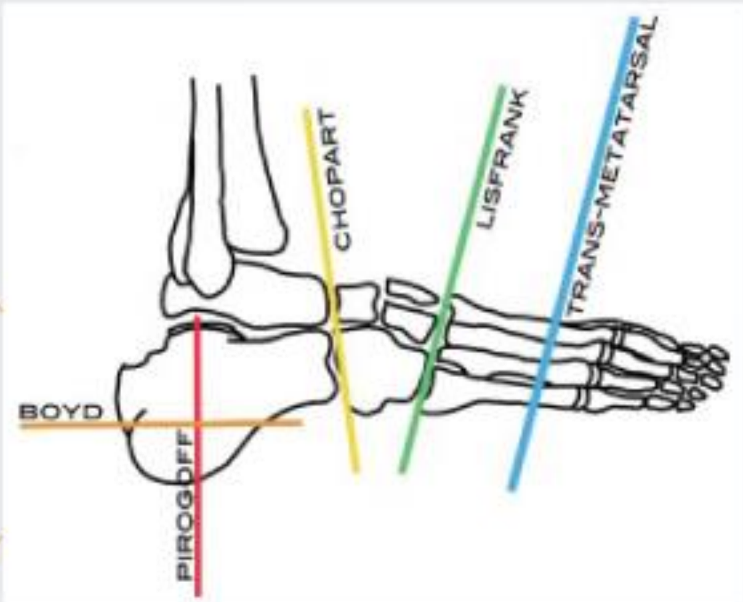
Partial Foot Amputations

Specialized Course in Orthotics and Prosthetics



WWW.SCOPE.COURSES

CONTACT@SCOPE.COURSES

SCOPe
Specialized Courses in Orthotics and Prosthetics

INTRODUCTION

This document contain all the materials our teacher used for the SCOPe course called *Partial Foot Amputations.*

Official name Subject: **Partial Foot Amputations - SCOPe**

Course code:

Credit weight:

This subject consist of following materials:

- Study notes
- Video lessons
- Assignments/Exercises (if applicable)
- Quizzes (if applicable)

Lessons are opened weekly on the internet platform. Video lessons and presentations are not included in this document. Therefore, links are attached in order to download the rest of the learning materials.

TABLE OF CONTENTS

L01: ANATOMY OF LOWER LIMB AND FOOT

General objectives

- Review on lower limb amputations
- Surgical techniques

Introduction

The human leg is the entire lower extremity or limb of the human body, including the foot, thigh and even the hip or gluteal region. In order to avoid confusion, the term "leg" is not commonly used in anatomy, it is more correct to use the term lower limb.

Lower limbs are used for standing, walking, running, and other activities of daily life and constitute a significant portion of a person´s mass. The partial or complete loss of the lower limb can have severe effects on locomotion.

In this lecture we are going to see the main amputation levels and its landmarks or references for prosthetic fitting.

Bony structure of the lower limb

In the following picture (Figure 1) the main structures of lower limb skeleton can be observed

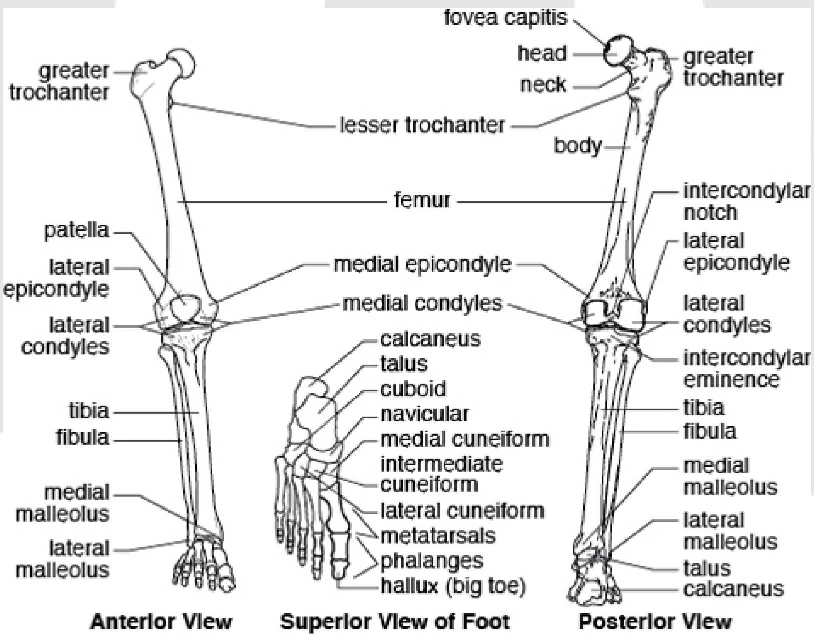


Figure 1: Lower limb osteology

Muscles

The muscle makes up the bulk of the soft tissues of the residual limb. A muscular, well-padded, and balanced residual limb (stump) is less prone to chronic pain. Maximum retention of functioning muscles is essential to provide the residual limb with effective strength, size, shape, circulation, metabolic exchange and proprioception. Proper muscle function depends on the anatomic origin and insertion of the muscle. Without fixed resistance against which a muscle can forcefully contract, progressive weakness and atrophy uses to develop.

There are 4 types of muscle stabilization after an amputation

- ***Myofascial Closure**:* This procedure encases the bone and transected muscle by simply closing the outer fascial envelope over the top of the muscles. This does not effectively stabiliz e muscle nor adequate distal attachment of the muscle to the bone. This technique is used primarily when severe ischemia prevents more effective distal muscle fixation.

-***Myoplasty:*** In most diaphysial amputations, which includes most transfemoral and trans tibial amputations, the muscle bellies are transected, this makes it more difficult to attach the muscle to the bone. The surgeon brings the muscles over the end of the bone and sews them to opposing muscle groups. Unfortunately in this technique the muscle is sliding back and forth over the distal end of the bone and often creates bursal tissue and can cause severe pain. Such a scenario is easy to detect on physical examination, as the movement and accompanying crepitance is easy palpable over the end of the bone. A simple myoplasty is not usually recommended, because it is important to secure the tissue directly to the bone, and this leads us to the next muscle stabilization.

-***Myodesis:*** (Figure 2) In Myodesis, the muscle groups are attached directly and securely to the periosteum or the bone itself. The deepest layers of muscle are secured to the bone, and the superficial layers are sewn to each other as a myoplasty. At the end, the myofascial envelope is closed over the top of the muscular reconstruction.

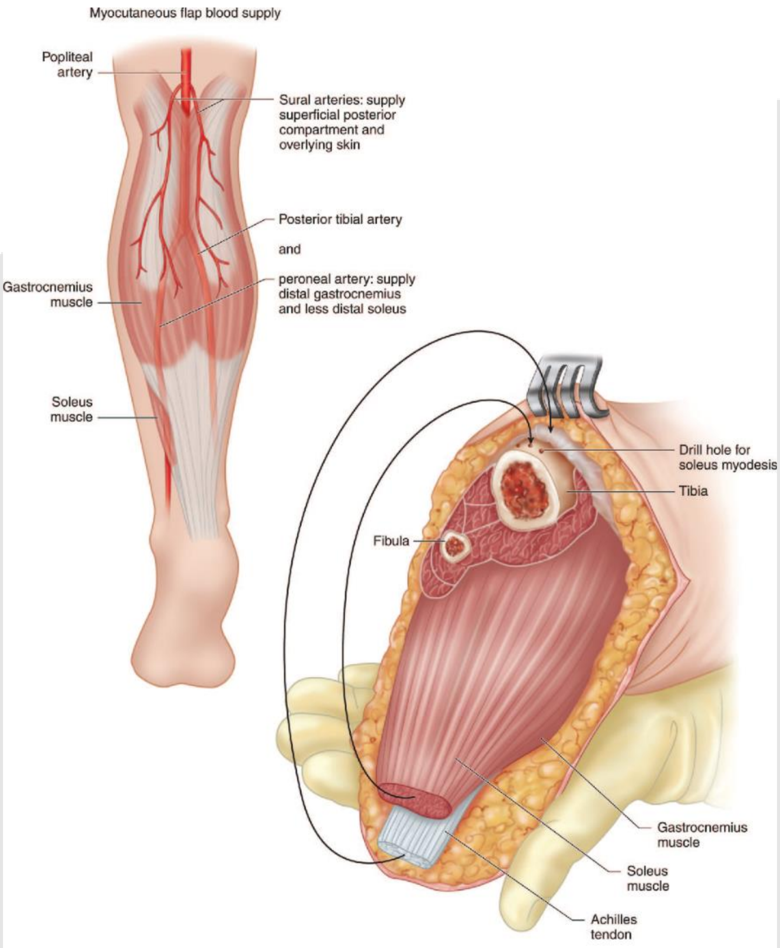


Figure 2: Myodesis muscle stabilization in a Transtibial amputation

Some advantages and disadvantages of myodesis:

Advantages:

- stronger attachment
- maximize muscle strength
- less muscle atrophy
- prevents the joint contraction

Disadvantages:

- It is contraindicated in patients with severe peripheral vascular diseases (PVD), because the blood supply to the muscle may be compromised.

-***Tenodesis:*** (Figure 3) It involves the firm distal attachment of the severed tendon to the bone and is the most physiologic and effective way to stabilize muscle, but it is often not possible anatomically. It is only possible when the muscle belly is not transected and the tendon is intact. This is most commonly used in disarticulations, in which the patellar tendon is secured to the origin of the cruciate ligaments on the distal femur. This technique should be used when anatomic circumstances permit it.

Figure 3: Syme amputation and stabilization of the heel pad with achilles tenodesis to the tibia

You can review muscles in detail in an interactive way in the following link http://www.innerbody.com/anatomy/muscular/leg-foot, that will help you to review your muscle knowledge. But here is also additional material on the platform to revise Anatomy.

Amputation levels

This term is used to describe the location at which the body part is amputated. Lower extremity amputation is one of the oldest known surgically performed procedures. Amputation levels developed through tradition, as surgeons passed down knowledge and lessons learned about specific techniques, the best ones provided the fastest healing, as well as a residual limb that was well padded and could best retain its physiology. Specific amputation levels were determined by how well they accommodated prosthetic fitting. Nowadays surgeons practice well known techniques to make possible the best prosthetic fitting in each case. According to this we have the following main amputation types:

Partial foot an ankle disarticulation (AD and PF)

Even if in this course we are going to focus on partial foot, we are also going to revise the ankle disarticulations.

Amputations and disarticulations within the foot offer important advantages over more proximal levels, including direct weight bearing with proprioceptive feedback along normal neural pathways. The degree on which full walking function can be restored is relative to the loss of forefoot lever length and associated muscles.

Longitudinal rather than transverse amputation should be the goal whenever functionally feasible. Narrowing the foot rather than shortening it greatly simplifies postoperative shoe fitting. All well vascularized tissue should be saved for secondary reconstruction regardless of configuration to assist in preserving foot length for maximum function.

To absorb the shear and direct forces generated during gait, the soft-tissue envelope must be mobile, this is ideally formed of plantar skin, subcutaneous tissue, and investing fascia. Adherence of skin directly to bone must be minimized to prevent ulcerations.

Toe disarticulations and amputations (Figure 4) are the less invasive technique and subsequently the less affective to the gait, because the entireness of the windlass mechanism in most cases is preserved. Interphalangeal disarticulations have a wide range of difficulties according to which toe is affected. E.g. Hallux valgus deformity in the case of the second toe disarticulation at the MPT (metatarsophalangeal) joint.

Figure 4: First toe disarticulation

The main landmarks or reference points in this level are: Distal end of phalanx or metatarsal head, adjacent toe if existing.

-In ray amputation (Figure 5 & 5.1), a toe and part or all the metatarsal is removed. In case of massive infection, the metatarsals can be divided obliquely cutting somewhat longer with progression toward the first ray. This strategy will retain both rollover function a full foot length.

The main landmarks or reference points in this level are: Distal metatarsal end and adjacent rays

Figure 5: Amputation of the fourth metatarsal

Figure 5.1: Picture B shows amputation of the first ray and toe, Picrute C shows the X-ray of the same patient – First ray ampuation

-**<u>Transmetatarsal amputation (figure 6)</u>** should be considered when two or more medial rays or more than one central ray must be amputated. It is a trhoug-bone amputation of the metatarsal bones.

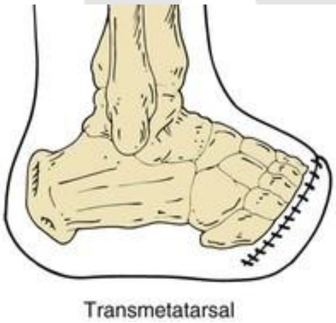


Figure 6: Transmetatarsal amputation level

The main landmarks or reference points in this level are: Distal metatarsal end and adjacent rays and medial and lateral malleolus and calcaneus

-**<u>Tarsometatarsal (Lisfranc) disarticulation</u>:** (Figure 7 and 8) This is a disarticulation at the tarsometatarsal joint described by Lisfranc in 1815. This disarticulation represents a major loss of forefoot length with a corresponding decrease in barefoot walking function.

The main landmarks or reference points in this level are: All 3 cuneiforms, cuboid, medial and lateral malleolus and calcaneus

-**<u>Midtarsal (Chopart) disarticulation:</u>** (Figure 7 and 8) This is through the talo-navicular an calcaneo-cuboid joints. As in the Lisfranc disarticulation this is most useful in trauma or tumor. Although this allows direct end bearing, it has no inherent rollover function, anyway the amputee can walk without a prosthesis for short distances, however the prosthesis is essential for functional walking.

The main landmarks or reference points in this level are: talus, medial and lateral malleolus and calcaneus

Figure 7: Lisfranc and Jopart amputation levels

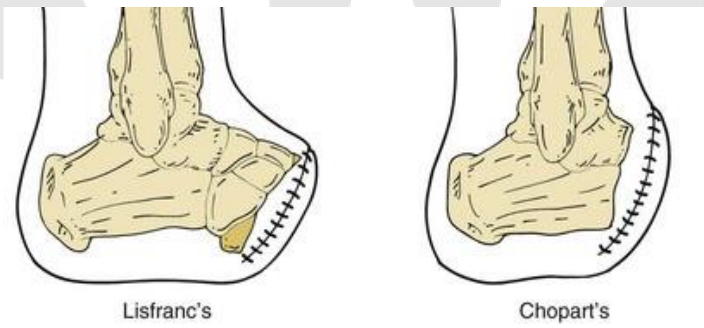


Figure 8: sagital view of Lisfranc and Chopart amputation levels

Syme ankle disarticulation: (Figure 9) This technique described in 1843 by James Syme is a disarticulation through the ankle joint with preservation of the heel flap to permit weight bearing on the end of the stump and allow walking without prosthesis for short distances. The advantage of this method is that it provides enough vertical clearance to fit a variety of prosthetic feet. It is essential to maintain the heel pad in a central weight bearing position beneath the tibia. Careful initial prosthetic positioning of the heel is very important inside the prosthetic socket and ongoing adjustments/refittings as necessary. The goal is to prevent the heel pad to migrate. It could even happen within the prosthesis, leading to painful weight bearing and ulceration.

The main landmarks or reference points in this level are: medial and lateral malleolus and tibia crest.

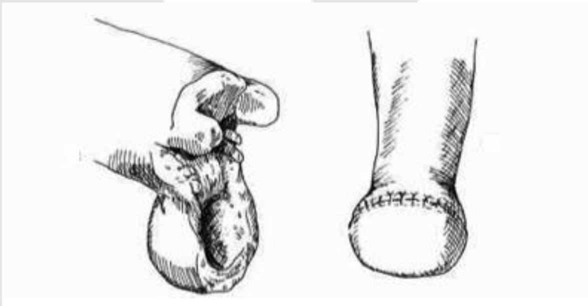


Figure 9: Syme amputation

The Pirogoff ankle disarticulation (figure 10) the procedure is as follows; After mid-tarsal disarticulation, the talus is removed. The calcaneus is then sectioned in the frontal plane (vertical) and its anterior portion is discarded. The distal tibia is divided transversely through the cancellous metaphysis and the calcaneus is then rotated forward 90º to contact the denuded inferior tibia. The two bones are then fixed. A disadvantage of the original Pirogoff method compared with the Syme procedure is that the thinner skin over the posterior aspect of the calcaneus becomes weight bearing. The original impetus for development of the Pirogoff procedure and its variants was to provide a stable heel pad with less limb-length discrepancy to allow a comfortable barefoot gait without a prosthesis by simply using a boot (This procedure was used in Europe over many decades for injuries sustained during wars).

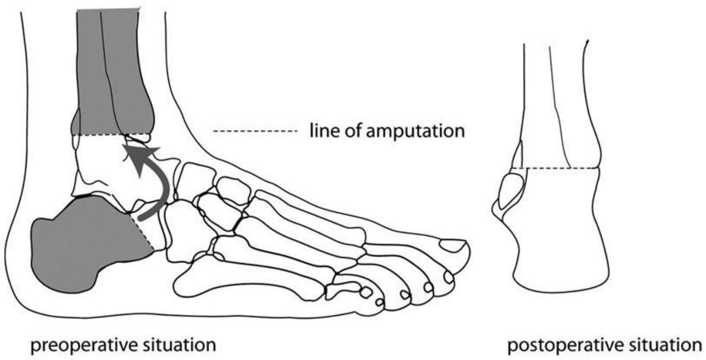


Figure 10: Surgical procedure and postoperative situation

Boyd´s ankle disarticulation: This Amputation level is an ankle disarticulation like the pirogoff amputation. In fact, it could be defined as a variation of the previous one. It is the removal of the talus and fusion of the tibia and calcaneus. Unlike in Pirogoff, a horizontal cut is done in the calcaneus to fuse it with the tibia. (Figure 11)

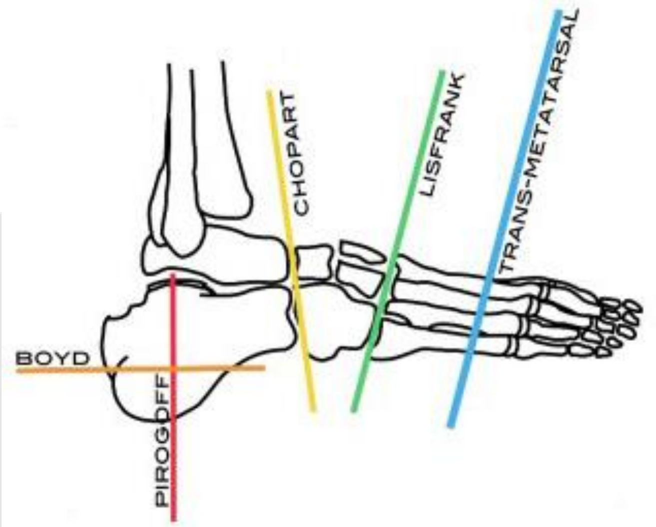


Figure 11: Revision of main amputation levels in the foot including Boyd and pirogoff ankle disarticulations

Resources:

- Wikipedia, http://en.wikipedia.org/wiki/human_leg
- Atlas of amputations and limb deficiencies: Chapter 2 " general principles of amputation surgery" chapter 24 "amputations and disarticulations within the foot" chapter 40 "knee disarticulation: surgical management" chapter 42 "transfemoral amputation: surgical management" chapter 44 "hip disarticulation and transpelvic amputation: surgical management"
- Ottobock images.
- Decision making before surgery - Lower limb amputation post-op management. Lecture by Dr. Wong Nang Man Raymond (United Christian Hospital)
- www.cliffsnotes.com images.

Video Lectures and Power Point presentations

Lesson_1	Lower Limb – Video 1
	Lower Limb – Presentation 1

L02: BIOMECHANICS OF PARTIAL FOOT AMPUTATION AND ANKLE DISARTICULATION

General objectives

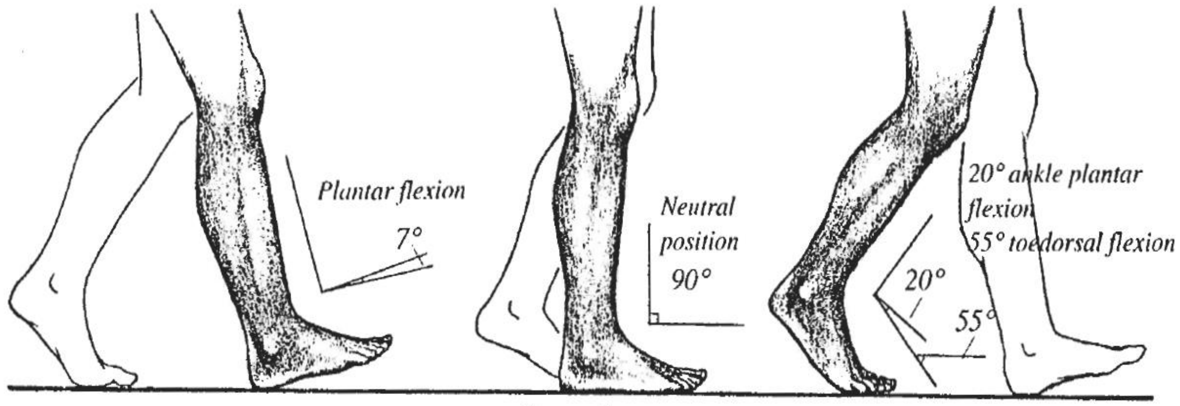
- Learn and understand the biomechanical features of the different partial foot amputation levels

Normal Biomechanics of the foot

The normal foot is an extremely complex structure; the detailed function is still only partially understood. (David N. Condie 2004). In this lecture we are going to analyze the ground reaction forces generated during walking and its effect on the residual foot. First we are going to review the gait phases and how a foot behaves during normal walking to better understand the forces according to each amputation level.

It is important to remark that the angle values given below are average amounts and they can vary according to the author.

Stance phase

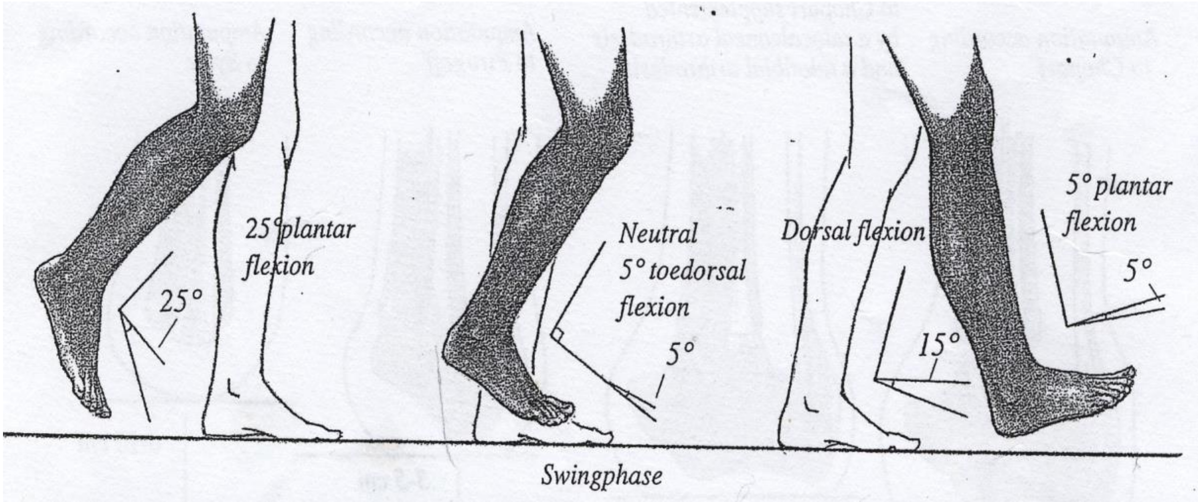


Stancephase

After initial contact the ankle joint goes into a plantarflexion of about 7°. This movement occurs mainly in the ankle joint (i.e.: talocrural joint). The high impact from the GRF is reduced by knee flexion and plantar flexion of the foot. This is one reason why it is desirable that partial foot amputees, who wear prosthesis, also have the possibility to plantar flex in the ankle at heel-strike. During mid-stance, the foot is in neutral (i.e. 90 degrees in relation to the shin). The bones in the foot sink downwards towards the ground surface which stabilizes the joints before initial swing.

During preswing to initial swing, the foot will achieve approximately 20° plantar flexion in the ankle joint, and in the metatarsophalangeal joints the dorsiflexion at toe-off is approximately 55°.

Swing phase



At the start of the swing-phase, the foot plantarflexes another 5° to reach approximately 25° during toe-off.

During mid-swing, the foot is back in a neutral position and with only a 5° toe dorsiflexion to avoid toe drag. These figures are valid during walking on flat surfaces, and allow a minimum amount of energy consumption.

Biomechanics in partial foot amputations

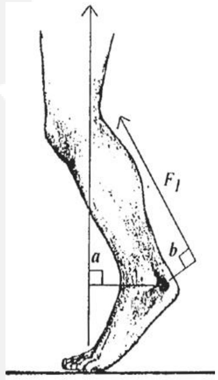
A prosthesis that immobilizes the range of ankle joint movement will transfer that immobility to the proximal joints, resulting in increased hip and knee flexion during midswing, to avoid toe drag. But even with a below ankle prosthesis, it can be very difficult for a partial foot amputee to dorsiflex the remaining foot because of muscle imbalance, which will also result in increased hip and knee flexion. All joint motion increases with increased velocity. Therefore, for partial foot amputees, it becomes increasingly difficult to increase velocity if they are fitted with a prosthesis that reduces any joint motion.

The toe-off should occur under the hallux area. It is very important that this is also the case for partial foot amputees, and this should be reproduced in the prosthesis. If the toe-off occurs more laterally there will be a medial/lateral imbalance in the knee, which will also create rotational movement during swing phase. This is commonly seen among partial foot amputees. This is due to the tendency for a varus position of the lower limb due to muscle imbalance. The foot is normally 5° to 15° externally rotated in relation to the line of progression. The right external rotation stabilizes the lower limb in a medial-lateral position during gait. The position of the foot is of great importance for the biomechanics of the leg. As a result, a partial foot amputation subsequently affects the whole biomechanics of the leg.

The internal and external forces

It is important to differentiate between the external and internal forces, which affects the balance of a joint. The magnitude of the external forces is related to, for example: how heavy a person is (weight), how fast the person moves (velocity) and the distances between the center of the joint and the ground reaction force (length). The internal forces are controlled by the muscles and ligaments. The magnitude of the internal forces is related to the external forces, the position of the ligaments (relative to the center of the joints), and if the body accelerates, decelerates, or is kept at the same speed.

Let us assume that a body is in balance. If for example, a person would stand completely still on their toes, the following equation can describe the forces acting around the ankle Joint.



Assume in fig. 3, that a person weights **70 kg** and stands still on his toes, on one leg. We call **Fg** to body weight x g. The lever arm to **Fg**. is then **9 cm** (the distance between the direction of the weight and the ankle joint centre) and the lever arm from the ankle joint to the mid-position of the Achilles tendon insertion is approximately **3cm.**

From the equation of Moment = Fg x a = Fi x b

Fg = body weight x g

If body weight = 70kg, and g= 9.81N

Then Fg **is 70kg x 9.81 N = 687N.**

The forces which are acting through the joint are even greater and can be calculated from the sum of the external and the internal forces

From the equation Fi (internal force) = $\frac{Fg*a}{b}$

Then: $687N * 9 = 2061N$

Internal muscle force **Fi =2061N**

The forces which are acting through the joint are even greater and can be calculated from the sum of the external and the internal forces which is **687N + 2061N = 2748N**

Now it is visible that the body is affected by very high forces which are body internal forces in the muscle and ligament structures as well as from external forces.

Note: *The short lever arm **b** compared the long lever arm **a** effects the internal muscle power **Fi**. (Internal force) to be many times greater than the external ground reaction' force **Fg**.*

Biomechanics in Partial Foot Amputations (PF) Prostheses

Socket Forces in Partial foot and Ankle disarticulation Prostheses

The loss of normal foot function after an amputation is progressively more severe the more proximal the site of amputation. The extent of the loss may be summarized as relating to three primary aspects of the foot function, load-bearing capacity, stability and dynamic function. Ironically the forefoot ground reaction force has been shown to increase following partial foot amputation because of the reduced forefoot lever arm when the patient attempts to walk in a normal manner.

During gait, the shift in the GRF will lead to changes in socket pressures and magnitudes of the forces acting on a stump. These changes will again vary according to the amputation level and socket design. The two critical incidents in gait occur at heel contact and preswing.

Amputation of the Toes

When surgery is confined to the toes, prosthetic forefoot loading, which is significant after heel off, is simply being transferred directly onto the metatarsal heads. This action results in an external moment that will, unless resisted, cause the prosthesis to rotate (in the direction of dorsiflexion) relative to the residual foot. An amputation of the big-toe predominantly requires an unloading of the plantar surface of the amputation area, which can be achieved with a foot-bed that is combined with filler to improve the third-rocker during gate, also to minimize pain and misalignment.

Due to the loads and the forces the residual foot has to resist, during standing and walking are important factors that determine the design and choice of materials.

Amongst toe amputees, the foot has the largest pressure around the amputation area at toe off. As seen in the picture on the right, During push off, the moment will create forces at the plantar surface of the foot at the metatarsal heads and the dorsum of the foot (due to the shoe)

At heel contact, the moment generated by the ground reaction force will create forces at the heel and the dorsum of the foot (created by the shoe) See figure on the right.

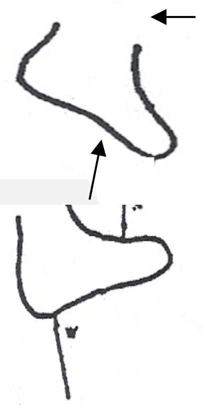
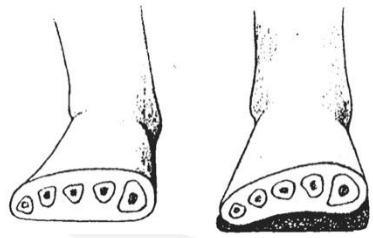


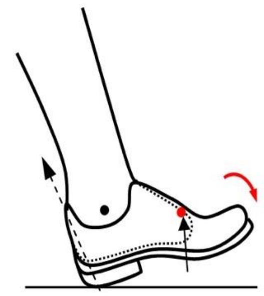
Figure 4

Transmetatarsal amputation

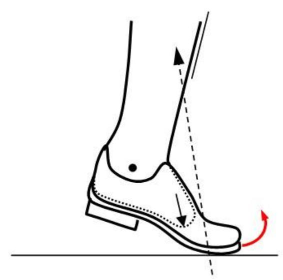
The removal of the metatarsal heads means that there is practically no longer an anterior area onto the plantar surface of the residual foot, to transfer the forefoot ground reaction force, therefore the rotational stability of the stump/socket interface needs special attention. The aim is to use the remaining surface of the longitudinal arch of the foot as a loading bearing area. The prosthesis will need to generate the force to resist the external moment that tends to rotate the prosthesis during gait. An amputation through the metatarsal bone requires a prosthesis which incorporates the heel to counter the forces at the heel strike and push-off. A reduction of the weight-bearing surface creates increased pressure on the remaining foot. Because of an imbalance between the plantar and dorsiflexor muscles, there is an increased plantarflexion and a tendency for supination as the level becomes more proximal. If supination is present, the insole may accommodate this with a medial wedge for support, as seen in the picture on the right.



