BIOMECHANIC OF PROSTHESIS

For

Department of prosthesis & orthosis production Techniques

First stage/ course 1

By

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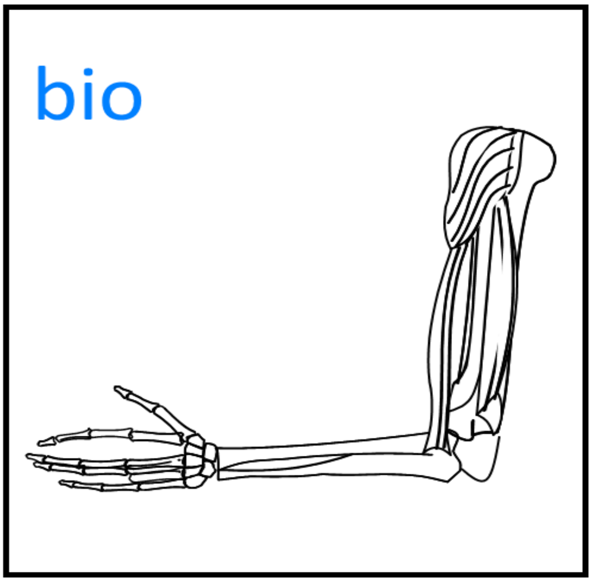
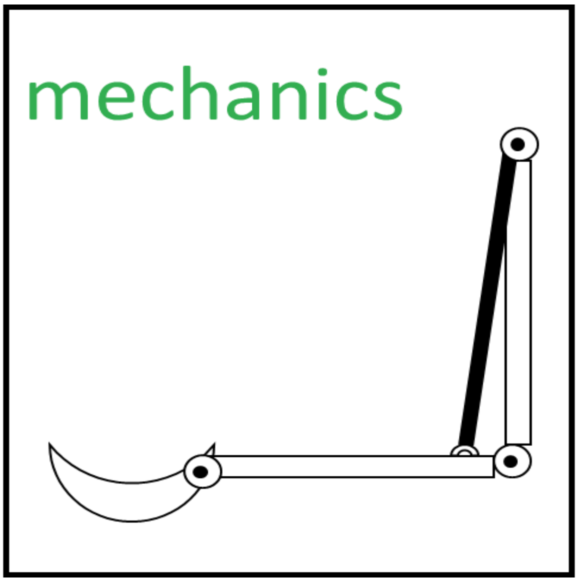
Introduction of Biomechanics

Mechanics is a branch of science that deals with forces and the effects produced by these forces. The application of this science to the biological system is referred to as biomechanics. Human biomechanics focuses on how forces act on the musculoskeletal system and how the body tissue responds to these forces.

biomechanics is the study of structure and function of biological systems by the means of mechanics. The goal of biomechanics related to human movement is to improve physical performance (through improved technique, equipment or training) and injury prevention and rehabilitation





The term biomechanics combines the prefix bio, meaning "life," with the field of mechanics, which is the study of the actions of forces, (both internal muscle forces and external forces.) In biomechanics we analyze the mechanical aspects of living organisms.

Sub-branches of biomechanics:

- **Statics:** study of systems in constant motion, (including zero motion)
- **Dynamics:** study of systems subject to acceleration
- **Kinematics:** study of the appearance or description of motion
- **Kinetics:** study of the actions of forces (Force can be thought of as a push or pull acting on a body.)

What is kinematics?

What we visually observe of a body in motion is called the kinematics of the movement. Kinematics is the study of the size, sequencing, and timing of movement, without regard for the forces that cause or result from the motion. The kinematics of an exercise or a sport skill is known, more commonly, as formor technique.

What is kinetics?

Kinetics is the study of forces, including internal forces (muscle forces) and external forces (the forces of gravity and the forces exchanged by bat and ball).

GENERAL TERMS

The following general terms are common to mechanics in general, although they are also used widely in biomechanics:

Units: we use SI units (System International Units) which use four fundamental quantities (length, mass, time and force) as below:

Length meter (m)

Mass Kilogram (Kg)

Time second (s)

Force Newton (N)

$N = Kg.m^2$

Peak – the peak value of any measurement is the point with the greatest magnitude in a data set. Peak values are often seen in biomechanics, such as when measuring joint angles (the maximum joint angle reached).

Mean – the mean value of any measurement is an average of a data set and is calculated by taking the sum of all the values and dividing this number by the number of values. Mean values are also commonly used in biomechanics, such as when measuring joint moments.

Vector – a vector is a quantity that has a direction as well as a magnitude. Example of vector quantities are velocity, acceleration, force and moment.

Scalar – a scalar is a quantity that has no direction but only a magnitude. Examples of scalar quantities are time, volume, density and mass.

Component – components of vectors are used to help make calculations of vectors easier. Every vector in mechanics or biomechanics can be broken down into 3 orthogonal components, which are labelled as x, y, and z. Orthogonal means that each component acts at right angles to the others. In biomechanics, these three orthogonal components refer to the frontal, sagittal and transverse planes, respectively.

