could bear more weight on the stump, the other limb was relieved of much weight bearing. As a result the pain free walking distance increased from two furlongs to about three furlongs.

Five out of six patients expressed the view that the socket made by the pressure casting technique is a definite improvement over the one in existing use. The remaining individual felt that it is only marginally better than the one he had been using in the past.

(ii) Subsequent follow up. The follow up at subsequent two monthly intervals showed that the patients remained happy with the successful outcome of this socket fitting.

The stumps on examination were found in healthy condition. The callosities and terminal pigmentation on those stumps present earlier, had disappeared.

In one patient at three months follow up, the socket was found a bit loose. Snug fit could be restored by the use of two stump socks over the stump instead of one. The same socket at five months became further
loose and required recasting. This patient had been amputated only about a year back and the socket became loose due to maturation of the stump.

All the successful wearers expressed the wish to continue with the new type of socket in preference to their old ones.

3. Conclusions

The clinical trials of the pressure cast sockets have produced favourable results. Besides clinical evaluation, the use of transparent check sockets in the experimental stages and radiological evaluation of definitive sockets has helped in determining the soundness of the air pressure casting technique for the production of successful below knee sockets.

It is realised that the number of the patients is too small to arrive at definite long term conclusions. It would be worthwhile to expose the technique to a larger number of patients over a period of years under normal working conditions in contractors prosthetic room environments.
CHAPTER XI

THE CONCLUSIONS

1. Review of the Project

The current method of plaster of paris cast to obtain a model of the stump for construction of the Patellar Tendon Bearing below-knee sockets has many drawbacks. It requires a high degree of skill on the part of the prosthetist and even then a considerable amount of error can occur. The various attempts made by other casting techniques to eliminate its drawbacks have also not produced very satisfactory results.

The socket is the most important component part of the prosthesis. In the absence of an accurately fitting socket, even the most modern prosthesis will be of no help to the amputee. It was with this aim in mind that the author took up a project at the Biomechanical Research and Development Unit, Roehampton, London, to devise a casting technique which could minimise the factors of human error as far as possible in the production of final plaster positive mould.

The use of air pressure of controlled magnitude and uniform distribution was employed for casting the stump with the technique devised by the author and known as "The Pressure Casting Technique". This technique results in a negative cast which conforms to the shape of the stump, and in which most of the necessary positive rectifications are incorporated. The positive mould made out of this cast requires minimum plaster work, and thus eliminates the necessity of major rectifications, which otherwise requires a great deal of time and skill. The positive mould obtained by this technique requires no work to be done other than to cut a patellar tendon groove and construction of flare for the posterior socket brim.

Before actually implementing the theoretical concept to field trials, trials with polycarbonate check sockets under laboratory environments were carried out. The transparent check sockets proved of immense help in evaluating the results of the socket fit by this technique. The trials with the check sockets were encouraging and paved the way for the actual field trials.

For the field trials it was decided to restrict the fitting of the socket to six amputees only. The decision to limit the trials to six patients only was taken in view of time factor and the nature of the work. In an experiment project like this it was considered essential to limit it to a smaller number of patients till the technique was well established and had
proved its merit.

For field trials limbs with Glass Reinforced Plastic laminate sockets were made from the positive cast obtained by a pressure casting technique. The sockets were found to be satisfactory as they had all the features considered necessary for a Total Contact Socket, as per the principles of the Pressure Casting theory.

The results of clinical evaluation showed that the socket fitted well and the patients felt comfortable in it. Radiological evaluation of the socket helped in confirming the accuracy of fit in terms of presence of total contact and in achieving other parameters so essential for the successful outcome of the socket fit.

The trials showed that all the patients felt that the socket made by pressure casting technique were better, and that they wore it in preference to their previous type of socket. The satisfactory results are attributable to achievement of total contact fit and distribution of weight bearing forces over the greatest possible surface area of the stump, in this type of socket. On follow up their stumps were found healthy, without any evidence of signs which might suggest an ill fitting socket. In fact the callosities and terminal pigmentation due to terminal congestion in the past, disappeared, giving way to smooth textured healthy skin.

It is not intended to put very high claims about this technique for production of satisfactory below-knee sockets, just because a high success rate has been achieved by the author. It is well realised that it is due to idealised circumstances under which this project was carried out. Further the selected number of patients exposed to clinical trials is too small to allow definite long term conclusions.