The highest pressure on the distal end of the stump is created just before toe-off. If there is increased pain at toe-off, the patient will react to the pain, and normally compensate by lifting the foot into swing phase before the third rocker, and this leads to an asymmetric gait. A stiffer sole will move the mechanical 'roll-over edge' forward, placing it closer to the natural place, but this stiffness will also generate higher pressures against the distal end of the stump during toe off. Because of this reason, for sensitive stumps, a more flexible sole is recommended.



Forces at loading response



Forces at push-off

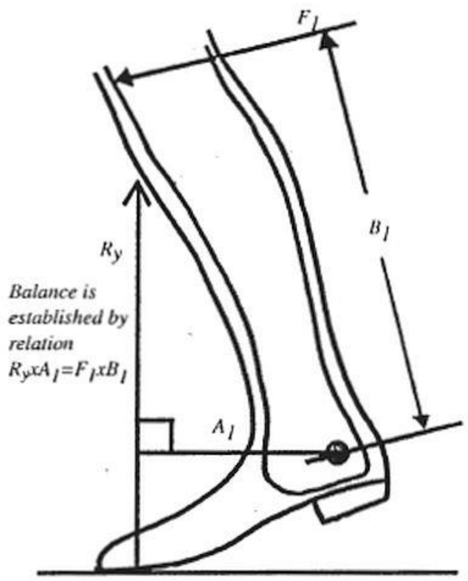
During heel strike, moment generated by ground reaction force will create socket–stump forces at the anterior distal dorsum of the foot created by the shoe, while at push-off the moment will create stump-socket forces at metatarsal ends and anterior stump (see pictures below)

Lisfranc amputation

The Lisfranc amputations offer several prosthetic alternatives depending on the functional needs of the user. At the Lisfranc amputation level, all of the metatarsal bones have been removed. Approximately 50% of the original supporting area is remaining.

The loss of function at this amputation level must be replaced during gait, particularly in the phases of midstance and toe-off. The lost surface area must be restored to improve balance, an equinus position due to muscle imbalance must be avoided, and the tendency for supination due to the Achilles tendons disposition towards pulling medially must also be considered.

To minimize stump-socket forces, it is important to keep in mind the relationship between the length of lever arm, when the ankle movement is fixed, and its influence on the external forces on the socket. For example in the figure on the right, a stiffer foot without rocker bar results in a longer lever arm **A1** and stronger forces **F1**, against the shin. The length/height of socket B1, on the shin also affects the dimension of force **FI.**

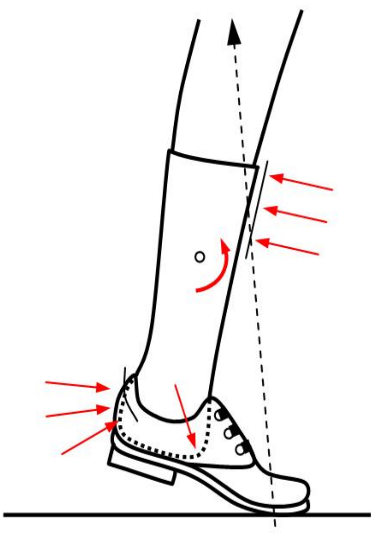


The stump/socket at heel strike generated by ground reaction moment will occur at the dorsum of the anterior dorsum of the foot created by the shoe.

On the other hand, at push off the moment will create forces at the calcaneal and anterior distal surface of the stump for low profile design, and for high profile design, socket forces transferred to proximal anterior brim of socket and posterior at the calcaneal

Chopart amputation

In Chopart amputation, the stump and shank has a tendency for a varus deformity. The varus tendency of the stump creates a lateral deviation of the knee during walking. To minimize this tendency, the foot plate should be placed as far laterally as possible and aligning the foot in slightly more external rotation. Also shoe adjustment such as rocker bar placed just proximal to MTP joint and the use of lateral flare may be added to reduce supination tendency. Stiffen the lateral border of the sole and good containment over the heel will limit movement and it is believed to reduce varus moment and to minimize movement between the socket and limb.



Biomechanical principles are what determine the socket design. It is important to distribute pressure as much as possible, particularly in areas where high pressure occurs.

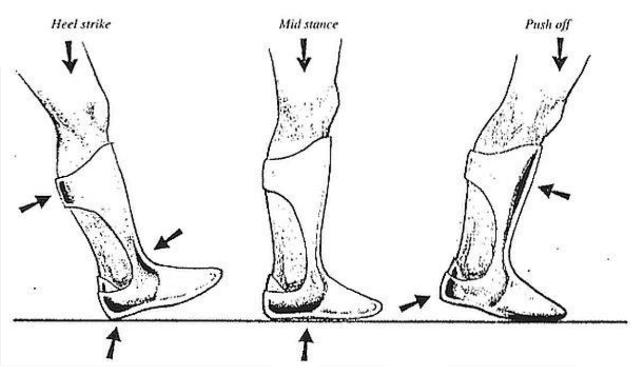
Forces are studied during initial contact, midstance and toe-off. If the ankle joint is rigid, which eliminates internal muscle forces that act over the ankle joint, the leg can be regarded as a rigid stump with a very long lever arm.

The largest forces acting on the stump at heel-strike are around the calf muscle, around the heel, and the anterior-distal area on the shin.

Through midstance, the load is predominantly located directly under the stump, which is tolerated well as the stump allows for total end- bearing.

At toe-off, the largest load is concentrated on the dorsal surface of the heel and the proximal surface of the shin. (see picture on the right)

It is important to remember that the load on the shin is about four times greater than the load on the back of the calf, depending on the length of the forefoot and its stiffness. Therefore, as the socket is built higher up on the shin, the forces are distributed better, and the result is less pressure on the shin.



Forces at stance fase

Biomechanics in Ankle Disarticulation (AD) Prostheses

The ultimate goal for individuals with ankle disarticulations is to return to the highest level of function possible. A complete understanding of the mechanics and biomechanics of gait is necessary to achieve this goal.

Obtaining appropriate alignment, although somewhat difficult in the ankle disarticulation prosthesis, is critical to achieving an appropriate gait pattern. The complicating factor is that the limited space between the socket and the foot does not permit use of an adjustable alignment unit. This forces the practitioner, to "cut and paste" the position of the foot until an appropriate socket/foot relationship is achieved.

Initial Contact to Loading Response

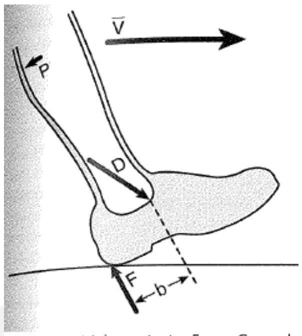


Figure 12 Initial contact. F = Ground-reaction force; b = Distance from the ground-reaction force to the center of mass; D = Approximate location of distal forces on the residual limb at this phase of gait; P = Approximate location of proximal forces on the residual limb at this phase of gait; V = Resultant vector force determined by the distance from the ground-reaction force to the center of mass, the speed of walking, the density of the heel of the foot, the density of the heel of the shoe, and the opposing forces at D and P. Should the proximal posterior wall be lowered, the pressure at D will increase significantly to attempt to compensate for the decreased control posteriorly.

The lack of space (from residual limb to floor) inherent in the ankle disarticulation level of amputation, limits the use of certain feet, especially those with articulating ankles. At initial contact, the heel of the prosthetic foot must be soft enough to absorb some of the impact of ambulation yet firm enough to provide adequate forward propulsion of the limb. The knee joint helps to compensate for some of the loss of mal shock absorption by flexing slightly more at initial contact than in normal gait. This increase in knee flexion, also allows for a natural-appearing gait pattern.

As the patient moves from initial contact through the loading response portion of the gait cycle, the center of mass will fall between the heel and the toe of the prosthetic foot, and the ground-reaction force will be posterior to the center of mass. This will cause a torque about the socket in a forward direction. In an effort to control this forward moment of the socket, the knee joint extends and the residual limb presses against the walls of the prosthesis in an attempt to slow the forward progression of the socket. In doing so, the forces on the residual limb are significantly higher in the area of the posterior proximal and the anterior distal aspects of the socket (see figure on the right). The sagittal position of the prosthetic foot relative to the socket and the durometer of the prosthetic heel will have a significant impact on the gait pattern, the magnitude of force on the residual limb, and ultimately the long-term comfort and function of the device.

Loading Response to Midstance

After a period of knee flexion during initial contact, the knee begins to actively extend through loading response. At this phase of gait, because of the lack of true ankle plantar flexion in the prosthetic foot, the knee will extend fully to stabilize the system. This is contrary to normal gait, in which the knee continues to flex at this phase to act as a shock absorber.

The horizontal pressures around the proximal posterior portion of the prosthesis at initial contact decrease during the loading response phase of gait and become more vertical. If the limb is end bearing, the pressures around the distal end shift from anterior to straight distal and then to slightly distal posterior as midstance is completed. The actual location of the distal residual limb pressure when the foot is flat is determined by the foot/socket angular relationship and the amount of proximal anterior support given the residual limb inside the prosthetic device. At this phase of gait, the body is moving forward over the prosthesis and the subsequent pressures within the device are changing considerably. Through loading response, the center of pressure under the prosthetic foot is moving forward as a result of load acceptance onto the prosthetic foot. Consequently, the vertical ground-reaction force is moving from behind the knee to the front of the knee, causing an extension moment at the knee joint (see picture on the right). The effect of coronal-plane foot position is discussed below.

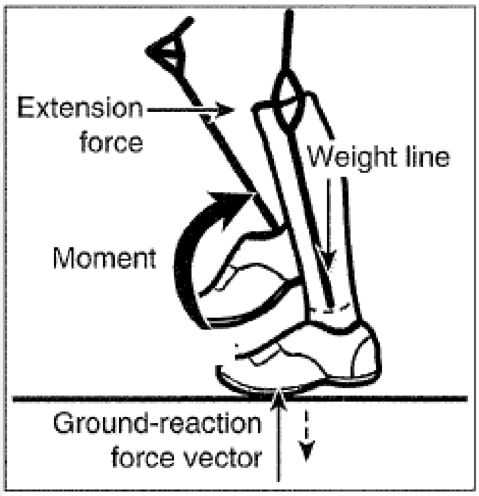


Figure 13 As the patient continues through midstance, the ground-reaction force vector moves anterior to the weight line. This provides an extension moment to the knee and redirects the socket pressures to the proximal anterior and posterior limb.

Midstance to Terminal Stance

As the gait cycle shifts from midstance to heel-off, the knee continues to play an active role in the continuation of a smooth gait pattern by compensating for the lack of range of motion at the ankle. The pressures on the residual limb shift to proximal anterior and distal posterior as the patient tries to overcome the knee extension moment from the ground-reaction force being anterior to the knee joint. The patient must use active knee flexion to overcome these pressures and ambulate comfortably. Peak pressures occur at the anterior proximal portion of the socket during this phase of gait and must be controlled by an appropriate proximal contour and enhanced socket construction. The peak knee extension moment occurs at the beginning of the terminal stance/ preswing phase of gait. The greatest test of the socket's structural integrity will occur at this phase of the gait cycle (See picture on the right).

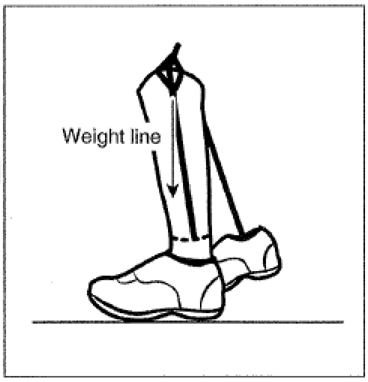


Figure 14 Vertical forces at midstance. Note the socket/foot angle in this example is approximately 85°.

Mediolateral Foot Placement, Angulation and Toe-Out

Mediolateral foot placement should be such that the plantar aspect of the foot is parallel to the floor at midstance and creates a slight varus thrust at the knee. This foot position will keep the pressures of ambulation focused in the pressure-tolerant proximal medial and distal lateral regions of the socket and will result in a natural and comfortable gait pattern. When significant medial bowing of the tibia is present, the foot is placed at the most lateral aspect of the distal socket that is technically feasible. Transverse foot rotation should mimic that of the opposite side (see picture on the right).

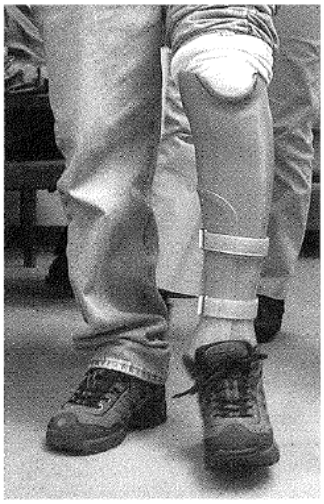


Figure 15 As the patient arrives at mid-stance and shifts the body weight over the prosthesis, the ground-reaction force through the foot will be medial to the weight line, causing a torque about the knee in a varus direction. This figure shows the typical coronal-plane foot placement on an ankle disarticulation prosthesis. Note the valgus appearance of the ankle during swing phase, and the lateral position of the foot on the distal socket.

Ground-Reaction Forces and Energy Consumption

The pattern of ground-reaction forces, centralized in the prosthetic foot, supports the notion that the ankle disarticulation amputee has a normal lever arm for push-off at late stance that accounts for a smooth and energy efficient gait pattern. The ankle disarticulation amputation has been shown to be even more energy-efficient than midfoot amputations. This surprising phenomenon seems to be due to the long limb length and adequate lever arm of the prosthetic foot with an ankle disarticulation prosthesis.

There is little functional disparity between an individual with an ankle disarticulation prosthesis and one with no amputation. Patients with ankle disarticulation prostheses seldom require physical therapy and rarely require hospitalization for prosthetic gait training.

Sources:

1. Partial foot amputation. Bengt Soderberg, Anders Wykman, Roland Schaarschuch Bioorn
2. Clinical aspects of lower extremity Prosthetics (transtibial,Symes and partial foot)
3. Atlas of Amputation and Lower limb Deficiencies. Douglas G. Smith MD, John W. Michael Med, CPO, John H. Bowker, MD (3rd Edition)
4. Partial foot Prosthetics Course Work Manual ICRC (INTERNATIONAL COMMITTEE OF THE RED CROSS)
5. ***GISHIGAKU*** -S, Sawamura.. Page. 167-218. (1988)

Resources:

- Anatomy and Human Movement, Nigel Palastanga
- Gray's Anatomy of the Human Body, Henry Gray
- Clinically oriented anatomy, 7th edition, Keith Mooore et al.

Video Lectures and Power Point presentations

Lesson_2	Lower Limb – Video 2
	Lower Limb – Presentation 2

L03: GENERAL PROSTHETIC PRINCIPLES AND TREATMENT PROTOCOL IN ANKLE DISARTICULATION AND PARTIAL FOOT

General objectives

- To underestand the general implications after foot amputations
- Underestand the loss of functionality after a partial foot amputation

Introduction

Partial foot amputation and ankle disarticulation present advantages and challenges to the patient and prosthetic rehabilitation team. This is due to the preservation of some foot structures, ankle and heel in partial foot amputation, and most of the length of the lower limb in ankle disarticulation. But also an important advantage is added: the distal end bearing capability. The patient with partial foot or disarticulation through the ankle with preservation of the heel pad, permit weight bearing on the end of the stump and the patient is often able to ambulate with or without prosthesis. Because of preservations of heel pad along the normal proprioceptive pathways, gait with ankle disarticulation is more energy efficient than with transtibial amputation.

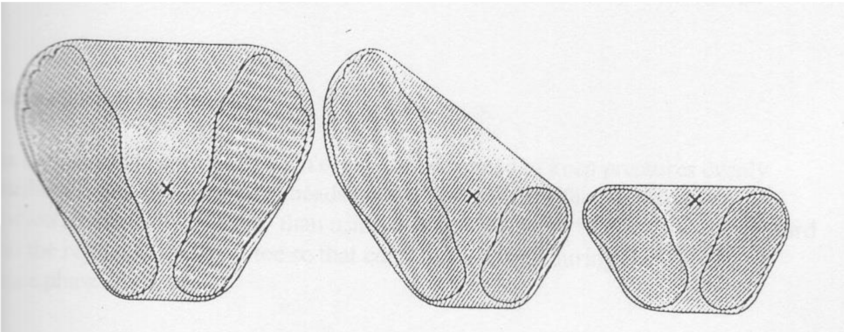
Functional loss and special considerations of the partial foot amputation

Functional loss after foot amputation affects the foot function in relation to *weight bearing capability*, *stability* and *dynamic function.* Any partial foot amputation reduces the *weight bearing area* and in more proximal to metatarsal heads affects the normal longitudinal arch of the foot which eliminates the normal *medial lateral stability* of the foot. As the active flexion of the first metatarsophalangeal joint is lost, eliminates the final *push off* and as a result *dynamic function* will be affected. The following are functional loss which need special considerations.

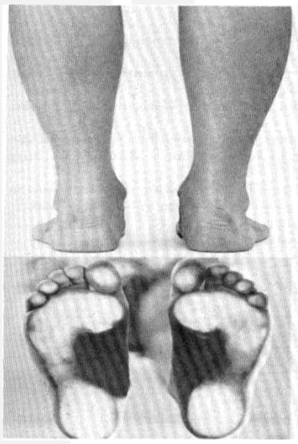
1. Area of support

In normal condition amputation of one or more toes and partial foot amputees may be able to walk for short distance without a prosthesis. Due to reduction of the *forefoot load bearing areas*, the *stability* will also be reduced and pressure on the metatarsal heads will be increased.

The problem of stability becomes even bigger for a bilateral amputees. (See picture below)



2. Weight bearing capability



The normal weight bearing structure has been destroyed during the amputation as the plantar aponeurosis and plantar ligaments have been cut and the longitudinal arch thereby has flattened, resulting in uneven force distribution along the sole of the foot. The removal of metatarsal heads and loss of longitudinal arch result in lack of ability to transfer the forefoot ground reaction force directly to the surface of the stump.

With the majority of patients the weight should be carried through the end of the stump, it is important that pressure is distributed evenly along the full plantar aspect with reliefs for sensitive bony prominences. If end bearing is not possible some weight can be transmitted proximally at the patellar tendon area.

3. Loss of active push off

As the level of amputation moves proximal to the metatarsal heads, as well as the loss of active flexion of the first metatarsophalangeal joint, the action of active push off is lost. This must be compensated in the prosthesis so that some flexion is present at what was the metatarsal-phalangeal joint, (to avoid vaulting) and the prosthesis must provide some sole stiffness to give a rigid lever action of the forefoot during toe off.

4. Muscle imbalance

As the amputation level becomes more proximal more muscles lose their insertions. The stump will end up with very strong plantarflexors that will tend to pull the calcaneus and the stump into a plantarflexion position and with strong invertors/supinators that will tend to pull the stump into an inversion/supination deformity. Also because of the strong action of the plantarflexors, the calcaneus will tend to migrate posteriorly, so that the anterior section of the stump becomes much smaller and the calcaneus "sticks" out posteriorly and creates problems with cosmesis. The plantar flexion and inversion deformity will give a functional longer leg, and will cause too high pressures at the lateral border and the end of the stump.

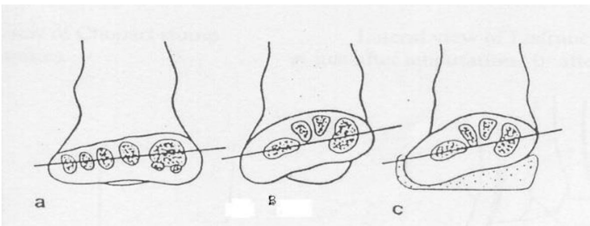
This problem will become bigger as the level of amputation moves more proximal, tarsometatarsal (Lisfranc) and midtarsal (transtarsal or Chopart) levels of amputation represent a major loss of forefoot lever arm with severe equinus contracture if the use of appropriate surgical procedures for restoration of dorsiflexor function and weakening of flexors is not well applied.

The deformities can often not be corrected entirely within the prosthesis so it is important that the surgeon understands the associated problems with these amputation levels and tries to correct and avoid the problems during the operation. In the picture on the right a Chopart amputation where the calcaneus migrated posteriorly.

5. Stump condition

Partial foot stumps will still have the fatty tissue that is covering the normal heel. The majority of the patient's weight should be transmitted through this naturally adapted area. The stumps will mostly have many bony prominences (e.g. lateral process of Calcaneal tuberosity with thin skin cover that must not be exposed to high pressures otherwise callosities may develop)

The mid-foot amputations will further have more complications with an inversion position of the distal/anterior part of the stump. (See illustration below). This must, to some degree, be compensated with a medial wedge.



a. Transmetatarsal amp. b. Lisfranc amp. c. Chopart amp.

6. Donning and Doffing

When an "above ankle" prosthesis solution is used for partial foot amputations, the bulbous end of the stump will give similar problems with donning and doffing of the prosthesis as with the Syme amputation. A push fit solution will not be desirable in this case, as this will greatly compromise cosmesis. Instead, it should be possible to make a removable panel or to leave a section completely opened.

7. Length

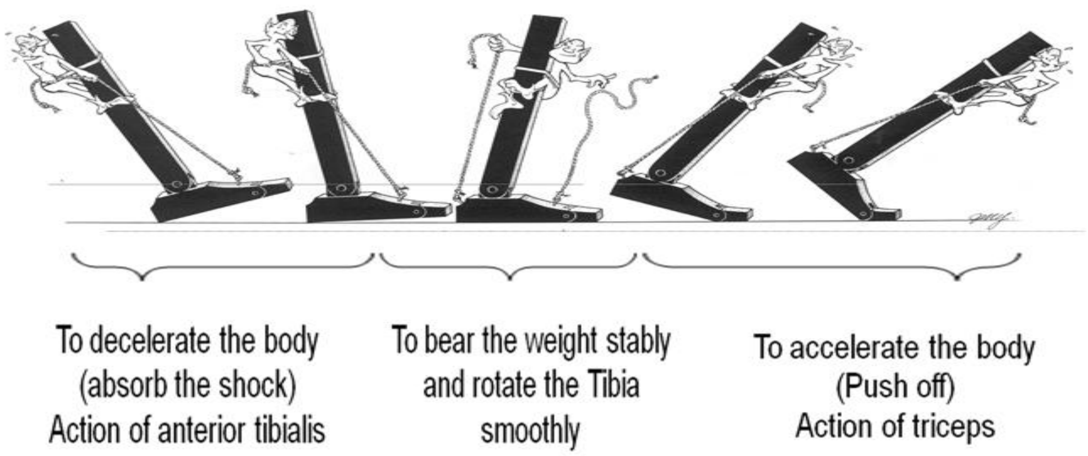
The partial foot amputation has kept the full length of the normal leg. Therefore any addition to the length in form of a prosthetic device will have to be compensated for, at the other leg. Due to limited room, these amputation levels, hinder foot selection and complicate the alignment procedure, also some designs can have poor structural integrity.

General requirements of the prosthesis and the socket design

The successful prosthetic management of partial foot amputation and ankle disarticulation demand a clear understanding of the normal biomechanics of the foot *and biomechanical consideration for the socket design*. In standing and/or walking, the foot and ankle would bear the body weight, accommodating to uneven surfaces.

Ankle Function during Stance Phase

- For optimal gait pattern the prosthesis should possess the following *functions*:
  a. Action of shock-absorbing at initial stance phase
  b. Stability at midstance
  c. Smooth rollover after midstance
  d. Action of pushing off during terminal stance phase



- In addition to these functions, *cosmetic* appearance of the prosthesis should be optimized. The prosthesis foot should look like a normal foot and be able to a fit into a ready-to-wear shoe.

- The socket design should fulfil the biomechanical considerations in terms of:

  a. load distribution
  b. correction of misalignment
  c. control of motion
  d. pain reduction

Sources:

1. Partial foot Prosthetics course work manual by Cambodian School of Prosthetics and Orthotics Clinical aspects of lower extremity prosthetic.
2. Atlas of Amputation and Lower limb deficiency. Surgical, Prosthetic, and Rehabilitation Principles. 3rd edition. (2004)
3. Ankle Disarticulation Prosthetics Course Work Manual ICRC
4. Partial Foot Amputations. Guidelines to Prosthetic and Surgical Techniques. Bengt Söderberg, Anders Wykman, Roland Schaarschuch, Björn M. Persson. 2nd Edition. 2001
5. General prosthetic principle and Treatment protocol in AD and PF. Sirindhorn School of Prosthetics & Orthotics. Mahidol University. M. 2011

Resources:

- Anatomy and Human Movement, Nigel Palastanga
- Gray's Anatomy of the Human Body, Henry Gray
- Clinically oriented anatomy, 7th edition, Keith Mooore et al.

Video Lectures and Power Point presentations

Lesson_3	Lower Limb – Video 3
	Lower Limb – Presentation 3

L04: PATIENT ASSESSMENT FOR PARTIAL FOOT AMPUTATION (PF)

General objectives

- Understand the importance of a well conducted assesment in order to prescribe the correct device acording to the patient needs.

A clinical evaluation and assessment is an examination or review of a patient's medical needs that leads to an appraisal of his/her condition and an opinion for treatment. During this procedure the prosthetist collects the patient's data, defines and describes the condition, needs, abilities and preferences of the patient. For Prosthetics, like in most other fields, the assessment consists on the medical history, a physical exploration, and a social and emotional evaluation.

Questionnaire objective

The focus in this lesson is to understand assessment criteria and define the best treatment protocol for the patient, material selection, rehabilitation measures, etc. Therefore we have an initial assessment, as well as a follow up.

During the time of treatment, the prosthetist must create a relationship focused on building trust, so that the patient feels comfortable and confident.

Procedure

There is a four part system for documenting an assessment defined by Dr. Lawrence Weed in 1971 called SOAP. The goal is to organize a medical record to develop the treatment plan

Subjective (Patent's goal)

Objective (Collecting data)

Assessment (Clinician opinion)

Plan (Manage patent's treatment)

The Subjective assessment has two type of questions:

- The first questions are about patient information with open question like "What kind of problem are you having? / Do you feel any pain?
- The second questions are closed ended like "When did you start using prosthesis?"

In the subjective assessment we also include the personal questions like "Do you live alone?" / "How many prosthesis have you used until now? / Hobbies, job, etc.

The Objective assessment is data that can be measured, like, X-ray, medical report, general inspection and palpation, range of motion (ROM), manual muscle testing (MMT), muscle contraction measuring, gait pattern (if the patient already uses prosthesis), skin color and temperature, etc.

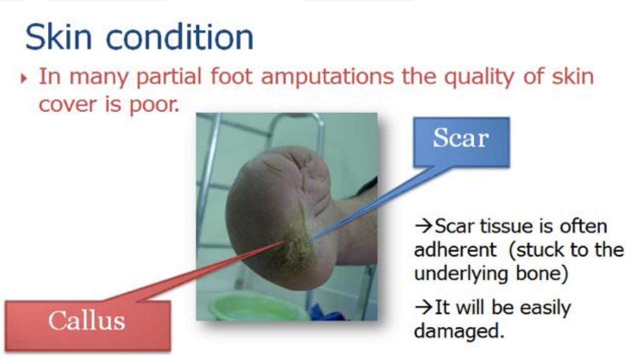
The Plan will include the complete treatment protocol defining the materials and components for the prosthetic device and therapy plan. It is crucial that the interdisciplinary team meet to define the plan and set the best treatment for each patient.

The patient has to speak freely and without interruptions. In some cases it is necessary to involve the family or friends (e.g. children)

General observation of the patient

We can get a lot information when the patient is entering the room or we see him or her for the first time. Does the patient use crutches? (none, one or two), sitting in a wheel chair, or if he or she forgot the prosthesis at home (in case of using one).

Observing how he or she is getting undressed, gives us also a lot information about the patients autonomy. In this general observation we also have to look at the body like weight, upper limb conditions, sound leg, back condition, etc.



In the observation of the affected limb we have to look at: skin status, scars, pressure points, shape (atrophy, edema…) and visible deformity.

Palpation

Because of hygienic and protection reasons, it is recommended to use protection gloves.

- Skin state: Temperature, quality (wound, abrasions, pressure points)
- Scar state (healed, attached to the bone, infected....)
- Affected limb nervous sensibility (lost of feeling)
- General affected limb sensitivity (pain)
- Weight bearing areas sensitivity
- Pressure sensitive areas
- Bones: the way they were cut, bone sensitive, bony protuberances…
- Distal padding: Normal, heavy, thin
- Neuroma: Mention precise exact location on measuring chart
- Trigger points: Sensitive spots on the stump

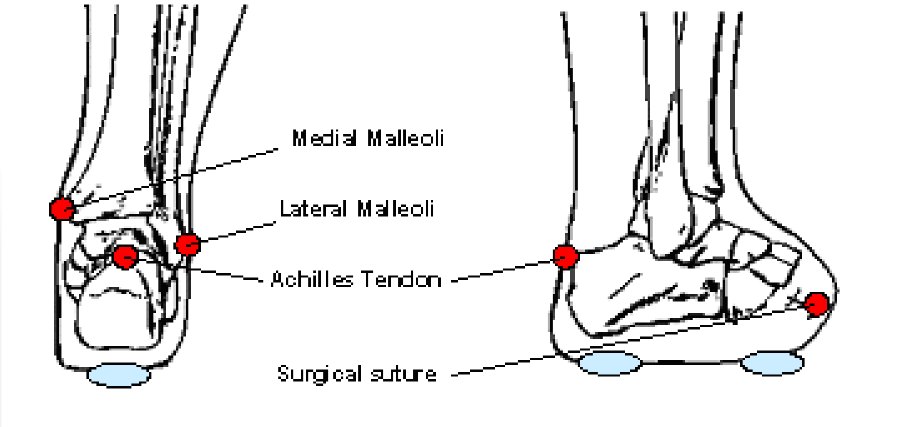
The palpation and observation is according to the type of amputation and type of the future device.