Resultant – the resultant vector is the vector calculated when summing together other vectors, often in the form of components but also in the form of two or more vectors acting in different directions on the same object. For example, during running, there are forces acting both vertically and horizontally and also both forwards (propulsive) and backwards (braking) but ultimately there is a resultant force that moves the runner forwards.

FORCE AND MOMENTS

Force and moments are kinetic variables. Force in biomechanics is usually exerted either by muscles acting on joints or by heavy external objects (like barbells or the ground) acting on the human body. Kinetics falls into two categories: linear and angular. Linear kinetics are usually those associated with overall forces exerted upon an athlete (like ground reaction forces during jumping) and angular kinetics are those associated with the turning forces at specific joints.

LINEAR KINETICS

Force – is the action of one body on another. Force equals mass times acceleration (F = ma) and where mass (kg) and acceleration (m/s2) are expressed in standard international (SI) units, force is automatically expressed in Newtons (N).

Ground reaction force – When you jump, sprint, or perform an Olympic lift, you exert force into the ground. During vertical jumping, most of the force produced is vertical. However, in sprinting, you have vertical forces as well as horizontal forces.

Muscle force – when muscles contract or are stretched, they create muscle force. This muscle force pulls on bones which creates joint torque. In general, force, including muscle force, is measured in Newtons.

Work – work is force multiplied by the distance moved as a result of the force acting, expressed in Joules (J).

Power – power is the rate at which work is done, and can be calculated either by dividing the work done by the time in which the work was done or by multiplying the force applied by the velocity at which it was applied, expressed in Watts (W).

Momentum – momentum is mass multiplied by velocity, expressed in kg m/s.

Joint moment – a moment is the turning effect produced by a force, and is calculated by multiplying the force by the perpendicular distance from the pivot (or axis of rotation).

MOVEMENT

Movement and position are called kinematic variables. Kinematics also falls into two categories: linear and angular.

LINEAR KINEMATICS: Linear kinematics are usually those associated with overall movement of an athlete (like running velocity or jumping height).

ANGULAR KINEMATICS: angular kinematics are those associated with the movement of specific joints.

Displacement: displacement is a change in position of an object. Jumping height is an example of a displacement that is often measured in biomechanics.

Ground contact time: ground contact times are the durations of time in which feet are in contact with the ground during athletic movements, such as drop jumps or sprint running. Sprint running displays some of the shortest ground contact times, which are around 0.1

seconds, which does not allow much time for the athletes to exert force to propel themselves forwards.

Flight time: flight times are the durations of time in which an athlete is not in contact with the ground during athletic movements, such as during vertical jumps or sprint running. During vertical jumps, flight time can be used to estimate jump height by using Newton's laws of motion.

Velocity: velocity is the rate of change of position of an athlete (in m/s), which is the displacement divided by time. It is a vector quantity (meaning that it has a direction associated with it) and speed is its scalar equivalent.

Acceleration – acceleration is the rate of change of velocity of an athlete (in m/s^2), which is the change in velocity divided by time. It is also vector quantity (meaning that it has a direction associated with it) and is proportional to the external force exerted.

Range of motion (ROM): the displacement in angular movement is generally measured by reference to ROM, which can be reported in either degrees or radians.

Center of mass (COM) – the center of mass is the unique point within an object. It is the average position of all the parts of the system, weighted according to their masses. For simple rigid objects with uniform density, the center of mass (COM) is located at the centroid.

TERMS OF LOCATION

Anatomical Position: a person standing with feet, face and palms of the hands facing straight forward.

Planes of the Body: see figure.

Frontal Plane: any plane drawn from side to side of a body and at right angles to the sagittal plane. The frontal plane divides the body into anterior and posterior parts.