It is imperative that the clinical trials should be continued, and to expose the technique to a larger number of patients over a period of years, under normal working conditions prevalent in various contractor's prosthetic fitting room environments. However, since the technique is easy to learn and has resulted in very satisfactory results in this pilot project it is hoped that the results will prove to be similarly successful in a more extensive trial.
2. **Future Work**

It is hoped that long term clinical trials may be continued and gradually extended to more Limb Fitting Centres. When sufficient experience has been gained on the longer term results of wearing the socket, it may be recommended for general issue to suitable amputees.

In the meantime, improvements in design of the casting plinth, popliteal pad and the material for making relief pads is required.

At present to support the stump during casting procedure, a wooden seating board is employed which is not considered very satisfactory. Built-in extension boards in the casting plinth would be a much better proposition.

The design of the popliteal pad requires some research. It would be an added advantage if the pad, besides producing the required popliteal impression in the cast, could also produce the flare at the top posterior brim, thereby eliminating the necessity of doing this plaster work on the positive mould.

It is to be investigated whether the patellar tendon bar could be incorporated in the negative cast itself. If this, along with the flaring of the top posterior brim, could become part of the casting technique, the positive mould would not involve any plaster work at all.

The surgical felt used to make the relief pads has been found very satisfactory. The fashioning of the relief pads is a very important step of the procedure and takes time. If some suitable material could be found which would not deteriorate, these relief pads once made could be stored and used on a permanent basis in future casting procedures. This would considerably reduce the time taken for casting the stump in future. At present the casting procedure takes approximately 30 - 40 minutes.

The present method of manufacturing the glass reinforced plastic laminate sockets is a time consuming procedure. It is proposed to investigate a vacuum forming technique for making the sockets from some Thermoplastic material, so that the sockets could be quickly fabricated and the delivery time of the prosthesis reduced.

3. **Other Applicabilities**

The clinical application of Controlled Pressure Casting in situations which require close fitting casts requires to be investigated. The author has tried the application of the principle for applying rigid casts to the amputation stumps for early mobility on a detachable pylon shin and foot.
The technique has produced very satisfactory results. It is now used as a routine at the Limb Surgery Unit, Queen Mary's Hospital, Roehampton. It helps in early mobility and quicker maturation of the stump. The technique has been successfully tried out on foot amputation stumps, Symes and below-knee stumps.

The author hopes to extend the use of Controlled Pressure Casting for the application of post-operative plaster cast dressings following various surgical procedures, including amputations. It is hoped that its use in the near future may be extended to Immediate Post-operative Limb fitting, and fracture casts.

Its use in making Total Contact Sockets for the upper extremity is under investigation. The preliminary trials carried out so far have produced very encouraging results. In the near future its use in fracture bracing and the manufacture of accurately fitting splints and braces is contemplated.

The Pressure Casting Technique developed by the author seems to have achieved its objective in making accurately fitting, comfortable below-knee sockets, thereby allowing the patient to lead an active life free from pain or discomfort. It is hoped that these advantages could be extended in future to a larger number of the below-knee amputee population.
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### APPENDIX A(i)

#### CLINICAL FEATURES OF THE PATIENTS

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Subject</th>
<th>Age</th>
<th>Sex</th>
<th>Date of amp.</th>
<th>Sight of amp.</th>
<th>Cause of amp.</th>
<th>Relevant stump characteristics</th>
</tr>
</thead>
</table>
## Appendix A (ii)

### Prosthetic Measurements

<table>
<thead>
<tr>
<th>S.N</th>
<th>Subject</th>
<th>Wt. Kg.</th>
<th>Height</th>
<th>Stump Measurements</th>
<th>Sound side measurements</th>
<th>Shoe size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>J.A.</td>
<td>60</td>
<td>5' 7&quot;</td>
<td>3 1/4&quot;</td>
<td>3 1/2&quot;</td>
<td>5 1/2&quot;</td>
</tr>
<tr>
<td>2</td>
<td>R.T.</td>
<td>69</td>
<td>5' 10&quot;</td>
<td>3&quot;</td>
<td>3 1/2&quot;</td>
<td>6 1/2&quot;</td>
</tr>
<tr>
<td>3</td>
<td>A.F.</td>
<td>63.5</td>
<td>5' 7&quot;</td>
<td>3 3/16&quot;</td>
<td>3 1/2&quot;</td>
<td>6 1/2&quot;</td>
</tr>
<tr>
<td>4</td>
<td>S.J.S.</td>
<td>69</td>
<td>5' 6&quot;</td>
<td>3 1/2&quot;</td>
<td>4&quot;</td>
<td>6 1/2&quot;</td>
</tr>
<tr>
<td>5</td>
<td>C.F.M.</td>
<td>69</td>
<td>5' 10/2&quot;</td>
<td>3 1/16&quot;</td>
<td>4 1/16&quot;</td>
<td>5 1/2&quot;</td>
</tr>
<tr>
<td>6</td>
<td>F.D.</td>
<td>95</td>
<td>5' 11&quot;</td>
<td>3 1/2&quot;</td>
<td>4 1/2&quot;</td>
<td>7 1/2&quot;</td>
</tr>
</tbody>
</table>
## Appendix B