Palpation for Syme and Pirogoff amputations:

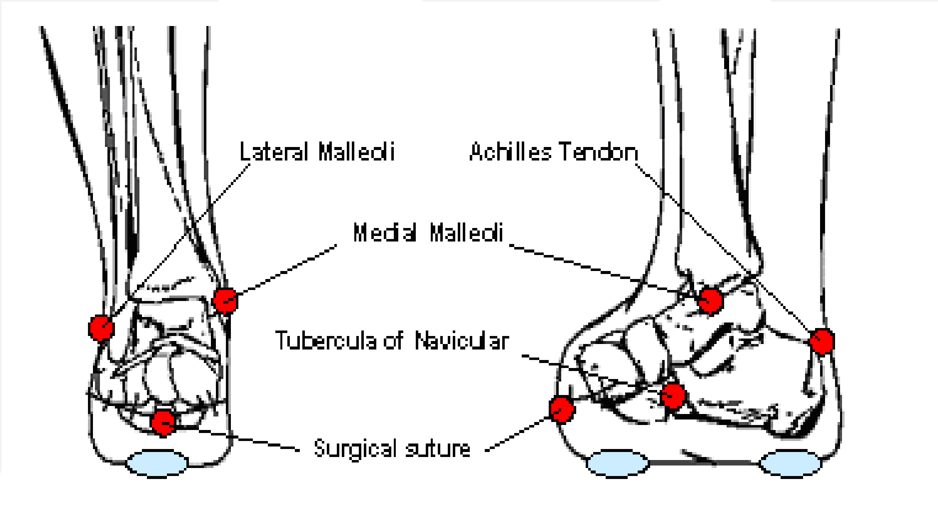
Weight bearing areas:	Pressure sensitive areas:
• Medial flare of the tibia. • Lateral flare between tibia and fibula • Posterior flare (gastrocnemius) • End of the stump (main weight bearing area) • Patellar tendon (in case the end of the stump cannot be fuleight bearable)	• Surgical scare or structure • Tibial crest • Fibula head • Achilles tendon • Popliteal area (in case of patellar tendon bearing)

Palpation for Chopart and Lisfranc

Weight bearing areas:	Pressure sensitive areas:
• Calcaneus	• Achilles tendon • Medial and lateral malleolus • Surgical scar • Bony distal areas



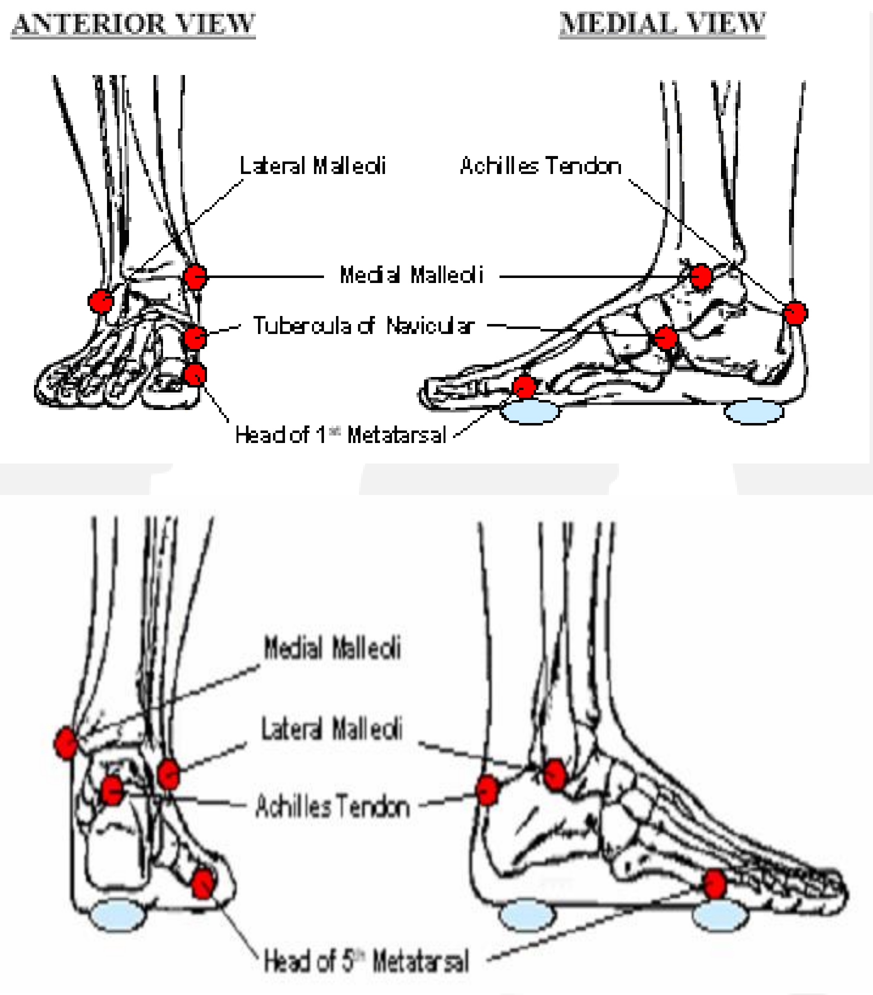
Posterior View Lateral view (Lisfranc)



Anterior View Medial view (Lisfranc)

Palpation for trans-metatarsal and metatarsal disarticulation

Weight bearing areas:	Pressure sensitive areas:
• Calcaneus • Longitudinal arch • Plantar part of the I and V metatarsals (for metatarsal disarticulation)	• Achilles tendon • Medial an lateral malleolus • Navicular • End of the bones for trans-metatarsal amputation • Lateral side of the I and V metatarsals • Surgical scare or structure.



Posterior View Lateral view

Joint evaluation

The Range of motion (ROM) is a passive evaluation where the patient is relaxing and the evaluator is doing the movement. But in some cases, you can also ask the patient to do the movement.

Evaluate the the joint directly involved in the amputation. But do not forget the other joints involved during gait cycle on the affected side and the sound leg. Here we have a closer look into the ankle evaluation. The degrees are only references, and may change slightly form one patient to the other.

As these evaluations have been already studied in Category II and in Orthotics, we only mention the Ankle Plantar and Dorsiflexion as an example. For these movements, the axis of the goniometer has to be placed in the middle of the lateral malleolus, with the fixed branch on the lateral slide of the tibial and the movable branch on the lateral side of the foot, on the second tarsals direction.

Average Ranges of Motion for the Lower Extremities
(in degrees from selected sources)

Joint	Motion	American Acad of Orthopedic Surgeons	Kendall and McCreary	American Medical Assoc
Hip	Flexion	0-120	0-125	0-100
	Extension	0-30	0-10	0-30
	Abduction	0-45	0-45	0-40
	Adduction	0-30	0-10	0-20
	Lateral Rotation	0-45	0-45	0-40
	Medial Rotation	0-45	0-45	0-50
Knee	Flexion	0-135	0-140	0-150
Ankle	Dorsiflexion	0-20	0-20	0-20
	Plantarflexion	0-50	0-45	0-40
	Inversion	0-35	0-35	0-30
	Eversion	0-15	0-20	0-20

Therapeutic Concepts 23

As the movements in the subtalar joint generate sometimes confusion, below the explanations of each of these movements as a review:

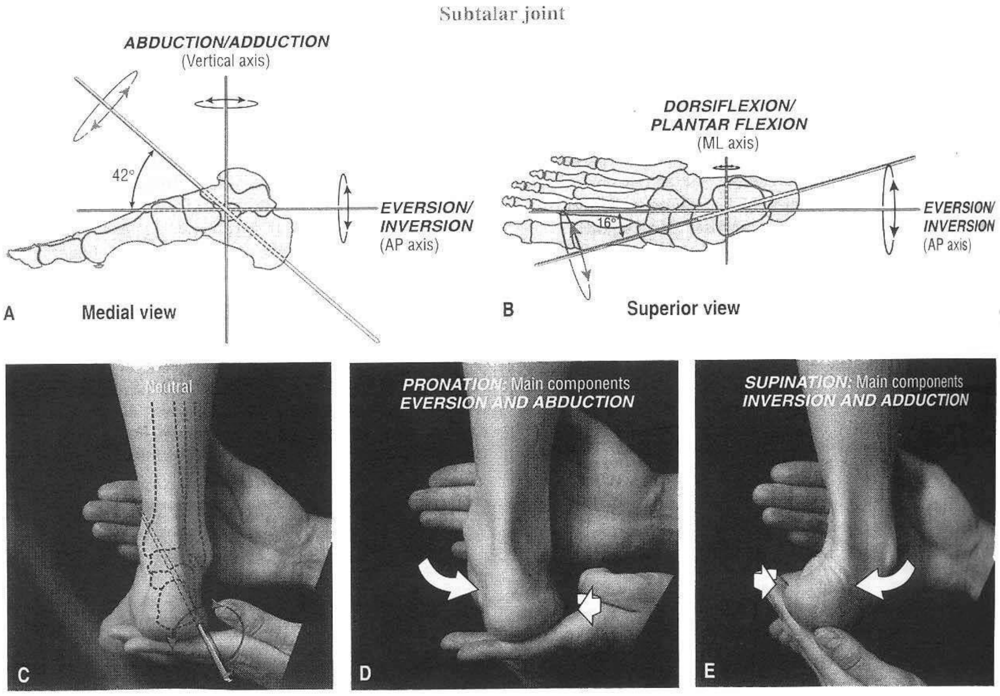


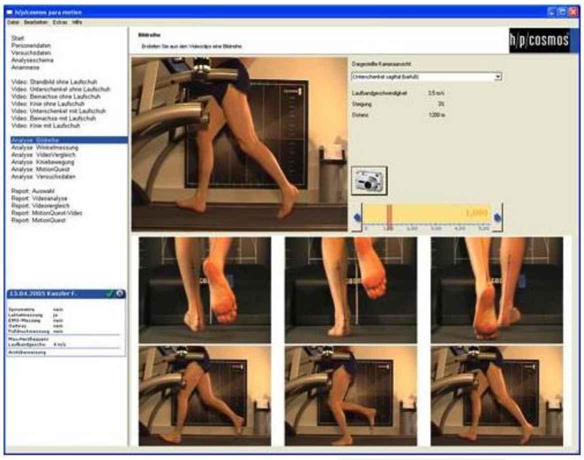
FIGURE 14–20. The axis of rotation and osteokinematics at the subtalar joint are shown. The axis of rotation (red) is shown from the side (A) and above (B); the axis of rotation is shown again in C. D, The movement of pronation, with the main components of eversion and abduction, is demonstrated. E, The movement of supination, with main components of inversion and adduction, is shown.

Supination and pronation are a combination of the above motions. It is common to use supination and inversion interchangeably and pronation and eversion interchangeably. But, supination is actually a combination of inversion, plantarflexion and adduction. Pronation is a combination of eversion, dorsiflexion and abduction.

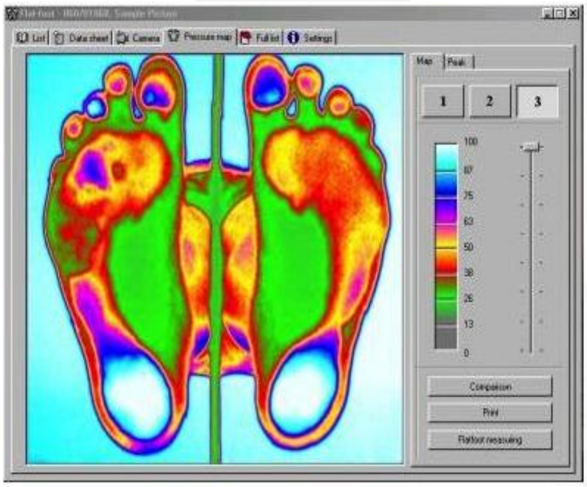
Functional evaluation

There are also other ways to assess the functionality of foot structures. Even if they are not specific for amputees the following methods are useful to have a complete functional evaluation:

Glass mirror boxes or blueprint to inspect the areas of pressure under the foot during standing



Video evaluation in a treadmill with different speeds to study gait in slow motion



Pressure insoles that provide information as the normal forces are acting on the sole of the foot during gait

Force plates that give us information about the ground reaction force (GRF) in relation to the joints

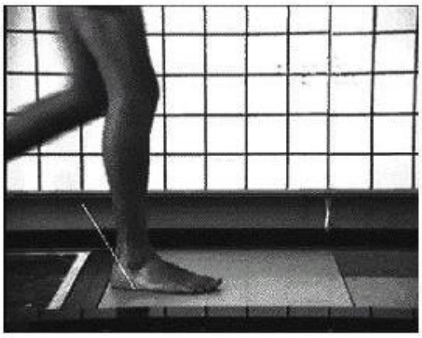


Figure 6: Striking the Force Plate.

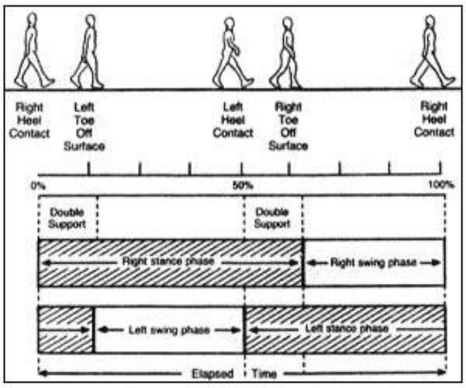
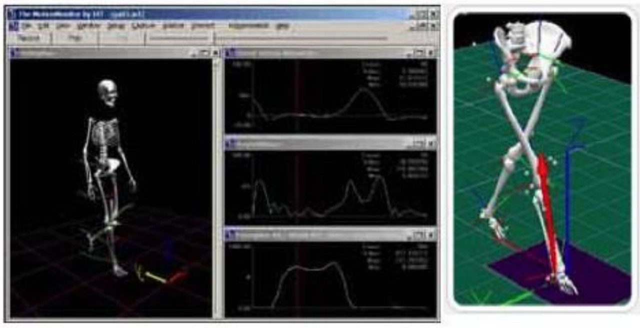


Figure 7: Stages of the Gait Cycle.



Gait analysis systems with 3D systems that provide kinematic information and calculate moments and forces.

Muscle testing

This is to check the general muscle strength of the lower limb. The affected one and the sound side. Including hip, knee and ankle. The testing level is from 0 to 5

Grade 0: No muscle contraction at all. No response, not able to move the

Grade 1: Slight contraction but not strong enough to do a movement.

Grade 2: Contraction, complete movement but without gravity.

Grade 3: Contraction, complete movement against gravity.

Grade 4: Contraction, complete movement against the gravity and a slight resistance.

Grade 5: Complete movement against maximum resistance.

A not balanced muscle strength especially at the ankle joint and subtalar joint could be the cause of important malalignment that must be considered in the design of the prosthetic treatment.

Before we can start to fabricate the prosthetic device: Casting and measurement taking are the next steps. We will study these procedures in the following lessons.

Sources:

1. Wasakorn Chapoempol lecture of 2011 (Mahidol University)
2. Patient assessment before fitting lecture (Mahidol university)
3. Patient assessment and casting lecture. Pakwan Nualmin (SNMRC)
4. "Human Study lecture of biomechanics of the foot"
5. http://image.slidesharecdn.com/ktintrotherapeuticconceptsfinal-120921170533-phpapp01/95/therapeutic-concepts-23-638.jpg?cb=1350923397 (Photo)
6. http://www.wisegeek.com/what-is-a-patient-assessment.htm
7. http://www.wisegeek.com/what-is-a-patient-assessment.htm
8. http://www.wisegeek.com/what-is-a-patient-assessment.htm

Resources:

- Anatomy and Human Movement, Nigel Palastanga
- Gray's Anatomy of the Human Body, Henry Gray
- Clinically oriented anatomy, 7th edition, Keith Mooore et al.

Video Lectures and Power Point presentations

Lesson_4	Lower Limb – Video 4
	Lower Limb – Presentation 4

L05: VARIATION OF MATERIALS IN PARTIAL FOOT AMPUTATION PROSTHESES

General objectives

- Identify and underestand the material properties used in Partial Foot Amputation prosthesis.
- Be able to select a specific material acording to the patient needs

Nowadays a wide variety of natural and man-made materials are used in Partial Foot Amputation Prosthesis. Whether natural or man-made, however, they must still conform to the special standards: biocompatibility, strength, durability, light weight, and ease of fabrication. The most common materials used in prosthetics today are plastics, but the more traditional materials such as leather, metal, and cloth still have a role to play. Wood is often used in lower-limb prostheses, although is less used nowadays, but it has not many uses in partial foot amputation prostheses.

History

Prosthetics have been mentioned throughout history. The earliest recorded mention is the warrior queen Vishpala in the Rigveda. The Egyptians were early pioneers of the idea, as shown by the wooden toe found on a body from the New Kingdom.

Leather

Leather is still commonly used in prosthetics for suspension straps, waist belts, and socket linings. Leather is easy to work with, has a soft natural feel, and is biocompatible. Many years ago hides were available from horses, elk, deer, as well as cattle, but today cowhide is modified by the tannery to provide the same feel and working properties as the hides of other animals.

Thermoplastics have replaced leather in some applications, as they are more hygienic, but it will probably never completely replace this readily available biological material.

In Partial Foot Amputations, leather is used for insoles that include padding replacing the amputated segment, and also sockets for perimalleolar and higher designs in Chopart and Lisfranc amputations.

Cloth

Cloth is used for prosthetic socks, waist belts, straps, and harnesses for upper-limb prostheses. Probably the greatest use of cloth is for prosthetic socks, which can be considered analogous to athletic socks since they keep the skin dry, cushion the limb, absorb shear forces, and take up volume to improve the fit. Prosthetic socks are commonly made of wool, cotton, or blends of these natural fibres often combined with nylon, Orion, acrylics, or other man-made materials.

Wool is the most common material used for prosthetic socks because of its characteristic elasticity, cushioning, and ability to absorb moisture without feeling damp. Wool also has good resistance to acids from perspiration. The blend of different wool fleece used in prosthetic socks provides greater resistance to shrinkage. Pure wool, however, must be washed carefully in a mild soap that will dissolve in lukewarm water. The sock should be rinsed in lukewarm water as well since a change in temperature will affect it adversely. Wool prosthetic socks should be dried carefully by first removing the excess water, wrapping them in a towel, and then drying them away from sunlight or any other direct heat. The recent development of machine-washable wool should reduce the need for hand washing in the future.

Cotton is also used for prosthetic socks but is more common in the form of a stockinet used to protect the limb during casting procedures. Cotton is also blended with wool in prosthetic socks, and some 100% cotton prosthetic socks are available. Cotton is a natural vegetable fibre that is soft, pliable, and absorbent, but falls short of wool in all of its properties. Cotton, however, is easier to care for and less expensive than wool, which makes it more practical for many uses.

In Partial Foot Amputation Prostheses cotton stockinet is used into latex laminations of perimalleolar designs for the fabrication of the sockets and also for the external cover of the prosthesis in the final lamination.

Padding materials

Many different padding materials of different shore hardnesses and dampening levels with a significantly wider range of applications are available nowadays.

Most used padding materials are usually based on polyethylene (e.g. Pedilin®, Plastazote), copolymers of polyethylene such as Ethylene-vinyl acetate (EVA: e.g. Evazote) or polyurethane (PU).

Thermoplastic foams made of polyethylene (PE) and ethylene-vinyl acetate (EVA) are the first choice for materials with direct contact with the body. They can be used in many different partial foot amputation prostheses as soft pads to contact with the skin and as replacement to fill the space for a missing structure.

Plastics

Nylon is used for prosthetic sheaths, plastic laminations, bushings, suction valves, and nylon stockings to cover prostheses. The major advantages of this man-made fibre are its strength, elasticity, and low coefficient of friction. Nylon prosthetic sheaths are in common use for transtibial and partial foot amputees. A thin sheath worn directly over the skin significantly reduces shear stresses and helps to pull moisture away from the skin. A nylon stockinet provides inherent strength to nearly all prosthetic laminations. Three to eight layers of nylon are impregnated with polyester or acrylic resins during the lamination process to provide both structural strength and a pleasant appearance to the finished device. Nylon is a thermoplastic material, which means that it can be heated and remoulded without adversely affecting its physical properties.

Polyester resin is a thermosetting plastic that is most commonly used for laminations in prosthetics. Thermosetting plastics cannot be heated and reformed after moulding without destroying their physical properties. Polyester resins come in a liquid form that can be pigmented to match the patient's natural skin tone. A benzoyl peroxide catalyst is then added to this resin to initiate the setting process, and a promoting chemical is added to speed up the setting time.

Polyester resin is a resinous substance made by reacting anhydride mixtures (usually phthalic and maleic). Polyester resins, which are most commonly used for boatbuilding, contain about 60 percent polyester and 40 percent styrene (vinyl benzene). The end user then adds organic peroxide, and the vinyl groups on the styrene polymerize with similar sites on the maleic portion of the polyester to cure the material.

The use of styrene in polyester and vinyl ester resins raises some issues. First, polyester and vinyl ester resins retain styrene’s characteristic pungent odor. Since styrene’s odor is so pungent and detectable in trace amounts, you might run the risk of adjacent businesses complaining to authorities about noxious fumes. Styrene is considered to be a dangerous chemical and recommend limiting workplace exposure. It has also been listed as a suspected carcinogen by the International Agency for Cancer Research (IARC). Another danger in using styrene is that it is highly flammable. Styrene also poses an explosive risk if exposed to certain atmospheric conditions.

Acrylic resins have greater durability and strength than polyester resins. Acrylic fibres are also frequently used in the newer synthetic blends for prosthetic socks since this material is soft, durable, and machine washable. Acrylic resin is increasingly popular for laminations in prosthetics because its high strength permits a thinner, lighter-weight lamination and its thermoplastic properties allow easier adjustments of the prosthesis by reheating the plastic and slightly remoulding it locally, although the structure can lose mechanical properties. Acrylic resins tend to have a softer feel than polyester resins but are more difficult to use during fabrication.

Laminating structures are used in Partial Foot Amputation structures like sockets and insoles and for the rigid parts of pretibial and patellar tendon bearing designs. Carbon fibre, glass and nylon are used to reinforce the resin laminated areas of the prostheses. Soft resins are more flexible and can be combined with the rigid structures to get surfaces that can adapt to moving areas like edges at the ankle in perimalleolar designs. The disadvantage of soft resins is that the solvents that make the resin flexible evaporate making the material brittle over the time.

Acrylic resin dust is toxic, as is the monomer and its vapors. And the organic peroxides are especially poisonous, some of them being explosive and others causing instant blindness if they get in one's eyes.

Epoxy resin works similarly, doesn't smell as bad, but it—and the hardener that makes it set—is a sensitizer, meaning that you can get a nasty allergic reaction after repeated exposure. Some hardeners are not as bad as others in this respect. Epoxy won't set water-clear like acrylic, and doesn't resist sunlight (UV) degradation as well, but works better with high-tech cloths, like Kevlar and graphite.

Polypropylene (PP) is used for hip joints, pelvic bands, knee joints, and lightweight prostheses. Polypropylene is used in great quantities in industry for everything, from fan shrouds in passenger cars to carpets and shipping containers. Polypropylene is an opaque white material, that can be coloured and is relatively cheap, strong, durable, and easy to mould. This material can be welded by using hot air.

Polypropylene sheets 1 to 9 mm (1/16 to 3/8 in.) thick are heated and vacuum-formed over the mould of a socket or complete limb. In Partial Foot Amputation Prostheses Polypropylene is used to create rigid structures already mentioned for resins.

Polyethylene (PE) is an opaque white thermoplastic that can be coloured and looks like polypropylene but feels waxier. The properties of polyethylene vary depending on the density of the material. Low-density polyethylene (LDPE) is very flexible and easy to heat and mould; it is used for triceps cuffs in transradial (below-elbow) prostheses and for tongues in plastic thigh corsets and hip disarticulation sockets. High-density polyethylene (HDPE) is more difficult to modify and is used to make bushings in joint mechanisms. Ultrahigh-molecular weight (UHMW) polyethylene is sometimes used in partial-hand or partial-foot prostheses due to its tear resistance.

Polyurethane (PU) foams are widely used in prosthetics for both soft cosmetic foam covers and rigid structural sections. Polyurethanes, also called urethanes, are available in three broad groups: flexible foam, rigid foam, and elastomers. In partial foot prosthesis, polyurethane can be used as gel in insoles or as rigid or soft foam for the frontal build up.

Rigid polyurethane foams compete with wood in providing structural stability to knee units and ankle blocks. Prosthetists routinely use this foam to provide both strength and shape to exoskeletal prostheses. A plastic lamination covers the foam to provide additional strength and cosmesis. Some silicone prostheses can have an embedded polyurethane structure inside to reduce weight compared to a complete silicone structure much heavier.

Silicones are used in prosthetics for distal end pads in sockets, to provide a flexible rubberlike end in air-cushion sockets, and for silicone gel insets, e.g. in insoles.

Silicones can be classified as fluids, elastomers, or resins, and all three are used in prosthetics. Silicone is synthesized from sand (a combination of silicon and oxygen) and undergoes a number of chemical reactions before liquid or solid silicone results.

The room-temperature-vulcanizing (RTV) silicones are used most widely in prosthetics. Silicones have relatively uniform properties over a wide temperature range, repel water, are chemically inert, resist weathering, and have a high degree of slip or lubricity. Silicone fluid is used for lubrication of moving parts, as the liquid inside hydraulic knee mechanisms, and as a parting agent. A two-component silicone elastomer is used for foaming end pads in sockets while the patient is weight-bearing to ensure total contact. Silicone gel-impregnated gauze is an excellent cushioning and force distribution material for weight-bearing prosthetic sockets. Although the gel adds weight and bulk to a prosthesis, it has been proved to work well for many problem cases, particularly those with burns or severe scarring.

HTV Silicone Rubber (High Temperature Vulcanization Silicone Rubber) is very used in Partial Foot Amputations prosthesis. With HTV silicone aesthetic prosthesis with the best natural appearance are made. It could be customized achieving a very similar to the skin look. It has the possibility of being tinted with personalized custom colours.

The fabrication technique requires very specialized staff and long time is necessary to produce human looking hands, feet, fingers and any part of the external body. This complicated and specialized process make these prostheses very expensive compared to other techniques with similar functionality but much less accurate and natural in appearance.

Silicone is ideal for creating prosthetic parts that come in direct contact with the skin. The different shore (hardness) possibilities make possible to create combined flexible and rigid structures in a wide range of prosthetic applications.

Silicone is also a very durable material, ideal for its use in PF prosthesis. The main limitation for a more spread use is the price and the complexity of the fabrication technique.

Fibre reinforcements

Two basic types of high-strength fibre reinforcements are used in prosthetics today: glass and carbon. fibreglass is commonly used to reinforce polyester resin laminations where mechanical attachments such as bolts and screws will fasten. It is also used to stiffen thin areas and to prevent breakage in vulnerable areas. fibreglass is difficult to finish smoothly, so care must be taken to avoid exposed areas of this material. The added strength fibreglass provides is proportional to the amount used and also depends on the arrangement of the fibres relative to the stresses it must tolerate. A unidirectional arrangement of fibres found in continuous-strand roving allows the best reinforcement if placed directly in line with the stresses. Multidirectional fibres such as woven mat or fabrics provide equal strength in all directions but are less effective when only one stress must be tolerated.

Carbon fibres are more expensive than fibreglass but have superior strength and stiffness. They are also being used by component manufacturers to replace metal. Carbon fibres are generally set in epoxy or acrylic and can provide a material with a stiffness twice that of steel at a fifth the weight. In addition to this high strength-to-weight ratio, carbon fibre composites have a fatigue resistance twice that of steel, aluminium, or fibreglass. Prefabricated carbon fibre prosthetic components such as pylon tubes, knee joints, and connectors can significantly reduce the weight of the prosthesis while increasing its strength.

Carbon fibre structures are used in PF Amputation prostheses combined with other materials (padding materials, rubber or silicone) to create the flexible-rigid structure of the foot sole, to achieve a dynamic gait. This function can also be obtained with steel flexible plates.

Sources:

1. http://en.wikipedia.org/wiki/Prosthesis
2. Chapter 4 - Atlas of Limb Prosthetics: Surgical, Prosthetic, and Rehabilitation Principles
3. Prosthetic Management: Overview, Methods, and Materials
4. Michael J. Quigley, C.P.O.
5. What Resin Am I Using? Let the Truth Be Known - By Greg Mattson, CPA, CTPO - Content provided by The O&P EDGE - May 2013
6. Ottobock Materials Catalogue, 2013.
7. http://juxtamorph.com/difference-between-polyester-acrylic-and-epoxy-resins/ Accessed January 2016.
8. http://www.oandp.com/articles/2013-05_11.asp Accessed January 2016.

Resources:

- Anatomy and Human Movement, Nigel Palastanga
- Gray's Anatomy of the Human Body, Henry Gray
- Clinically oriented anatomy, 7th edition, Keith Mooore et al.

Video Lectures and Power Point presentations

Lesson_5	Partial foot amputation – Video 5
	Partial foot amputation – Presentation 5

L06: VARIATION OF PROSTHETIC DESIGNS FOR PARTIAL FOOT AMPUTATIONS I

General objectives

- Identify and underestand the different socket variations for partial foot amputations acording to the amputation level.
- Learn about the different functions of partial foot prosthetic designs

Introduction

Devices used in the management of partial foot amputations include principles used in foot orthoses (FO), ankle foot orthoses (AFO) as well as those used in lower limb prosthesis. Shoe modifications are also commonly provided to enhance function for these levels of amputation. It is important to mention that footwear is an important aspect of the treatment.

The aim in prosthetic treatment at this level, is mainly to restore the foot function as well as restore the appearance.

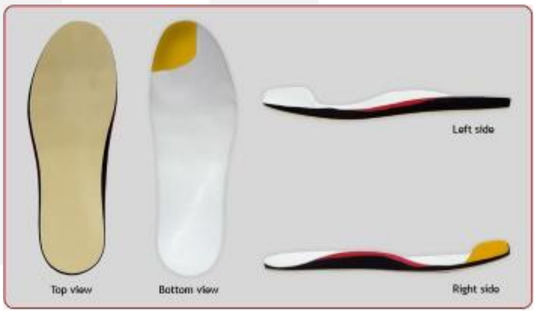
Toe and ray amputations

1st toe amputation

This amputation type causes a high loss of function. The first toe carries more than 50% of the body weight during push off. When the first toe is missing, medial and lateral rays get overloaded causing an insufficient roll-over.

Nowadays we have 3 main fitting solutions:

-Semi-rigid insole: It is made out of a soft padding material to fill out the gap of the first toe. This is made to prevent the movement of the remaining toes. The insole has also a metallic bar placed under the first ray, going from the heel center to the padding material. (see picture on the right)



-Carbon insole: As in the semi rigid insole, there is a padding to fill the gap. But the carbon properties make the insole flexible and resistant emulating the function of the first toe, getting a better toe-off without a longitudinal bar. (see picture on the right)

-Prosthetic silicone toe: This solution is in most cases only for appearance. (see picture on the right)

Other toe amputation

By the 2nd, 3rd, 4th and/or 5th toe amputation the loss of function is not really measurable. Anyway, to compensate balance and to avoid the shifting or deviations of the rest of the toes, the common solution is an insole with padding material in order to fill the gap of the amputated toe or toes.

When only the 1st toe is preserved, the recommendation is to make an insole to avoid hallux valgus.

It is also common to add medial or lateral wedges to stabilize the foot in the frontal plane and padding elements behind the metatarsal heads to stabilize the medial arch.

When only a phalanx is amputated, a silicone cap can be used to restore the appearance, but in many cases it could be more troublesome than useful for the patient.

Ray amputation

The ray amputation (phalanx and metatarsal) requires different fitting solutions as it has many variations.

-An intermediate ray amputation, does not need a prosthetic solution. Functionality and aesthetics are preserved

-For a first ray amputation we need an insole with similar characteristics than the one for the first toe.

-Lateral ray amputation requires a semi-rigid insole with padding to rebuild the missing part, including a bar or a carbon sheet, going from the heel to the fifth metatarsal, to restore balance in stance phase.