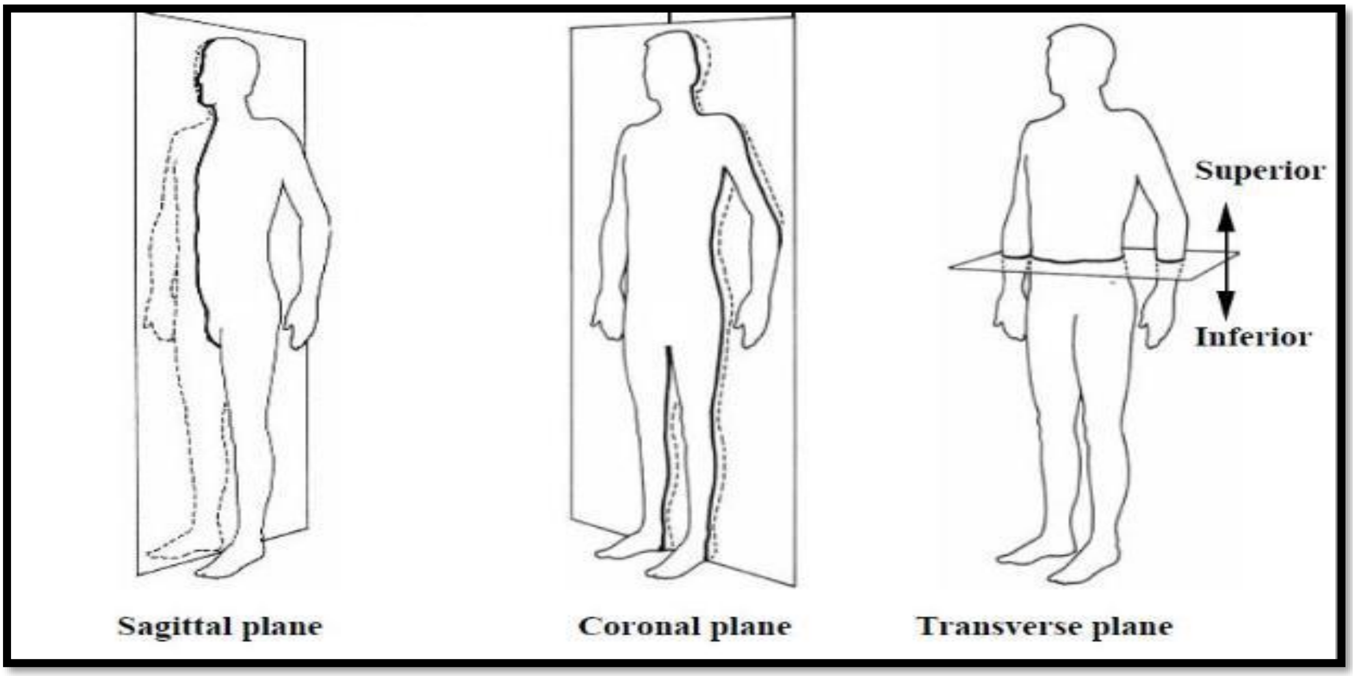
Coronal Plane: Frontal Plane.

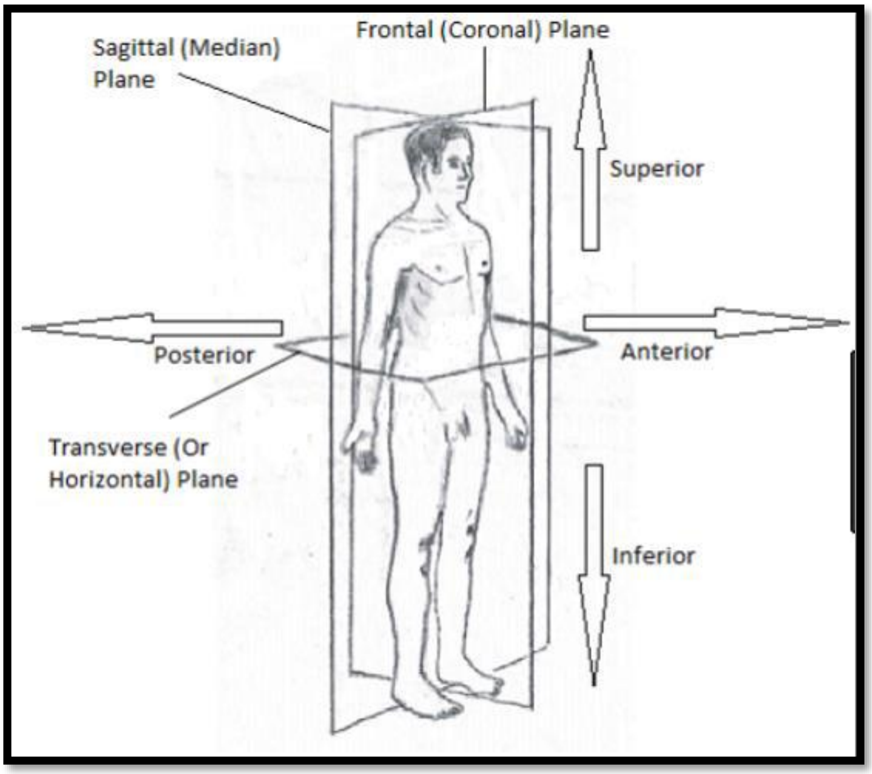
Sagittal Plane: any plane drawn from front to back of a body, at right angles to the frontal plane. The sagittal plane divides the body into right and left parts.

Transverse Plane: any plane drawn in cross section of a body and at right angles to both the frontal and sagittal planes. The transverse plane divides the body into superior and inferior parts.

Horizontal Plane: Transverse Plane.

Midsagittal Line or Plane: a line or plane drawn from front to back of a body that is at right angles to the frontal plane. The midsagittal line passes directly through the center of the entire body and divides it into equal left and right parts.