### Check list - Pressure Cast Socket

<table>
<thead>
<tr>
<th>Subjects</th>
<th>J.A.</th>
<th>R.T.</th>
<th>A.F.</th>
<th>S.J.S.</th>
<th>C.F.M.</th>
<th>F.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the socket as per specifications.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Is the patient comfortable while standing with mid lines of the heels not more than 6&quot; apart.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Is the A.P. alignment satisfactory.</td>
<td>Satisfact</td>
<td>Satisfact</td>
<td>Satisfact</td>
<td>Satisfact</td>
<td>Satisfact</td>
<td>Satisfact</td>
</tr>
<tr>
<td>Is the M.L. alignment satisfactory.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Is the prosthesis the correct length.</td>
<td>Negligible</td>
<td>( \frac{1}{4} )&quot;</td>
<td>( \frac{1}{4} )&quot;</td>
<td>Negligible</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>Is the piston action minimal when the patient raises the prosthesis.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Are the anterior, medial, lateral &amp; posterior walls of adequate height</td>
<td>Adequately</td>
<td>Adequately</td>
<td>Adequately</td>
<td>Adequately</td>
<td>Adequately</td>
<td>Adequately</td>
</tr>
<tr>
<td>Do the medial &amp; lateral walls contact the epicondyles.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Can the patient sit comfortably with minimal bunching of soft tissues in the popliteal region, when the knees are flexed to 90°.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Is there adequate relief for the hamstring tendons.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Is the patient's performance in level walking satisfactory.</td>
<td>Yes No</td>
<td>Yes No</td>
<td>Yes No</td>
<td>Yes No</td>
<td>Yes No</td>
<td>Yes No</td>
</tr>
<tr>
<td>Is piston action between the stump &amp; socket minimal.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Appendix B (Cont'd)</td>
<td>Subjects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>J.A.</td>
<td>R.T.</td>
<td>A.P.</td>
<td>S.J.S.</td>
<td>C.F.H.</td>
<td>F.D.</td>
</tr>
<tr>
<td>13. Does the patient go up and down inclines satisfactorily.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>14. Are the socket &amp; suspension system comfortable.</td>
<td>Comfortable</td>
<td>Comfortable</td>
<td>Comfortable</td>
<td>Comfortable</td>
<td>Comfortable</td>
<td>Comfortable</td>
</tr>
<tr>
<td>15. Does the knee cuff maintain its position.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>16. Is the patient able to kneel satisfactorily.</td>
<td>Yes without discomfort</td>
<td>Yes without discomfort</td>
<td>Yes without discomfort</td>
<td>Yes without discomfort</td>
<td>Yes without discomfort</td>
<td>Yes without discomfort</td>
</tr>
<tr>
<td>17. Does the prosthesis function quietly.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>18. Is the appearance of the prosthesis satisfactory.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>(d) Prosthesis Off the Patient</td>
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</tr>
<tr>
<td>19. Is the patient's stump free from abrasions, discolourations &amp; excessive perspiration immediately after the prosthesis is removed.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>20. Does the weightbearing appear to be distributed over the proper areas of the stump.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>21. Is the general workmanship of the prosthesis satisfactory.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

II. Radiological Assessment

(a) A.P. View

| 23. Is there evidence of total contact fit in weight bearing films. | Yes | Yes | Yes | No, distal gapping due to excessive relief in socket design. | Yes | Yes |
| 24. Are the lateral & medial walls of adequate height. | Yes | Yes | Yes | Yes | Yes | Yes |
(a) **A.P. View (cont'd)**

25. Is the relief for head of fibula adequate and correctly located.


(b) **Lateral View**

27. Is there evidence of total contact fit.

28. Are the anterior and posterior socket walls of adequate height.

29. Is the patellar tendon bar situated at knee joint level.

30. Has the posterior socket wall adequate inward contour.

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<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No, Distal gapping present</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</table>
# Appendix C