Transmetatarsal amputation

This amputation level is functional if the following conditions are given:

-Presence of plantar soft tissue for padding
-Have a distal shape or cut like index plus (1>2, 2>3, 3>4, 4>5)
-It is an option to more distal amputations that could be less functional.
-Weight bearing distribution in the whole plantar surface

A plantar support made of semi-rigid materials with an equal length of the contralateral side is a possible prosthetic solution. It has a spring in its base that goes from the heel to the first ray, or even a carbon insole. There is also padding material in the front part which is made of:

-At skin contact anterior and distal areas, the most sensitive ones, a very soft material for stuffing (Plastazote, silicone, polyurethane, etc.) should be used, due to the acting forces during gait. This is also the area where the scar is usually placed.
-The rest of the stuffing or padding should be more consistent, like Pelite or Pedilen to fill out and get the right shape.

The prosthesis may have also correcting or compensating elements, like wedges under the forefoot area to avoid supination, metatarsal bars to avoid overloads, etc. The device should be thin enough to fit into a normal shoe, filling and padding, should also have the appropriate shape to do so.

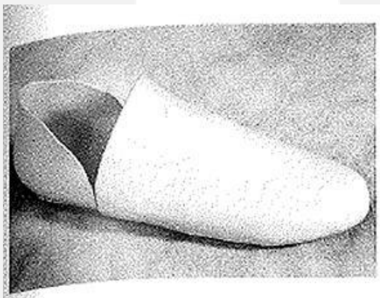


Figure 8 Transmetatarsal prosthesis with hinged laminated socket to facilitate donning.

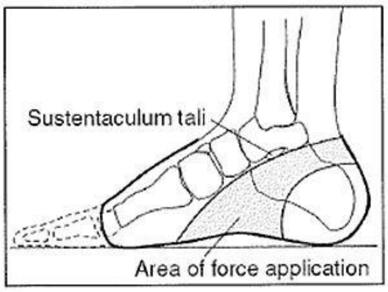


Figure 9 Loading the sustentaculum tali to resist pronation of the hindfoot.

It is also possible to make modifications at the shoe, like a rocker sole to minimize the pressure at the frontal side of the stump.

Another option is a modification of the University of California Biomechanics Laboratory (UCBL) foot orthosis, covering the dorsum of the foot. The plastic socket may be hinged to facilitate donning (Figure 8). The tendency of the foot to pronate can be addressed either by medially wedging the prosthesis to support the forefoot or by applying a pronation-resisting force to the area of the sustentaculum tali in the socket. (Figure 9).

Lisfranc amputation

This amputation level got his name thanks to a surgeon that made this technique for the first time to Napoleon's soldiers.

In this level we have less lever arm than in the transmetatarsal amputation, and the muscle imbalance is higher, with more tendency to plantar flexion, even though it is a good option.

The prosthetic solution is similar to the transmetatarsal amputation, but with a stiffer spring or carbon insole, due to the higher loss of function at push off.

A prosthetic solution known as Bellmann prosthesis, can be an inframalleolar socket design, made of transparent soft plastic and padding materials in the forefoot to maximize function and comfort as shown in the picture on the right. The aim of this prosthetic solution is to get a better attachment of the prosthetic device to the residual limb containing the stump into the socket. The low profile flexible socket allows a full range of motion to the ankle joint.

The material used for the socket is a soft thermoplastic with good skin adhesion and very comfortable for the patient (commercial brands are for example Erkoflex or Thermolyn SupraFlexible). The main reasons of using thermoplastics instead of a laminated socket for this amputation level, is that a better suspension is achieved, the proximal brim is more flexible and it is easier to clean.

The forefoot area is made of soft paddings, for the sole area a carbon insole or a metallic bar is added for reinforcement, as well as for balance and push off. This is a good option if there is no severe plantar flexion or varus, as the prosthesis cannot correct this.

It is covered with a flexible material like leather to ensure elasticity and wearing resistance. It is shaped to fit into a normal shoe.

Silicone prosthesis

This prosthesis is also an inframalleolar design. The only difference is the material of which it is made of: silicone. See the picture on the right.

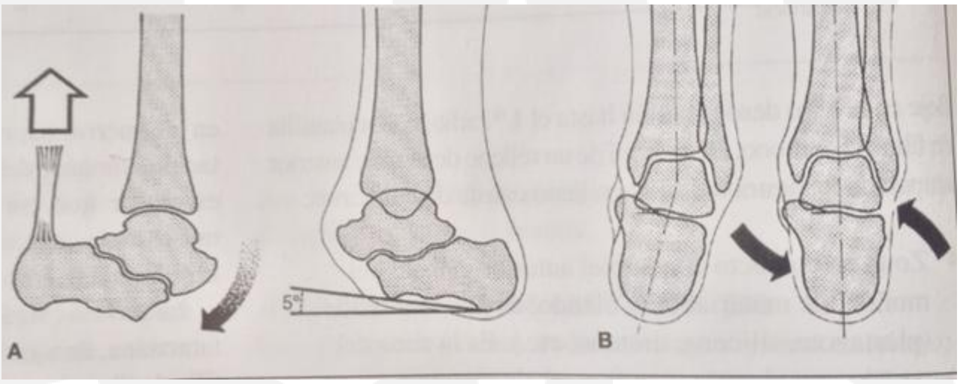
Silicone allows a good and aesthetic finish, it is also possible to personalize the appearance making very similar to a natural foot reproducing the texture and colours of the skin. Acrylic nails can help to make it even more realistic. Silicone has also an excellent skin adherence and is able to make a good soft tissue compression.

A harder and softer silicone can be combined using for example a more rigid cup that controls the lateral and medial part of the calcaneus, and softer silicone for the rest of the prosthesis.

Both inframalleolar designs described above, are made under the “total bearing surface” socket principle.

Other considerations for heavy or active users:

For heavy or active patients or when an important varus deviation is present it is recommended to use a higher level prosthetic design like the supramalleolar designs used for Chopart amputation we will describe in the next section. These could be either supramalleolar designs, a pretibial design or patellar tendon bearing prosthesis when weight bearing is not possible at the heel area.



In the picture below a semi-rigid insole with frontal padding (A) and a inframalleolar design (B) is shown.

Chopart amputation

This is a complicated level for the prosthetic management. Due to the muscle imbalance and short lever arm, plantar flexion and varus are usual deviations of these stumps.

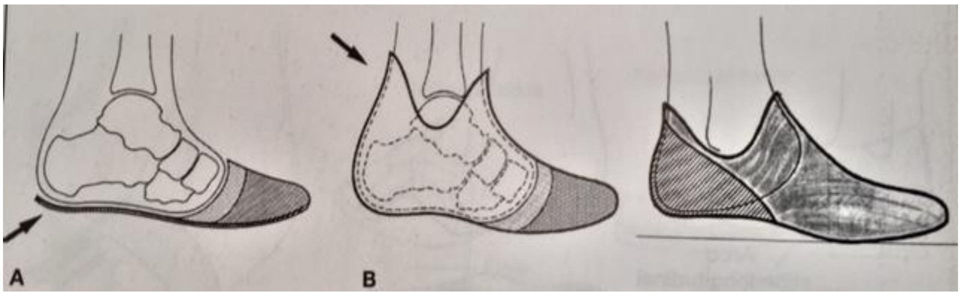
To minimize these effects some authors propose a tibio-talar arthrodesis. This operation is followed by a larger postoperative treatment and restricts the ankle movement. Anyhow, there are 2 common used prosthetic variations:

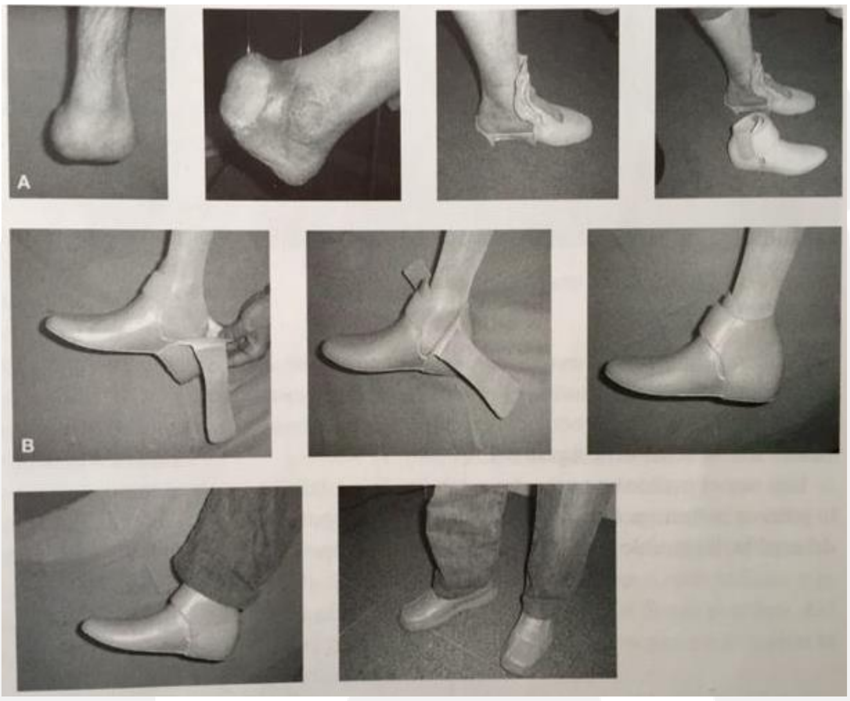
Supramalleolar prosthesis

Its purpose is to maintain the foot in a neutral position, controlling plantar flexion and varus and to avoid the overloads in the plantar region making weight redistribution.

The prosthesis wraps up the calcaneus, then it extends forward under the sole to the medial and lateral side until the toes area. At the forefoot area there is padding or filling to restore the length and shape of a normal foot.

The posterior part is reinforced with a rigid heel counter that helps to avoid varus. A flexible pad covers the anterior area. This area must at the same time, offer some resistance to get a proper roll over. The sole area is reinforced with a carbon insole or a metallic bar to stiffen the device and avoid plantar flexion.





It is covered with a flexible material to ensure elasticity and wearing resistance. Latex laminated cotton stockinet is a good option.

This prosthetic solution fits into every shoe, even though it is recommended that the hind foot and instep are properly contained into the shoe

There are 2 more variations of supramalleolar prosthesis.

-One variation is to finish the prosthesis in leather, which makes it more breathable and comfortable.

-The other variation is to make the proximal part in two pieces and the closure with Velcro. This makes donning and doffing easier. (Picture B)

Long design prosthesis

This variation consists of a laminated or thermoplastic leg prolongation over the shin and calf. Indicated for ankle disarticulations or Chopart amputations. This device redistributes the weight bearing areas by unloading the distal end of the stump. It improves the stability of the rear foot in the frontal plane and restores the 3rd rocker. The aim of including the calf, a larger surface is given to distribute pressures. (See picture on the right)

It is important to take a look at the area between the end of the stump and the padding; this area supports a lot of stress during walking and could break if it is not properly reinforced.

In some cases, this designs in combination with other materials such as carbon, can be used for lower amputation levels to increase stability during sports. The patient normally has a daily prosthesis. See picture on the right.

It is also possible to combine an AFO (e.g. made of carbon) with the daily prosthesis for more stability.

Sources:

1. Prótesis, ortesis y ayudas técnicas. Ramon Zambudio Periago. Elsevier Masson Chapter 6 (Felip Salinas and Oriol Cohí)
2. Lower extremity prosthetics catalogue Ottobock.
3. http://www.persey-orto.ru/images/stelki/english/p-22-en.jpghttp://www.persey-orto.ru/images/stelki/english/p-22-en.jpg
4. http://www.polarispt.com/img/other/toe-fillers-bolingbrook-il-downers-grove-illinois-woodridge-il.jpg

Resources:

- Anatomy and Human Movement, Nigel Palastanga
- Gray's Anatomy of the Human Body, Henry Gray
- Clinically oriented anatomy, 7th edition, Keith Mooore et al.

Video Lectures and Power Point presentations

Lesson_6	Partial foot amputation – Video 6
	No presentation in this lesson

L07: PARTIAL FOOT AMPUTATION PROSTHETIC PRESCRIPTION

General objectives

- Be able to prescribe a prosthetic device acording to the amputation level and patient needs.
- Critical thinking about the different socket designs

Introduction

The successful prosthetic management of partial foot amputations demands a clear understanding of the notions of the normal foot and the mechanical consequences of each amputation variant.

The loss of normal foot function after amputation is progressively more severe the more proximal the site of amputation. The extent of the loss may be summarized as relating to three primary aspects of foot function: load-bearing capacity, stability, and dynamic function.

Any partial foot amputation reduces the forefoot load-bearing area, and any amputation proximal to the metatarsal heads totally eliminates this load-bearing site. Ironically, the magnitude of the forefoot ground-reaction force has been shown to increase following partial foot amputation because of the reduced forefoot lever arm when the patient attempts to walk in a normal manner.

Similarly, any amputation proximal to the metatarsal heads removes the contribution that these structures make to the normal mediolateral stability of the foot. The natural shape of the longitudinal arch of the foot results in a residual foot with an apparently supinated forefoot, which if left untreated will inevitably result in *compensatory* pronation of the hindfoot.

As the level of amputation moves proximally, the active flexion of the first metatarsophalangeal joint at final push-off is eliminated, followed by loss of the supinatory/pronatory capability of the forefoot. Fortunately, if the amputation surgery has been performed according to the best current practice, both ankle and subtalar joint function most likely will be preserved, although mid tarsal joint function will be lost following tarsometatarsal and transtarsal amputation.

Biomechanics - Normal Foot Function

The normal foot is an extremely complex structure, the detailed function of which is still only partially understood. This discussion will be restricted to a brief consideration of the load-bearing structure and the function of the foot joints during normal walking.

The foot receives the ground-reaction forces generated during physical activities and are transmitted to the rest of the body. During normal level walking, these loads are directed initially onto the heel, the specially adapted fatty tissues of which are ideally suited to the absorption of the high forces generated at impact and during the subsequent loading of the limb. Once the foot is flat and until the heel leaves the ground as push-off is initiated, the supporting forces are shared between the heel and the forefoot, with only a small contribution from the lateral aspect of the midfoot. This method of load transmission is commonly attributed to the arch structure of the foot, even though it is now clearly understood that its effectiveness is a function of a number of neuromuscular mechanisms. Once the heel leaves the ground, the increased ground force associated with push-off is transmitted through the area defined by the metatarsal heads and the pads of the toes. As body weight is transferred to the contralateral limb, this load reduces and localizes on the plantar surface of the hallux.

The functions of the joints of the foot have been the subject of endless investigation. The ability of the foot to alter its shape and alignment is of considerable importance in adapting to variations in the slope of the walking surface. A more subtle but equally important role, however, concerns the absorption of the longitudinal rotations of the lower limbs that occur with each stride (Figure 1).

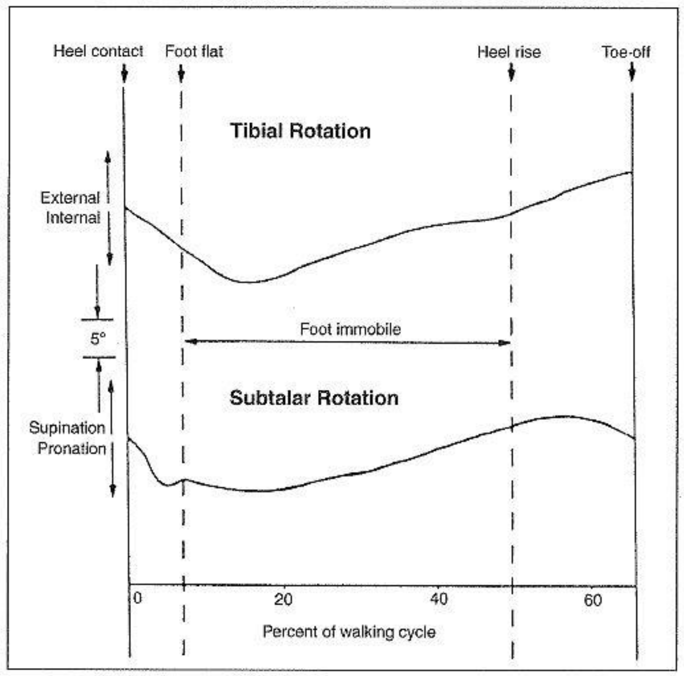


Figure 1 Longitudinal rotations of the leg and associated subtalar joint motions during walking.

Internal rotation of the tibia commences during the swing phase and continues after heel contact until the foot is flat on the ground. During this phase, the foot pronates about the subtalar joint axis, thereby maintaining the normal toe-out position of the foot. Elevation of the lateral margin of the foot, which is a consequence of hindfoot pronation, is counteracted by supination of the forefoot, thus ensuring that ground contact is achieved across the entire forefoot. After the foot is flat on the ground, the tibia rotates externally and the foot supinates about the subtalar joint axis to absorb this motion, thus preventing slippage occurring between the foot and the ground. The associated elevation of the medial margin of the foot is counteracted by pronation of the forefoot, enabling the maintenance of full forefoot loading. After the heel leaves the ground, the foot pronates, transferring the area of support medially onto the first metatarsal head and then the hallux as the foot loses contact with the ground.

During the initial loading phase, the midtarsal joint acts in concert with the subtalar joint. Thereafter, as the subtalar joint supinates, the midtarsal joint locks and stiffens the long arch of the foot to prepare it for the increased dorsiflexion moment that it is subjected to after the heel leaves the ground.

Prosthetic Assessment and Designs

Devices used in the management of partial foot amputations are frequently referred to as both prostheses and orthoses; sometimes the term "prosthosis" is used. Many of these designs incorporate principles used in foot orthoses or ankle-foot orthoses (AFOs), as well as those used in lower limb prostheses. Shoe modifications are also commonly provided to enhance function for these levels of loss; therefore, a knowledge of pedorthic principles is important.

As with all levels of amputation, assessment of a number of factors must precede prescription. The amputee's control of the remaining joints of the foot and ankle must be assessed. The presence of muscle imbalance and joint instability or deformity, either fixed or correctable, should be noted. The tissue coverage at the amputation site and the sensitivity and any adherence of the scar should be assessed. Vascularity, sensation, and the presence of neuropathy must be noted, and the foot should be checked for callosities or other skin lesions. The ability to comfortably bear weight through the residual foot and the amputee's balance should be checked. The patient's aspirations with regard to activity level and the cosmetic appearance of the prosthesis are of major importance and will help influence the prescription process, because higher levels of function are often at the expense of cosmesis.

The methods of compensation for each of the more commonly encountered amputation levels will be discussed in detail, but one important biomechanical issue should be mentioned here. When the surgery is confined to the toes, prosthetic forefoot loading, which is most significant after heel-off, may simply be transferred directly onto the metatarsal heads and any remaining toes. When the surgery involves removal of the metatarsal heads, however, this force is anteriorly offset from the residual plantar tissues. This action results in an external moment that will, unless resisted, cause the prosthesis to rotate (in the direction of dorsiflexion) relative to the residual foot (Figure 2). The management of this particular requirement is one of the most critical issues to be considered in the selection, manufacture, and fit of prostheses for these more proximal levels of amputation.

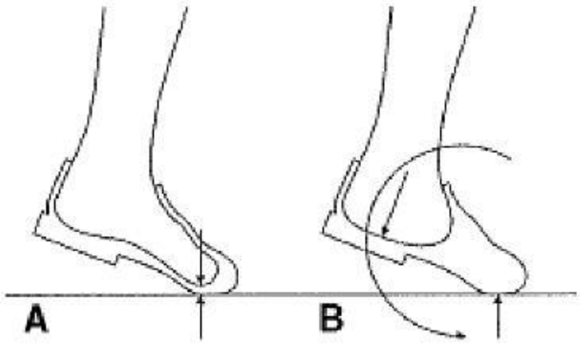


Figure 2 A, Amputation of the toes: ground-reaction force transferred directly onto metatarsal heads. **B,** Amputation proximal to the metatarsal heads: ground-reaction force results in a dorsi-flexion moment.

Amputation of the Toes

The functional loss associated with the amputation of one or more toes is primarily a reduction in the forefoot load-bearing area, resulting in increased pressure on the metatarsal heads, which are also more exposed by the removal of the toes. These symptoms will be most pronounced if the hallux is removed, when foot function also will be compromised by the loss of active plantarflexion of the first metatarsophalangeal joint, which normally occurs at the end of push-off. For normal walking, the loss of the toes is not a major functional problem, but loss of the great toe makes running and participation in competitive sports more difficult because of the loss of active push-off.

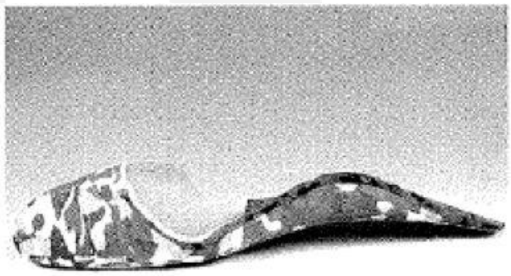


Figure 3 Modified insole (inlay) with filler for amputation of the toes.

Cosmetic issues need to be addressed. Most prostheses for toe amputations consist of a toe filler to reinstate normal foot shape and prevent deformation of the shoe, which also may be a cause of discomfort. Some patients elect to pack the shoe with a soft foam or cloth. Alternatively, the prosthesis may consist of a modified sole (inlay), with a built-up foam section acting as a replacement for the lost digits (Figure 3). If required, this foam section may be formed in a manner that resists any tendency of the remaining toes to deviate in the transverse plane. In contrast, when the hallux has been removed, the prosthesis is best custom fabricated to a plaster model of the foot. Modifications at the amputation site redistribute pressure away from this area and onto the medial longitudinal and transverse metatarsal arches, resulting in improvements in comfort and gait.

The provision of a toe spacer may be beneficial in patients where one of the central toes has been removed (Figure 4). For these designs, a plaster model of the foot is not generally required for fabrication of the prosthesis.

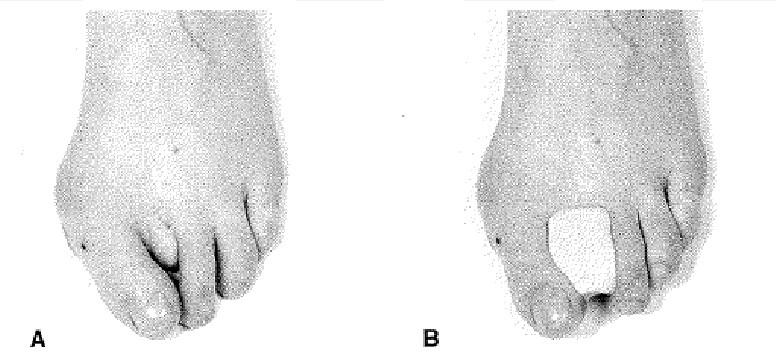


Figure 4 A, Foot with amputation of one of the central toes. B, Toe spacer improves the alignment of the remaining toes.

Silicone replacement of the toes offers optimum cosmesis (Figure 5), but this highly specialized technique may be unavailable at some prosthetic facilities, and specialist manufacturers may need to be consulted. The psychological benefits of a foot that appears normal when wearing open shoes or sandals can be very significant and should not be underestimated.

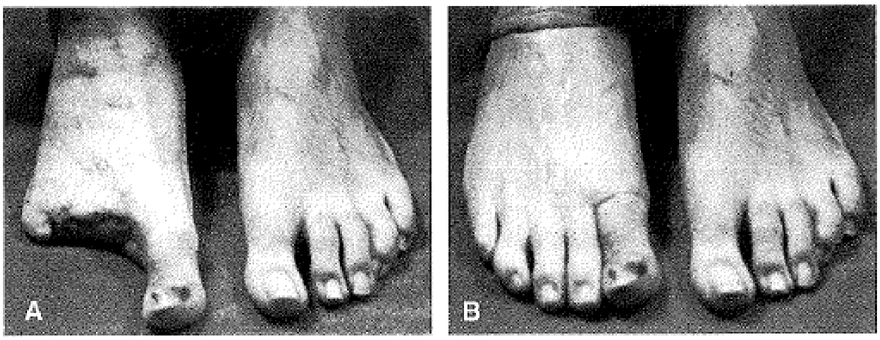


Figure 5 A, Amputation of the second through fifth toes. B, Silicone prosthesis in place.

Any tendency of the shoe to deform may be resisted by reinforcing the sole with a steel plate or a footplate composed of a carbon composite material; however, this material should not be too rigid, or normal foot "third rocker" will be inhibited. When further pressure reduction is required at the amputation site, a rocker sole with its apex behind the metatarsal heads may be added to the shoe.

Ray amputations

The functional consequences of amputation of one or more rays of the foot depend on the position and extent of the tissues removed. In every instance, there will be a reduction in the forefoot load-bearing area, resulting in increased pressure on the remaining forefoot plantar tissues, which may be a problem for insensate patients or patients with diabetes mellitus. If the amputation includes either the first or fifth rays, either singly or with adjacent rays, there is an associated loss of mediolateral foot stability affecting the patient's balance. Additionally, supination and pronation of the forefoot will be virtually eliminated.

The stability of the prosthesis on the residual foot requires intimacy of fit. It therefore typically takes the form of an insole that is custom moulded to a plaster model of the residual foot, consisting of a soft, pressure-sensitive material next to the skin, reinforced with a firmer, more durable base layer, which will improve both its function and longevity. The prosthesis is built up to reinstate normal foot shape, thus restoring mediolateral stability and indirectly facilitating subtalar joint function. Silicone prostheses combine these functions with excellent cosmetic restoration (Figure 6).

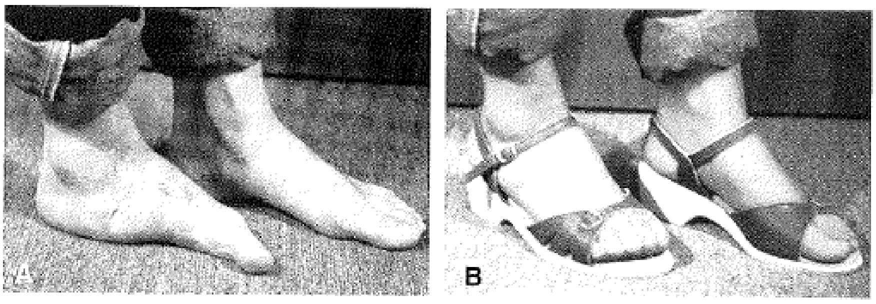


Figure 6 A, Ray amputation of the right foot. B, Silicone prosthesis in place.

If necessary, mediolateral stability may be further enhanced by wedging the prosthesis itself, or by the addition of either a wedge or flare to the shoe. The use of a prosthesis will prevent deformation of the shoe and may remove the need for split size or custom-made footwear.

Transmetatarsal amputation

The functional loss that occurs when the amputation procedure involves the removal of the metatarsal heads is substantially greater than in toe amputations. In these amputations, the entire normal forefoot load-bearing capacity is eliminated. In addition, forefoot mediolateral stability will be impaired, which may result in pronation of the hindfoot. Finally, forefoot supination and pronation are largely eliminated.

The removal of the metatarsal heads means that it is no longer practical to transfer the forefoot ground-reaction force (see R in Figure 7) directly onto the plantar surface of the residual foot; therefore, the rotational stability of the patient/prosthesis interface will require special attention. Attempts should be made to use the remaining surface of the longitudinal arch of the foot both as a load-bearing area (F1) and to restore mediolateral stability. However, for this mechanism to be effective, it will be necessary for the prosthetic socket to generate a posteriorly directed force (F2) on the dorsum of the residual foot (Figure 7). This same force generates a moment that resists the tendency of the prosthesis to rotate (in the direction of dorsiflexion) relative to the residual foot when weight is applied to the prosthetic forefoot.

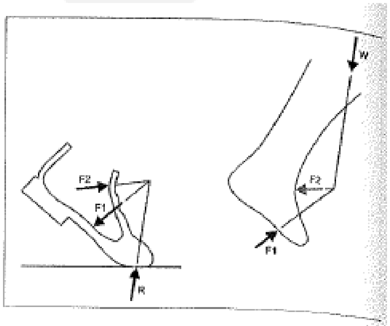


Figure 7 Forces occurring between the residual foot and the socket of a transmetatarsal amputation prosthesis at push-off. F1 = force at plantar surface of the residual foot; F2 = force at dorsal surface of the residual foot; R = ground-reaction force; W = body weight.

Some designs of prostheses for this level are similar to the moulded insole type used for toe amputations, functioning as forefoot fillers maintained in correct relation to the residual foot by the patient's shoe. Better results can be achieved by custom fabrication to a plaster model, which has been carefully shaped so as to transfer the forefoot ground-reaction force behind the cut bone ends. If correctable, the arches of the foot should be reinstated, and this is best done during casting. If the arches are not correctable, the prosthesis must accommodate and support them to prevent further deformation.

A preferred option is to construct a prosthesis with a moulded or laminated socket, built up to replace the lost forefoot, including a soft liner or anterior pad if required. This prosthesis resembles a modified University of California Biomechanics Laboratory (UCBL) foot orthosis, covering 'the dorsum of the foot. The plastic socket may be hinged to facilitate donning (Figure 8). The tendency of the foot to pronate can be addressed either by medially wedging the prosthesis to support the forefoot or by applying a pronation-resisting force to the area of the sustentaculum tali in the socket. (Figure 9).

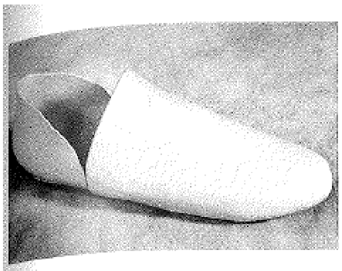


Figure 8 Transmetatarsal prosthesis with hinged laminated socket to facilitate donning.

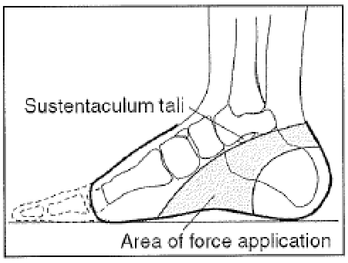


Figure 9 Loading the sustentaculum tali to resist pronation of the hindfoot.

The addition of a rocker sole to the shoe, with its apex proximal to the amputation site, can further relieve the cut bone ends. This also has the effect of reducing the moment that tends to cause rotation of the prosthesis relative to the residual foot at end-stance.

Tarsometatarsal and Transtarsal Amputations

Inevitably, the functional loss and the associated demands for successful prosthetic management are greatest when the surgery entails complete removal of all the metatarsals (tarsometatarsal or Lisfranc amputation) or amputation through the mid tarsal joint (transtarsal or Chopart amputation). All of the functional limitations described for transmetatarsal amputation will be present. In addition, the shape of the residual foot and the much-reduced surface area available make the task of interfacing a prosthesis to it even more challenging.

As mentioned earlier, use of appropriate surgical procedures, even with these most proximal partial foot amputations, can result in retention of a useful degree of ankle and even subtalar joint function. Conversely, when this is not the case, the unresisted action of the intact calf muscles will inevitably produce a deformed equinovarus position of the residual foot over time.

The designs of prostheses that have been produced for these amputation levels are categorized as **perimalleolar and high-profile designs**. Perimalleolar designs include **inframalleolar** designs, where the proximal trimline is below the malleoli, and **supramalleolar** designs, where the proximal trimline encloses the malleoli. The choice of which category and which variant within that category to employ will depend on a number of factors that will be discussed later. First, however, it is important to fully understand the biomechanical basis on which each category functions.