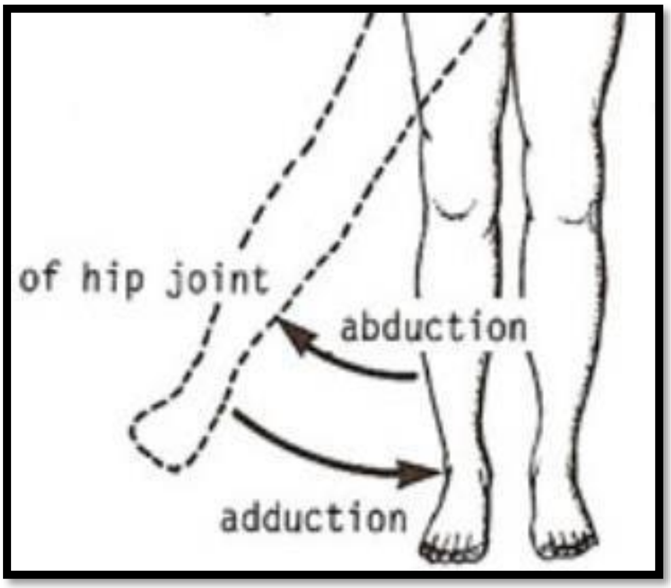
TERMS OF MOVEMENT

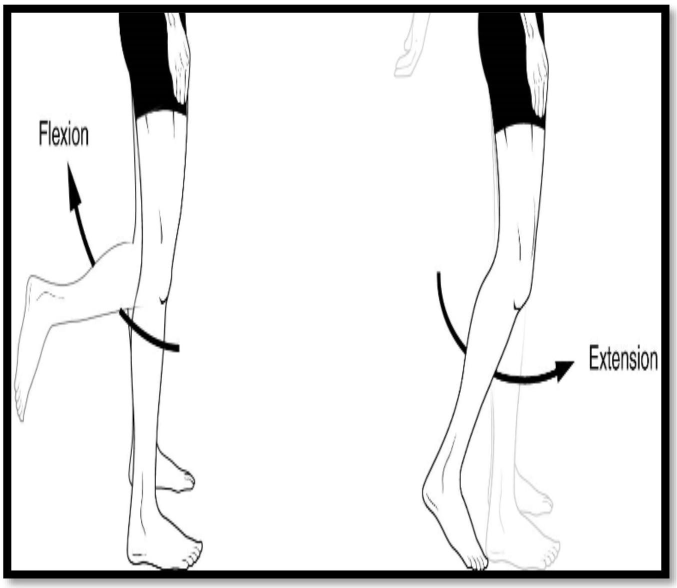
Adduction: a motion in which the segment distal to a joint move toward and/or across midline.

Abduction: a motion in which the segment distal to a joint move away from midline.

Flexion: the bending of a joint.

Extension: the straightening of a joint.



