Aknowledgements

Substantial parts of the information and reference material provided in This Technical Manual for Lower Limb Prosthetics has been compiled from various medical and university sources. Without their long practice, know-how and extensive publications, this manual would simply not exist. We would like to mention in particular:

*Course Work Manual*, Carson Harte and Anne Henriksen, National School of Prosthetics and Orthotics from Phnom Penh, Cambodia:
- Partial foot prosthetics
- Ankle disarticulation prosthetics
- Below knee prosthetics
- Knee disarticulation prosthetics
- Above knee prosthetics
- Hip disarticulation prosthetics.

*Clinical aspects of Lower extremity prosthetics, Trans-tibial, Symes and Partial foot amputations*, The Canadian Association of Prosthetists and Orthotists.

*Traité d’Anatomie Artistique*, Dr. Paul Richer, Inter livres.

*Lower Limb Prosthetics*, 1990 revision, New York University Medical Centre.

*Lower Limb Prosthetics*, 1990 revision Prosthetics and Orthotics, New York University Post Graduate Medical School.
Trans-tibial Prosthetic-Tome 2

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SECTION - 1

BELOW KNEE PROSTHETIC COMPONENTS
BELOW KNEE PROSTHETIC COMPONENTS

Introduction.

The BK Prosthesis has four major components:
- a) Socket
- b) Suspension
- c) The shank.
- D) Foot and ankle.

When the prosthetist is selecting the right components the overall state of the patient must be considered. For example, a man who works in a rice field should not be given a leg with a soft cosmetic. He needs a water resistant leg.

Sockets.

The socket is designed to transmit the patients weight comfortably through the leg to the ground. The current accepted design for the PTB was developed in 1958 in California. Slight variations exist but the principal remains the same.

The patellar tendon bearing socket PTB

Ideally this should be a Total contact socket.

Anterior: The trim line should be 1/3 up the patella. The PTB bar should hit the middle of the patellar tendon. This is not the only weight bearing surface on the stump. Medial flare of tibia and to a lesser amount the lateral flare are also major contributors.

PTB socket
**Medial Lateral:** The trim line is about the level of the adductor tubercle. The lateral wall has a pocket for the head of fibula. The lateral wall presses on the fibula and so locates the medial tibial flare on its shelf.

**Posterior:** The posterior wall is flared at the top to allow for the hamstrings. The back wall presses in on the popliteal fossa to push the stump forward and locate the PTB.

The PTB socket can be made with a hard or soft liner. The PTB socket can be used for all BK stumps except for those with specific pathological conditions that would point to the use of a socket variation. Very short stumps and severely flexed stumps can cause problems. The hard or soft socket is a matter of patient tolerance, material availability, and hygienic facility.

**Suspension**

**Supracondylar cuff suspension.**

Several versions for the cuff have been designed. The cuff can be made of leather or webbing with or without elastic. It fastens tight above the condyles. The attachment points are arranged posterior and above the joint line so that as the knee is flexed the down straps shorten. *(See annexe for the fabrication and installation of a cuff suspension strap.)*

The major disadvantage of the cuff is the impossibility of not having pistonning of the prosthesis. It also does impinge on the circulation. It cannot be used in cases of excessive scarring or joint instability. The chief advantage, for the amputees, is that it does give them a feeling of security.
**Supracondylar Supra patellar Socket**

The medial, lateral and anterior wall of the socket extends much higher. The socket is good for very short stumps and unstable stumps. The extra length provides extra purchase on the thigh and so allows the socket to be a firmer fit. The Quadriceps bar reduces the tendency towards hyperextension.

The socket is good for patients with short stumps or mildly unstable stumps. No need for cuff suspension. Good for patients with scars in the popliteal area. A good socket is difficult to fit. The high anterior wall can make kneeling difficult. May also present difficulty for cosmetic, particularly when sitting with the trousers.

**Supracondylar Socket**

The SC socket is very similar to the SCSP socket except that the trim line is lower at the anterior wall. The trim is 2/3 down the patella. It is also possible to go lower anteriorly, as long as it doesn’t weaken too much the lateral and medial wall. This two supracondylar extension should be rigid enough for the suspension. This is a very commonly used socket as it requires no straps.
**Joints and Thigh Corset.**

The thigh corset is generally made of leather but sometimes can be made of thin plastic. It extends distally to just above the patella and at the back 3 or 4 cm above this line. When the patient sits the corset must be postero proximally high enough to not pinch the thigh. The corset is trimmed a few centimetres below the groin. It is attached to the socket by a pair of external knee joints, usually metal and single axis. The joints are attached on the medial and lateral sides of the socket at the position shown in the diagram. A back check strap is also fitted to stop the joints before being overloaded in extension. This reduces wear and tear.

**Thigh Corset**

In the past because BK sockets fitted so badly the Thigh Corset was also used to carry the patients weight. Today the sockets are much better and so the corset is used only in cases where the knee joint is unstable or damaged. Thigh corsets are bad for circulation and cause thigh muscle atrophy. Also, the amputee wearing a thigh corset does loose the reflex of controlling the knee when walking. Thigh corset can also be used to off-load the stump when the stump is badly scarred or painful. Thigh corset are bulky, heavier and non cosmetically. Therefore they must be used only when strictly necessary.
**Hip belt suspension with fork strap**

Hip belt suspension with fork strap is perhaps one of the most effective, yet unpopular, suspension methods with most patients. It consists of a webbing hip belt, elastic at front, attached to the fork strap on the prosthesis. The stud location can be the same as described for the cuff suspension, but it can also be more anteriorly. The fork strap can also be attached to the supracondylar strap and most often must be part of the external hinges and thigh corset.

**Advantages:**
1) excellent suspension for vascular amputees;
2) non-restrictive;
3) versatile and simple;
4) does not limit trim line of socket;
5) totally relaxed at sitting position.

**Disadvantages:**
1) unpopular with most amputees because it is uncomfortable;
2) somewhat difficult to don.

Even for the PTB-SC with a wedge, when you are fitting a patient with a very short stump, the hip belt suspension with fork strap can be very helpful, relieving some of the weight while walking, and reducing the distal pressure on the distal end of the stump.
Sleeve suspension

The sleeve can be made out of latex, neoprene (spenco), silicone or elastic fabric. Except for the fabric sleeve, they are all air tight. The sleeve is pulled over the proximal portion of the prosthesis, using skin contact proximal on the thigh of the amputee to obtain an air seal. The prosthesis is suspended by the somewhat stretched fabric and the negative pressure produced.

Advantages:
1) excellent suspension due to the near suction effect;
2) no circulatory restriction;
3) prevention of tissue bulge at the posterior of the knee;
4) good cosmetic.

Disadvantages:
1) excessive heat causing perspiration and sometime dermatic problem;
2) difficult to don;
3) fragile;
4) amputee cannot kneel.

Suction suspension (Negative pressure suspension NPS)

Many attempts were made in the past, to use negative pressure as a means of suspension for trans tibial prosthesis, without too much success. Prosthetists were trying to use the same principle of NPS with a valve like for the above knee amputee. But recently, with the use of silicone or gel insert, it has been successful enough to be used on a regular basis by many prosthetist. At the distal end of the silicone insert, a pin is attached.

When the patient is donning his liner, a total contact air tight fit happens between the stump and the liner. Then when the patient inserts the stump into the socket, the pin slides into a locking mechanism in the bottom of the socket. The locking mechanism holds the liner which holds to the stump.

The combination of silicone or gel insert with the suction suspension make it extremely comfortable while offering optimum suspension. It does eliminate the problems of bulging, pressing, cutting the blood circulation, atrophying and so on.

Desavantages:
1) more expensive then others;
2) fragile to use and require change;
3) need very good care in daily use;
4) very warm to wear.
**Prosthetic Shanks**

**Introduction.**

The function of the shank is:
1/ To hold the foot and socket in the right position.
2/ To transfer the load from the socket to the foot.
3/ To provide Cosmesis.

The shank can be said to be endoskeletal or exoskeletal. The endoskeletal system has its skeleton (the structure that carries the load) inside, just like the human being. The exoskeletal has the loading structure outside, like the lobster. The outside shell has the function of been both the skeleton and the cosmetic at the same time.

**Exoskeletal Shanks.**

The major materials used are GRP (glass reinforced plastic), aluminium or polypropylene. It can be hollowed or filled inside with wood, foam or other material.