In perimalleolar designs, it is appropriate to attempt to use the residual plantar surface of the hindfoot (F1) to replace the support normally provided by the absent forefoot between heel-off and toe-off. As with transmetatarsal amputations, achieving this goal requires the prosthetic socket to generate a posteriorly directed force on the dorsum of the residual foot. Unfortunately, because of its more restricted area of application and its much shorter lever arm, this force is not capable of successfully resisting the dorsiflexing moment created by the prosthetic forefoot ground-reaction force (R) if the patient attempts to walk normally. As a result, the socket will tend to rotate relative to the residual foot.

An alternative biomechanical solution to this problem, which was described as early as 1955, is to shape the socket so that it grasps the calcaneus firmly medio-laterally. As the socket attempts to "dorsiflex", this action is resisted by downward forces (F2) generated on both sides of the calcaneus (Figure 10).

High-profile designs of prostheses for these amputation levels solve this problem in an entirely different and generally more satisfactory manner. In these designs, the forefoot dorsiflexion moment is resisted by a force couple created by socket interface forces located anteriorly at the socket brim (F2) and posteriorly at heel level (F3). This latter force combines with the plantar support force (F1) to create a single, oblique force (F4).

Obviously, the higher the trimline and hence the wider the separation between F2 and F3, the lower will be their magnitude and consequently the pressure on the residual foot at their sites of application (Figure 11).

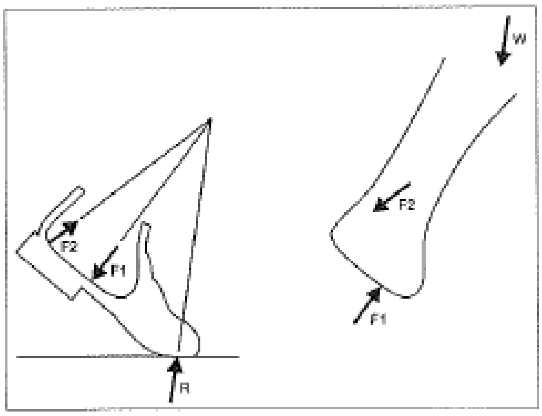


Figure 10 Tarsometatarsal and transtarsal amputation prostheses/perimalleolar designs. Forces occurring between the residual foot and the socket at push-off. F1 = force at plantar surface of residual foot; F2 = force at calcaneus; R = ground-reaction force; W = body weight.

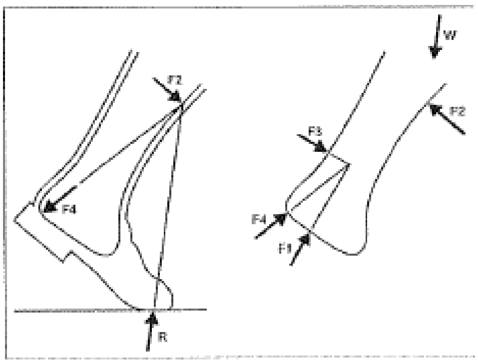


Figure 11 Tarsometatarsal and transtarsal amputation prostheses/high-profile designs. Forces occurring between the residual foot and the socket at push-off. F1 = force at plantar surface of residual foot; F2 = anterior force at socket brim; F3 = posterior force at heel level; F4 = oblique force created by combination of F1 and F3; R = ground-reaction force; W = body weight.

One final biomechanical consideration must be mentioned before discussing prescription criteria and related design issues. Irrespective of which category of device is supplied, if the user attempts to simulate normal push-off, requiring the generation of a significant forefoot ground-reaction force, the construction of the device must be stiff enough to withstand the resulting dorsiflexion moment without deforming.

In most respects, the similarities between tarsometatarsal and transtarsal amputations mean that they can be considered together. In both cases, if control of the talocrural or subtalar joints is impaired and results in deformity, this must be addressed whenever possible by realigning these joints during the casting procedure and with further modification of the positive cast. If mobile, the heel pad must be stabilized in the correct position to avoid medial deviation.

A number of prosthetic designs are available for these amputation levels, and prescription will depend on several factors, including the functional and cosmetic aspirations of the amputee, the presence of joint instability or deformity, the ability to tolerate full body weight, and the sensitivity of the amputation site.

Short designs (Perimalleolar)

Many popular modern designs of prostheses for these amputation levels terminate around the level of the ankle joint. Inframalleolar designs of prostheses are unobtrusive and combine reasonable function and good comfort with very satisfactory cosmesis. They permit the amputee to make use of the talocrural and subtalar joints, but it should be noted that this is appropriate only in patients in whom there is no requirement for significant joint realignment, restriction of motion, or augmentation of function (Figure 12). If necessary, minor realignment of the subtalar joint can be achieved by appropriate wedging of the prosthesis or by wedging or flaring the shoe.

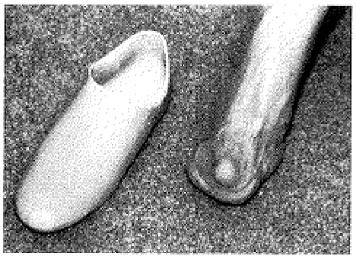


Figure 12 Slipper-type elastomer prosthesis (STEP).

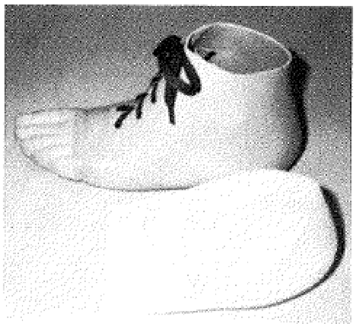


Figure 13 Imler prosthesis.

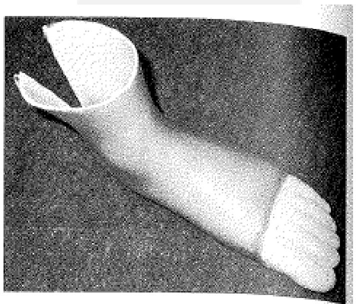


Figure 14 Lange silicone prosthesis.

In all perimalleolar designs, resistance to the end-stance dorsiflexion moment is achieved by the intimacy of the socket fit over the anterior/dorsal aspect of the residual foot and, importantly, by the firm grip on either side of the calcaneus. Skilful modification of a plaster model of the foot is an important factor in achieving success. The use of soft interface padding, or silicone or polyurethane liners, which have excellent pressure and shear management properties, also may be beneficial. Naturally, for slipper designs to be successful, the amputee must be able to tolerate full plantar surface weight bearing.

The major shortcomings of perimalleolar designs are related to suspension problems, discomfort at the anterior aspect of the residual foot at end-stance, and inability to generate adequate push-off, all of which limit the activity level of the user. Some of these shortcomings may be overcome by providing a prosthesis in the form of a bootie that encloses more of the residual foot, with a corresponding reduction in contact pressure. The stability of the prosthesis on the residual foot also is improved, as is suspension. A number of designs with varying degrees of flexibility have been used successfully and combine reasonable levels of function and cosmesis (Figures 13 and 14). Some of these prostheses are fitted with zip or Velcro closures to facilitate donning.

Originally introduced for their excellent cosmetic appearance, silicone prostheses (Figure 15) have proved particularly successful for amputees with adherent or fragile scar tissue. In addition, they permit successful restoration of balance and a more normal gait when appropriately reinforced to achieve the degree of rigidity required to match the amputee's functional needs. As a general rule, greater rigidity is indicated for the more active user.

The anticipated **activity level of the user** is perhaps the most important factor to be considered when deciding a suitable prescription for the tarsometatarsal or transtarsal amputee. There is no scientific evidence that perimalleolar designs allow the more active users to generate the forefoot ground-reaction force necessary to achieve normal push-off. In contrast, a recently published Swedish study clearly demonstrates the ability of users of a modern high-profile design to successfully generate and transmit these forces to their residual foot.

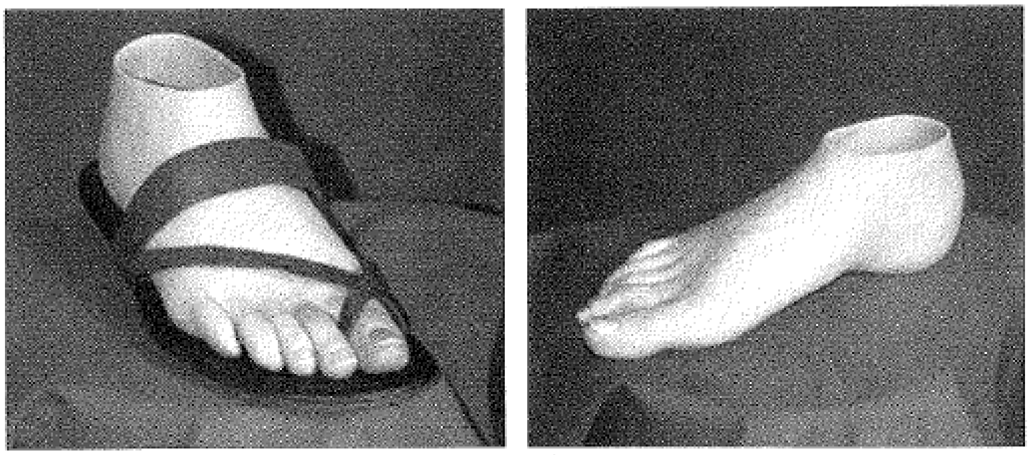


Figure 15 Silicone prosthesis by M. Alaric, Paris. *(Reproduced with permission from Soderberg B, Wykman A, Schaarschuch R, Persson BM: Silicone prosthesis, in* Partial Foot Amputations: Guidelines to Prosthetic and Surgical Management. *Helsingborg, Sweden, AB Boktryck, 2001, pp 80-85.)*

High-Profile Designs

The absence of push-off at the end of stance phase seriously compromises the quality of gait. This situation is analogous to the problem faced by non-amputees with inadequate plantar flexor strength, who are often successfully treated with a rigid AFO. Prostheses based on a rigid AFO design (Figure 16), albeit with an appropriate sole plate and forefoot filler, prevent dorsiflexion by blocking the ankle at an appropriate angle. An important socket interface force required to resist dorsiflexion is located anteriorly at the socket brim. Therefore, a prosthesis constructed with an anterior shell and a posterior opening is more appropriate than the posterior shell AFO-type designs (Figure 17). Naturally, this anterior shell approach will require the plaster model to be modified to protect the tibial crest and the amputation site. Some modern designs incorporate a full-length energy-storing footplate of carbon composite material, built up with a foam material to create the desired foot shape.

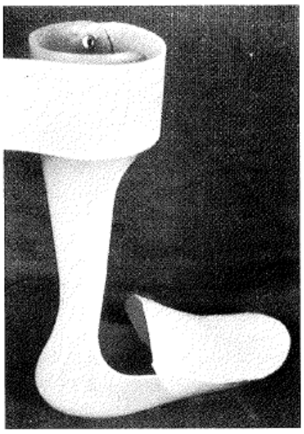


Figure 16 Prosthesis based on a modified AFO. *(Reproduced with permission from Stills ML: Partial foot prostheses/orthoses.* Clin Prosthet Orthot *1988;12:14-18.)*

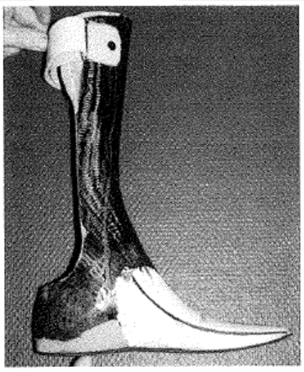


Figure 17 High-profile design prosthesis with anterior tibial shell and footplate of carbon fiber. *(Reproduced with permission from Soderberg B, Wykman A, Schaarschuch R, Persson BM: The chopart amputation, in* Partial Foot Amputations: Guidelines to Prosthetic and Surgical Techniques. *Helsingborg, Sweden, AB Boktryck, 2001, pp 51-59.)*

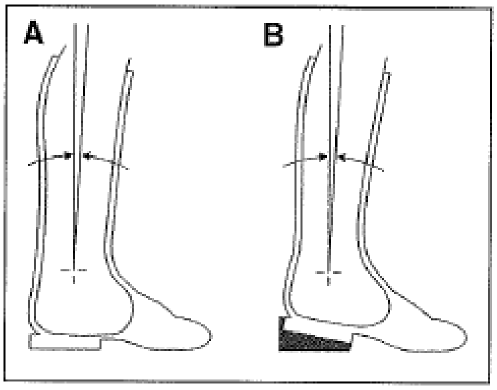


Figure 18 Preferred anterior tilt angle of 5° to 10°. **A,** Normally achieved by ankle dorsiflexion. **B,** A heel wedge is required in the presence of an equinus deformity.

The angle at which the ankle is aligned is important. An anterior tibial tilt of 5° to 10° is desirable if a smooth rollover in late stance is to be achieved. It is the anterior tilt angle of the tibia relative to the floor that is important, rather than the true angle of the talocrural joint, because the heel height of the footwear always must be considered (Figure 18, A). This alignment should avoid the need for a rocker sole on the footwear, which otherwise might be required, and might still be required if the desired angle of dorsiflexion cannot be achieved. If necessary, a wedge build-up under the heel may be incorporated to accommodate any equinus deformity (Figure 18, B). If the wedge is made from a compressible material, plantar flexion will be simulated in a manner similar to the solid ankle-cushion heel (SACH) prosthetic foot. However, when an accommodation for equinus is necessary, the length of the prosthesis will be increased, requiring a compensatory lift on the contralateral side.

Excessive toe-in of this style of prosthesis can lead to the development of a varus moment at the knee. Therefore, it is important to ensure that the forefoot section of the prosthesis is formed so that its rotational alignment matches the sound side. It also has been suggested that making the soleplate stiffer on the lateral side will help resist this varus knee moment.

The use of a rigid high-profile design will sacrifice all movement about the remaining joints of the foot and ankle; however, because these movements are often reduced or absent, this may not represent a serious loss. In any case, the loss of these movements may be worthwhile to achieve improvements in comfort and gait. SACH modification to the heel of the footwear will improve shock attenuation in early stance and simulate plantar flexion, but careful selection of footwear with a compressible heel, e.g., a sports shoe, may make this modification unnecessary. A more sophisticated approach is to incorporate an ankle joint in the prosthesis that permits plantar flexion but blocks dorsiflexion at the appropriate angle, thus permitting more normal ankle joint motion (Figure 19).

Figure 19 Prosthesis based on a jointed high-profile design permits plantar flexion while blocking dorsiflexion at an appropriate angle. *(Reproduced with permission from Soderberg B, Wykman A, Schaarschuch R, Persson BM: Evaluation of different prosthetic solutions for Lisfranc amputees, in* Partial Foot Amputations: Guidelines to Prosthetic and Surgical Management. *Helsingborg, Sweden, AB Boktryck, 2001, pp 76-79.)*

In some cases, the combination of a very small plantar surface area of the residual foot and the presence of a fixed equinovarus deformity makes distal weight bearing impractical. In these situations, a prosthesis employing proximal weight-bearing techniques similar to those seen in transtibial prostheses is indicated. In general, patients who perform at higher activity levels will derive benefit from the provision of prostheses with higher trimlines.

Summary

A comfortable socket, a balanced foot, and an optimal gait pattern are the clinical objectives for all users of partial foot prostheses. The choice of the particular design to be used will depend on a number of factors and requires a careful assessment of the user and a full appreciation of the individual's aspirations. New materials and fabrication techniques have permitted the development of both cosmetically and functionally improved designs that may make partial foot amputation a practical alternative to higher amputation where the pathology permits.

Sources:

1. **Atlas of Amputation and Lower limb Deficiencies**. Douglas G. Smith MD, John W. Michael Med, CPO, John H. Bowker, MD (Editors - 3rd Edition) – Chapter 35: Amputations and Disarticulations within the Foot: Prosthetic Management - David N. Condie, CEng, Roy Bowers, SR Pros Orth (Authors)

Resources:

- Anatomy and Human Movement, Nigel Palastanga
- Gray's Anatomy of the Human Body, Henry Gray
- Clinically oriented anatomy, 7th edition, Keith Mooore et al.

Video Lectures and Power Point presentations

Lesson_7	Partial foot amputation – Video 7
	Partial foot amputation – Presentation 7

L08: CASTING TECHNIQUE OF PARTIAL FOOT AMPUTATION

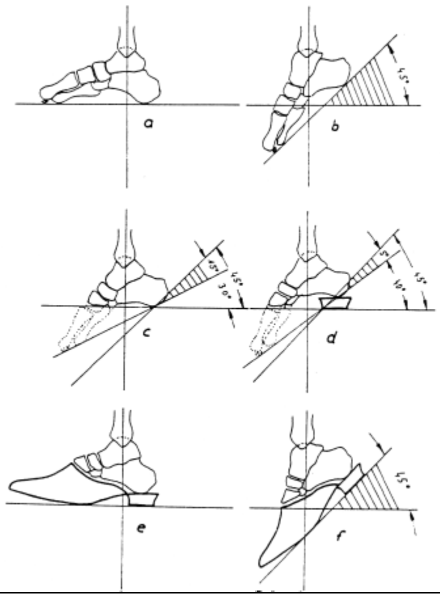
General objectives

- Underestand the different options to cast a patient with partial foot amputation
- Learn the correct foot position acording to the amputation level

1. Casting principles

To cast a partial foot amputation, one of the keys, is to understand how to position the foot during the casting process. Since a part of the normal support area is lost at amputation, the entire remaining sole surface must be utilised for weight-bearing, to avoid, if possible, heel overloading.

To preserve whatever remains of the foot arches, and to prevent dislocations and potentially severe attendant stump pain, the calcaneus must be well supported beneath the sustentaculum tali, with the heel seated in a hollow in the cast. Together with the lower leg section and heel counter, this helps to anchor the heel in the prosthesis. The remnants of both the lateral and medial longitudinal arch must be supported and used as pressure bearing surfaces. In stumps of suitable length, the transverse arch can provide support and thus contribute greatly to relieving pressure on the end of the stump.



a) Normal foot position in standing
b) Maximum plantarflexion in normal foot
c) Maximum residual plantarflexion movement for foot stump in a plantigrade cast.
d) Maximum residual plantarflexion movement with stump cast in equinus position corresponding to height of shoe heel.
e) Position of stump skeleton in adopted "relatively dorsiflexed" casting position.
f) Resultant maximum residual plantarflexion movement

Short tarsal and hindfoot stumps must be seated in a hollow. This helps to reduce the load on the heel since the side surfaces can also be used for pressure load sharing. Any bony prominences or calluses are carefully relieved within the cast profile. A free space of 15 mm at the distal end of the stump prevents loading of the scar tissue during rollover.

In second place we are going to analyse how the different positions of the foot affect the range of motion in the sagittal plane.

Correct positioning of the foot stump in the prosthesis is important. The normal ankle joint is capable of about 45° of plantarflexion (Fig. B). Following forefoot amputation, with loss of the anterior insertion points, the stump plantar flexes. This equinus deformity intensifies with decreasing stump length, only about 15° of possible active plantarflexion remaining in long tarsal stumps (Fig. c). If we add heel height, then plantar movement is almost entirely lost (Fig. D). By casting the stump with the calcaneus in its normal attitude (i.e. the joint maintained in an apparently dorsiflexed attitude) the normal range of movement of the ankle joint is restored (Figs E and F). However, this is merely a "relatively dorsiflexed" position, since it corresponds to the normal position of the tarsus in the healthy foot.

Increased dorsiflexion leads to reduced knee stability with a flexed-knee posture. In contrast, the active plantarflexion achieved when casting in the above dorsiflexed position permits a relatively dynamic gait pattern in patients with long foot stumps. Stump loading is reduced and knee stability increased, since the shock of heel-strike is attenuated by movement of the ankle joint. At the same time loading of the sensitive anterior distal stump area is also reduced by adopting the above dorsiflexed position.

1.2. Sole plate, forefoot filler and rollover

It is important to have in mind what components and how we are going to build the prosthesis before we cast.

It is recommended that the sole plate under the stump socket, to be constructed of stiff material and ends in front of the distal end of the stump, in the region of the 5th metatarsal head. In long stumps it is angled upwards in front of the distal end, preventing unwanted upward bending of the sole and pressure on the distal end of the stump. In short stumps with a rigid midfoot filler, the sole remains flat and is bonded to the midfoot filler.

The toe filler should be somewhat flexible, so that it not only keeps the toe of the shoe stretched but also yields somewhat during rollover. Mechanical joints are not used in this area, since they add unnecessary weight and require maintenance.

The midfoot filler, which extends as far as the 5th metatarsal head (corresponding to about two-thirds of total sole length) is constructed of a rigid material, such as wood, hard rubber, cork or crepe rubber. As a rule, the midfoot filler is bonded to the sole plate or laminated with acrylic resin.

The rocker action is of particular importance. It must replace the natural rollover of the lost forefoot and compensate for the impaired ankle joint mobility. It must also support the stump in the adopted dorsiflexed position and reduce the forces acting on the stump. In long stumps the apex of the rocker is placed in the region of the stump tip to secure the dorsiflexed position. This decreases the mechanically effective forefoot length and markedly reduces the load on the stump during rollover. In short stumps, if fitted with a leg shell, rollover can be set in the normal region.

To permit rollover and swing-through of the prosthesis, the forefoot must be capable of adequate dorsiflexion to effect toe-lift. Otherwise a compensatory action, or gait deviation, would be necessary. In fixed ankle joints a soft heel wedge should be provided. Where this is not possible, the shoe must be fitted with a cushioned heel to attenuate the shock of heel-strike.

2. Partial foot casting technique

Once we understand the foot position and what is the best way to cast it, we can proceed to the casting technique.

The aim of taking a plaster cast is to ensure an accurate model of the stump, which reproduces the stump in its load bearing or partial weight-bearing position as physiological as possible.

2.1. Measurements

Stump measurements are taken having the patient standing or sitting with partial loading on the distal end of the stump. The measurements are taken at the anatomical reference points depending on the design of the device. They include circumferences, diameters, and heights of the stump as well as sound side measurements. All measurements and findings are recorded carefully on the measurements chart:

Stump circumferences:

- At the malleoli
- Apex of fibular head
- Biggest area at the calf
- Mid patellar tendon level (For PTB)
- Minimum circumference above Malleoli
- Maximum circumference at calf of stump
- Maximum circumference at bulbous end of stump

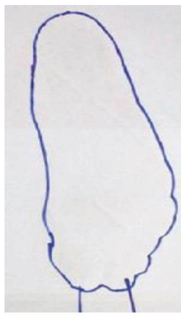
Stump Diameters (M-L Diameters):

- At the malleoli
- Above malleoli
- At bulbous end of stump

Stump lengths and heights

- Height from the end of the stump to floor with patient standing and equal levelled hips
- Length from the floor to where circumference and diameters have been taken

Sound leg measurements



- Copy of the sound-side footprint and appropriate foot toe-out, and copy the reverse side of the footprint to help in positioning when build-up of the foot.
- Length of the foot.
- Heel height of the shoe.

2.3. Casting procedure

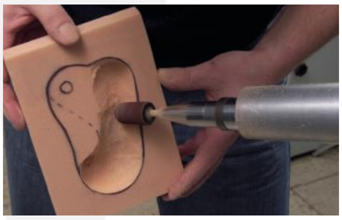
Using the correct casting technique is extremely important to achieve a good result. Casting technique can be either stage casting or circumferential wrapping. Stage casting not only allows easy removal of the cast without having to cut or to distort the cast while removing, but also to concentrate on one aspect of the stump at the time.

To protect the skin is an important aspect of this process, there are many ways to do so, applying Vaseline over the skin, a stockinet or cling film.

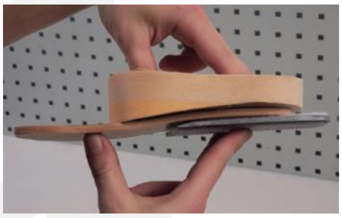
Mark the following landmarks

- Tibial crest (For long socket designs)
- Shaft of fibula (For long socket designs)
- Medial tibial flair (For long socket designs)
- Head of 5th metatarsal
- Tuberosity of navicular bone
- Medial and lateral malleoli
- Achilles tendon
- Other prominences like distal bone structures

For long socket designs it is recommended to place a plastic tube or strip to protect the patient stump when cutting the plaster bandages.



One option is to fabricate a soft base in order to accommodate and position the residual foot. It is possible to grind an approximate negative relieve of the foot, but it is not mandatory. This soft base can also compensate a leg length discrepancy as seen in the pictures



It is recommended to cast with a foot plate, this will facilitate the alignment. It can also give us an idea of how the prosthesis will look like.

It is possible to wrap the stump in one step or do it in stages. If it is done in stages:

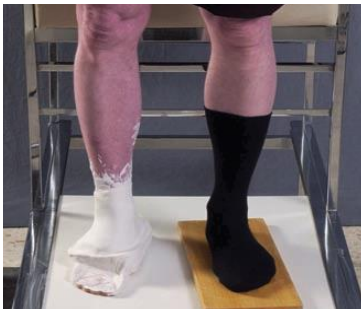
a) Place a 3 -layer plaster splint on the readymade padding for weight bearing during the casting procedure.

b) When it is half way set, lift the foot and place a 3 to 4-layer splint on the plantar surface covering the whole dorsum over the malleoli in the anterior aspect. Let the posterior aspect free covering only the lower part of the calcaneus. And let the patie nt step in.

c) The rest of the cast is done in 2 parts, so it is easy to be opened without cutting the plaster. It is done as following. Cover the lateral aspect with plaster creating a wall at the Achilles tendon level as shown in the picture.

d) Wait until it is set and apply grease of Vaseline to apply the plaster on the lateral aspect. Using this technique, the cast is easy to remove opening the posterior aspect of the negative.

e) Remember to cast in weight bearing position if possible, aligning the residual foot accordingly and compensating a leg length discrepancy if needed.



f) Remove the negative once the plaster is set.

Sources:

1. ICRC Ankle Disarticulation Fabrication Manual
2. GTZ - Orthopaedic Technologist - 3rd Year Training Course - OT302 (GTZ) GB 1991
3. Clinical aspects of lower extremity Prosthetics by CAPO (Canadian Association for Prosthetics and Orthotics)
4. Ottobock partial foot casting technique.

Resources:

- Anatomy and Human Movement, Nigel Palastanga
- Gray's Anatomy of the Human Body, Henry Gray
- Clinically oriented anatomy, 7th edition, Keith Mooore et al.

Video Lectures and Power Point presentations

Lesson_8	Partial foot amputation – Video 8
	Partial foot amputation – Presentation 8

L09: RECTIFICATION TECHNIQUE FOR PARTIAL FOOT AMPUTATION PROTHESES (PFA)

General objectives

- Underestand the main guidelines for partial foot rectification
- Be able to identify specific patient characteristics during cast rectification

Introduction

Among all the available plaster modification techniques, two of them are described in this lecture: the "high profile" and a "low profile" approach for silicon sockets.

Casting and modification are closely related together. If a proper work has been done while casting, it will be easier to modify the plaster model. If the alignment or the pressure areas are corrected during casting (e.g. varus, valgus, plantar flexion or make some plantar pressure for weight compensation) plaster rectification will be easier, faster and more precise.

As toe, and ray amputations mostly are fitted with functional insoles, we are going to focus on the modification for Lisfranc and Chopart amputations prostheses, which have similar modification techniques.

Rectification for partial foot prosthesis

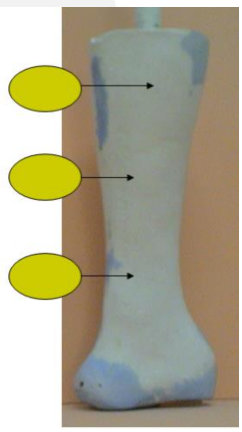
The intention of this technique is to produce a socket that unload the pressure on sensitive areas and load the pressure on tolerant areas of the stump, and of course get a functional result to improve gait. In order to achieve this, plaster is removed from the tolerant areas and is added at the sensitive areas.

For this technique we have **two** options, a high and a low profile design.

Rectification "high-profile" prosthesis:

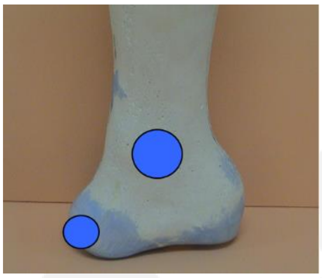
1st Step

Transfer the alignment lines from the negative cast to the positive mould. After stripping out and removing the casting plaster bandages we have to check the measurements in the positive mould.



2nd Step

Reduction should be done on the circumferences of the calf to match with the measurements of the patient or apply reduction if needed. Landmark the pressure sensitive areas in order to release them by adding plaster. The thickness should be between 2mm and 4mm depending on the area and stump type:



The build-up areas are:

-Distal frontal part of the stump (cuboid for Lisfranc)

-Medial and lateral malleoli.

If you took the mould under load over a semi-rigid surface (a foam), it is not necessary to build up with plaster, as the calcaneus already copied its shape under load.

-At the sole, the build ups should be made on any problematic plantar prominences, staying as anatomical as possible, not as flat as possible. Remember that the socket also acts as insole for weight redistribution.

The arches and physiologic structures of the foot should be restored as good as possible.

High profile socket – PTB or Distal-end bearing design?

If the plantar surface is not able to accept weight, a PTB socket is designed in order to do partial or complete pressure relieve. If the plantar surface is able to accept weight bearing a distal-end bearing design is chosen. Trimlines are set uniform horizontally, approximately 2cm below the fibula head.

The distal part of the stump is modified as shown above. Notice that the rectification technique over the malleoli is as in the long transtibial prosthesis, taking care of the tibia crest

The aim in both designs is to reach the volume of the limb in the rectified negative. If there are many soft tissues, it can be reduced 1% or 2%.

After rectification, smoothen the plaster to avoid edges and grooves.

Rectification for "low profile" silicone partial foot prosthesis.

(SILICONE ONLY!)

This technique is more "aggressive". This type of socket will involve the whole stump in a total surface bearing. The technique should not be undertaken unless *silicone as final material is used for the socket*, as the silicon is very elastic and expand when the stump is into the socket.

1st Step

Check the measurements on the mould and landmark the problematic areas like the scar and pressure sensitive areas. Such as the anterior aspect of the residual foot.

2nd Step

- Reduce the heel diameter in around 4%
-The insole and malleoli diameter can be reduced about 8%
-The M-L measurement over the malleoli can be reduced in around 25%
-The total length should not be shortened at all, only smoothen the heel and anterior part. (Take care of the scar and pressure sensitive areas)
-The A-P measurement over and around the malleoli stays untouched for a good tendon functionality.
-To ensure vacuum inside the socket, it is recommended to make a groove with the round Surform of about 3mm and then smoothen it.

Notice that all reductions are given for normal soft tissue conditions.

3rd Step

Smoothen the plaster and fill the holes.

Indications to use one or the other socket design, are going to be described in the next lectures.