## Pressure Cast Socket Assessment

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Subject</th>
<th>Assessment by Patient</th>
<th>Authors Assessment</th>
<th>Prosthetists Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>J.A.</td>
<td><strong>At initial fitting</strong>&lt;br&gt;Socket fits snugly and is more comfortable to wear.&lt;br&gt;The entire stump feels in contact with the socket including distal end.&lt;br&gt;An unaccustomed constant feeling of touch at terminal end, though not painful.&lt;br&gt;No discomfort or pain at any site.&lt;br&gt;Feels the socket fit to be good.</td>
<td><strong>The socket design, fit and alignment satisfactory.</strong>&lt;br&gt;<strong>The stump examination for stump sock imprints reveals weight bearing and relief of pressure at appropriate areas.</strong>&lt;br&gt;<strong>No evidence of any abrasions or spots of high pressures.</strong></td>
<td><strong>Satisfied with the socket design, fit &amp; alignment.</strong>&lt;br&gt;<strong>No evidence of any areas of high loading or friction.</strong>&lt;br&gt;Feels that technique of pressure casting has eliminated factors of human errors, but in the hands of an experienced prosthettist similar results can also be achieved. Also suggested that it would be better if patellar tendon bar &amp; posterior flare could also be incorporated at the time of casting stump.</td>
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</table>

**At follow-up**<br>Very happy with the fitting.<br>Socket fits like a glove.<br>Can use prosthesis for longer hours without discomfort.<br>Can walk longer distances & play football with children as the prosthesis feels more secure on the stump.<br>Better sensations as to what is under the foot.<br>No more aware of the feeling of constant awareness of distal touch.<br>Socket a definite improvement, would like to use it in preference to the old one.
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<tr>
<td>2</td>
<td>R.T.</td>
<td><strong>At initial fitting</strong>&lt;br&gt;. At initial fitting&lt;br&gt;. The socket fits like a glove and is held in intimate contact with socket all round.&lt;br&gt;. No pain or discomfort at any spot.&lt;br&gt;. The socket is very comfortable to wear.&lt;br&gt;. Feels a peculiar sensation due to distal touch.&lt;br&gt;<strong>At follow-up</strong>&lt;br&gt;. Very satisfied with the results of this socket fit.&lt;br&gt;. Can walk and dance for longer hours without discomfort. Danced till late night on marriage anniversary.&lt;br&gt;. Gets better sensory feedback and has developed better gait.&lt;br&gt;. Frequency of phantom pain has diminished markedly. Does not take pain killers any more.&lt;br&gt;. Prefers to use this socket to old one.</td>
<td><strong>Design of socket good.</strong>&lt;br&gt;. Fitting and alignment satisfactory.&lt;br&gt;. Result of check socket fit satisfactory.&lt;br&gt;. No evidence of any high pressures or signs of friction over the stump after use of prosthesis.&lt;br&gt;. Evidence of weight bearing and relief of pressure at correct places.&lt;br&gt;. At follow-up prosthetic fit found satisfactory&lt;br&gt;. Stump does not show any signs of ill fitting socket.&lt;br&gt;. Thickening and depigmentation of skin at terminal end has reduced.&lt;br&gt;. Happy with the outcome of socket fitting.</td>
<td><strong>Agrees with the authors evaluation</strong>&lt;br&gt;. Satisfied with the successful outcome of socket fit.</td>
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</table>
### Pressure Cast Socket Assessment

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<td>3</td>
<td>A.F.</td>
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</table>

#### At initial fitting
- Feels the socket in touch with the stump all round.
- Cannot wriggle his stump inside the socket.
- Stump feels comfortable, but the distal touch sensation is not very much appreciated.
- Would like to use the limb for some time before arriving at definite conclusions.

#### At follow-up
- Limb marginally better than previous one.
- Does not feel distal touch, but gets discomfort over the lateral side of the stump at the end of the day.
- Thickening and callosities over the stump have improved.
- No definite improvement in use of prosthesis, as even with the previous socket he is very much satisfied.

- Socket design, fitting and alignment satisfactory.
- Check out procedures found limb satisfactory.
- Use of prosthesis does not produce areas of high pressure or friction.
- Proper distribution of load over weight bearing areas & of relief at pressure sensitive areas.

- Follow-up reveals adequate prosthetic fit.
- Stump healthy with no signs of ill fitting socket.
- Thickening and depigmentation of skin over head of fibula, lateral side of patellar tendon & terminal end of stump much less.