Alignment is carried out first and then the alignment jig is removed and the shank is built up. The process of removing the alignment device is called Transfer. The relationship between foot and socket must be retained.

**Advantages.**

Strength, durability, cheap, easy to clean, and can be set up to suit the level of activity.

**Disadvantages.**

Alignment cannot be easily adjusted, sockets cannot easily be changed, and the cosmetic may be poorer.
Endoskeletal Shanks.

A tube of metal or plastic connecting the socket to the foot and ankle. All stresses pass down this tube and not through the cosmetic covers. Cosmetic shape is given by the addition of a soft cover. Endoskeletal Systems are usually called MODULAR. This means that it is made up of several parts that can be assembled, disassembled and interchanged.

Alignment devices are part of the structure of the leg. After alignment is completed the device is “locked” so the alignment cannot change. There are two major types of alignment device.

1/ Tilt/ Shift. In this type the alignment can be changed as a tilt or a shift from the one alignment device. The major limbs to use that system is Blatchford Endolite and ICRC.

2/ Tilt/ Tilt. In this system the alignment ent can only be changed using a series of screws to change the angle of the socket. Shifts are achieved using a tilt at the socket and an opposite tilt at the foot end.
Prosthetic Feet

The prosthetic foot must be cosmetic and functional. It must behave as much like the real foot as possible. There are many designs of foot. They can be simple in action or very complicated.

SACH (Solid ankle cushioned heel) Foot.

The most common foot in the world. It functions well, can be light weight and rather strong. It has no moving parts and given the right conditions, it can be long lasting.

The shock absorption at heel strike is carried out by the heel cushion which compresses and softens the action. At push off the foot’s springy toe section gives the push off action.

Foot action.
1) Plantar flexion is achieved by compression of the heel wedge.
2) Dorsiflexion is not permitted except at the springy toe section.
3) Medial / lateral forces are absorbed by the soft soul.

The SACH foot is an excellent foot. Cosmesis is excellent because there is no ankle movement. The normal SACH foot is used in normal length BK patients. A low level SACH, also named Syme foot, is available for patients with long stumps or Ankle disarticulation.

Syme’s SACH foot

External keel SACH foot
Single Axis Foot

This is a much more old fashioned design. The action of the natural ankle is copied by an ankle joint. The joint is made of metal. The action of the foot is quite natural except that there is no inversion-eversion movement. Heel strike and shock absorption are the job of the heel rubber. The spring of toe off is the job of the toes rubber. The Plantar flexion bumper is responsible for making the roll over mid stance more smooth. Because of the metal joint at the ankle, the foot is quite heavy and also wears out quickly. It is not a good foot for use in dirty or wet conditions. Cosmetic is poor because the movement at the ankle means that a gap is seen between the foot and the shank.
**Multi axis feet**

Multi axis feet suggest that the foot can move around in many directions. The Multi axis foot can move easily in plantar flexion, dorsiflexion, pronation/supination and in rotation. The firmness of the resistance to movement can be suited to the patient by selecting the right firmness of rubber bumper. The motion is controlled by a rubber ring around a ball joint. As the foot moves the ring is compressed. It provides a very natural foot action but has reduced standing stability. The rubber buffer ring wears away quickly so the foot is not very good in wet or dusty conditions.
Energy Recovery Feet

These feet, born in the late 70 early 80, were first designed for the amputee who is able to run or walk very quickly. In running the load on the foot is increased x 3. The firsts feet were very hard and did not perform well during normal walking. Today, some of those feet are well adapt to walking. Yet if you are using a foot that was design and setup for running, it will not function very smoothly while walking.

The feet all have a very strong heel spring to absorb the high load of running and a very strong toe spring to give the high impetus required in push off. Their major draw back is the expensive purchase price.

There are many other models of feet that are said to be dynamic and energy restoring. They tend to vary in characteristics and certainly in price.

The ICRC polypropylene spring blade foot is base on the principle of those feet.
SECTION - 2

NORMAL GAIT
NORMAL GAIT

Introduction

To understand the problems involved in amputee gait, it is first necessary to comprehend normal human gait.

Normal gait, has been described as a series of rhythmical, alternating movements of the limbs and trunk which results in the forward progression of the centre of gravity.

Centre of gravity.

The centre of gravity is the representative point on the body on which the force of gravity acts. This is generally found to be in the midline of the body lying slightly anterior to the second sacral vertebra.

Characteristics of normal gait.

Human gait is usually described in terms of the various components of the gait cycle.

Gait cycle.

One gait cycle begin with the heel contact and end with the heel contact of the same leg.

The gait cycle is divided into two major phases - stance phase and swing phase. In one gait cycle, the average relationship between stance and swing is 60% to 40% respectively.
Stance phase is defined by the period in which the foot is touching the ground.

Swing phase is the period when the foot is not touching the ground.
**Stance phase**

Stance phase may be divided into intervals designated by the terms shock absorption (weight acceptance), midstance, and push-off.

**Shock absorption.**

Begin with heel contact and end with the foot flat. This action protects the body from the impact.

**Mid Stance Phase.**

The midstance interval begin with the foot-flat position and ends with heel-off. When the greater trochanter is in vortical alignment with the vertical bisector of the foot, as viewed in the sagittal plane (from the side).

*Foot flat to heel off.*

**Push off phase.**

From heel off to toe off
This pushes the body forward

The stance phase is also known to be subdivided into five discrete events which are the following:
heel contact, foot-flat, midstance point, heel-off, and toe-off.

**Heel contact**

The point at which the heel first touches the ground.

**Foot flat.**

When the forefoot touches the ground.

**Mid Stance**

The point at which the heels are side by side.

**Heel off.**

The time when the heel of the foot starts to leave the ground.

**Toes off.**

The point at which the toes leave the ground.
Swing phase

Swing phase may be divided into three intervals designated by the terms acceleration, mid swing, and deceleration. Each of these subdivisions constitutes approximately one-third of swing phase.

Acceleration Phase.

The toes leave the floor and the leg picks up speed as it catches up and passes the body.

Mid swing.

The heels pass each other.

Deceleration.

After mid swing the leg slows down to a stop just before heel strike.

Double support.

The brief period of time between stance phase and swing phase, when both feet are simultaneously in contact with the floor. As the speed of walking increases, double support becomes shorter and shorter until it finally disappears. The absence of a period of double support distinguishes running from walking. *Running is defined as having no double support.*

In opposition to double support, single support refers to the period when only one limb is in contact with the floor.

Timing

The relative amounts of time spent during each phase of the gait cycle at usual walking speed are:

1. Stance Phase - 60 per cent of the cycle
2. Swing phase - 40 per cent of the cycle
3. Double Support - 10 to 20 per cent of the cycle.

With increased walking speed there is a relative increase in time spent in swing phase, and at slower speed a relative decrease.
Path of the Centre of Gravity

The laws of mechanics make it clear that the least amount of energy is required when a body moves along a straight line, with the centre of gravity deviating neither up and down nor side to side. Such a straight line path would be possible in normal gait if the lower limbs terminated in wheels instead of feet. Since this is not the case, the body’s centre of gravity deviates from a straight line but, for the sake of energy conservation, the deviation or displacement should be kept to an optimal level. In normal gait, the centre of gravity oscillates in a rhythmic manner similar to a sinusoidal curve. This alternating displacement is normally about 5 centimetres. There is a balance between the storage of energy (potential energy) and the use of energy (kinetic energy).

Gait characteristics influencing the path of the C.G.

Vertical displacement

In the normal walking pattern the centre of gravity goes through a rhythmic upward and downward motion as it moves forward. Centre of gravity rises at Mid-Stance and falls at Double support The average amount of this vertical displacement in the adult male is approximately 5 cm.

Lateral displacement.

The centre of gravity, as it moves forward, also oscillates from side to side as well, swaying in the direction of the leg that is on the ground. The total amount of this side-to-side displacement is approximately 5 cm.
Walking Base.

The width of walking base is the distance between the mid points of the heels. Average of 5 to 10 cm. Since the pelvis must shift toward the weight-bearing side to maintain stability at midstance, the normally narrow walking base minimizes the lateral displacement of the centre of gravity.

Pelvic Dip.

The pelvis will drop towards the side that is in swing phase. The size of the drop is 5 degrees. It is a normal characteristic which serves to decrease the rise of the centre of gravity.

Pelvic Rotation.

In addition to dipping, the pelvis rotates forward in the horizontal plane approximately 8 degrees on the swing-phase side (4 degrees on each side of a centre line). This characteristic of normal gait enables a slightly longer step length without further lowering of the centre of gravity, and thus minimizes total vertical displacement.