Sources:

1. Lecture "Rectification technique in PF amputation and Ankle Disarticulation" from June 2011 in SNMRC
2. Technical information for Silicone partial foot prosthesis. (Ottobock)

Video Lectures and Power Point presentations

Lesson_09	Partial foot amputation – Video 09
	Partial foot amputation – Presentation 09

L10: FABRICATION TECHNIQUE IN PF AMPUTATION PROSTHESIS

General objectives

- Underestand the general fabrication steps for two different technologyies
- Learn about lamination and polypropylene techniques for partial foot prosthesis

Introduction

Education in prosthetics after foot amputation requires knowledge and preparedness in various disciplines. The participant should have the basic medical knowledge about anatomical structures and should understand the functions of lower extremities. The understanding of biomechanical basis and socket shaping is the prerequisite for the work with patients, the production and fitting of the prosthesis. Specialized knowledge about the materials and production engineering as well as basic knowledge in mechanics are necessary to build a prosthetic device individually.

In order to examine the functionality of the prosthetic device one has to be familiar with some biomechanical aspects. An appropriate evaluation of the residual limb and its remaining capabilities can be done only when the different kinds of amputations are properly differentiated.

Work place preparations:

1. Elevated sitting position of the patient
2. Patient evaluation
3. Palpating and marking of anatomical landmarks
4. Measurement technique (see measurement sheet)
5. Preparations for measurement and modification technique
6. Isolate the end of the cut bone with a thick layer of fat (Vaseline)
7. Pull over a lady’s stocking if there is too much hair
8. Test the heel-board and adjust it

Work steps of measurement and modification technique

Needed plaster bandages:

- 1-2 elastic plaster bandages 12 x 2
- 1-3 fixed plaster bandages 12 x 4
- plaster bandage leftovers as multi-layered plaster panels

Work steps of measurement and modification technique

-Position of the patient: sitting

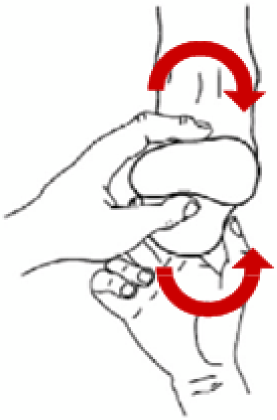
1. Take the blue print of both feet
2. Put a plastic-stripe in the instep area (surface to cut the plaster)
3. Mark possible bony prominences
4. Mark the proximal edge/trim-line on the stocking
5. Cut and put on the plaster panels at:
    - front side/distal stump end
    - sensitive spots/bone spurs

   (isolate the plaster panels with fat/Vaseline)

-Forefoot prosthesis (Ankle joint remains completely free)

- Put in plaster panels (10 - 12 layered) to the right and left of the Achilles tendon and do not isolate them!

6. Circular wrapping of elastic plaster bandage
7. Wrap a plaster bandage that is not elastic (fixed) just above the Malleoli in the shape of the number eight (8).
8. Shape and model the plaster bandages extensively around Malleoli and Achilles tendon.
9. Model grasp to correct the supination and plantar flexion position

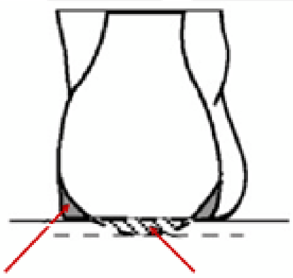


10. Cut open the plaster negative
11. Trim plaster negative to the required socket design and remove the isolated plaster panels
12. Close the model, fill it with fluid plaster and put in the reinforcement steel

Work steps of measurement and modification technique

Model technique

1. Remove uneven spots with a SURFORM rasp
2. Flatten the distal surface of the heel



3. Forefoot prosthesis:
    - Make the crossing of the heel deeper
4. Smooth out the whole plaster positive with fly-grid gaze and wet sandpaper

Attention! Do not smear the contour!

5. If the production includes lamination technique, it is recommended to leave the plaster positive to dry before lamination.

Production and Alignment

Introduction

In the following text, the following phases of the production procedure are presented:

- Basics on socket shaping
- Forefoot prosthesis

As it was made clear in the previous education modules on foot prosthetics, in this education module the individual diversity of foot prostheses is continued. Depending on the kind of amputation the design of the prosthesis must be varied. Because of that only basic or universally applicable production techniques can be presented.

The individual shaping and adjustment raise high demands on the participants. Dealing with materials and work techniques should be mastered so that the participants can concentrate on the patient related clinical aspects of the work.

The participants should become familiar with the work steps and the process details related to production and alignment as well as prosthetic fitting and evaluation.

Basic socket design

Padding

Very soft padding should be avoided in the area of foot treatment.

Those are indicated only for diabetic neuropathy. These patients do not feel the pressure points because their pain sensation is damaged.

For the treatment of all other patients it is valid to pad as little as possible because every compressible material makes worse the adjustment precision.

The padding of the distal end of the stump is an exception. While walking small displace ments and movements occur, that is why the stump end should be protected with padding material of 30-40° Shore A.

The trimlines of a Forefoot prosthesis

The trimlines of the prosthesis are extensively determined so the design respects anatomical characteristics.

The heel area

The socket should reach a level between 1,5 - 2 cm proximal to the calcaneus. Dorso-medial, directly on the Achillo-tendon the trimline of the socket can be cut out downwards or deepened (picture 3).

In that way the pressure on the tendon will be reduced during plantar flexion.

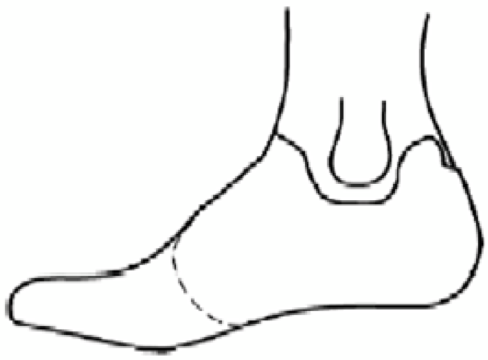
Medial and lateral trimline

In order not to limit the movements in the upper and lower joints and to avoid abraison, the joints have to be cut out.

Instep area

The edge of the socket rises to the instep. The exact length or height of the instep tongue must be determined within the walking test. It should be as high as possible so it can offer enough support.

On the other hand it should not hinder dorsi-flexion, during the roll-over phase.



The trim lines of a Forefoot prosthesis

Work steps at the production

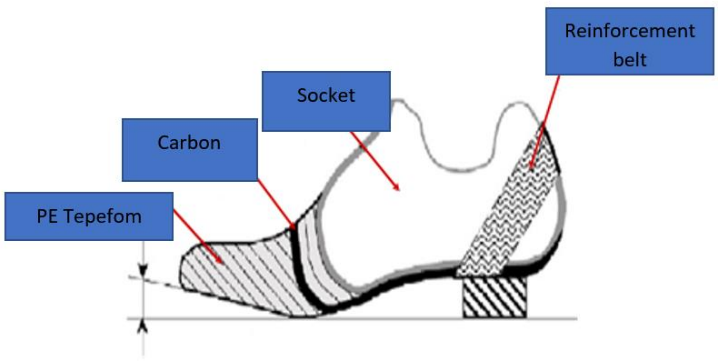
Forefoot Prosthesis

Needed materials:

- 1 sheet high flexible PE deep-drawing material, 6-9 mm (erkoflex 4mm)
- 2 layers of fiberglass (Nylglas) stockinet
- 3-4 layers of carbon stockinet
- 2 PVA bags
- PE-foam of 30-40° Shore A
- Acryl-resin (80/20)
- Belt-strap 20 mm wide
- Neoprene glue

Production technique:

1. Thermoform the PE material without creases over the very smooth and isolated plaster positive
2. Build up the missing middle foot part with PE foam (Tepefom) up to 1 cm before the roll-over edge
3. Laminate 1 layer of fiberglass (Nylglas) stockinet, carbon stockinet
4. Cut the laminated part along the trimlines and glue it to the flexible socket
5. Fix the bandage belt as reinforcement



Alignment:

1. Glue the layers of the PE-material one on the other under the ankle of ca. 45° until the toe area is filled according to the blueprint of the received side
2. Adjust the top of the foot (toe shape) by smoothing the other side
3. Determine the roll-over edge according to the blueprint
4. Determine the toe hoisting according to the heel height

Prosthetic Fitting and Evaluation

Introduction

The theoretical basis of the human gait is assumed to be known, therefore it will not be dealt with here.

When making the foot prosthesis, individual solutions play a bigger role than for some other prosthetic solutions. That is why the biomechanical basis is important. Experiences with visual gait analysis of proximate amputations are preconditional and will be used in order to have an effective prosthetic evaluation.

Testing - checklist and protocol 1 /1

Date: ____________________

Patient name: ____

Function: _______________________

Date of birth: ___________________________

Testing - checklist and protocol 1 /2

Static testing

Are there any changes in general condition after cast removal?

yes no

Observations:

Condition of shoes: new old

In what condition is the sole of the shoe?

In what condition is the heel?

Testing - checklist and protocol 1 /3

Static testing

Conditions of prosthesis:

What is the heel cover like?

Is it too open? yes no

Are there some changes which have to be done on the shoe?

yes no

If yes, which?

Testing - checklist and protocol 1 /4

Static testing

Is the prosthesis fitting the shoe? yes no

It has to be changed in the area of:

Instep

In the width of the front part of the foot

In the shape of the front part of the foot

In the area of the heel

On the sole

Observations:

Testing - checklist and protocol 2

Static testing

Donning of the prosthesis:

Easy: yes no

Difficult because of:

Before further testing changes have to be made:

On the proximal trim line, frontal yes no

On the entrance area yes no

On the closure area yes no

Other:

Testing - checklist and protocol 3

Static testing

Position of pelvis is horisontal? yes no

The prosthesis is (in cm): too long too short

Trim lines are according to anatomical/functional criteria?

Does the proximal edge lean on, without tightening? yes no

Is there enough space for dorsal extension in the instep area

yes no

Are the belts for tightening exact positioned? yes no

Testing - checklist and protocol 4 /1

Dynamic testing

The body is rising very much during the stance phase?

Yes No

Cause :

The heel-height of the prosthesis is too big

he body is rising very much during the stance phase?

Yes No

Cause :

The heel-height of the prosthesis is too big

The elevation of the toe hoisting according to the heel height is not dealt with sufficientlly

The lever of the front part of the foot is too long/the roll-over edge of the foot is moved too much forward

Testing - checklist and protocol 4 /2

Dynamic testing

The body is lowering very much during the stance phase?

Yes No

Cause:

The height of the heel of the prosthesis is too small

The lever of the front part of the foot is too short/

The roll-over edge of the foot is moved too much backwards

Testing - checklist and protocol 4 /3

Dynamic testing

During stance phase the patient feels too much pressure on the medial malleolus?

Yes No

Cause:

Socket is too wide proximal to the medial malleolus

The foot does not have enough support medially

Testing - checklist and protocol 4 /4

Dynamic testing

During roll-over, when crossing the roll-over edge of the foot the patient feels pressure at the stump end?

Yes , No

Cause :

The stump end can slide forward because the tibial area is not contained correctly

The stump end does not have enough free space

Final Steps

In order to make the needed final working steps clearer, the different device types will be distinguished so as in the previous text.

At the end, the check-out protocol will be presented (which can be used for other services as well).

Introduction

During the final fitting the check list protocol should be used.

All necessary final adjustments need to be carried out at that stage

The check-out protocol is to be filled in cooperation with the patient and to be signed by both the patient and the technician in charge.

Completion

Forefoot Prosthesis

The completion of the forefoot prosthesis is organized as follows:

1. Smooth the PE edges with a smooth polishing roll and polish with a rubber roll
2. Smooth all material crossings and edges
3. Fix thin leather on both side edges of the reinforcement belt and smoothen the crossings
4. Cover the entire foot prosthesis with cowhide nappa leather or goat leather.
    - Glue on the leather beginning with the back of the foot, then over the top of the foot and the lateral areas to the heel
    - Thin out the leather on the heel and glue it on to overlap
    - Thin out the leather cover towards the heel
    - Cut the leather along the PE edge and smoothen the leather along the edge with a polishing roll
5. Cut the sole out of the same leather, thin out the edges and stick it on
6. End fitting and filling in the check-out protocol

Example of Production of a Forefoot Prosthesis (after forefoot amputation)

Content:

- Introduction of materials
- Production of a plaster negative
- Modification of the plaster positive
- Deep drawing of a flexible socket
- Laminating of a strength-absorbing socket cover
- Production of the spring for the front part of the foot
- Carrying out of a socket fitting and a walking test

Demands on the Workshop

Machines

- Heating-fan
- Oscillation saw
- Router machine
- Vacuum pump
- Oven

Tools

- Heel board
- Vacuum pipe
- Plaster container
- Plaster bucket
- Plaster knife
- Plaster scissors
- Indelible pen
- Modelling Tools
- Brush
- Sand box
- Router
- Polishing wheel
- Scissors
- Fly-grid
- Thermo-gloves
- Deep-drawing frame and plate

Materials

Materials needed

- Carbon-Acryl-Resin
- Plaster bandages 20 cm wide
- Plastic cup
- Plaster isolating cream
- Plaster reinforcement-stick
- Perlon-belt strap 25mm
- Hardener
- Neoprene glue
- Wooden spatula
- Glue for DAW Skin
- Model plaster
- Powder
- Router
- Router with rasp/grinding tools fine/rough
- Sealing Resin

Matrix and Reinforcements

- Carbon fabric
- Perlon-tricot 10 cm
- PVA-Foil
- Glass fiber mat

Plastic Materials

- Cat-Flex Soft 6 mm
- Multisoft skin 10 mm
- Multisoft skin 4 mm
- Plastazote Skin 24 mm

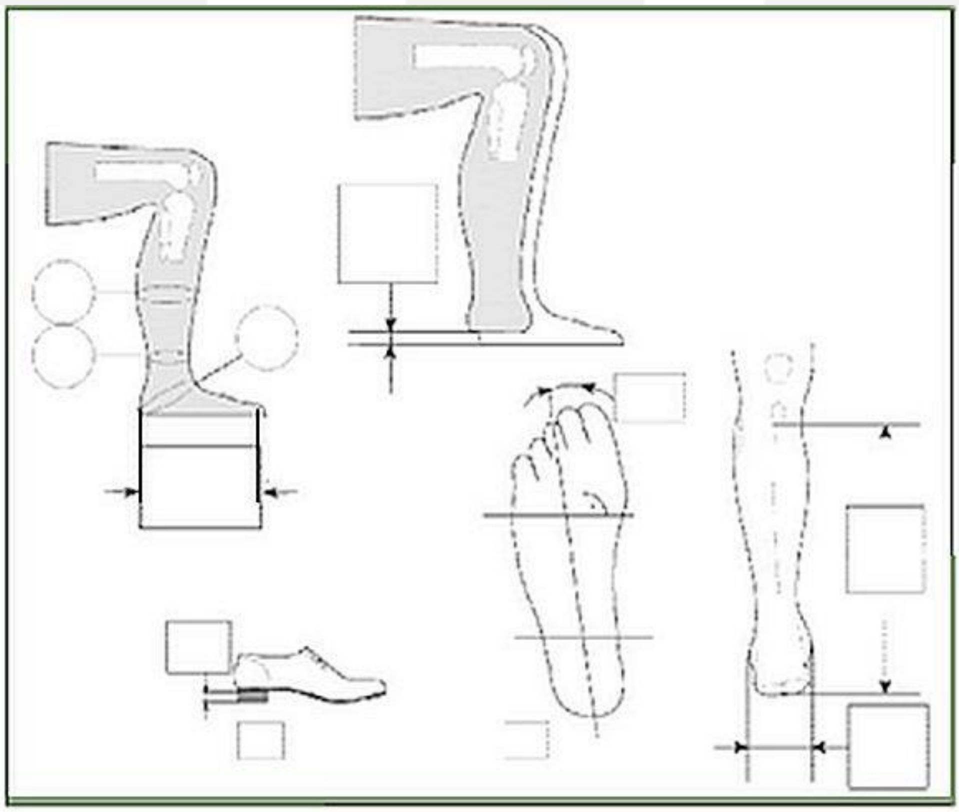
Prefabricated components

- DAW Skin
- Nylon stockings

Measurement

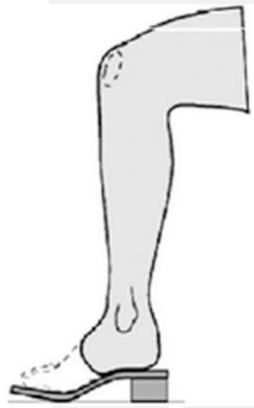
1. Make the outline drawing of the stump + healthy foot
2. (Put the sheet lengthways to the walking direction, set the marking for the inner and outer ankle)
3. Draw in the foot middle line (middle-metatarsus, middle-heel)
4. Divide the length of the foot in three equal parts (1/3 = heel, 2/3 =
5. longitudinal arch, 3/3 = front part of the foot)
6. Draw in the outwards position (the center line is the first marking point (heel))
7. Draw in the roll-over edge (90 to the outwards position)
8. Taking the measure of the stump (these must not be reduced!!!)
9. Measure the height of the heel (Keep one of the shoes for the production of the prosthesis)

Measurement sheet



Work place preparations

1. elevated sitting position of the patient
2. Patient evaluation (see evaluation protocol)
3. Palpating and marking of anatomical landmarks
4. Measurement technique (see measurement sheet)
5. Preparations for measurement and modification technique
6. Isolate the end of the cut bone with a thick layer of fat (Vaseline)
7. Pull over a lady's stocking if there is too much hair
8. Test the heel-board and adjust it (see picture 4)



Picture 4

Production of a plaster negative

• Grease the stump with isolating cream or cover it with two nylon stockings.

• Mark the prominent as well as the pressure sensitive areas.

• Apply the plaster panel on the stump as a dorsal half-pipe.

Attention:

After applying the plaster panel against the stump the patient should be able to restrain it with control, here the Achilles tendon must be vertical

(The base of the tendon is located slightly lateral at the heel bone)

• Insulate with a fat cream or Vaseline the dorsal overlaps of the cast with plaster isolating cream

The medial and lateral areas of calcaneus are used for suspension, which is formed with hands, also we control the supination of the residuum and the dorsal extension!

• Shape the ventral cast (under load)

Attention:

The length of the stump must not be shortened!

• Tie the cast together and fill with model plaster (plaster of Paris).

Production of a plaster positive

Suspension is on the calcaneus, lateral, medial, antero-lateral and antero-medial

- Lateral more
- Fill the dents
- Painful areas should be added
- Distal part of calcaneus is even
- Scar tissue-unload
- Free the plaster positive from unevenness, level out the undercuts (scarves)

Attention:

Test the position of the foot, effective heel height and the vertical line of the tendon (picture 5)

Pic. 5

Flexible inner socket

Posterior part of the flexible socket not less than 4mm!

- Seams should not be posteriorly medial or lateral, only tolerant anterior
- Do not use socks before draping the plastic
- Heat model a bit before start with thermoforming

Making the socket wall thinner (like this the inner socket will be more flexible and the handling will be easier)

Attention:

The frontal foot aspect must be smoothened quite thin so its flexibility acts like a buffer.

- Cutting trimlines and polishing the socket edge area

Attention:

The flexible socket should be removed from the model only under great strength.

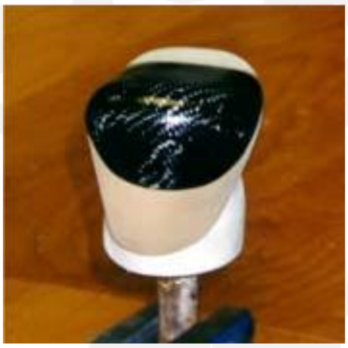
The heel frame has to be high enough so that the patient does not slip out of the prosthesis with the increase of frontal foot weight.

The shorter the stump is the higher the heel frame needs to be, because that is the only part that provides hold and prevents slipping out while walking

- Shaping and gluing over of the ventral buffer zone in 45°
- Keep the buffer zone at least 2 - 3 cm strong!
- For shorter stumps the buffer zone has to be bigger since it will respond later to the frontal foot part
- For diabetic patients the buffer zone should be as soft as possible (sensibility disturbances) and made as short as possible because otherwise the frontal foot part forces will become too big for the heel

Production

- Reinforce the heel cover with carbon fabric for lamination
- From middle of calcaneus, sides 8 mm round, anterior up to 2/3 of that area, posterior part of carbon is flexible!



- Gluing over of the carbon heel cover to the soft socket
- Shape and apply 2 heel cushions made of Multisoft 10 mm.
- Shape and adapt a heel reinforcement strap that keeps the heel inside the socket.

- Building up the cosmetic compensation with PE material (TEPEFOM)

- Checking the shape and drawing continuously!

Attention!

Here the foot position must be very precisely taken into account! (Supination, pronation, shape)

- Shape and fix the dynamic spring of the front part of the foot

Attention:

The width of the spring is determined according to the patient's demands .

The wider the spring the higher is the resistance!

- Testing the handling of the prosthesis (donning-doffing)
- Use a PVA foil, around the residual limb, just not distally
- One sock for partial foot amputations level

Evaluate the fit and function of the device

- Cosmetic cover for the prosthesis made of a washable artificial skin.

- The final device

Resources:

- *Partial foot amputations*. Bengt Söderberg, Anders Wykman, Roland Schaarschuch, Björn M. Persson. 2nd edition, 2001
- Ottobock Technical information: Footplate for Chopart prosthesis.

Video Lectures and Power Point presentations

Lesson_10	No video
	No video
	Partial foot amputation – Presentation 10

L11: PARTIAL FOOT AMPUTATION PROSTHETIC FITTING

General objectives

- Learn a standard fitting protocoll for partial foot prosthesis
- Underestand the importance of an organised workflow with the patient

Introduction

Once the prosthetic device is manufactured and before making the last trial and delivery it, it is important to review and check some aspects:

The aspects to check before and during fitting are:

-The device meets the prescription
-The quality of fabrication:
 -Is the prosthesis assembled correctly?
 -Is it free from rough edges?
 -Is the prosthesis comfortable and free of pain/discomfort?
-Functional Evaluation
 -Is the device restoring gait as good as possible?
-The device meets the patient´s needs/expectations
 -Can the user develop his activities of daily living/at work?

The patient has to be informed about the features of the device:

-Parts of the prosthesis and their functions
-Final appearance or custom possibilities if it is a temporary or test prosthesis
-How to don and doff the device
-Hygiene and care of the prosthetic parts
-Encourage the patient to ask, especially if it is the first prosthesis

In this lecture we are going to study the specific things to take care about tin??? prosthetic fitting for static and dynamic alignment.

Toe amputation

It is not always necessary to supply toe amputees with a prosthesis. The reason is that it is sometimes difficult to keep the prosthesis in place without involving surrounding areas. Therefore, the patient can reject the device.

A foot bed which relieves the pressure of the metatarsal heads is often sufficient. The remaining toes, which have to bear the increased pressure at toe-off, need to be addressed to avoid pressure and misalignment because the neighbouring toes are not there for support, as well as other complications. This pressure relief can be achieved by using a metatarsal pad or pressure relief.

Foot bed after toe amputation 2-5. Notice that the big toe is placed a little bit laterally to achieve better terminal stance and better support medially and laterally for the big toe.

If there is a pressure problem at the distal end of the stump, the same pressure relief foot-bed is made, as for big-toe amputations

It is important to remember that during the third-rocker, the distance between the distal end of the stump and the shoe filling is shortened. Therefore, it is recommended soft material to be used next to the end of the stump to avoid unnecessary pressure during toe-off.

Finally check if the insole matches the shoe.

Alignment

Proper alignment of the foot-bed is important for adjustments against pronation and supination, and to improve the biomechanics during toe-off. A medial hindfoot wedge can be used to compensate for a valgus-pronation alignment. A lateral wedge under the forefoot can be used to compensate for a lateral toe-off.

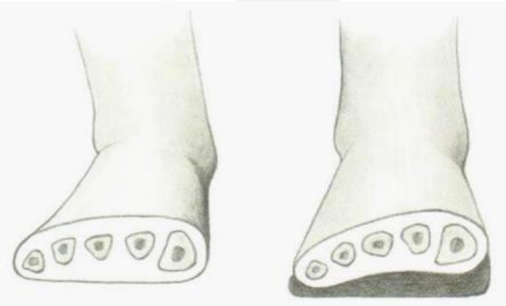
Transmetatarsal amputation

This type of amputation, as in a toe amputation has also one clear advantage, the patient is able to walk, at least indoors, without a prosthesis. If a prosthesis is provided, total contact has to be ensured. The arches have to be restored as good as possible and the anterior aspect as to be cushioned, since many forces are acting during push off.

Alignment

The amputation causes a loss of supporting bones on the medial side of the foot, which results in a pronated position. The medial arch missed support distally and has to be filled up, as a well modified medical arch.

It is important to ensure that the pronation tendency, as shown in the left foot on the picture is avoided. The medial arch in the insole is responsible for this.

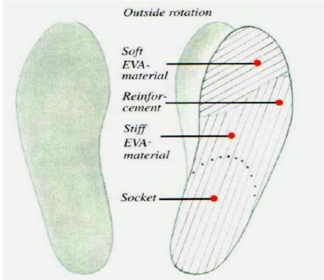


Medial support

Lisfranc amputation

An important goal of the socket is to fixate the stump and counteract forces that are generated during walking.

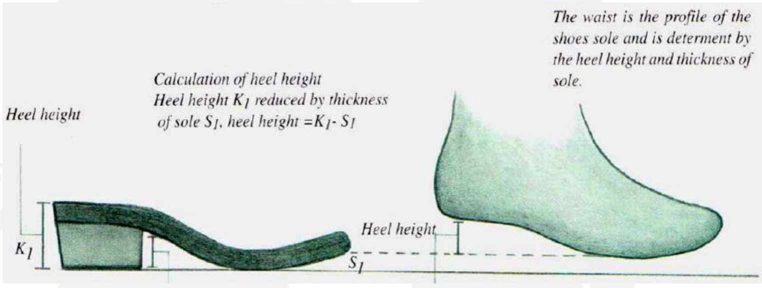
An insole/foot bed with toe filler is normally not sufficient for this level of amputation because the forces acting on the end of the stump during walking cause pressure-related problems. Depending on the shape and volume of the stump, the socket can be closed or be in two pieces for easier donning and doffing. Sometimes during test fitting it is necessary to change the design if needed.



To avoid a lateral deviation of the knee, a varus position, it is of importance to create the right roll over of the prosthesis over the big toe. Another way to avoid varisation of the knee is to outward rotate the prosthetic foot and to reinforce the sole in the area of the fifth metatarsal bone. B. Söderberg 1998.

Alignment

The angular relationship between the ventral support of the prostheses and the foot-sole in relation to the heel height is of great importance for gait.



The stiffness of the footplate and its rotation in relation to the stump is of equal importance and has to be checked.

To achieve the correct "roll-over" the lateral part of the sole is reinforced to achieve certain resistance during toe off.

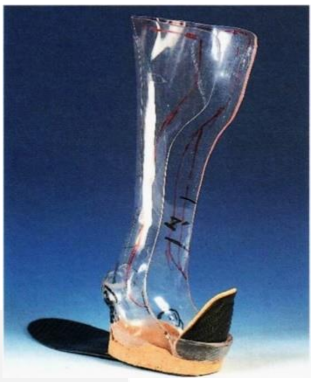
It is also recommended the two plumb lines taken during casting to be taken into account to achieve the correct bench alignment that will mimic the dynamic gait pattern. The placement and outward rotation of the sole should be symmetrical to the sound-side. In any case an internal rotation must be avoided.

Another important aspect is the correct fit of the sole to prevent the prostheses from moving into the shoe.

If the position of the stump or prominent

areas at the anterior aspect are painful, the choice of a lower heel height can solve the problem.

Chopart Amputation



There is considerable strain and stress placed on this type of prosthesis and stump, particularly with the use of a stiff footplate. As shown in previous lectures, the stiffness of the forefoot has to be adapted to the patient, as this can affect gait and socket comfort.

Alignment

Structure of the foot

At this amputation level there is no space under the socket to place a prefabricated foot. The solution to this problem is to choose a material that is as thin as possible. The most common choice is to use a prefabricated sole of carbon as shown in the pictures or a forefoot filling with a plastic construction.

It is important to know the relationship between the stiffness of the prosthetic foot and step-length; the stiffer the foot, the longer the step-length. For this reason a rocker bar or a too long or rigid sole is contraindicated because it will produce an asymmetric step length and gait. The carbon (or other composite materials) spring in "Energy storing" prosthetic feet can improve gait, but sometimes it is difficult to optimise the result, because of the need to adjust the stiffness according to the patient's activity level. (In further lessons we will also discuss about shoe adjustments that can be useful).

Alignment of the prosthesis on the foot

The stump and shank have a tendency for a varus deformity. Therefore, the foot-plate/sole must be placed as lateral as possible in relation to the socket. Follow the plumb line from the middle of patella taken during casting. For cosmetic purposes, it would be easier to place the foot directly under the distal end of the socket, but it is more functional to displace it to the lateral side.

The varus tendency of the stump creates a lateral deviation of the knee during walking. To minimize this disadvantage, the foot can be externally rotated more than usual, and the lateral part of the sole can be made stiffer up to the base of the fifth toe. This step only partially reduces the lateral thrust of the knee. Aside from this correction, only smaller adjustment are possible (e.g. plantar or dorsiflexion).

Resource:

- Partial foot amputations. Guidelines to Prosthetic and Surgical Techniques. Bengt Söderberg, Anders Wykman, Roland Schaarschuch, Björn M. Persson. 2nd Edition. 2001

Video Lectures and Power Point presentations

Lesson_11	Partial foot amputation – Video 11
	Partial foot amputation – Presentation 11

L12: PARTIAL FOOT AMPUTATION - GAIT ANALYSIS

General objectives

- Underestand the need of gait analysis in partial foot amputation fittings
- To use the theoretical content to put it in practice

Introduction

Partial foot amputation (PFA) is a common sequel to advanced vascular disease secondary to diabetes and its complications, but may also occur due to injury, infection, or birth defect. PFA affects about 2 per 1000 people in industrialised countries making it the most common type of amputation surgery. PFA is associated with a significant failure rate and numerous complications including skin breakdown, ulceration and equinus contracture which can lead to subsequent and more proximal amputation.

A variety of interventions have been used to manage the partially amputated foot including insoles or toe fillers through to extensive prostheses that encompass the leg and remnant foot. These devices may serve several functions such as relieving pressure from sensitive areas or restoring the effective foot length.

Formally evaluating how persons with PFA walk and the influence of prosthetic intervention is a relatively recent phenomenon. Investigations have identified a number of abnormal movement patterns once the foot has been affected. These movement patterns are consistent with the inability to generate power at the ankle joint using the calf musculature and restore the lost length of the foot so it can be used effectively for weight bearing. A number of compensatory adaptations have been observed that may be useful to spare the end of the residuum from high pressures, such as keeping the centre of pressure well behind the end of the stump until the opposite limb is on the ground when body weight can be shared between both limbs.

Research has confirmed that prostheses in combination with footwear can relieve pressure from the end of the residuum and that specific designs can restore the effective foot length. Further investigation is needed to better understand the influence of prosthetic intervention and paint a more comprehensive picture of the effects of prosthetic intervention.

Characteristics of PFA gait and the influence of prosthetic intervention

To characterise the gait of persons with PFA, a range of different adaptations in different studies was analysed and explored by Dillon MP. (2010), in his article "Partial Foot Amputation: Aetiology, Incidence, Complications, Prosthetic Intervention and a Characterisation of Gait" in which this lecture is based. This study included: reductions in walking velocity in those with diabetes and vascular disease, changes to the normal excursion of the centre of pressure (CoP); reductions in the rate of work or power generation at the affected ankle and compensatory increases in muscle work at the hip joints. Reductions in ankle plantarflexion during terminal stance and increases in peak forefoot pressures are illustrative examples of other adaptations typically observed in persons with PFA.