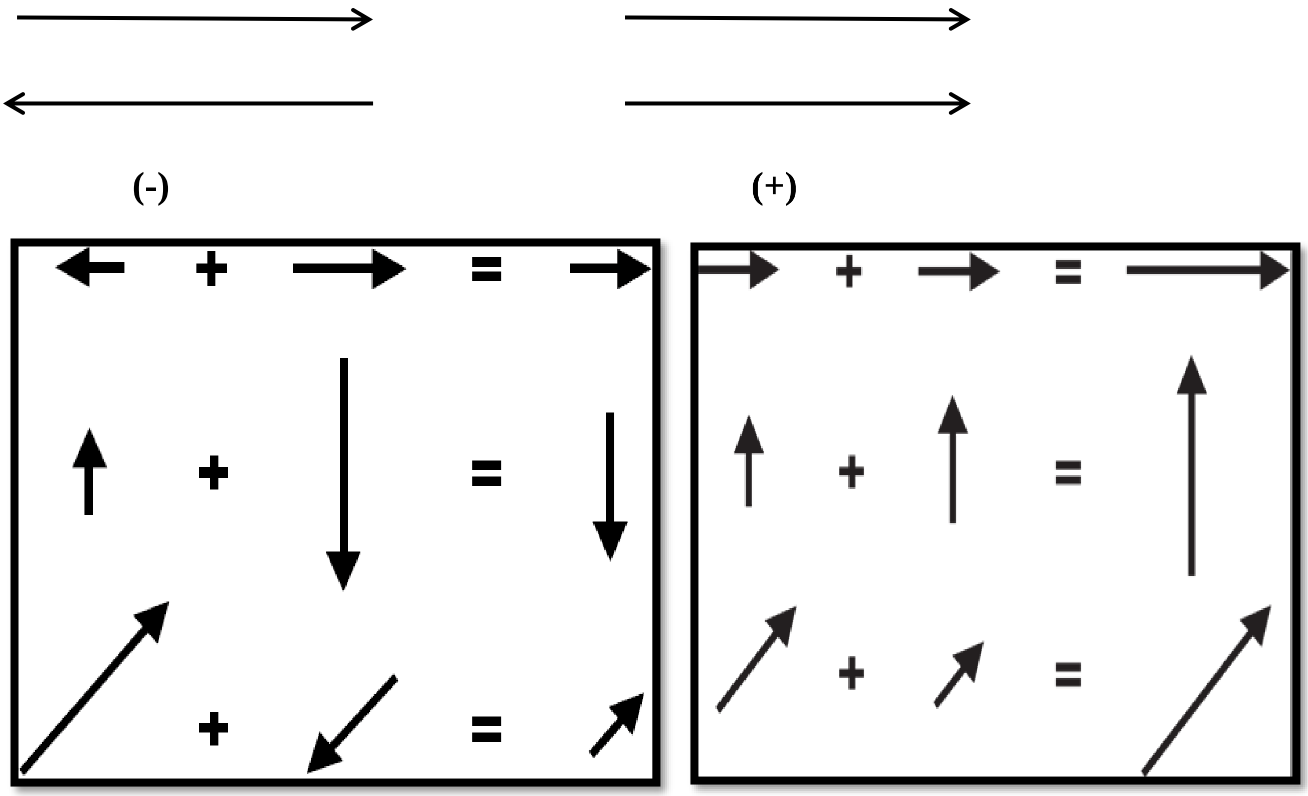


Analysis the component of force

Force : is the action of one body on another. Force is represented by a vector, a quantity that has both direction and magnitude. Vectors are represented by arrow-shaped symbols.

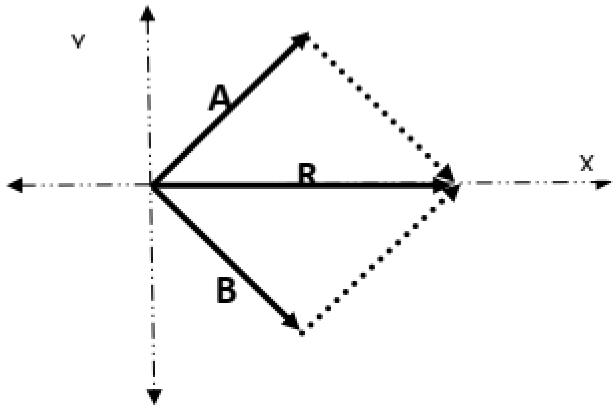
Force Polygon

Addition of Vectors Quantities



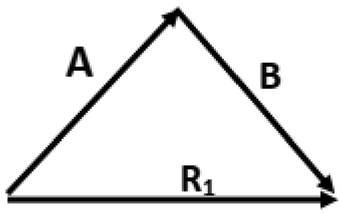
- **Parallelogram Law (Theory):**

$$\vec{R}_1 = \vec{A} + \vec{B}$$

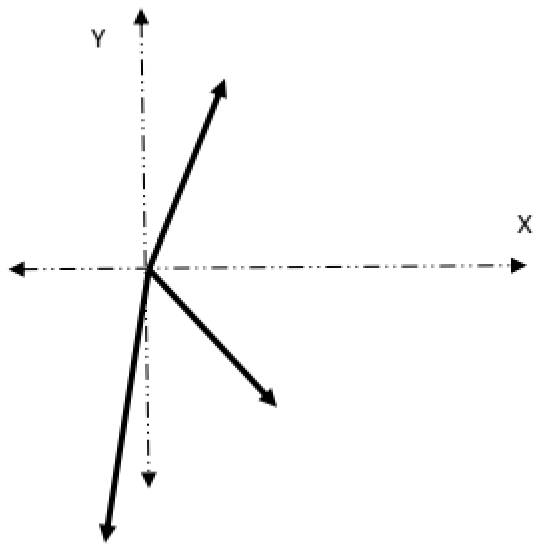


- **Triangle Law (theory):**

$$\vec{R}_1 = \vec{A} + \vec{B}$$



- **Force Polygon for multi forces**



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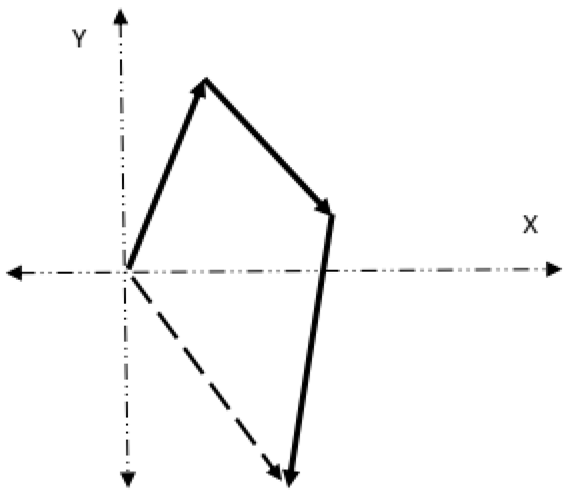