Knee flexion during stance phase

Shortly after heel contact, flexion of the knee begins and continues during the early part of stance phase (from heel strike to mid stance) until approximately 20 degrees of flexion is reached. This characteristic of normal gait by shortening the leg a little does reduce effectively the upward displacement of the centre of gravity.

Cadence.

70 strides per minute is said to be normal. 130 strides per minute is the fastest we can walk without running. Slower or faster cadences then 100 to 115 steps per minute, have a pronounced effect on the values of joint angles, externally generated forces, and muscular activity.
Ground Reaction Forces (GRF).

During the gait, there are horizontal and vertical reactions forces, called ground reaction forces (GRF), from the ground acting on the foot and the limb. (If you are pushing on the floor, the floor is pushing back. This is the third law of Newton.) To study the GRF actions on the different joints of the body, we observe the resultant of these forces at different phases of the gait. The resultant from the GRF creates moment of force on the joints of the leg.

Moment of forces.

A moment can be defined as the tendency of a force to create rotation about a point. The mathematical formula for a moment is:

\[ M = F \times D \]

- \( M \) moment (Newton metres)
- \( F \) force (Newton)
- \( D \) perpendicular distance from the force to the centre of rotation (metres)

During stance, the GRF is always acting in a given direction with a specified magnitude and at a given distance from a joint axis. Therefore, the GRF will tend to create various flexion or extension moments at each joint, depending on the position of the body at that particular instant.
Anterior to hip causing flexion moment.
Except for “Heel strike” the GRF is posterior to knee causing flexion moment.
Posterior to ankle causing plantarflexion moment.

Passes through hip joint, no moment.
Posterior to knee causing a flexion moment.
Anterior to ankle causing dorsiflexion moment.

Posterior to hip causing extension moment.
Anterior to knee causing extension moment.
Anterior to ankle causing dorsiflexion moment.
By toe-off the reaction has lost most of its significance as the majority of weight is borne by the other foot.

There is no GRF during the swing phase of the leg.
SECTION - 3

BELOW KNEE AMPUTEE

GAIT DEVIATIONS
BELOW KNEE GAIT DEVIATION

Introduction

A below knee amputee supplied with a well fitted socket and an optimum aligned prosthesis should demonstrate gait patterns similar to that of a non-amputated peer.

Prior to ”optimum” alignment the prosthesis is checked at three stages –

1) Bench alignment
2) Static alignment
3) Dynamic alignment.

During bench alignment the technician assembles the adjustable prosthesis to instruction which, based on experience, allow the prosthetist the maximum range of adjustment at the subsequent fitting stage. During static alignment the prosthetist will ensure that the amputee is comfortable and stable in the stance position. Careful bench and static alignment will minimise the prosthetic causes of gait deviations. Dynamic alignment is performed as the amputee walks and adjustment will be made to eliminate any gait deviations.

Acceptable Below-Knee Amputee Gait

The prosthetist must ensure that the alignment of the prosthesis is such that ground reaction force has a similar effect on the amputee’s joint movement as in the case of normal subjects.

Viewed from the side an amputee’s knee flexes and extends during the stance period as the line of action of the ground reaction force passes behind and in front of the knee joint. At the instant of heel strike the knee is almost extended; full extension is not usual due to bench alignment of the socket. During early stance between heel strike and foot flat, the ground reaction force tends to flex the knee

This knee flexion is controlled by quadriceps activity. After mid stance the ground reaction force passes ahead of the knee tending to extend the knee. This knee extension is controlled by the hamstrings. During late stance, immediately prior to toe off, the ground reaction force again tends to flex the knee. In an incorrectly aligned prosthesis the distance from the line of action of the ground reaction to the knee joint may increase to the extent that the amputee may not be able to control the knee flexion/extension by muscle activity. Gait deviations may result.
Careful selection and adjustment of the prosthetic foot in the shoe should ensure good amputee gait. Careless adjustment of the prosthetic foot may result in an increased/decreased knee moment from the ground reaction force and hence excessive/insufficient knee flexion. Viewed from the front or rear stability at mid-stance is necessary with the foot flat on the ground. An incorrectly medial/lateral aligned prosthesis will upset the stability. The two extremes are a knee that moves laterally at mid-stance or an abducted gait. Other features of acceptable amputee gait are smooth rhythmic movements with even step length, step timing and arm swing. The degree of toe out on the amputated side should match that of the sound side.

**Below-Knee Gait Deviations**

Gait analysis consists of identifying if a gait deviation exists and determining the cause. Keep in mind that the below-knee amputee may be able to compensate and perhaps overcompensate for alignment changes.

Three major deviations may be present in a below knee amputee’s gait
1) EXCESSIVE KNEE FLEXION
2) INSUFFICIENT KNEE FLEXION
3) LATERAL THRUST OF THE KNEE

**1) Excessive knee flexion**

Description: At normal walking speeds (60 to 90 metres/minute) knee flexion early in stance is approximately 15 to 20 degrees decreasing to approximately 40 degrees at toe-off. Knee flexion larger than these levels should be considered to be excessive. A common expression used by amputees to describe this gait deviation is that they feel as if they lack knee control.

**When to observe:** During stance phase.
**How to observe:** View from the side.
A) Excessive dorsiflexion of the foot.

If the prosthetic foot is set in too much dorsiflexion the socket and therefore the stump are tilted forward relative to the foot. The knee joint position moves forward relative to the supporting ground reaction force. This results in a larger knee flexion moment being applied early and late in the stance phase. After heel strike the patient feels precipitated forward.

B) Excessive posterior displacement of the foot.

Excessive posterior displacement of the foot increases the distance between the line of action of the ground reaction force and the knee joint resulting in a larger knee flexion moment being applied. Again if the amputee fails to compensate then excessive knee flexion occurs during early and late stance. During stance phase the patient rolls over too fast. At late stance phase, it looks like if the patient is falling in a hole.
C) Excessively stiff plantarflexion bumper (heel cushion of foot).

In normal locomotion during the shock absorption period the ground reaction force applies a plantar flexion moment to the ankle joint and a flexion moment to the knee. If the compression of the rear rubber of a foot is insufficient to simulate the correct plantarflexion during early stance, the shock of foot impact is absorbed by excessive knee flexion during early stance. Again, the patient may seem to be precipitated forward.

D) Excessively soft dorsiflexion bumper.

As the body’s centre of gravity passes forward over the support foot, balance is maintained until the c of g passes ahead of the foot. If the front support from the prosthetic foot is inadequate (too soft) then the socket and hence the amputee’s c of g will pass ahead of the support foot too quickly. There will be excessive knee flexion at the end of stance.

E) Flexion contractures.

There are non/prosthetic causes of this gait deviation e.g. an amputee with a knee flexion contracture from tight or contracted hamstrings will walk with an excessive degree of knee flexion throughout stance.

F) Suspension features which prevent full knee extension.

Conception and modification of the cast for a PTB SC and a PTB SCSP can restrict too much the extension. They create too much pressure just above the patella level, and prevent full extension of the knee. The deviation will occur throughout stance.

If you are using a suspension with a supracondylar strap, fixing the anchorage of the cuff too posterior on the socket will also limit the extension of the knee.

G) Small prosthetic foot.

If the front support section of the prosthetic foot is inadequate due to too small a foot being selected the amputee’s c of g will move ahead of the support foot too quickly causing excessive flexion late in stance. Just like a too soft front support of the prosthetic foot.
2) **Insufficient knee flexion.**

Description: This gait deviation is the opposite of that described earlier and the prosthetic causes tend to be the exact opposite. A common expression used by the amputee to describe this gait is that they feel as if they are walking up a hill.

When to observe: During stance phase.  
How to observe: View from the side.

A) **Excessive plantar flexion.**

If the prosthetic foot is aligned with too much plantar flexion the socket and therefore the stump are tilted backwards relative to the foot. The knee joint is posterior relative to the line of action of the supporting ground reaction force. The knee joint is subjected to a smaller flexion moment and if the plantarflexion is too excessive the joint may be subjected to an extension moment. If the amputee fails to compensate, lack of knee flexion early and late in stance may be observed.
B) Excessive anterior displacement of the prosthetic foot.

If the foot is displaced anteriorly, the distance from the knee joint to the line of action of the ground reaction force reduces. The flexion moment applied to the knee reduces and if the foot is displaced anteriorly too excessively a knee extension moment may be applied throughout stance.
C) Anterior-distal socket discomfort.