- Findings same as those of author.
- The discomfort at lateral distal stump due to more lateral stabilising force.
- Changing the alignment of foot by slightly outsetting it, relieved this discomfort.
- Patient felt very much better thereafter.
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<tr>
<td>4</td>
<td>S.J.S.</td>
<td>- At initial fitting</td>
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<tr>
<td></td>
<td></td>
<td>Socket fits comfortably and in close contact with stump all around except at distal end.</td>
<td>Inspection of socket design, &amp; check out procedures show evidence of adequate design, fit and alignment.</td>
<td>Prosthetist's findings agree with those of the author.</td>
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<td></td>
<td></td>
<td>Socket fits snugly, and feels part of the body.</td>
<td>The stump does not show evidence of abrasion or areas of persistent redness after use of prosthesis.</td>
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<td>No areas of discomfort or pain.</td>
<td>Evidence of proper distribution of weight &amp; relief in appropriate areas.</td>
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<td></td>
<td>Appreciates the socket fit.</td>
<td>Lack of distal contact due to excessive relief to accommodate bony spur at the terminal end.</td>
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<td></td>
<td>- At follow-up</td>
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<td></td>
<td>Due to contact of the stump with the socket, limb feels more secure.</td>
<td>Prosthesis in good shape. Fitting satisfactory.</td>
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<td></td>
<td></td>
<td>Has developed better gait and improved the walking distance.</td>
<td>Stump healthy.</td>
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<td></td>
<td></td>
<td>Gets better sensory feed back.</td>
<td>Callosity over Head of fibula &amp; thickening over end of stump regressing.</td>
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<td>Phantom pain has diminished.</td>
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<td></td>
<td>Prefers to use this socket as it is more comfortable to wear.</td>
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## Appendix C (Cont'd)

### Pressure Cast Socket Assessment

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>C.F.M.</td>
<td><strong>At initial fitting</strong>&lt;br&gt;Feels comfortable as tissues are supported all around. &lt;br&gt;No feeling of pain or discomfort. &lt;br&gt;Distal tissue support though not uncomfortable feels a bit peculiar. &lt;br&gt;Develops claudication pain in the stump &amp; sound leg on walking for 2 furlongs due to T.A.O. &lt;br&gt;Likes the socket fit.</td>
<td>Check out procedure satisfactory. &lt;br&gt;Evidence of proper loading &amp; relief at appropriate areas. &lt;br&gt;No signs of too excessive loading or friction.</td>
<td>Same as that of the author.</td>
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<tr>
<td></td>
<td></td>
<td><strong>At follow-up</strong>&lt;br&gt;Can now walk for about 3 furlongs. &lt;br&gt;Can take more weight on the stump and thus sound leg does not get tired soon, as earlier. &lt;br&gt;The limb feels part of the body. &lt;br&gt;Prefers the present limb over the earlier one due to more comfortable fit &amp; improvement in function.</td>
<td>The prosthesis in good condition and feeling good. &lt;br&gt;Stump doesn't show signs of ill fitting socket. &lt;br&gt;Bunching of soft tissues in the popliteal region due to earlier fitting has diminished remarkably. &lt;br&gt;Depigmentation of skin in the patellar tendon and popliteal region has disappeared.</td>
<td>Same as that of the author.</td>
</tr>
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</table>
### Appendix C (Cont'd)

#### Pressure Cast Socket Assessment

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>F.D.</td>
<td>- <strong>At initial fitting</strong>&lt;br&gt;- Stump feels comfortable and is supported all around including distal end.&lt;br&gt;- Abnormal sensation of touch at lower end though not uncomfortable.&lt;br&gt;- No pain or discomfort anywhere.&lt;br&gt;- Socket feels fine.&lt;br&gt;- <strong>At follow-up</strong>&lt;br&gt;- Can stand whole day without discomfort, as the job demands such an activity.&lt;br&gt;- Does not feel tired at the end of the days work.&lt;br&gt;- Socket feels comfortable, and has now better sensory feedback. Can appreciate what is under the foot.&lt;br&gt;- Has developed a better gait and balance &amp; thus feels more active.&lt;br&gt;- Likes the socket immensely.</td>
<td>- Socket design, fit &amp; alignment good.&lt;br&gt;- No areas of excessive weight bearing &amp; adequate provision for relief at pressure sensitive areas.&lt;br&gt;- No excessive piston action.&lt;br&gt;- Patient happy with fitting.&lt;br&gt;- Condition of the prosthesis and its fit good.&lt;br&gt;- Stump healthy without evidence of signs of ill fitting socket.</td>
<td>- Prosthetist's opinion same as that of the author.</td>
</tr>
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</table>
### Appendix D.