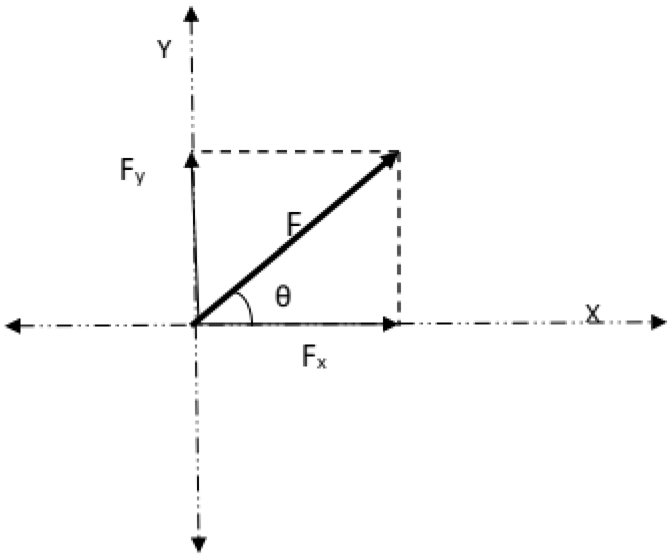
Analysis of Forces

Analysis of forces into a pair of perpendicular components is very important subject to be studied in order to have a full knowledge about the effect and distribution of forces on rigid bodies, which are remaining of rest.

Analysis of forces into a pair of perpendicular components as shown in figure :

Fx: The component of F for the x- axis fx

Fy: The component of F for the y-axis fy



$$\sin\theta = \frac{F_y}{F}$$

$$\cos\theta = \frac{F_x}{F}$$

Or

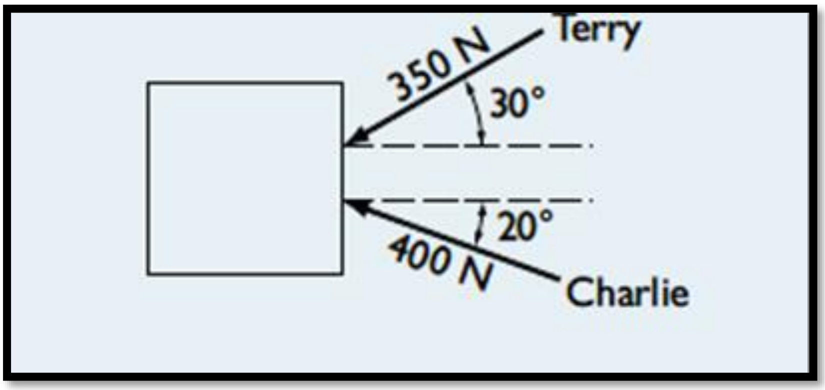
$$F_y = F\ \sin\theta$$

And

$$F_x = F\cos\theta$$

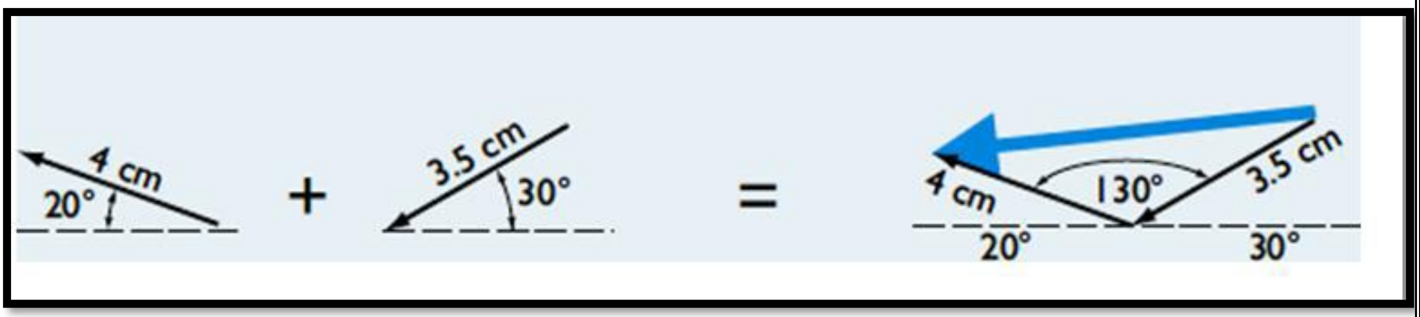
Example

Terry and Charlie must move a refrigerator to a new location. They both push parallel to the floor. Terry with a force of 350 N and Charlie with a force of 400 N. What is the magnitude of the resultant forces produced by terry and Charlie? If the amount of friction force that directly opposes the direction of motion of the refrigerator is 700, will they be able to move the refrigerator?



Graphic solution

Use the scale 1 cm= 100 N to measure the length of the resultant



The length of the resultant is approximately 6.75 cm or 675 N.

Since 675<700, they will not be able to move the refrigerator.

Trigonometric Solution

Given FT=350 N

FC=400 N $C2=A2+B2-2(A)(B)COS\ \theta\ (the\ law\ of\ cosines)$
$R2$=4002+3502−2(400)(350)COS 130 R=680 N

Since 680 < 700, they will not be able to move the refrigerator unless they exert more collective force while pushing at these particular angles.