When the ground reaction force flexes the knee, the degree of flexion is controlled by the quadriceps resulting in stump/socket interface pressure in the anterior-distal area. During bench alignment the socket is flexed to emphasise the patellar bar. If, as a result of incorrect cast rectification of the anterior-distal area or incorrect alignment, the pressure causes discomfort at the anterior-distal area of the stump, the amputee will compensate by adopting a gait during which the knee is not subjected to flexion. This can be accomplished by:

-1) shortening the prosthetic step;
-2) digging the heel into the ground with increased hip extensor activity;
-3) leaning well forward to ensure the line of action of the ground reaction force does not pass behind the knee joint;
-4) some combination of these.

D) Weakness of the quadriceps muscles.

Some below knee amputees have weak quadriceps and are unable to control knee flexion moments. Adopting a gait, similar to that for (c), reduces or eliminate the need for quadriceps controls since no knee flexion moment will be applied by the ground reaction force during stance.

E) Habit.

Some amputees may have developed an established pattern of walking which relies on the prosthesis’ resistance to hyperextension, for example a standard P.T.B with thigh corset. When these established amputees are transferred to a supracondylar, P.T.B their usual gait will result in hyperextension of the knee. A short period of gait training should eliminate this gait deviation.

Likewise an amputee’s knee hyperextension may have been controlled by his precedent PTB SC prosthesis.
3) Lateral thrust of the knee

Description: Lateral thrust of the knee may be described as lack of lateral knee stability during stance. The knee moves in a lateral direction on weight bearing, as the medial socket brim presses against the stump and the lateral socket brim tends to gap. The standard walking base is 5 to 10 cm as described in the normal locomotion section. Any prosthetic cause which results in the amputee walking with a narrower walking base will often result in lateral thrust of the knee.

When to observe: During mid stance.
How to observe: View from in front behind the amputee.

A) Excessive medial foot displacement.

The ground reaction force passes through the body’s centre of gravity at mid stance and hence passes medial to the weight-bearing area of the socket. This results in a tendency for the prosthesis to rotate around the stump. This is resisted by lateral distal and medial proximal stump socket interface forces. The tendency to rotate and the medial proximal socket force produce a gap at the lateral socket brim as the pressure at the medial socket brim forces the knee to move laterally.

An inset (medially displaced) foot results in the ground reaction force passing even more medially to the weight bearing area of the socket. The more medial the prosthetic foot at mid stance the greater the medial socket brim force, the greater the lateral knee thrust and the greater the lateral gap at the lateral socket brim.
B) Inverted foot medial tilt of the socket brim.

During bench alignment the socket has been mounted to provide the maximum range of adjustment with the alignment unit. If, during subsequent adjustments the prosthetic foot is inverted or the socket brim is medially tilted (abducted socket), when the amputee stands or walks the position of the stump and hence the socket remain unchanged. However the prosthetic foot will be displaced medially and the amputee will walk on the lateral border of the foot.

Other gait deviations

4) Asymmetrical pelvic tilt

Description: On weight bearing the pelvis should tilt approximately 5 degrees to the unsupported side. If the rhythmic tilt of the pelvis is disturbed this deviation is present.

When to observe: Mid stance to late stance.
How to observe: View from in front or behind the amputee.

Causes:
a) Too short a prosthesis. The pelvis tilts excessively to the prosthetic side at the end of stance phase on the normal limb.

B) Too long a prosthesis. The pelvis tilts excessively to the normal side at the end of stance phase on the prosthetic limb.
5) Uneven timing.

Description: The steps are of unequal duration, usually a very short stance phase on the prosthetic side.

When to observe: Throughout the gait cycle.
How to observe: View from the side.

Causes:

A) Improperly fitting socket may cause discomfort and a desire to shorten the stance phase on the prosthetic side and an increased swing period.
B) Alignment instability.
C) The amputee may not have developed good balance.
D) Amputee’s fear and insecurity.

6) Uneven arm swinging.

Description: The arm on the prosthetic side is held close to the body.

When to observe: Throughout the gait cycle.
How to observe: View from the side.

Causes:

A) Amputee may not have developed good balance.
B) Fear and insecurity accompanied by uneven timing.
C) Stump discomfort.
D) Habit pattern.
SECTION - 4

FABRICATION OF SOCKET

AND THE ALIGNMENT
ALIGNMENT & THE FABRICATION OF BK SOCKET

Although different materials such as aluminum, wood and leathers are still used for the fabrication of socket, practically speaking, we could say that plastic is the main material for socket fabrication. With the plastic, there are two main approaches to socket fabrication; they are the resin laminated sockets and the thermoplastic sheet forming socket. Generally speaking both technology use the vacuum for the forming of the socket. All sockets can be made with or without a liner.

Much has been written about the fabrication technologies. Therefore we shall avoid that subject and leave the details to the instructors.

Nevertheless, there is one aspect of the fabrication which is of interest to us. It is the set up for the alignment. In the fabrication of prosthesis, two main approaches are used. One consists of adding to the socket, all components for the alignment, after the socket has been fabricated. Another one consist of integrating some components for the alignment in the socket fabrication process. This is the approach that ICRC is using with the polypropylene vacuum thermoforming technology. When the space is available, the tibial sockets are fabricated with an adaptor for the alignment.

Basically speaking, where this integrating alignment approach is used, we can say that the initial alignment (bench alignment) start at the moment of socket fabrication and therefore, care must be taken for positioning the adaptor at the right position. This adaptor should be placed with respect of the initial flexion (5 - 7 degrees of anterior tilt) and any so call valgum or varum of the knee. Placing the adaptor at the proper angulation and the right position will give the prosthetist the optimum possibility for alignment and proper fitting. On the contrary, if the alignment adaptor is wrongly placed it will render the process of alignment pain taking and time consuming. Furthermore, the cosmetic of the prosthesis can be difficult to completed properly later.

After the vacuum thermoforming or the lamination is complete and cooled down, the socket is trimmed along the proximal edge and the plaster cast broken out or blown out with compressed air. The edge of the trim lines are determined according to the type of socket and the particularities that the prosthetist wants his socket to perform.

*Here you should pay attention to the angle of the cast cutter blade while cutting the socket. If your angle is not appropriate, you will cut into the liner, making this latter, shorter than the socket.*
SECTION - 5

ALIGNMENTS
ALIGNMENTS

Alignment may be defined as the relationship between the socket and the foot. Proper alignment and good socket fit go hand in hand; one will not do without the other. A well-fitting socket will be uncomfortable with poor alignment, and vice versa.

In the field of prosthetic, we do consider three kinds of alignments: the bench alignment (initial alignment), the static alignment and the dynamic alignment.

**Bench alignment** (initial alignment) is attaching the socket, shank and foot to each other in the proper relation, according to the measurements and the informations recorded during the patient assessment. This is done before fitting the prosthesis onto the patient for weight bearing.

**Static alignment** is the alignment done with the patient standing up and putting weight on the prosthesis but not walking. Usually this alignment is done between the parallel bar.

**Dynamic alignment** is done with the patient walking, first between the parallel bar then outside of them.

The alignment can be modified under the socket or just over the foot. It can be done by tilting (changing the angulation) or by shifting (sliding the socket or the foot without changing the angles). Also, when you do tilt one part you usually need to shift the component to replace it at the original place. Some of the tilting require shifting to reposition the socket at the same position in relation to the foot. System like the Otto Bock pyramidal alignment device does require tilting in order to shift.
When you are doing the initial alignment (bench alignment), we have a tendency of talking about the angulation and the position of the socket. In practice we often talk of shifting or tilting the socket. This is because the foot stays put on the table while the socket is moving. When you are doing the static or the dynamic alignment, any change in angulation or in shifting does reflect on the foot. This is because the stump doesn’t move, hence the socket is also not moving. Therefore, the foot will move.

Those two different points of view regarding the alignment tend to be confusing at times. When we are reading the literature on the subject of alignment, are we talking of moving the socket or the foot.

For the practical purpose, keep in mind that if you tilt or shift the socket in one direction you are moving the foot in the opposite direction and vice versa.
**Bench alignment** *(initial alignment)*

**Tilting (angulation) of the socket.**

The socket and foot are attached to each other so that the socket is flexed approximately 5 to 7 degrees. In order to expose appropriate areas of the anterior stump surface to weight-bearing forces and to reduce forces tending to hyperextend the knee during the latter half of stance phase.