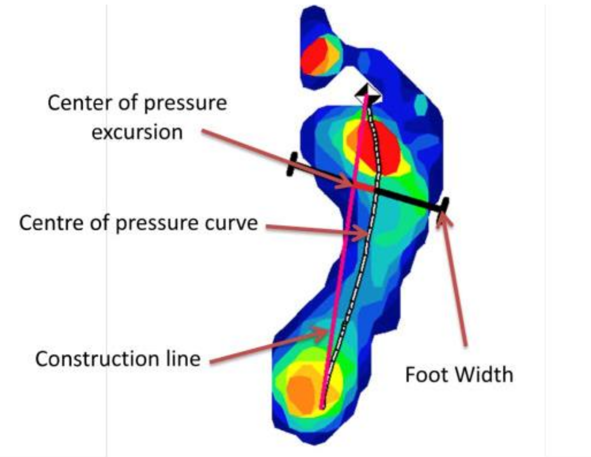
Walking velocity

Persons with PFA secondary to diabetes and peripheral vascular disease walk at about two-thirds the speed of healthy persons without amputation (Kanade et al. 2006; Kelly et al.2000; Mueller et al. 1997a; Mueller and Strube 1997; Salsich and Mueller 1997). The slower walking velocity so often characteristic of PFA gait is likely to be attributable to the influence of diabetes and other systemic disease rather than the amputation per se. When appropriately matched to control for the influence of systemic disease, it appears that persons with PFA (and no systemic illness) walk at the same speed as their peers without amputation (Kanade et al. 2006; Pinzur et al. 1992). In addition, pain or discomfort in the socket or stump also affects the walking speed.

Changes to the centre of pressure (CoP)

In a sound foot the CoP is moving during gait, progressing forward as shown in the picture on the right.

In partial foot amputation, the CoP remains well behind the end of the residuum until the opposite foot contacts the ground and body weight can be transferred to the unaffected limb (Dillon and Barker 2008; Dillon and Barker 2006a). This adaptation would be an effective strategy to spare the end of the residuum from the extremes of force observed during late stance (Dillon and Barker 2008). The below-ankle interventions commonly provided to these groups have not been shown to restore the normal progression of the CoP along the length of the foot.



It has been hypothesised that the ability of the prosthesis to restore the effective foot length relies on three elements:

- a suitably stiff forefoot capable of supporting the amputees body mass
- a socket capable of comfortably distributing pressures caused by loading the prosthetic forefoot to the leg and residuum, and
- a relatively stiff connection between the foot and leg segments to help control the moments caused by loading the prosthetic forefoot

Only some of the above-ankle interventions (e.g. high-profile rigid ankle prostheses, Blue Rocker Toe-Off AFO –figure on the right-) fulfil these criteria and have shown that the CoP was able to progress beyond the end of the residuum according to the peak ground reaction forces (Dillon and Barker 2008; Dillon and Barker 2006a; Wilson 2005).

Figure on the right: Blue Rocker Toe-Off AFO in combination with a low-profile partial foot amputation prosthesis

Reductions in ankle power generation and compensatory adaptations

Once the metatarsal heads are compromised, power generation across the affected ankle is virtually negligible (Burger et al. 2009; Dillon and Barker 2008; Mueller et al. 1998; Tanget al. 2004) irrespective of residual foot length or the type of intervention. Interestingly, while the below-ankle devices provided to these amputees, allowed ankle motion, power generation was comparable to that observed in persons with transtarsal amputation wearing high-profile prostheses (Figure on the right) where ankle motion was eliminated (Dillon and Barker 2008).

Figure on the right: high-profile partial foot prosthesis. This design with removable window (obturator) does not allow ankle movement.

It is unclear why persons with amputation proximal to the metatarsophalangeal joint, do not use the available plantar flexor musculature to generate power but it may be a useful means of avoiding localised pressure or shear force on the end of the residuum (Dillon and Barker, 2008).

Reductions in ankle power generation on the prosthetic limb during late stance are comparable with increased power generation across the contralateral hip (Dillon and Barker, 2008). Similarly, increased hip power generation was also observed on the affected limb during early stance (Dillon and Barker 2008). This suggests that the hip joints have become the primary source of power generation to compensate for the limited power generated across the affected ankle (Dillon and Barker, 2006).

Reductions in ankle plantarflexion angle

Reductions in ankle plantarflexion have been observed in a number of investigations when amputation is proximal to the metatarsophalangeal joint (Burger et al. 2009; Dillon and Barker 2008; Mueller et al. 1998; Tang et al. 2004). In persons using below-ankle devices, the normal pattern of plantarflexion motion was observed but the peak angle was greatly reduced. In the high-profile above-ankle designs, the ankle is immobilized inside the prosthetic socket so this cannot be measured.

Increased forefoot plantar pressure

A number of investigations have observed increased peak forefoot pressures compared to the contralateral limb in persons with PFA (Armstrong and Lavery 1998; Garbalosa et al. 1996; Lavery et al. 1995; Mann et al. 1988; Mueller et al. 1997b; Randolph et al. 2002).

While this observation is consistently reported, there is insufficient evidence to suggest that prosthetic intervention has an effect compared to footwear alone.

In the picture on the right, the static pressures while standing on the plantar surface are observable. The foot on the left has a metatarsal-phalangeal disarticulation with an almost intact longitudinal arch and the foot on the right side has a transmetatarsal amputation with a clear loss of the longitudinal arch.

Clinical implications - conclusion

Evidence on the understanding of partial foot prostheses is not yet sufficiently developed to answer a range of questions or to make strong recommendations about how specific individuals with PFA can best benefit from prosthetic intervention.

Clinicians routinely provide below-ankle devices that maintain ankle motion (Condie 1970; Heim 1994; Imler 1985; Lange 1991; Schwindt et al. 1973), which has been assumed to allow propulsion or 'push off' during late stance (Burger et al. 2009; Rubin 1984; Rubin 1985; Rubin and Danisi 1971; Stills 1987). The synthesised evidence (Dillon et al. 2007a) shows that once the metatarsal heads have been amputated, power generation across the ankle is virtually negligible irrespective of the device fitted.

Persons wearing below-ankle devices that were designed to allow ankle motion and preserve the ability to generate power at the ankle, showed no greater power generation than did persons using high-profile devices where ankle motion was eliminated. While a device that allows ankle range of motion may be beneficial in a range of circumstances yet to be investigated, such as descending slopes or rising from a chair, the evidence clearly shows that the power generated at the ankle or push-off during gait will not be improved. Selection of such below-ankle designs should, therefore, be based upon other factors such as cosmesis or the need to prevent ulceration in persons at high risk.

Main concepts

- Gait in partial foot amputations is considerably altered, especially when the head of metatarsals are not present.
- Persons with PFA secondary to diabetes and peripheral vascular disease walk at about two-thirds the speed of healthy persons without amputation. This speed reduction is more likely to be attributable to the influence of the systemic disease rather than the amputation per se.
- In partial foot amputation, the Centre of Pressure (CoP) remains well behind the end of the residuum until the opposite foot contacts the ground and body weight can be transferred to the unaffected limb, a suitable high-profile prosthesis is necessary to restore the effective foot length.
- Ankle power generation is negligible for any partial foot amputation when the head of metatarsals are not present, irrespective of residual foot length or the type of prosthetic solution applied.
- In persons using below-ankle devices, the normal pattern of plantarflexion motion was observed, but the peak angle was greatly reduced.
- In persons with Partial Foot Amputation, peak plantar forefoot pressures are increased compared to the contralateral limb (regardless the prosthetic fitting or the footwear).
- Further investigation is required to better understand the influence of prosthetic intervention in a number of areas so that clients and clinicians can make better informed decisions about treatment options.

Glossary

Centre of Pressure (CoP): describes a single point which represents the sum of all pressure over a particular area. This position of this point can be tracked through a gait cycle or with respect to a body segment such as the foot. In this way, it is possible to identify when and how far the CoP has travelled. This is known as the excursion of the CoP.

Ground Reaction Force: force exerted by the ground on a body in contact with it. For example, a person standing on the ground exerts a force upon it. At the same time and equal an opposite force is exerted by the ground on the person.

Kinematics: description of movement of body segments without regard for the cause of the movement

Kinetics: descriptions of the underlying cause of human movement including: muscle forces, torques

Observational study: a type of investigation whereby individuals are observed and outcomes measured without any intervention.

Plantar pressure: pressure experienced by the sole (plantar surface) of the foot

Power generation: Power is a measure of the rate at which work is done or energy is expended. Power generation reflects concentric muscle activity (muscle contraction where the muscle shortens in length). Power absorption describes eccentric muscle activity (muscle contraction where the muscle gets longer).

Transtarsal: a partial foot amputation that divides the talonavicular and calcaneocuboid joints. Also known as a Chopart amputation after the surgeon who pioneered this procedure.

Walking velocity: measure of the speed of walking

Resources:

- **Partial Foot Amputation: Aetiology, Incidence, Complications, Prosthetic Intervention and a Characterisation of Gait**
  Michael P Dillon, B. P&O (Hons); Ph.D. 2010
  National Centre for Prosthetic and Orthotics
  Musculoskeletal Research Centre, La Trobe University. Melbourne. Australia

Video Lectures and Power Point presentations

Lesson_12	Partial foot amputation – Video 12
	Partial foot amputation – Presentation 12

L13: DEVICE EVALUATION AND ADJUSTMENTS

General objectives

- Underestand the need o fan evaluation and quality proctocoll for the fabricated prosthetic device
- Critical thinking about the treatment and outcome
- Be able to use shoe modifications to improve the prosthetic outcome

1. Examples of Prosthetic generic device evaluation tools

To evaluate a prosthesis there are many aspects that can be taken into consideration. Something as simple as the weight can be easily determined but also more complex parameters like mobility, activity, cosmetic appearance, satisfaction of the patient, functionality, etc. can be assessed.

There are also different approaches or 'points of view' from which a patient or the characteristics, advantages, and disadvantages of a prosthesis could be considered.

Many measurements tools and scales can be used for the evaluation of a prosthetic device. Amputee patients' characteristics can also be assessed with some other tools.

Evaluation tools can be classified in:

- Mobility/physical outcome measurement tools
- Generic Rehabilitation Tools
- Quality of Life / Satisfaction Scales

We will describe some examples of these three types of generic evaluation tools:

1.1. Mobility physical outcome measurement tools

1.1.1. Amputee Activity Score

A measure of function for outpatient lower limb amputees wearing a prosthesis. It is a self-report tool, carried out by interview. The level of activity achieved depends both on functional capacity and amount of activity carried out.

1.1.2. K Classification

A scale containing descriptive functional levels for prosthetic users, developed by the American Orthotic & Prosthetic Association. Often used in classifying components for prosthetic prescription. This scale goes from 0 to 4 and is classified as following:

K0	The patient does not have the ability or potential to ambulate or transfer safely with or without assistance and a prosthesis does not enhance their quality of life or mobility
K1	The patient has the ability or potential to use a prosthesis for transfers or ambulation on level surfaces at fixed cadence - a typical limited or unlimited household ambulator.
K2	The patient has the ability or potential for ambulation with the ability to traverse low-level environmental barriers such as curbs, stairs, or uneven surfaces - a typical community ambulator.
K3	The patient has the ability or potential for ambulation with variable cadence - a typical community ambulator with the ability to traverse most environmental barriers and may have vocational, therapeutic, or exercise activity that demands prosthetic use beyond simple locomotion.
K4	The patient has the ability or potential for prosthetic ambulation that exceeds basic ambulation skills, exhibiting high impact, stress, or energy levels - typical of the prosthetic demands of the child, active adult, or athlete.

1.2. Generic rehabilitation tools

1.2.1. Barthel Index

Originally developed for neurological populations, but also useful for amputee clients, this index is in common usage. It evaluates 10 activities of daily living using an ordinal scale. There are different versions, and there may be a ceiling effect where clients score well but continue to have significant disability.

1.2.2. Functional Independence Measure (FIM)

Another scale in widespread use with all diagnostic groups in rehabilitation. It measures disability and the impact of disease on the person's functional abilities, describing the amount and type of assistance required. It is therefore said to assess the burden of care. It uses a seven point scale to score 18 functional items.

1.2.3. 10m Walk Test

Measures timing and spatial aspects of walking, including velocity, cadence, and step/stride lengths. The test is carried out over 14m, but the measurement only occurs in the middle 10, leaving the first and last 2m for acceleration & deceleration.

1.3. Quality of life / satisfaction scales

1.3.1. Attitude to Artificial Limb Questionnaire (AALQ)

Used to measure quality of life for amputees wearing a prosthesis. Items include satisfaction with prosthesis, attitude of others, mobility, and restoration of body image. It is a self-report tool, carried out independently, or via interview.

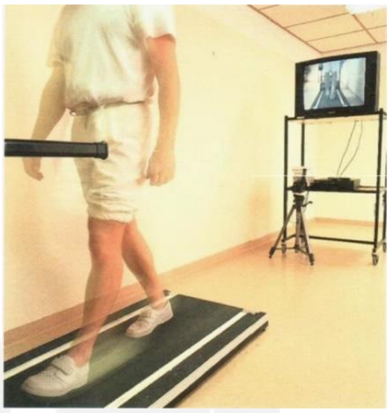
1.3.2. Socket Comfort Score (SCS)

It has adapted the numerical rating scale for pain (Downie et al.) to form a 11 point scale to record the socket comfort score (SCS).

2. Specific evaluation and adjustments according to different Partial Foot Amputations levels

2.1. Toe amputations

2.1.1. Evaluation



Depending on whether the prosthesis is functional or purely cosmetic, different criteria have to be fulfilled.

A patient with a cosmetic toe-prosthesis has to be satisfied according to her/his demands and wishes.

For the patient who is fitted with a functional prosthesis the following criteria can be analyzed: (normal) step length, limping and comfort.

A useful tool for analysis, in addition to observation, is a slow motion video system (That can also easily be used in your smartphone). By looking at the patient in slow motion, heel-strike, mid-stance and toe-off (the 3 rockers) can be analyzed.

2.1.2. Shoe adjustments

The most common adjustment in this amputation level in order to improve the third rocker, especially if the stump is sensitive at the distal end, a rocker sole can be used.

The rocker bar should be placed just behind the amputation level for maximum unloading.

2.2. Transmetatarsal amputations

2.2.1. Evaluation

Considering what we learnt in the previous lesson about the Centre of Pressure that remains well behind the end of the residuum until the opposite foot contacts the ground, a good indicator of a correct prosthesis is the step-length.

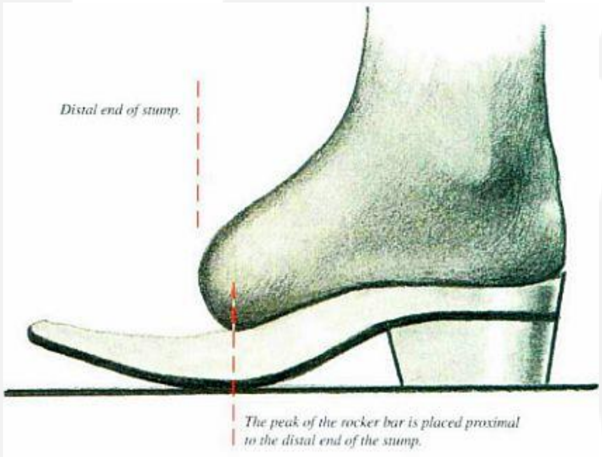
The goal is to achieve a normal step-length, the same compared to the sound side, without limping and good comfort.

As in the previous amputation level it can be evaluated by observation or with a slow motion video system.

2.2.2. Shoe adjustment

If the lateral support in the prosthesis is not sufficient, a lateral flare on the heel of the shoe and the forefoot should be constructed.

Even a rocker bar can be necessary for better roll-over during gait. This is especially recommended if we use a low-profile design to diminish the pressure at the distal end at toe-off.



2.3. Lisfranc amputation

2.3.1. Evaluation

Normal step length and a gait without limping is evidence of a good prosthetic result. Depending on the degree of functionality of the prosthesis, different scoring criteria are required.

A silicone prostheses performs only partly as a functional prostheses. A good fitting and shape as well as a natural color that is close to the sound foot is indicative of a good result.

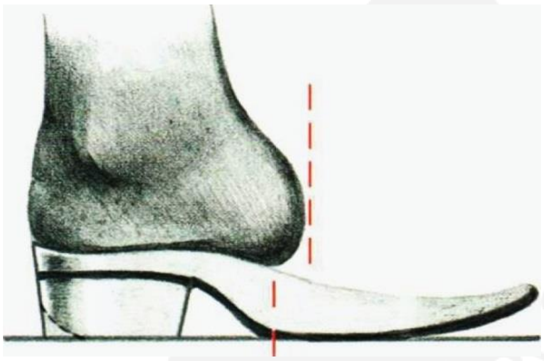
The goal for patients that are fitted with a prosthesis is to preserve as much natural function as possible. With this goal in mind, a patient's gait can be judged using the following criteria: a smooth gait pattern, presence of pressure problems during stance phase, whether the patient limps, an equal step length, and the ability to balance on one leg.

During fast walking a certain limping is expected due to the lack of push-off function.

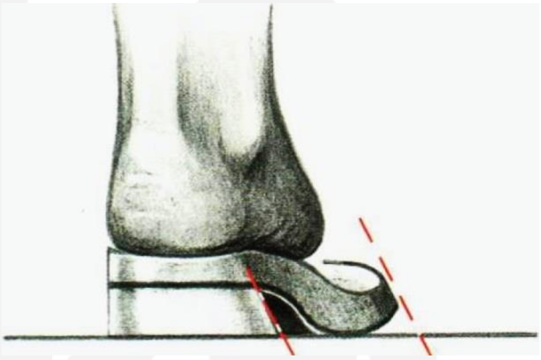
2.3.2. Shoe adjustments

It has been proven that a sports shoe or an ordinary shoe with a soft heel and sole reduce the shock during heel strike (act as a shock absorber) and makes it easier to roll-over. This is important especially when a prosthesis with a stiff ankle is being used.

The rocker bar/sole must be placed behind the end of stump, more proximal than usual. A lateral flare on heel and sole is used in cases where there is a tendency towards supination. This modifications are shown in the pictures below.



Heel flare



Rocker bar or long rocker sole

2.4. Chopart amputation

2.4.1. Evaluation

It can be expected that a patient will be able to walk without walking aids. A deviation of the knee to the lateral side should not take place. If the ankle joint is well fixed in the socket, a normal capacity of walking is expected.

If the prosthetic design does not allow a certain amount of plantar flexion, it will be difficult to run. This can be compared to running with ski boots.

Specially designed prostheses with special components for running are available. By varying the stiffness of foot-plate the step-length can be changed for a better symmetry.

It is particularly important at this amputation level that there are little or no movement of the stump in the socket.

When we made our prescription we should have decided with the opinion of our patient if we should:

- fabricate a below-ankle socket, which does not limit the ROM in the ankle joint, or an above-ankle socket, which minimizes the movement of the ankle.
- make stiff or soft foot

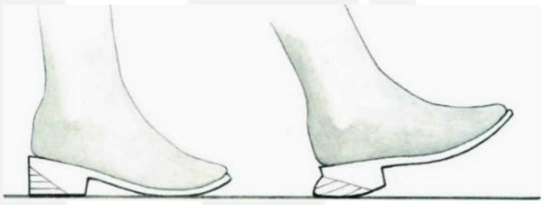
Another surgical option is to perform an arthrodesis to limit the ankle joint movement, hereby reducing the risk of sores in the socket. An arthrodesis always results in a shortening of length, which is of some advantage, as the space will be used to build up a functional prosthetic foot.

All these questions can only be answered after determining the user´s demands and expectations. And in some cases these decisions must be reconsidered after test fitting.

2.4.2. Shoe Adjustments

It is important to choose a shoe with good medial/lateral stability. A sports shoe with a soft heel and sole is preferred to minimize the shock from the heel at heel-strike (as seen in the previous amputation level). As this will also make it easier for the patient to roll-over.

If pressure occurs on the end of the stump, a rocker bar can be applied. It is important to place the rocker bar/sole just proximal to the end of the stump, far more proximal than the usual position, which is under the MPT-joints. A lateral flare on the heel and the sole can be used to compensate for a supination tendency.



A shoe with a stiff heel can be adjusted by changing the rear part to a soft material.

Resources:

- Partial Foot Amputations. Guidelines to Prosthetic and Surgical Techniques. Bengt Söderberg, Anders Wykman, Roland Schaarschuch, Björn M. Persson. 2nd Edition. 2001
- New South Wales Physiotherapists in Amputee Rehabilitation, http://www.geocities.ws/nswpar/tools.htm
- Rehabilitation Measures Database http://www.rehabmeasures.org/Lists/RehabMeasures/Admin.aspx

Video Lectures and Power Point presentations

Lesson_13	Partial foot amputation – Video 13
	Partial foot amputation – Presentation 13

L14: FINISHING PARTIAL FOOT AMPUTATION (PF) PROSTHESES

General objectives

- To learn about the several options of prosthetic finishing

Introduction

During the finishing process of a partial foot prosthesis, as in any other prosthetic device, we should preserve all the achievements we got during production and fitting: socket and alignment must not be altered. We should not start the finishing process until we are sure that the patient feels comfortable, and the device achieves the best functionality according to the goals we established in our prescription.

The finishing of a PF prosthesis includes the following steps:

1. Reinforcing components
2. Change test material to definitive components
3. Cosmetic covers (optional)
4. Quality check
5. Information and documentation for the patient

1-Reinforcing components

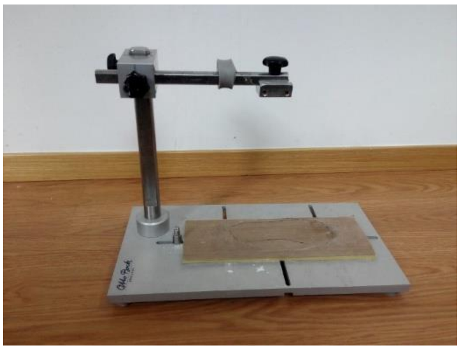
Make sure that:

- All the components are properly fixed, glued or screwed together
- Reinforce the socket according the patient activity and weight.

2-Change test material to definitive components (if needed)

In case of insoles for toe or ray amputation, make sure that the patient is comfortable with the padding materials and change them if needed for softer or stiffer ones.

If you made a test socket, copy the definitive socket with all modifications if a new one is made (e.g. lamination after thermoplastic check socket) be sure to keep the initial alignment by using a transfer apparatus if possible. If you do not have one, an alternative solution would be to fabricate a device that fix the socket, so you can mark on a surface the foot position and also set heel height. (The picture below shows a transfer apparatus for foot prostheses)

It is recommended to use an inner padding all over the prosthesis or a soft plastic socket in all peri-malleolar designs. This makes the prosthesis much more comfortable for the patient.

In case of high-profile sockets, place a strap or Velcro at least 20 mm under the fibula head.

Check all socket edges to be smooth.

Just a tip for finishing a laminated socket:

> Mix 50% thinner and 50% acrylic resin, and go through the proximal brim with a cloth to get a smooth and non-porous edge. You can also do this if the lamination is slightly scratched inside or outside.

3-Cosmetic covers

A very efficient and cheap solution is to use regular socks or nylon tights to cover the prosthesis, anyway there are many different options and solutions.

Many suppliers that offer cosmetic covers for finishing prosthesis; we can find them of many types, materials (mainly PVC and Silicone), custom made or prefab.

Some examples of cosmetic covering options:

PVC cosmetic covers characteristics:

- Available in different skin colors (as upper limb prosthetic gloves)
- Chart for color, side and sizes of foot length and calf circumference
- Water-resistant
- Expanded for easy donning
- Solid or split toe

- Protection of the inner structure and materials from corrosion
- Are thinner and lighter than silicone
- Relatively cheap solution for a good cosmetic result.
- Disadvantage is short durability

Silicone custom solutions:

It is not only possible to make an entire silicone for a big PF amputation, a regular prosthesis can also be produced and then make a custom-made cover for the patient. The advantage of this option is that you can make all the fabrication process in a regular way, sending the prosthesis to a specialized facility for the finishing if you do not have the technology.

By only doing the cover in silicone you also get a lighter prosthesis.

The silicone cover makes the prosthesis splash water resistant, more durable and resistant to corrosion.

Silicone covers are much easier to be kept clean than PVC and they are also more resistant and durable.

As the image in the right side, the cosmetic can be customized, by adding acrylic nails, customizing toe shapes, hairs, tattoos…

4-Quality check

Normally in most of the workshops the quality check is carried out by the responsible P&O, making sure that everything has been done according to the standard work process.

There is also a way to join International standards like the ones of the International Standards Organization (ISO). In many countries, manufacturers have to follow these standards to sell their products. Here you have an example of 2 regulations:

ISO 9000 is essentially a manufacturing and supply quality standard. Compliance with this standard is recognition that a manufacturer has developed sound quality methods, which ensure that the product is made the same way each time, and that the product can be traced even after it is sold and distributed.

ISO 10328: This covers all components in 3 weight categories 100, 80 and 60 kg. Test samples are taken from normal production for testing

If more information about ISO standards in P&O is required, this website can be useful: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=58010

5-Information and documentation for the patient

It is important to deliver all the prosthetic devices to your patient, supplying also all the information about his or her prosthetic device.

- Instructions for use
- Periodical maintenance recommendations if needed
- What to do in case of functional loss or broken parts
- Warranty

Resources:

- Fillauer cosmetic covers commercial brochures
- RSL STEEPER cosmetic covers commercial brochures
- ICRC guideline for manufacturing a partial foot prosthesis
- Standards from the Prosthetics and Orthotics department, “Monash University” Australia
- Picture of Ottobock transfer apparatus

Video Lectures and Power Point presentations

Lesson_14	Partial foot amputation – Video 14
	Partial foot amputation – Presentation 14

L15: FOLLOW UP

General objectives

- To understand the need of a follow up protocoll
- Be able to organise a follow up for a patient with a partial foot prosthesis

Introduction

After the delivery a regular schedule to get in touch with the patient is very important.

The time intervals for a proper follow up are up to the patient and may vary according the patient's needs. After the first fitting, and to make a correct follow up, it is recommended to see the patients a few days or one week after the first fitting, to ensure that fitting and function of the device really adapts to the patient's needs and that Activities of Daily Living (ADL) can be done without unnecessary restrictions.

It is not easy to establish a protocol or interval to check the prosthesis but normally it goes from 6 months up to a year. In diabetic patients it is necessary to be more often than in patients with PFA due to trauma.

Follow up of diabetic patients

People with diabetes are susceptible to skin ulceration because of peripheral neuropathy and vascular insufficiency. Diabetes is the most common pathology leading to partial foot amputation, and it has been reported that 28% to 50% of persons with amputation resulting from diabetes have a second amputation within 5 years after their first surgery. Diabetic shoes with custom foot orthotics have been widely used over the years to address diabetic foot ulcer issues.

Yet, studies have shown that diabetic shoes and custom inserts provide no statistically significant reduction in re-ulceration rate. With 82% of lower-limb loss because of vascular pathology complications, it is crucial that devices decrease interface stresses while minimizing gait deviations. There is obvious need for an alternative device that can decrease the re-ulceration rate. Given the positive effects of vacuum-assisted suspension on tissue health and healing, it may provide a useful tool for preventing further amputation in persons with diabetes, although this requires more research.

Prosthesis Evaluation Questionnaire-Mobility Section, PEQ-MSI2/5

Over the past 4 weeks, please rate your ability in the following activities when using your prosthesis: "Check ☑ for each statement"

	Unable or hardly able at all (ability < 5%) (0)	High difficulty (ability 5-34%) (1)	Moderate difficulty (ability 35-64%) (2)	Little difficulty (ability 65-95%) (3)	No problems or almost fully able (ability > 95%) (4)
1.To walk	☐	☐	☐	☐	☐
2. To walk in confined spaces	☐	☐	☐	☐	☐
3. To walk upstairs	☐	☐	☐	☐	☐
4. To walk downstairs	☐	☐	☐	☐	☐
5. To walk up a steep hill	☐	☐	☐	☐	☐
6. To walk down a steep hill	☐	☐	☐	☐	☐
7. To walk on sidewalks and streets	☐	☐	☐	☐	☐
8. To walk on slippery surfaces (e.g.wet tile, snow, a rainy street, or a boat deck)	☐	☐	☐	☐	☐
9. To get in and out of a car	☐	☐	☐	☐	☐
10. To sit down and get up from a chair with a high seat (e.g. a dining chair, an office chair)	☐	☐	☐	☐	☐
11. To sit down and get up from a low, soft chair (e.g. a deep sofa)	☐	☐	☐	☐	☐
12. To sit down and get up from the toilet of regular height (no aids)	☐	☐	☐	☐	☐

Follow up assessment for PFA

It is possible to use an assessment form to do a follow up, to know if the device is fulfilling its function.

See examples below:

Follow-up assessment: _____ weeks **Date ____ / ____ / ____**

Patient compliance to use device	(Low) ☐1	☐2	☐3	☐4	(High) ☐5

Range Of Motion:					(None)
Current ankle dorsiflexion ROM	☐ Normal		☐ -25%	☐ -50%	☐ -100%
Current ankle plantarflexion ROM	☐ Normal		☐ -25%	☐ -50%	☐ -100%
Current heel inversion ROM	☐ Normal		☐ -25%	☐ -50%	☐ -100%
Current heel eversion ROM	☐ Normal		☐ -25%	☐ -50%	☐ -100%

Concerns:	(Low)				(High)
Bony prominences Location: ________________	☐1	☐2	☐3	☐4	☐5
Open wounds Location: ________________	☐1	☐2	☐3	☐4	☐5
Healing wounds Location: ________________	☐1	☐2	☐3	☐4	☐5
Pre-ulcerative calluses Location: ________________	☐1	☐2	☐3	☐4	☐5

Overall Assessment:	(Worse)		(Same)		(Better)
Residual foot condition worse/better	☐1	☐2	☐3	☐4	☐5
	(Low)		(Medium)		(High)
Satisfaction with functional outcome	☐1	☐2	☐3	☐4	☐5

Comments:

The document above is a **Prosthesis Evaluation Questionnaire.** It is a proposed form for measuring mobility in people with lower limb amputation (LLA) wearing a prosthesis. The form includes a scale with 12 items, rated with a 5-level scale.

Conclusion

Partial foot amputation is the most commonly performed amputation — affecting approximately 2 in every 1,000 people — and complications such as ulceration and re-amputation are all too common sequelae in these challenging patients. There is little consensus regarding the appropriate post-partial foot amputation modalities. Following partial foot amputation, clinicians must attempt to maintain function and reduce force loading along the residual foot stump in order to reduce further skin breakdown and subsequent secondary limb loss in these challenging patients.