Normal Gait

Normal gait is a series of rhythmical, alternating movements of the trunk and limbs which results in the forward progression of the center of gravity. It is generally established by 4-8 years of age. Toddler's gait has increased trunk movement, wide base of support, arms in high guard position, high foot lift during swing, flat-footed contact, and short, quick, rigid steps with the toes pointing outward. Mature gait has reciprocal arm-swing and heel strike with increased velocity, cadence, step length, single-limb stance time, and ratio of pelvis span to ankle spread when both feet are on the ground, due to increased stability and limb length.

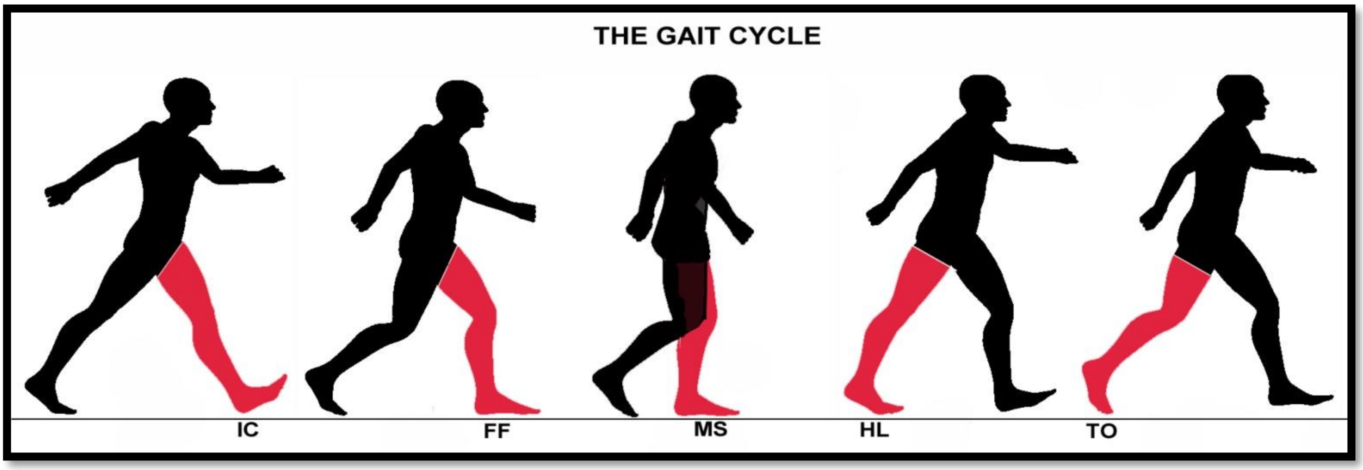
**The center of gravity (COG) of the human body is a hypothetical point around which the force of gravity appears to act. It is point at which the combined mass of the body appears to be concentrated[25]. COG is 5cm anterior to second sacral vertebra with 5 cm horizontal and vertical displacement during average adult male step. Maintaining COG over the base of support, including legs and assistive device, prevents falls. Minimized center of gravity (COG) movement vertically and horizontally creates gait efficiency. [4] Six determinants of gait minimize the excursion of COG and energy expenditure. The first five minimize vertical motion, horizontal planar pelvic rotation, frontal planar pelvic tilt, knee flexion, ankle and knee mechanisms. The sixth minimizes horizontal motion by lateral pelvic displacement.

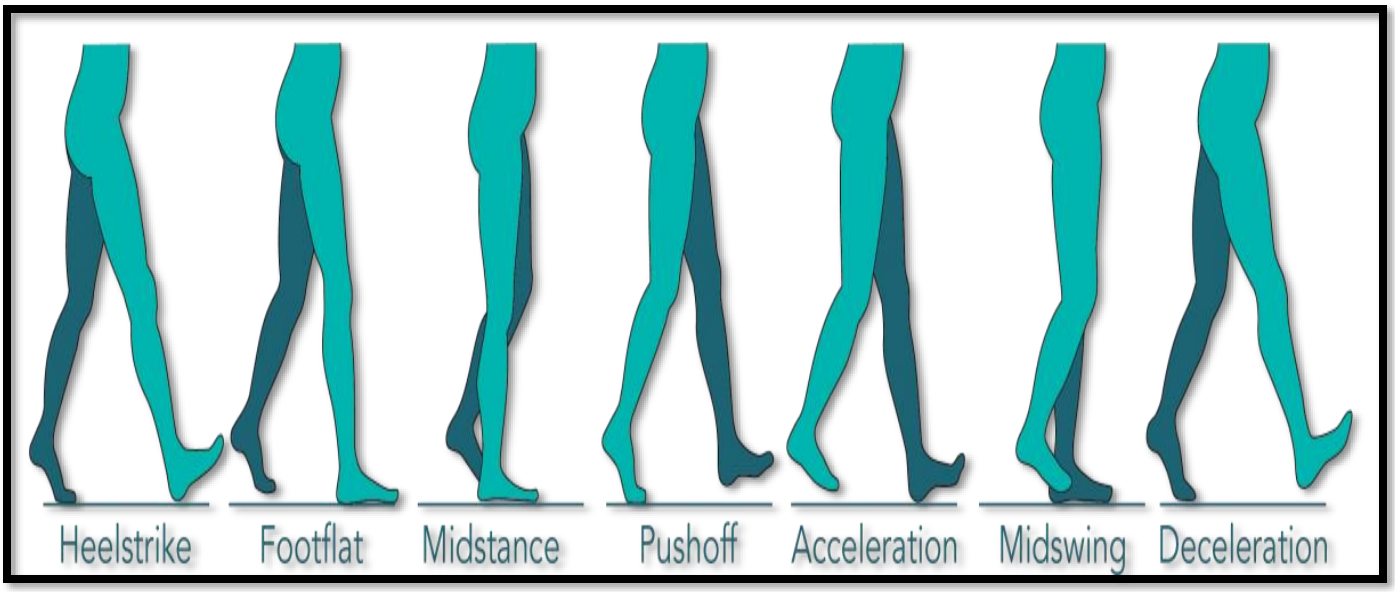
**Ground reaction force (GRF) applies Newton's Law of equal and opposite force so that during standing, GRF passes through the center of the foot anterior to the ankle (counterforce plantar flexors), slightly anterior to the knee (counterforce posterior ligamentous capsule), and slightly posterior to the hip (counterforce iliofemoral ligaments). In the frontal plane, the gluteus medius exerts abduction counterforce when standing on one leg.