For very short stumps the flexion should be increased up till approximately 15 deg.

*If the knee has flexum (flexion contracture) the socket should be initially set up with that amount of flexion. Some prosthetists would say to add 5° of flexion to the initial flexum.*

The socket is placed in adduction or abduction to correspond with the valgum or varum of the knee, which has been recorded during patient assessment. Usually, a short stump will seem to be in valgum while a long stump may look like being in varum. This is because of the “S” shape of the tibia and the bony structure of the residual bones.

A good reference mark for the mediolateral tilt is the PTB indent. Assuming the cast was modified properly, you look from behind and put the PTB indent horizontal. This should place the socket with the right mediolateral tilt.

**Shifting (position) of the socket.**

A plumb line from the antero-posterior centre of the socket will fall approximately 1/3 along the foot (schemas p.43), depending on the length of the keel in the foot.

A plumb line from the centre of the posterior wall will fall approximately 1 cm lateral to the centre of the heel.

The toes of the foot are turned out approximately 5 degrees with respect to the line of progression of the socket. *Generally speaking, the edge of the foot give the line of progression. The line of the middle of the foot with the line from the edge of the foot give a 5° angle.*

The height is taken from the lower edge of the PTB indent.
The pylon is an excellent visual reference point to see if the prosthesis is leaning too much in a direction or another. Therefore, the pylon should be as vertical as possible, to facilitate the observation of the shifting during walking.

The prosthetic foot should be of proper size, adjusted for the heel heights of the shoe worn by the amputee, and fitting snugly into the shoe.

The following 2 reference lines must be drawn on the socket:

**Posterior reference line.**

- Connecting the centre point at the posterior wall and the centre point near the posterior distal end.

*When you are looking from the posterior, the PTB indent should be horizontal.*

**Lateral view**

**Antero – posterior reference line.** - Connecting the mid point between the patellar tendon and the posterior wall with the centre point near the distal end.
Generally speaking, the edge of the foot gives the line of progression. The line of the middle of the foot with the line from the edge of the foot give a 5° angle.

Remember, this initial alignment should give the prosthietist enough free way to make all the changes needed during the static and the dynamic alignment without too much pain taking. This way we maximise our chances to obtain the optimum final alignment for the patient.
**Static alignment and fitting**

**Procedure**

1) Review the information on the measure chart. Re check the patient and make yourself familiar with the problems.

2) Check the prescription and see if the prosthesis you have been asked to fit is the same.

3) Check the bench alignment and see if it is approximately correct.

4) Examine the patient’s stump carefully. Note any cuts, abrasions or damage. This will help to work out if the new socket has caused any damage to the stump. Check also for signs of swelling.

5) Put on the normal stump socks and then try the liner. It should be a snug fit and the stump should go all the way in without a big effort. If the fit is bad it will be “better to abandon the fitting and recast”. Before doing that check the measures on the chart with the measures today and see if the patient has changed. If he has then find out why and assess the need to make a new socket.

**Static alignment.**

Preliminary alignment of the prosthesis is based on observation of the amputee as he stands between the parallel bars and shift his weight to distribute it equally between the prosthesis and the sound leg.

1) Put the leg on the patient and assess the fit. There should be no major gaps at the rim, and the patient should have no discomfort. Adjust or abandon as required.

In order to proceed correctly, check the patellar pocket in order to ensure that the stump fits into the socket. The prosthetist should keep in mind that the amputee will be expected to walk with a flexed knee, with weight borne over the middle third of the foot in midstance.

2) Ask the patient to stand and if he can comfortably, assess the fit and height of the leg. At this point the patient should be asked about pain. Primary patients will always have a little discomfort. Make sure the patient is putting proper weight on the prosthesis and does not flex his hip.

3) The next step is to check for the correct length of the prosthesis and the toe out. This should be done with the amputee standing with equal weight on both legs and feet approximately 10 cm apart at the heels. The toe out should be the same as the normal leg, keeping in mind that external rotation of the amputated side from the hip is possible. Both feet should be in line, with the prosthetic foot flat on the floor. At this time, the hips should be level and the pylon tube vertical.
For the height, you can check the level using three anatomical references points; the iliac crest, the antero superior iliac spine and the postero superior iliac spine. The last one, the postero superior iliac spine is the easiest to assess with your naked eyes, without the use of any tool. Because when you are checking the level of the hip, you are very close to the patient. The short distance between those two points fit very well in your visual range when you are that close to the patient.

4) Check the initial tilt of the socket.

If the heel is off the floor, give more flexion to the socket. If the front part of the foot is not touching the floor, give more extension to the socket. To be able to well use that reference the foot should have a snug fitting into the shoe. If too much pressure on the lateral upper side of the socket, the socket must be more abducted, (varum). If too much pressure on the medio proximal edge of the socket, adducted the socket (valgum).

As a rule of thumb, given the patient is not over compensating and he is putting proper weight on the prosthesis, most of the tilting adjustment of the socket can be done during the static alignment. As for the shifting of the socket, it cannot be observed during the static alignment, and must be handle during the dynamic alignment.

If the amputee should experience any socket discomfort at this time, have him sit down. Remove the prosthesis and quickly check for pressure marks. Using the amputee’s remarks as guidance, look for stump sock impression marks. If pressure is in an unwanted area, lipstick can be used on the stump sock at the pressure spot. Have the amputee don the prosthesis again and bear weight on it. Remove the prosthesis. A lipstick stain should indicate the pressure area in the socket. The socket should then be eased out before proceeding.

Remember the patient is the most important part of the process. Always listen to his comments and ask his opinion. But you must also use your judgment and your experience to understand what the patient is trying to tell you.
Dynamic alignment

The prosthetist should not expect a perfect gait from any amputee. Factors to consider include age, physical condition, joint function, length of stump, surgery, mental condition and skin condition.

The most desirable gait pattern is achieved when the amputee walks effortlessly in relative comfort and with near normal appearance. The walking base should be as narrow as possible in comparison to that of a normal person.

In a normal gait pattern, the amputee’s knee should be in about 10 to 12 degrees flexion at heel contact, with the prosthesis rotating smoothly but rapidly into full contact with the floor.

As anterior progression continues smoothly, the knee joint continues to extend at midstance. At this point the foot is flat and secure on the walking surface and the knee joint is in about 5 to 7 degrees of flexion (the amount of flexion built into the prosthesis) to allow further extension of the knee from midstance to toe off. The swing phase should be natural in appearance, with minimum piston action between the residual limb and socket. *(The initial flexion built into the prosthesis minimizes strain on the hamstring tendon at the time of push off.)*

The prosthetist should always listen to his patient’s feedback, but he should use his knowledge and trained eye to make the right decisions.

1) Once the amputee has become accustomed to standing on the prosthesis and shifting his weight from leg to leg, and after static alignment has been completed, refinements can be made by observing the amputee walk. Best to walk between the rails until he is confident.

2) If the alignment is not too bad allow the patient to walk for 2-3 minutes to settle in. If alignment is very wrong then adjust until it is nearly correct and then let the patient continue walking.

3) View the patient from behind or in front, then from the side. Observe the anomalies of the walking pattern and adjust as required (following pages).

4) Have the patient walking outside the parallel bars. If he is used to walk with a cane or a crutch, please have him use it for the fitting. Once a patient is accustomed to a way of doing, don’t try to change it. He will always go back to his old habits.

5) If the patient is walking with an incomprehensible pattern to you, have him walking on his old leg, if he has one. This will tell if he has any bad gait habits or peculiarities. Observe the action of the sound leg as well since both legs may be affected by the same deformity. Then have him re walk with the new prosthesis. From your observations see if their is way to improve or not.
Mediolateral alignment

1. Check toe out of prosthetic foot and line of progression. Compare with sound leg during walking.

2. Foot or sole of shoe must be flat on the floor.

3. Check the lateral or medial shift of socket or other motion at the proximal border of socket. The socket should remain stable at midstance, equal compression of tissue at medial and lateral proximal brim.

Mediolateral tilt adjustment:

If the foot or the sole of the shoe is not flat on the floor during midstance, a tilt adjustment is indicated. To confirm, check the pylon tubing for vertical position. If, for instance, only the lateral border of the shoe is in contact with the floor, the pylon tubing will, at this moment, lean laterally. The lateral proximal brim, at this moment, will gape. The medial proximal brim may show excessive bulging of tissue. The amputee may complain of pressure at the distal cut end of the fibula shaft.