#### Summary of Overall Evaluation of GRP Pressure Cast Socket

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Subject</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>J.A.</td>
<td>Prosthetic assessment as per check list for socket evaluation revealed evidence of good socket design, to provide comfort, stability and improved function. Radiological evaluation showed evidence of total contact fit, utilisation of suitable weight bearing areas of the stump at patellar tendon, popliteal and tibial flares, and provision of adequate relief for pressure sensitive areas. Snug fit confirmed by observing minimal piston actioning. Patients reactions to this socket were very favourable. He reported improvement in the state of his physical activities and of better feedback, due to a closely fitting total contact fit. Authors assessment of design of socket, fitting and alignment were satisfactory. No evidence of signs of ill fitting socket were found. In fact thickening and depigmentation due to previous socket showed signs of regression on follow up after use of the Pressure Cast Socket. Prosthetists opinion coincided with the findings of the author. Overall picture confirmed good socket fit.</td>
</tr>
<tr>
<td>2</td>
<td>R.T.</td>
<td>Prosthetic assessment as per check socket list evaluation - satisfactory. Radiological evaluation confirmed presence of total contact, proper weight bearing and relief over appropriate areas. Patient reported improvement of function and comfort with pressure cast socket. Reported diminution of frequency of phantom pain. Showed preference towards new socket. Authors assessment revealed satisfactory fit, in terms of weight bearing and relief of pressure. At follow up no signs of ill fitting were observed. Thickening and pigmentation of stump present earlier showed evidence of regression. Prosthetists findings were similar to that of the author. Overall picture revealed good socket fit.</td>
</tr>
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</table>
### Appendix D (Cont'd)

#### Summary of Overall Evaluation of GRP Pressure Cast Socket

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Subject</th>
<th>Results</th>
</tr>
</thead>
</table>
| 3     | A.F.    | - Results of check list evaluation showed socket to be good.  
  - Radiological evaluation confirmed presence of total contact, and proper relationship of contours and reliefs of the socket in relation to pressure tolerant and pressure sensitive areas of the stump.  
  - Patient reported only marginal improvement of function with the new socket.  
  - Authors assessment revealed proper fit. Socket was of proper design, fitted well and showed no evidence of signs of ill fitting. Thickening and depigmentation of the stump in the past due to ill fitting socket, improved with new socket.  
  - Prosthetists evaluation revealed slightly more lateral stabilising force over the stump and corrected by improving alignment. Patient felt happy thereafter. |
| 4     | S.J.S.  | - Results of check list showed socket to be as per specifications.  
  - Radiological evaluation showed gapping at distal end due to excessive relief provided in the socket to accommodate sensitive bony spur at lower end of tibia. Contours and reliefs in the socket wall were found in proper relationship with load bearing and pressure sensitive areas respectively.  
  - Patient's reactions to the new socket were good. He reported improvement in fitting, comfort & function.  
  - In authors assessment socket fit was found as per the specifications. The distal gapping was not considered a failure of technique, as the stump situation demanded those modifications. Stump improved with use of new socket as the thickening & callosities regressed.  
  - Prosthetist agreed with authors assessment criteria.  
  - Overall picture revealed good fit. |
<table>
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<tr>
<th>S.No.</th>
<th>Subject</th>
<th>Results</th>
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</table>
| 5     | C.F.M.  | Results of check list evaluation found, as per specifications of a good socket fit.  
- Radiological evaluation showed evidence of total contact fit with contours and reliefs of socket at appropriate areas of the stump.  
- Authors assessment revealed good socket fit. Bunching of soft tissues in the popliteal region and depigmentation due to past fit improved.  
- Prosthetist was in full agreement with authors findings.  
- Overall picture of a good fit. |
| 6     | F.D.    | Results of check list evaluation found as per specifications of a good socket fit.  
- X-ray showed evidence of total contact fit, with contours and reliefs of the socket at appropriate areas of the stump.  
- Patient reported improvement of socket design and fit and preferred to use it in place of the old one.  
- In authors assessment the socket fit was found to be as per the specifications of a good socket.  
- The prosthetist fully agreed with the results obtained by the author.  
- Overall picture revealed good socket fit. |