While there is a paucity of evidence-based medicine regarding the use of prosthetic interventions, there is increasing research into these topics. Much of the current literature suggests that the above ankle prosthetic interventions that eliminate ankle motion improve ankle power generation during the gait cycle and reduce overall strain on the patient's cardiovascular system while also reducing potential shear forces along the residual stump, thus reducing risk of re-ulceration.

While further research is necessary, prosthetists will always need to weigh various considerations including level of amputation and realistic functional expectations when prescribing a specific type of orthosis or prosthetic device following partial foot amputation to maintain the highest level of function.

Resources:

- http://www.oandp.org/jpo/library/2011_02_082.asp
- http://www.podiatrytoday.com/guide-orthotic-and-prosthetic-options-people-partial-foot-amputations
- http://www.prs-research.org/htmPages/PEQ.html

Video Lectures and Power Point presentations

Lesson_15	Partial foot amputation – Video 15
	Partial foot amputation – Presentation 15

W1.2 - BIOMECHANICS - FUNDAMENTAL CHARACTERISTICS OF NORMAL MOTION AND HUMAN LOCOMOTION

Lesson Summary

Human gait is a complex mechanism. The musculoskeletal system works in order to consume as less energy as possible, but at the same time being agile.

Different aspects have to be taken into consideration during normal gait in order to assess abnormal gait and the different gait deviations.

Objectives

- To understand the fundamentals of human gait
- To recognize normal gait patterns.

1. The gait cycle

The determination and analysis of abnormal gait requires first to have an understanding of the basic physiology and biomechanics of normal gait. The gait cycle is a time interval or sequence of motion occurring from heel strike to heel strike of the same foot. The gait cycle has been broadly divided into two phases: stance phase and swing phase. These phases can then be further subdivided and discussed in terms of percentage of each within the gait cycle (Fig 1).

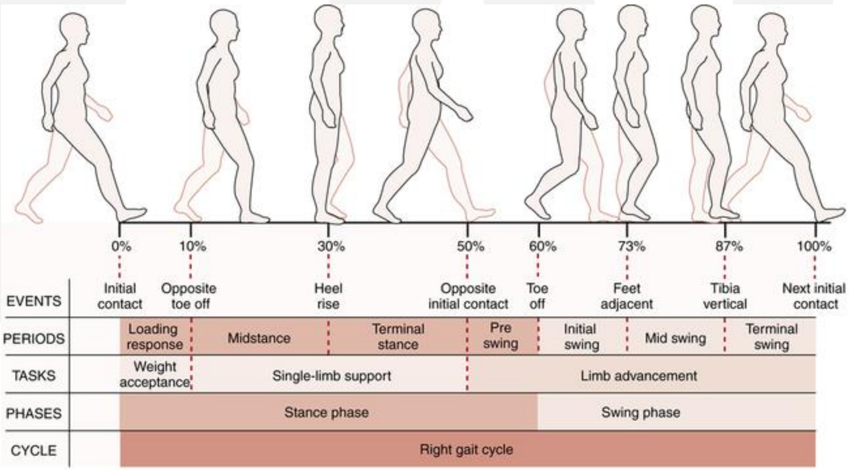


Figure 1: divisions of the gait cycle

The stance phase is 60 percent of the gait cycle and can be subdivided into double-leg and single-leg stance. In double-leg stance, both feet are in contact with the ground. At an average walking speed, it represents 10 percent of the entire gait cycle, but decreases with increased walking speed and ultimately disappears as one begins to run.

In order to analyse gait, it is split in different phases, therefore we are going to discuss the integrated functions of the lower limb according to Jacquelin Perry:

Initial contact: (Fig 2)

Floor contact by the heel is the critical event. Its purpose is to initiate the heel rocker for progression and shock absorption. The significant postures are ankle dorsiflexion (slight) and full knee extension. Initial floor contact by the heel is a forceful event, which begins with 1 cm of free fall between the foot and the ground. The impact registers 50% to 125% body weight during the first 10 to 20 ms of stance (1% to 2% of the gait cycle). The heel responds to the impact by initiating small arcs of ankle plantar flexion and subtalar inversion. Tibialis anterior control of the foot determines heel rocker effectiveness.


Figure 2 Initial contact

In the image: Initial contact by the heel with pretibial muscle control (tibialis anterior shown) establishes the heel rocker. Vertical line represents the body weight vector. Both ground impact (large arrow) and base of the body weight vector (small arrow) are at the heel.

Loading response: (Fig 3)

Loading response (initial double stance because the contralateral foot was already in stance phase): This is a highly demanding phase. At the ankle, the pretibial muscles (especially the tibialis anterior) preserve the heel rocker by intense isometric activity, while stretch of the tibialis anterior tendon allows a small arc of plantar flexion for shock absorption. This reverses the early plantar flexion arc to neutral (68 at 6% of the gait cycle) by the end of the loading response. The limb is destabilized by the heel rocker and then supported by strong extensor muscular response.

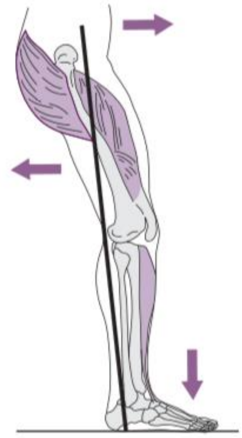


Figure 3 Loading response

In the image: Loading response vector (vertical line) is anterior to the hip (flexor moment is restrained by the gluteus maximus), posterior to the knee (quadriceps restraint of the flexor moment), and posterior to the ankle (plantar flexor moment is restrained by the tibialis anterior).

Mid stance: (Fig 4a and 4b)

The critical event is ankle dorsiflexion for progression of the stance limb over a stationary, flat foot. As momentum from the contralateral swing limb moves the vector along the foot, the soleus (quickly assisted by the gastrocnemius) modulates the tibial advancement so the lower leg proceeds less rapidly than the femur. This provides passive extension of the hip and knee for weight-bearing stability. As a result, the hip extensor and quadriceps muscles rapidly relax, and stability of the hip and knee become dependent on the strength of the plantar flexor muscles.

At the hip, there is also a major adducting moment as lifting the other limb for swing, removes the support for that side of the pelvis. This creates a large medial vector, which is restrained by the gluteus medius.

In the figure 4a: Midstance progression of the limb over the stationary foot generates two patterns of muscle action. In early midstance (left), the vector is behind the hip (no muscle action required), closer to the knee (less quadriceps) and anterior to the ankle (this dorsiflexor moment is retrained by the soleus). By late midstance (right), the vector is anterior to the knee, and no quadriceps action is needed. Ankle dorsiflexor moment has increased.

In the picture 4B: Single-limb stance creates an adductor moment at the hip as the pelvis, with midline vector medial to hip, is unsupported. Gluteus medius action (abductor) restrains adductor moment.

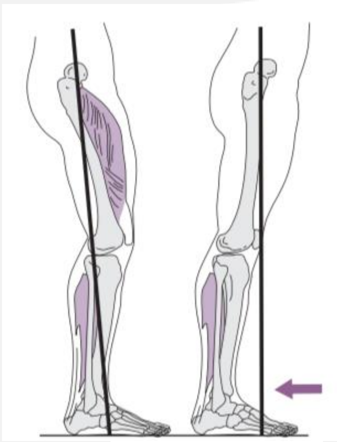


Figure 4a Mid stance sagittal plane

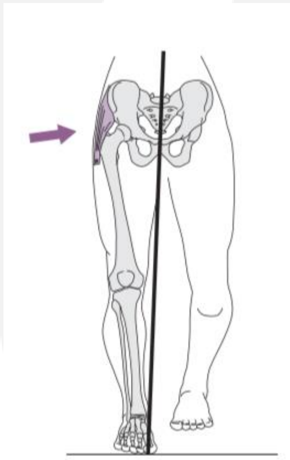


Figure 4b Mid stance coronal plane

Terminal stance (Fig 5)

Terminal stance (late single stance): Heel rise is the critical event that continues progression. Free dorsiflexion mobility of the MP joints also is essential. Both the foot and the limb roll forward over the forefoot rocker. The soleus and gastrocnemius muscles virtually lock the slightly dorsiflexed ankle, thus making the forefoot the site of limb rotation.

This creates a lever (ankle to metatarsal heads), which enlarges the arc of limb rotation. Heel height is preserved while greater advancement of the centre of mass adds to step length. Heel rise is 3.5 cm at the moment of contralateral initial contact.

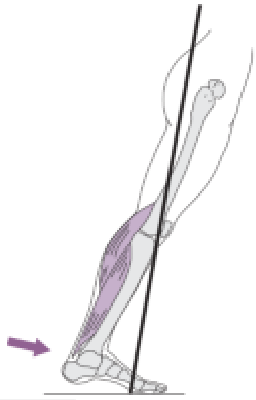


Figure 5 Terminal stance

In the picture: Terminal stance progression advances the vector across the forefoot, and the heel rises. The vector remains behind the hip and knee joints (knee hyperextension moment is restrained by the gastrocnemius). Vector alignment at the ankle creates a maximal dorsiflexion moment, which is restrained by the soleus and gastrocnemius.

Preswing: (Fig 6a)

Passive knee flexion to 40 degrees is the critical event because this is the primary contributor to foot clearance of the floor in swing. Following floor contact by the other foot, body weight is rapidly transferred to that limb to catch the forward fall. The equally abrupt unloading of the trailing limb initiates a series of actions commonly called push-off. A rapid arc of ankle plantar flexion to 20 degrees is accompanied by passive knee flexion to 40 degrees, increased toe dorsiflexion, and release of the extended hip. The initial force is a large burst of plantar flexion power. Because there is no corresponding EMG, the source of the power is attributed to elastic energy generated by the abrupt release of the previously tense soleus and gastrocnemius muscles: push-off positions the limb for swing and initiates the action, allowing several small forces to be effective. As the limb's trailing posture reduces the foot's floor contact to the anterior margins of the metatarsal heads and the toes (fourth rocker), there is no stabilizing force, so the foot and the leg are free to roll forward. This is accelerated by the rapid ankle plantar flexion stimulated by the release of the tension stored in the eccentrically stretched soleus and gastrocnemius. Passive knee flexion is initiated. Unloading the limb also releases the tension in the hip flexors. This force combined with adductor longus action initiates early hip flexion and assists knee flexion.

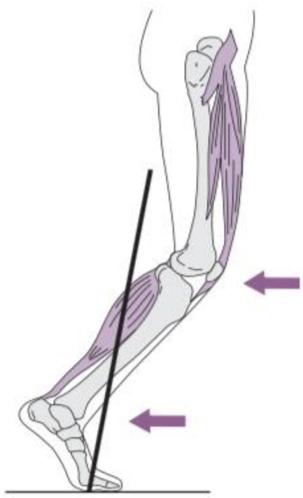


Figure 6a preswing

Preswing transfer of body weight to the other limb reduces the vector. The base of the vector now is at the metatarsophalangeal joint. The unloaded foot falls forward with the tibia as it follows the dorsiflexion moment. Gastrocsoleus tension induces ankle plantar flexion. The knee flexes in response to the posterior moment, with rectus femoris restraint if needed. Posterior hip moment is opposed by the flexor component of the adductor longus and rectus femoris

Initial swing: (Fig 6b)

The critical event is knee flexion sufficient for the toe to clear the floor as the thigh advances. This involves total limb flexion. Hip flexion may be a passive continuation of the preswing events or result from direct action by the iliacus, sartorius, and gracilis. Attainment of full knee flexion largely depends on the imbalance between the forward momentum of the femur generated by hip flexion and inertia of the tibia. Active assistance also is provided by the biceps femoris, short head. Brisk activation of the pretibial muscles initiates ankle dorsiflexion, but the arc is incomplete in initial swing.

In the picture: Initial swing advancement of the limb by simultaneous active flexion at the hip (iliacus) and knee (biceps femoris, short head) and ankle dorsiflexion (tibialis anterior)

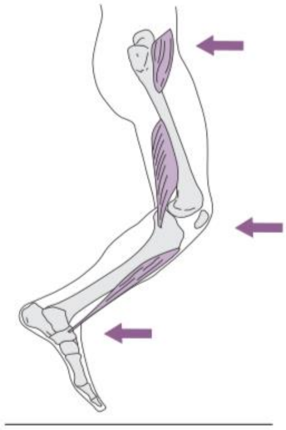


Figure 6b Initial swing

Mid swing: (Fig 7)

Ankle dorsiflexion to neutral is the critical event for floor clearance at this time. Additional hip flexion and partial knee extension advance the limb. The relative vertical posture of the lower leg requires pretibial muscle support of the ankle.

In the picture: Midswing limb advancement continues with residual active hip flexion, passive knee extension, and persistent ankle dorsiflexion to neutral by the pretibial muscles

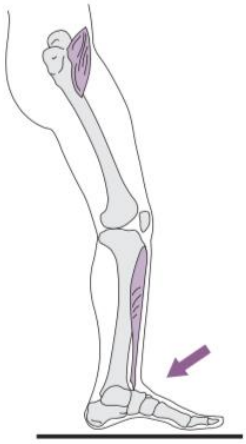


Figure7 Mid swing

Terminal swing: (Fig 8)

Forward swing of the limb for step length is accomplished by knee extension. The other actions relate to preparing the limb for stance as previously described. To prepare the swinging limb for stance, hip flexion is interrupted, the knee extends, and the ankle remains dorsiflexed.

Rapid, intense action by the hamstring muscles (semimembranosus, semitendinosus, biceps femoris long head) stops hip flexion and terminates swing. These muscles then reduce their intensity and allow the quadriceps to extend the knee. The continuation of mild hamstring action prevents knee hyperextension from the residual tibial momentum. Pretibial muscle action supports the dorsiflexed foot.

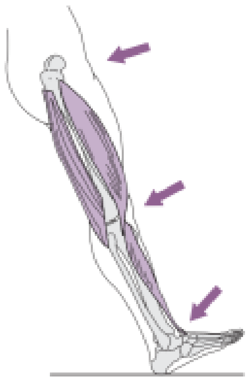


Figure 8 Terminal swing

In the picture: Terminal swing pattern of muscle control. The limb is positioned for stance by synergistic action of the hamstrings (posterior thigh), quadriceps (anterior thigh), and tibialis anterior (anterior leg).

2. Gait theories and models

A healthy gait pattern depends on an array of biomechanical features, orchestrated by the central nervous system for economy and stability. Injuries and other pathologies can alter these features and result in substantial gait deficits, often with detrimental consequences for energy expenditure and balance. An understanding of the role of biomechanics in the generation of healthy gait, therefore, can provide insight into these deficits.

Although walking poses little challenge to individuals who are healthy, those with gait pathologies such as hemiparesis from a stroke, spinal cord injury, or amputation can find it tiring and difficult. Pathological gait, for example, can frequently require two or more times the metabolic energy of a healthy gait.

2.1 Six determinants of gait theory

One of the most influential and longest-standing theories of gait was that proposed by Saunders et al, often referred to as the **six determinants of gait.** Even this theory is nowadays questioned, it is interesting to analyse normal gait. In fact, it consists of 6 kinematic features explained below.

During gait, three main events occur in which energy is consumed. This includes controlling forward movement during deceleration toward the end of swing phase, shock absorption at heel strike, and propulsion during push off, when the centre of gravity is propelled up and forward. The least amount of energy is required when a body moves along a straight line, with the COM deviating neither up nor down, nor side to side. Such a straight line would be possible in normal gait if man's lower limbs terminated in wheels instead of feet. This obviously is not the case, thus, our COM deviates from the straight line in vertical and lateral sinusoidal displacements (Fig 9).

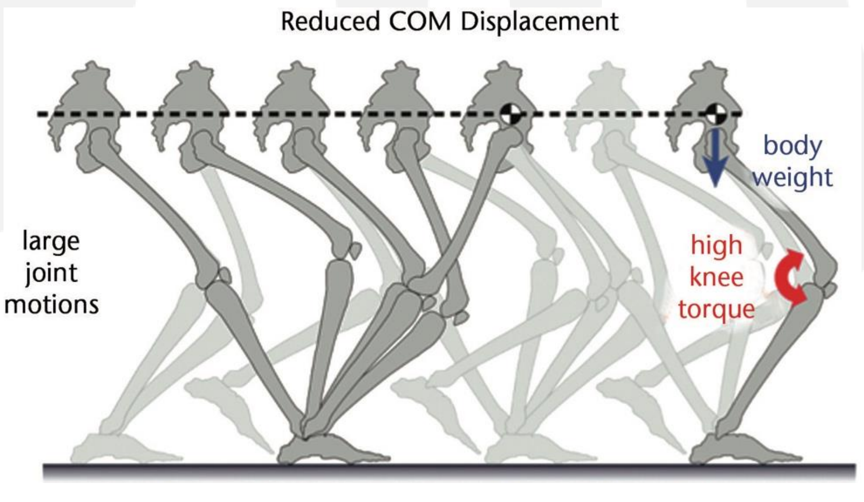


Figure 9 COM vertical displacement: ideally according to the determinants of gait theory

Remember 1st Newton's law: An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force. Consequently if the COM is always moving with the same speed and in the same direction (straight line) **no force (no energy) is required** to keep this state.

First determinant: (Fig. 10)

Pelvic rotation in the horizontal plane. This allows the swinging hip to move forward. It occurs anteriorly on the swinging limb and posteriorly during mid-stance. It is maximal just before heel strike with a total motion of pelvic rotation of 3-5° to each side. Pelvic rotation also produces a longer stride length for the same amount of hip flexion of the advancing leg and hip extension of the retreating leg. Thus, it allows for longer steps without changing the COM displacement significantly.

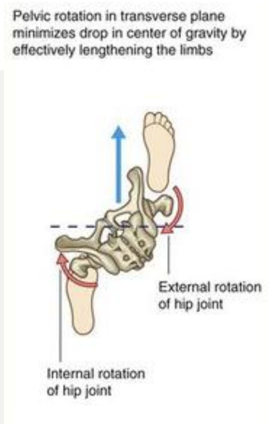


Figure 10 Pelvic rotation

Second determinant: (Fig. 11)

Pelvic tilt in the frontal plane. As the pelvis on the swing leg is lowered, the hip abductors of the stance hip control pelvic tilt. During normal gait, the pelvis drops 4-5° away from the stance leg and toward the swing leg. This pelvic dip decreases horizontal displacement of the COM during single limb support.

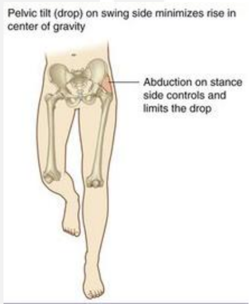


Figure 11 Pelvic tilt

Third determinant: (Fig. 12)

Knee flexion, which acts to decrease vertical displacement of the COM. This occurs during mid-stance, as knee flexion to approximately 15° occurs under the control of eccentric quadriceps contraction and remains flexed until the foot is flat on the ground. These first three determinants save 2.5 cm of vertical displacement with each stride.

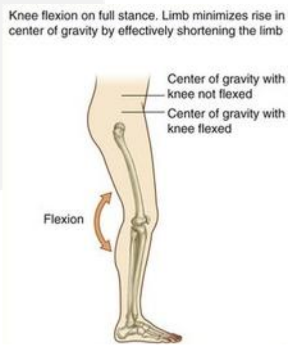


Figure 12 Knee flexion

Fourth and Fifth determinants: (Fig. 13)

Involve control of the knee-ankle-foot motion. This synchronized movement results in eccentric control of plantar flexion of the ankle and knee flexion, which occurs during the first portion of the stance phase. These factors help to avoid abrupt changes of the lowest portion of COM arc, producing a smooth, sinusoidal curve instead of an arched pattern.

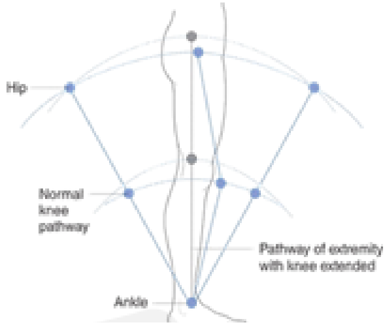


Figure 13 Knee-Ankle flexion motion

Sixth determinant: (Fig. 14)

Lateral pelvic movement. This is the lateral sway or side-to-side oscillation that occurs with each step. This defines the motion of the COM in the horizontal plane. The shifting of the pelvis occurs over the supporting foot to provide stability during the stance phase. The extent of sway is determined by the base of support. Normal knee valgus between the femur and tibia helps to reduce the amount of pelvic shifting required for stability and allows the feet to be closer together during forward progression.

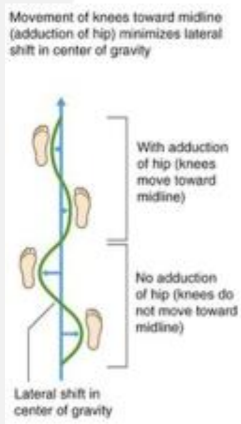


Figure 14 Lateral pelvic movement

2.2 Inverted pendulum model

Coexisting with the “six determinants of gait” theory is the inverted pendulum model of walking (Fig. 15). It states that the stance leg behaves like an inverted pendulum, allowing for economical gait. The advantage of a pendulum is that it conserves mechanical energy and thus requires no mechanical work to produce motion along an arc. Observations of mechanical energy exchange and leg length change during single-limb support provide a strong indication of pendulum-like behaviour. The inverted pendulum model explains human gait from another point of view than the “six determinants of gait” theory.

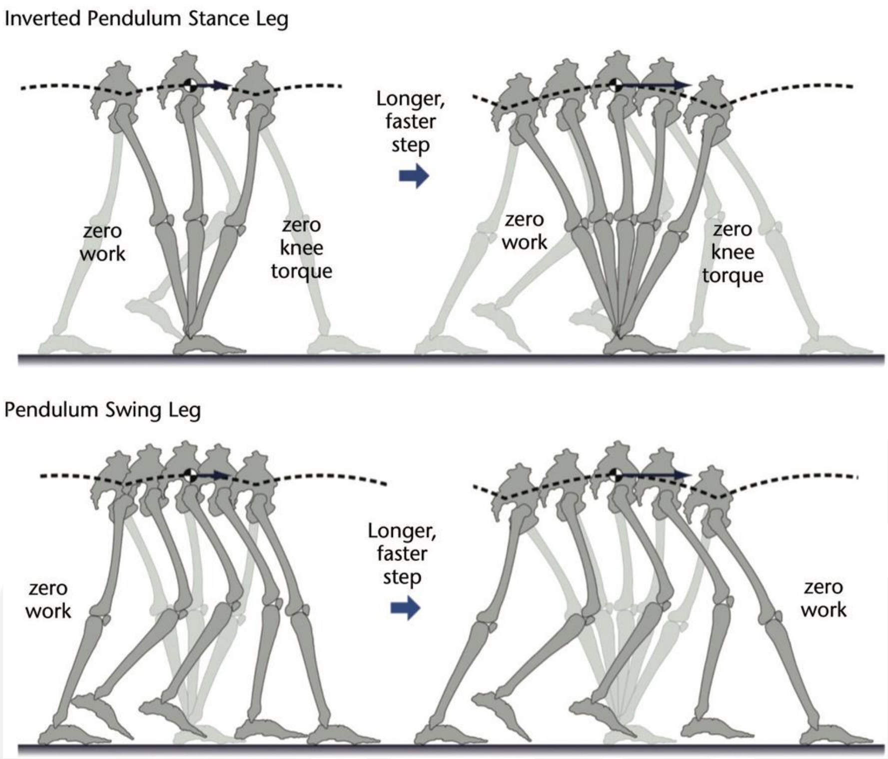


Fig 15 The inverted pendulum analogy

The inverted pendulum analogy for the stance leg and its corollary for the swing leg. The stance leg appears to act like an inverted pendulum, which allows the body centre of mass to move in an arc with conservation of mechanical energy. In principle, no mechanical work is needed to move or lift the body, and no knee torque is needed to support its weight. Longer and faster steps similarly require no effort. The swing leg also appears to move like a pendulum, whose ballistic motion "theoretically" requires no work. Mechanical energy conservation is unaffected by longer or faster steps.

A less appreciated advantage of the inverted pendulum comes from the straight leg. It is possible for the leg to act as an inverted pendulum without being kept straight by keeping a fixed distance between the ground contact point and the hip. For example, the knee could be kept at a fixed angle, and the flexed leg could still behave as an inverted pendulum and benefit from conservation of mechanical energy. However, humans evidently choose to keep the stance leg relatively straight, presumably because doing so reduces the moment of body weight (a vertical force with line of action through the COM) about the knee and thus also reduces the muscle force needed to support body weight. A person may walk with the knees kept at a flexed and fixed angle and find it nearly as exhausting as walking with the COM on a level path. The force savings of the straightened knee, therefore, may be just as significant as the work savings.

At the same time this model also helps us to understand body balance:

Consider the next image of an individual swaying back and forward while standing. Assuming that the ankle is the axis of the motion and knowing that most our weight is distributed proximally we can understand the similarities of the model with an inverted pendulum (Fig 16). Plantar flexors and dorsiflexors are in control of the ankle movement to control the forward and backward sway of our body in the sagittal plane.

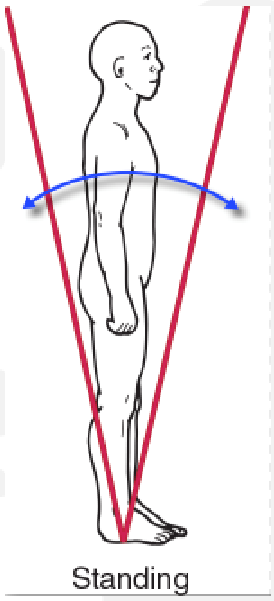


Fig. 16 forward and backward sway in the sagittal plane

We could discuss more in depth this model, but this is enough to have an inside track in the different gait theories. There are also others like the Dynamic Walking approach, that considers how passive dynamics alone can govern an entire gait cycle (Mc Geer). You can find more information about these theories in the additional material folder.

Sources:

- Kinesiology of the musculoskeletal system: foundations for physical rehabilitation, ed. 2, St Louis, 2010, Mosby.)
- Atlas of Orthoses and Assistive devices. Fourth edition. John D. Hsu, MD, Cm, FACS et. all. MOSBY ELSEVIER
- Dynamic Principles of Gait and Their Clinical Implications. Arthur D. Kuo and J. Maxwell Donelan PHYS THER. 2010; 90:157-174.
- Originally published online December 18, 2009 doi: 10.2522/ptj.20090125
- Human Study Cat II lectures in Biomechanics (LLP module)
- Human Study Cat I – Lecture 21 gait determinants of physiology and biomechanics of gait

W2.1 VARIATION OF PROSTHETIC DESIGNS FOR PARTIAL FOOT AMPUTATIONS II (SILICONE PROSTHESIS)

Description

These prosthetic devices are made out of high quality silicone in different shores (hardness) and may also include functional components as carbon plates, or springs for a better functionality.

Silicone offers a good skin sensation and optimum fit. The primary aim is to build a socket with a balanced weight and pressure distribution and improve gait pattern. The cosmesis is also an important advantage of this kind of prosthetic solutions.

The socket is based on total surface bearing technique. Suspension is made by compression and passive vacuum (air is pressed out while donning, and during the first walking steps). Thanks to the good and flexible fit, skin irritation is minimized as movement into the socket is prevented.

Silicone properties

Silicone is ideal for creating prosthetic parts that come in direct contact with the skin. It provides the best possible contact between the prosthesis and the skin thanks to the good adhesion and compression characteristics. It is also skin friendly and breathable.

The tear resistance of the material allows thin, almost invisible transitions to the skin. This is not only an aesthetic advantage; it also creates a very flexible proximal socket brim.

The elasticity of the material makes it easy donning and doffing without additional closures.

Silicone is also easy to clean with water and soap. Silicone can even be sterilized in an autoclave. This can be done from time to time to disinfect the prosthesis. In addition, it is also a very durable material.

Variation according to the amputation level

First toe amputation

In many cases the goal is to reproduce the missing toe as good as possible. Anyway, for this amputation it is preferred, to restore normal toe-off.

To do so, there are 2 possibilities:

1. Wear an additional carbon insole to restore toe-off and re-distribute weight.
2. Fabricate a bigger device with a carbon insole and the silicone prosthetic toe. This option is heavier and bulky.

Suspension is achieved with passive vacuum and or with a silicone elastic belt around the medial arch (depending on the residual foot conditions)

The nails can be made out of silicone or acrylic. (If they are made of acrylic, they can be painted with normal nail polish).

Below an example of a silicone prosthetic toe:

2nd, 3rd, 4th 5th, or multiple toes

This prosthetic solution is mainly cosmetic, nevertheless it also avoids the remaining toes to shift towards the gap of the missing toe. The nails can also be made out of silicone or acrylic.

Below an example of a 3rd toe amputation and its prosthetic solution in silicone. (Suspension is made by passive vacuum)

Below a silicone prosthetic solution for 1st and 2nd toe amputation. The suspension is made by a silicone belt around the medial arch.

Transmetatarsal solution

As in the 1st toe amputation, we have two options. A pure cosmetic solution or adding a functional insole (carbon or fibre glass). The anterior part of the socket it is commonly made with softer silicone to pad the metatarsals. It is high-pressure area at push off.

The posterior part of the socket should be made with a high shore silicone to stabilize the heel and ensure suspension.

Amputation of one or more metatarsals, Lisfranc, or Chopart

This type of prosthesis restores foot functionality by normal ankle motion thanks to the low profile brim. In this amputation levels it is common to have normal ankle motion, so calf muscles maintain for some extent, its function.

Carbon fibre springs or self-made laminated insoles are usually added to improve stability and push off.

The distal residual foot area is usually padded with softer silicone shores, to protect the distal bony areas.

The posterior part of the socket should be made with a high shore silicone to stabilize the heel and ensure suspension.

A disadvantage of this type of prosthesis is that it may become heavy for the patient due to the silicone density. To make the prosthesis as light as possible, it is helpful to build in some soft and lightweight foams embedded into the forefoot area.

As in the amputation levels above, nails can be made out of silicone or acrylic.

Contraindications

- Unhealed residual foot conditions such as open wounds
- Unstable residual foot volume with variations of more than 5%
- Ankle joint and residual foot ends that are unable to bear weight
- Severe plantar flexion or varus. The low profile socket does not correct these gait deviations.

This is an important reason to assess all these problems before establishing the prosthetic treatment. Anyway it can be solved combining the silicone prosthesis with an AFO for ankle stabilization and function support.

Donning and doffing

The only instruction for donning is to wet the skin or socket to make it easier to slip into the socket. Once the residual foot is in, the patient has to squeeze out any air between the prosthesis and the skin. Gel or fatty creams are not recommended, they may ulcerate the skin in the socket and can damage the silicone.

Doffing is made by separating the socket and the skin with one or more fingers. By putting the finger between the socket and skin air comes in and suspension is gone. Now the patient only has to pull out the prosthesis. Sometimes a tool like a small plastic spatula is used by certain patients.

Sources:

1. http://www.medicalartresources.com/state-of-the-art/prosthetic-toes-and-partial-feet/http://www.medicalartresources.com/state-of-the-art/prosthetic-toes-and-partial-feet/
2. Ottobock technical information about silicone partial foot
3. Dorset Orthopaedics Catalogue 2013.
4. http://www.dailymail.co.uk/health/article-2120223/Mums-bought-new-toes-I-walk-Prosthetics-meningitis-survivor-Ava-two.html