To correct:
1. Lateral tilt of the socket, which will bring the medial border of the shoe to the floor and pylon vertical. The tilt does correct the foot position but at the same time shifts the weight line further laterally to compensate.

2. Shift socket medially. As a general rule, whenever a tilt adjustment is made, always combine it with an opposite shift.
Mediolateral shift adjustment:

Observe and adjust the width of the walking base.
If the socket over the foot is too lateral, the foot or sole of the shoe will most likely be flat on the floor and the pylon tubing vertical. However, the amputee may complain of abnormal pressure at the medial proximal brim. At the same time, the prosthetist observes the socket in a lateral motion, causing gaping at the lateral proximal brim.
Often the patient feel insecure because of the narrow walking base.

To correct:
1. Shift the socket medially (foot laterally). Do not tilt.

If the socket was too medial, the patient would feel secure but the walking pattern could be awkward. (The patient is walking like a duck.) This is because the foot would be too far laterally from the centre of gravity. The amputee must then bring his c.g over the foot by tilting or shifting the hip.

Anteroposterior alignment.

Observe the amputee walking left to right. Sufficient distance from the amputee is of importance to observe fully the gait cycle and possible shortcomings.

The stance phase should be smooth and even from heel contact to toe off, voluntarily controlled by the amputee’s residual limb and knee. The knee should not lack stability, but at the same time, excessive effort should not be required to control stability or to flex the knee at the end of the stance phase.

The prosthetic foot should be of proper size, exact heel heights as compared to the shoe worn by the amputee, and the heel wedge or plantar flexion bumper of the proper firmness according to the weight and function of the individual amputee.
**Anteroposterior tilt & shift adjustment**

1. If at heel strike the amputee cannot control knee flexion, causing rapid and premature knee flexion, the prosthetic forefoot will contact the floor surface prematurely. The amputee will properly complain of pain at the distal anterior aspect of the tibia and posterior proximal brim. He feels and seems to be precipitated forward immediately after heel strike.

   **Cause:**
   Anterior tilt or socket flexion is excessive, often also causing drop off at toe off. Also, the socket may be displaced too far anteriorly.

   **To correct:**
   Tilt the socket posteriorly and observe gait. Avoid doing two different adjustments at the same time. At midstance the foot should be in contact with the floor surface, with the knee flexed approximately 5 - 7 degrees, and the pylon tubing vertical.

2. If the knee is forced into hyperextension, the heel cushion is excessively compressed, and the pylon tubing leans posteriorly, the anterior posterior placement of the socket is incorrect. The amputee may complain of extreme pressure at the anterior proximal brim and posterior distal aspect of the socket.

   **To correct:**
   Shift the socket anteriorly over the foot or make a firmer heel cushion.
   If the same symptoms at the socket are apparent, but the prosthetic foot is in contact with front only, the heel is off the floor and the pylon is vertical, an anterior tilt is the indication.
3. If, at time of toe off, a sudden drop off takes place, giving the appearance of the amputee walking downhill with his prosthesis and there is excessive pressure usually at the posterior proximal brim, the socket has been either placed too far anteriorly, or there is excessive anterior tilt.

To correct:
1. Shift the socket posteriorly over the support surface of the prosthetic foot. (Centring socket at P.T level, midway between heel edge and ball or foot, is a good indicator.) (1/3, 2/3)

2. Tilt socket posteriorly, and reduce socket flexion.

Once anteroposterior alignment has been completed, double check the mediolateral alignment for possible refinements. Re-check the socket fit, and the lengths of prosthesis.

If one or any gait deviation cannot be corrected through alignment changes, regardless of the extent of the changes, then the socket fit and support must be questioned. If so, a new socket may be the only answer.

A loose, unsupportable socket will allow the amputee’s residual limb to rotate within the socket. This may be in the anterior posterior plane and/or the medial lateral plane.

When the alignment is correct and the patient is happy, check the stump for new damage and then prepare the prosthesis to be finished. Check and mark the trim lines and the cosmetic measures.
**BK alignment procedure:**

1) Watch patient walk on old leg.

2) Check information on measure chart.

3) Check prescription.

4) Check bench alignment. (in workshop)

5) EXAMINE PATIENT’S STUMP CAREFULLY.

6) Put on stump sock and liner.

7) Put on Prosthesis

8) STATIC ALIGNMENT:
   - Check height.
   - Check stability.
   - Check for the initial tilt of the socket.
   - Check for toe out of the foot.
   - Check for comfort.

9) PATIENT WALK BETWEEN RAILS, if OK walk for 2 - 3 minutes.

**Look from the front and back.**

10) Toe out position.

11) Pole vertical.

12) Toe rise at heel strike.

13) Width of walking base. (M - L thrust at knee)
   - Medial thrust - move foot medial.
   - Lateral thrust - move foot lateral.

**Look from the side.**

14) Knee flexion:
   - Hyper extension - move socket anterior
   - Too much flexion - move socket posterior.

15) Check everything again.

16) Check trim lines with patient sitting.

17) Take prosthesis off - check stump.

18) Check measures for cosmetic finish.
SECTION - 6

BELOW KNEE

PROSTHETIC CHECK-OUT
BELOW KNEE PROSTHETIC CHECK-OUT

CHECK-OUT LIST

___ 1) Is the prosthesis as prescribed? If this is a second check-out, have the new instructions been followed?

___ 2) Can the patient easily put on the prosthesis?

Check with the patient standing.

(for point 3, 4, 5 and 6 patient should stand with good posture, even weight on both feet and heel centres not more than 15 cm apart.)

___ 3) Is the patient comfortable while standing?

___ 4) Is the anterior-posterior alignment good? (The patient should not feel that the knee is unstable, or that the knee is forced backwards.)

___ 5) Is the mediolateral alignment good? (The shoe should be flat on the floor and there should be no pressure at the lateral or medial brim of the socket.)

___ 6) Is the prosthesis the correct length?

___ 7) When the patient lifts the leg up a little, is piston action minimal?

___ 8) Are the proximal socket walls the correct height?

___ 9) Are the medial and lateral walls in contact with the epicondyles?

Check with the patient sitting.

___ 10) Can the patient sit comfortably? There should be no pinching of the soft tissues in the popliteal area when the knee is flexed 90 deg.

___ 11) Is the posterior wall high enough?

___ 12) Do any of the PTB modifications make the patient uncomfortable when sitting?
Check with the patient walking.

___ 13) Is the patient walking well on level ground? Indicate below any gait deviations that need attention.

___ 14) Is piston action between stump and socket minimal?

___ 15) Does the patient go up and down inclines and stairs well?

___ 16) Are the socket and suspension systems comfortable?

___ 17) Does the knee cuff maintain its position?

___ 18) Is the patient able to kneel satisfactorily? (A patient with a PTB SC SP socket will not be able to kneel for very long.)

___ 19) Does the prosthesis function quietly?

___ 20) Are size, shape and colour of the prosthesis approximately the same as the sound leg?

___ 21) Does the patient consider the prosthesis satisfactory?

Check with the prosthesis off the patient.

___ 22) Is the stump free from abrasion, discoloration and excessive sweating just after the prosthesis is removed?

___ 23) Does weight bearing appear to be distributed over the proper areas of the stump?

___ 24) Is the general workmanship satisfactory?

Special check for Thigh corset.

___ 1) Do the upper side steels follow the shape above the epicondyles?

___ 2) Are the joints close to the epicondyles?

___ 3) Does the thigh corset fit properly? Is there good possibility for adjusting the tightness of the corset?

___ 4) Is the corset the right size?
SECTION - 7

POST-FITTING

PROSTHETIC PROBLEMS
Many of the problems common to amputees of all levels are related to the adequacy of the prosthesis with respect to socket design, its fit, the alignment, residual limb condition, and most importantly, the individual’s physical and psychological changes (greater activity), and changes in tissue volume due to atrophy. The last is the most common problem. Once socket fit is not adequate any longer, it will most likely affect the alignment, leading to multiple problems if neglected.

Certain factors, however, are peculiar to the trans-tibial amputee as compared to any other level. The presence of a knee allows much greater control over the function of the prosthesis so that activity level is usually very high.

The trans-tibial residual limb, however, is anything but ideal in terms of shape, the number of bony prominences, and the poor muscle padding or skin coverage in many vulnerable areas (distal anterior aspect of the tibia as one example). Furthermore, all loading surfaces are sloped so that a much larger force is necessary at right angles to the weight line in order to give adequate support. To make matters more complicated, the loading and force distribution are constantly changing during the different phases of gait. Most of these can be compensated for with sound socket design and correct alignment if the amputee remains walking on level ground. Once uneven, constantly changing ground surface is facing the amputee, alignment and socket fit are nowhere near normal. Often the change of shoes (higher heel, lower heel) will have incredible effects on alignment.

If, for instance, the amputee is wearing a shoe with a higher heel than the prosthesis has been aligned for, an effect will be created as if the amputee were walking down hill. This may result in extreme pressure at the distal anterior aspect of the tibia and posterior proximal (hamstrings).

If the heel is too low, it will have the amputee walking constantly up hill, resulting in the opposite symptoms. These pressure areas may lead to abrasions, blisters and cysts, in turn leading to infection if neglected. Changes and/or adjustments are necessary to correct, stressing once more the importance of regular follow-up with the prosthetist for possible problems before they become acute.

Initial Examination

First, the prosthetist is guided by the amputee’s immediate complaints. Although not always correct or precise, it is most important to listen to them. The amputee’s comments, combined with the prosthetist’s knowledge, should lead to correct solutions.
Secondly the prosthetist should check socket fit in general (sinking too deep or too far out of socket). Check the length of the prosthesis by placing thumb tips on the postero superior iliac spine. If the socket is too loose, the prosthesis will be too short.

Thirdly have the amputee walk away and toward you and observe the gait pattern. Observe the gait and alignment in the anterior-posterior plane. Check heel height and inquire if there has been a shoe change.

Fourthly, have the amputee doff his prosthesis quickly. Remove the sock and look for sock imprints as visual feedback to confirm the previous discussion with the amputee. Decide if the socket needs easing or buildup in weight-bearing areas.

Often, the amputee will try to fix his prosthesis by adding material in the distal portion of his socket to hold himself out of it. However, this only serves to change the total contact socket to a near end-bearing socket, which is discouraged for a trans-tibial stump. He may also add one or more stump socks to take up the slack in the socket caused by loss of oedema, loss of fatty tissue or true atrophy of muscle tissue. However, the use of more than one extra stump sock tends to defeat its own purpose since the extra socks will also fill the relief pockets, allowing less space for the unchanged bony prominences.

**To determine if the residual limb is fitting properly in the socket:**

1) Check the patella in relation to socket brim;

2) Check the posterior brim for crowding of hamstring or tissue;

3) Remove prosthesis and immediately look for sock imprints. They should be quite visible in all loading areas but not over bony prominences.

4) If pressure is apparent at lower edge of patella, distal aspect of tibia and hamstrings at the posterior brim, the socket is fitting too loosely. Build up of weight-bearing areas is necessary. If full lining is needed, ease relief pockets before to the amount of lining material added in these areas.
5) If pressure is apparent at the distal anterior aspect of the tibia only, the relief pocket may be insufficient; therefore the area should be eased out.

If the volume has decreased at the distal aspect of the residual limb, causing anterior-posterior movement of stump, build up along the medial and lateral sides of the tibia, creating a bridging effect. The posterior aspect of the socket may also be built up, thus achieving A-P stability. Also check the heel height.

6) Pressure or friction at the hamstrings, medial and/or lateral, especially when the amputee is sitting, often combined with pressure at the upper edge of the tibial tubercle. Relief channels may not extend far enough if the flare is not generous enough. The posterior brim might be too high. The heel of the shoe might be too high. Caution is advised before lowering the relief channel or increase of flare.
7) If the lower edge of the patella catches at the patellar tendon shelf, only perhaps combined with pressure at the upper edge of the tibial tubercle, the patellar tendon shelf may be too wide, often as a result of post-fitting build up. Easing is required as shown.

8) Colour changes. Skin normally changes colour when pressure is applied briefly. However, colour will recover quickly to normal once pressure is removed. The amputee’s residual limb, however, is subjected, during a normal day of walking and activities, to continuous pressure within the socket on the skin and muscle tissue that if is not meant to be subjected to by nature. Therefore, colour changes will and must take place once the prosthesis is removed. However, it is of utmost importance to note what area the discoloration is restricted to and what time period it requires to disappear.

Normally after any extended period of walking and quick removal of the prosthesis, the skin will be almost white in the weight-bearing areas quickly turning pinkish to light red (this should not happen over the bony prominences). The redness should recede slowly to normal colour (5-10 minutes) depending, of course, on skin condition and the vascular state of the individual. If the prosthesis is not removed quickly enough, the loading areas will have already changed to light redness. One should not be alarmed by this, as stated before, as long as the redness appears in normal loading areas and not in the pressure sensitive areas, and redescs in the appropriate time.

If redness is caused by proximal constriction, extreme caution must be taken to recognize and eliminate this problem immediately. This is almost always caused by lack of total contact distally. The soft tissue is not being supported and compressed equally, causing restriction and return flaw of fluid, like forcing a finger in a narrow bottle neck and leaving it there for some time.
Usually, the discoloration is definitely outlined as if drawn. A circular line will show exactly where the last socket contact takes place. Of ten the patient will mislead the prosthetist by complaining of great pressure distally, encouraging him to enlarge the socket distally and perhaps remove the total contact pad. This will worsen the problem since more room has been given to be filled by oedema. This ill fitting must be corrected as soon as possible by assuring, first of all, a proper supporting, non-restricting fit proximally and then filling distal areas of the socket to provide supportive counterpressure to the soft tissue. Often the constriction is accompanied by much firmer tissue that will leave indentation marks. The temperature of the skin is also higher.

If constriction has been severe and neglected, it may be necessary to have the amputee discontinue use of the prosthesis. The patient should then definitely bandage the residual limb properly and a physician should be called in for consultation.

Most of the time the aforementioned problems are encountered with the dysvascular amputee who has, for whatever reasons, not used his prosthesis without bandaging the residual limb, causing the formation of oedema. If the patient then continues to use the prosthesis and the socket does not accommodate the increased volume of the stump. Often the amputee does not recognize this fact and keeps walking, causing further swelling distally since the residual limb does not provide total contact at this moment.

9) **Abrasions** are usually the first sign of problems caused by friction. This may happen at the distal anterior aspect of the tibia and/or the posterior proximal brim or other protuberances. Abrasions are often caused by poor suspension or loose socket fit. Check and correct. If neglected skin breakdown will become more acute leading to ulceration or cysts.

10) **Haematoma** will result when trauma has been induced to the residual limb long enough to leave bruising and blood mass within the tissue. The residual limb is usually hot, firm, red and sensitive. Prosthetic use becomes impossible and rest with stump bandaging should be the treatment. Call in a physician and re-check prosthetic fit after the haematoma has absolved.
11) **Suspension.** The importance of good suspension cannot be overemphasized. The best fitting socket and a perfectly aligned prosthesis will cease to be such if the suspension is not adequate, often leading to a chain reaction of prosthetic problems.

12) **Axial Torque,** or rotation within the socket, occurs if the residual limb is not securely fitted in the socket, or toe in or out is incorrect causing twisting between skin and socket interface. Amputees should also be discouraged from turning on the prosthesis during loading if possible. A rotator may be of some benefit.

13) **Length of prosthesis.** Before making changes, check the socket fit. The residual limb may have atrophied causing sinking. Oedema build up or poor use of the prosthesis may prevent the residual limb from fitting into the socket, causing lengthening on the amputated side.

14) **Shoes.** A so called good, sturdy walking shoe should be discouraged for prosthetic use since it will impair foot function and create undue forces on the residual limb.

A light weight, flexible rubber soled shoe that is laced and has a firm heel counter lends itself well for an amputee.

15) **Other considerations**

Patient education and **well planned regular follow-up service** is the best way to avoid prosthetic problems or at least keep these problems under control. Follow up in a clinical. Setting with back up from the surgeon-physician, physiotherapist, occupational therapist and nurse.
SECTION - 8

(ANNEXE)

CUFF SUSPENSION
CUFF SUSPENSION

The cuff suspension system has two functions:

- It suspend the prosthesis on the stump in swing phase.
- It acts slightly against hyperextension of the knee joint during stance phase.

The system consists of:

- a cuff, which is positioned just proximal to the femoral condyles;
- the tabs that are attached to the socket and act as suspenders;
- the yoke which serves to transmit the tab tension to the cuff.

Cuffs can be prefabricated or made individually. It is always important that the angular relationship between the cuff and tabs remains the same. The buckle is located on the lateral side.

To determine the attachment points for the tabs on the socket a line is made between the middle of the patella tendon and the posterior wall. The middle of this line is marked. The tabs should be positioned 1 cm posterior and 1 cm proximal to this point.
To determine the attachment points for the tabs on the socket, a line is made between the middle of the PTB and the posterior wall. The middle of this line is marked.

The tabs should be positioned 1 cm posterior and 1 cm proximal to this point.

It is important that an imaginary line between the two attachment points is horizontal.
When the prosthesis is tried on the patient, the position of the tabs should be checked.

Observe the patient slowly flexing the knees to sit down. The tabs should maintain tension over a range of approximately 60 and then relax to allow the stump to withdraw slightly from the socket with the knee flexed 90°.
SECTION - 9

(ANNEXE)

LOCATING MECHANICAL KNEE JOINT
(LOCATING MECHANICAL KNEE JOINT CENTRE FOR A PTB PROSTHESIS)

The anatomical knee joint is a Multi axis joint, with very complicated movements when the knee moves from flexion to extension.

The femoral condyles roll and slide on the tibial condyles as the knee joint moves.

The amount of sliding and rolling determines the axis of rotation of the knee joint at any instant.

The axis of the joint during different stages of the flexion is illustrated below.
Because the anatomical knee joint is Multi axis and the mechanical joint is single axis, there will be some relative movement between the amputated leg and the prosthesis when the leg is flexing.

The aim is to place the mechanical joints so that they will give the best function and will minimize the discomfort created by the relative movement.

**Effects on relative movement between amputated leg and prosthesis when the mechanical joints have different positions.**

In order to look at what effect a joint position will have on the relative movement, it will be assumed that the anatomical knee joint acts as a single axis joint.

Also it will be assumed that all the relative movement occurs between the thigh and the thigh corset, because the stump is held firmly in the socket.

The following figures shows the theoretical situation in which the socket is held fixed and the stump is not allowed to move in relation to the socket.

With the leg fully extended the upper side bar is parallel to the shaft of femur.

**Mechanical joint above anatomical centre**

As the knee flexes 90 the mechanical side bar tends to:

- move anteriorly on the thigh (distance A)
- be drawn distally along the thigh (distance B)

As a result pressure will be created between thigh corset and thigh posteriorly; and the stump is forced against the anterior part of the brim (area of patellar tendon)
As the knee flexes 90° the mechanical side bar tends to:

- move posteriorly on the thigh (distance C)
- move proximally on the thigh (distance D)

As a result pressure will be created between thigh corset and thigh anteriorly: and the stump is forced posteriorly causing pressure in the popliteal area.

As the knee flexes 90° the mechanical side bar tend to:

- be forced posteriorly with respect to the thigh (distance E)
- be forced distally with respect to the thigh (distance F)

As a result pressure is created anteriorly between the corset and the thigh; and the stump is forced against the anterior part of the socket brim.
**Mechanical joint behind anatomical centre**

As the knee flexes 90 the mechanical side bar tends to:

- be forced anteriorly with respect to the thigh (distance G )
- move proximally with respect to the thigh (distance H )

As a result pressure is created posteriorly between corset and thigh; and the sump is posteriorly causing pressure in popliteal area.

As the knee flexes 90 the mechanical side bar will tend to:

- be drawn distally on the thigh (distance I )
- no tendency for the bar to move anteriorly or posteriorly.

As a result the thigh corset tends to pull the stump anteriorly causing pressure on the patellar tendon.

**Mechanical joint on anterior 45° diagonal**
As the knee flexes 90° the mechanical side bar will tend to:

- move anteriorly with respect to the stump (distance J)
- no movements distal/proximal.

As a result pressure will be created between the corset and thigh posteriorly.

**Best mechanical relationship between Joint axis and Knee axis.**

When the side bars are attached to the thigh corset, then movement of the side bars will not happen but movement will happen between the stump and the socket.

There are two situations where relative movement is specially important:

1- when the amputee sits.

2- when the leg is swinging through in swing phase.

**1- when the amputee sits.**

Joint movement should draw the stump out of the socket, and move it forward so that there is no pinching of the skin between the socket and thigh corset.

If it is assumed that the amount of upward and forward movement should be the same, then the joint position should be directly above the anatomical joint centre.

**2- when the leg is swinging through in swing phase.**

There should be little or no movement between the stump and socket for swing phase control. Therefore the mechanical joint should be close to the anatomical joint centre.
In order to have the best function both when the patient is sitting and during swing phase, the mechanical knee joint should be positioned just slightly above the anatomical joint.

All the foregoing analyses are based on consideration that the anatomical knee joint is single axis. Since the anatomical joint is in fact Multi-axis, then ideally mechanical joints should be designed to match the anatomical joint. But experience has shown that the single axis joints can be positioned accurately enough when certain procedures are used.

The procedure for finding the location of the mechanical knee joint is to mark the Medial Tibial plateau during the casting procedure.

The mechanical joint will be placed 2 cm above the medial tibial plateau, and 1/3 anteriorly from the posterior border of the knee.

When positioning the mechanical knee joints it is very important that the joints are positioned:

- Parallel to each other in all planes.
- Parallel to the posterior wall of the socket when looking down into the socket.
- Parallel to the ground and the posterior wall when looking from the back.
Typical relationship between socket, joints and thigh corset.

**Rear View**

- Posterior wall
- Level of Patellar Tendon Protuberance
- Parallel

**Top View**

- Patellar Tendon Protuberance
- Midpoint
- Posterior brim

**Side View** (Knee Flexed 90°)

- 5.5 cm
- 2.5 cm Clearance
- Midpoint
SECTION - 10

(ANNEXE)

THE BK ALIGNMENT COUPLING
THE BK ALIGNMENT COUPLING

The basic purpose of a BK alignment coupling is to allow the prosthettist to change the relationship of the socket to the foot during the dynamic alignment procedure. This relationship is in terms of height, angulation and location (anteroposterior and mediolateral).

The BK 100 Alignment Coupling

Before the popular use of the modular endoskeletal system, this alignment jig was the most commonly used for the initial set up and fitting of the prosthesis.

This particular alignment coupling has essentially three parts:
1) the adjustable coupling
2) the foot attachment plate
3) the pylon tubing.

The B/K 100 alignment coupling offers the prosthettist a maximal amount of adjustability in both sagittal and coronal planes. These adjustments include shifting of the socket medially, laterally, anteriorly or posteriorly and tilting of the socket in the same four directions.

The height of the leg can be adjusted in approximately 1 cm increments by inserting any one of a number of pre-cut pylon tubes.
Tilting and shifting of the sockets of the sagittal and coronal planes are accomplished by means of four adjustable screws: one medial, one lateral, one anterior and one posterior. It is very easy to shift the socket without losing the tilt and vice versa.

Although the advantages of this alignment coupling are obvious, there are disadvantages, such as:
1) weight
2) require a special home-maid adaptor to be used with other than SACH foot;
3) tilting of the socket does not occur at an ideal location. Since the socket tilts from the distal end of the stump and not at the centre of the residual limb, which would be ideal, a compensatory shift in the opposite direction of the tilt must be done during the dynamic alignment.

The B/K 100 Alignment Coupling is an excellent device for dynamic alignment, but it does have certain drawbacks, as do most other alignments couplings.
Otto Bock Modular System

The Otto Bock modular endoskeletal system for the trans-tibial prosthesis consists of a foot base plate with connector pylon and, at the opposite end of the pylon, a second connector with a pyramid plate, connected to a wood block for socket attachment.

The alignment changes are achieved at the connector just above the foot and just below the socket. If only one coupling is adjusted (this may be at either the socket or foot), a tilt is achieved, mediolaterally or anterior-posteriorly. If both couplings are adjusted, the distal coupling in the opposite direction from the proximal coupling, a shift is achieved. After such an adjustment, the pylon is no longer vertical.

This system may be used for dynamic alignment only, or may be used for permanent alignment and given an external cosmetic finish with a shaped foam cover.

When this is complete, and the shoe is on the foot, the pylon should be vertical in both planes ready for static fitting or alignment.

Tilt of socket
Shift of socket

Loosen screw → Tighten screw → Loosen screw

Tighten screw → Loosen screw → Tighten screw

Lateral shift of socket Anterior shift of socket
ICRC BK Alignment Components
REFERENCES


3. Lower Limb Prosthetics, 1990 Revision, New York University Medical Center.

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