Important measures of gait include

1- walking speed,
2- cadence (number of steps per minute),
3- walking base width (measured from midpoint to midpoint of both heels),
4- step length (measured from the point of foot contact to the point of contralateral foot contact) and
5- stride length (linear distance covered by one gait cycle).

*****The gait cycle is divided*** into stance and swing phases. Stance is weight bearing on a single leg; swing is advancing the limb while off the floor. During walking, 60% of time is stance and 40% is swing, with 20% of time in double support, and 40% in single limb support. Stance phase is subdivided into initial contact (from 0% to 2% of the gait cycle), loading response (from 2% to 12% [opposite toe off] of the gait cycle), mid stance (from 12% to 31% [heel rise] of the gait cycle), terminal stance (from 31% to 50% [initial contact from opposite foot] of the gait cycle) and pre-swing (from 50% to 62% [toe off] of the gait cycle). Swing phase is subdivided into initial swing (from 62% to 75% [foot of the swing limb is next to the foot of the stance limb] of the gait cycle), mid swing (from 75% to 87% [tibia of the swing limb is vertical] of the gait cycle) and terminal swing (from 87% to 100% [immediately before the next initial contact] of the gait cycle)





SOCKET BIOMECHANIC

General consideration

Top view of the above knee socket known as a "plug fit socket". The section is round it is essentially and has an inner configuration approximating the cylindrical shape of above knee stump.

The amputee's stump is inserted into the socket as a plug into a cylinder. If the tissues of the stump were equally firm and pressure tolerant, a uniform distribution of stump socket pressures would be desirable.

Alignment

Alignment: - is a geometric relationship between socket, shank and foot assembly. Proper alignment and a good socket fit go hand in hand; one will not do without the other. A well-fitting socket will be uncomfortable with poor alignment, and vice versa. In the field of prosthetic there are three kinds of alignment as following: -

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

2- Static alignment: is the alignment done with the patient standing up and putting weight on the prosthesis but not walking.

3- Dynamic alignment: is done with patient walking, first between parallel bar then outside.

The alignment can be modified under the socket or just over the foot. It can be done by tilting (changing angulation) or by shifting (slide the socket or the foot without changing the angles). Also, when you do tilting you usually need to shift the component to reposition the socket at the same position in relation to the foot.

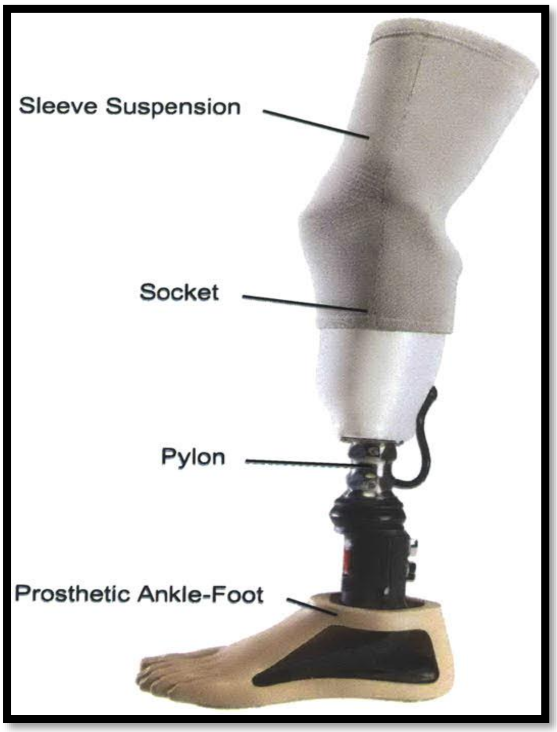
1- Bench Alignment

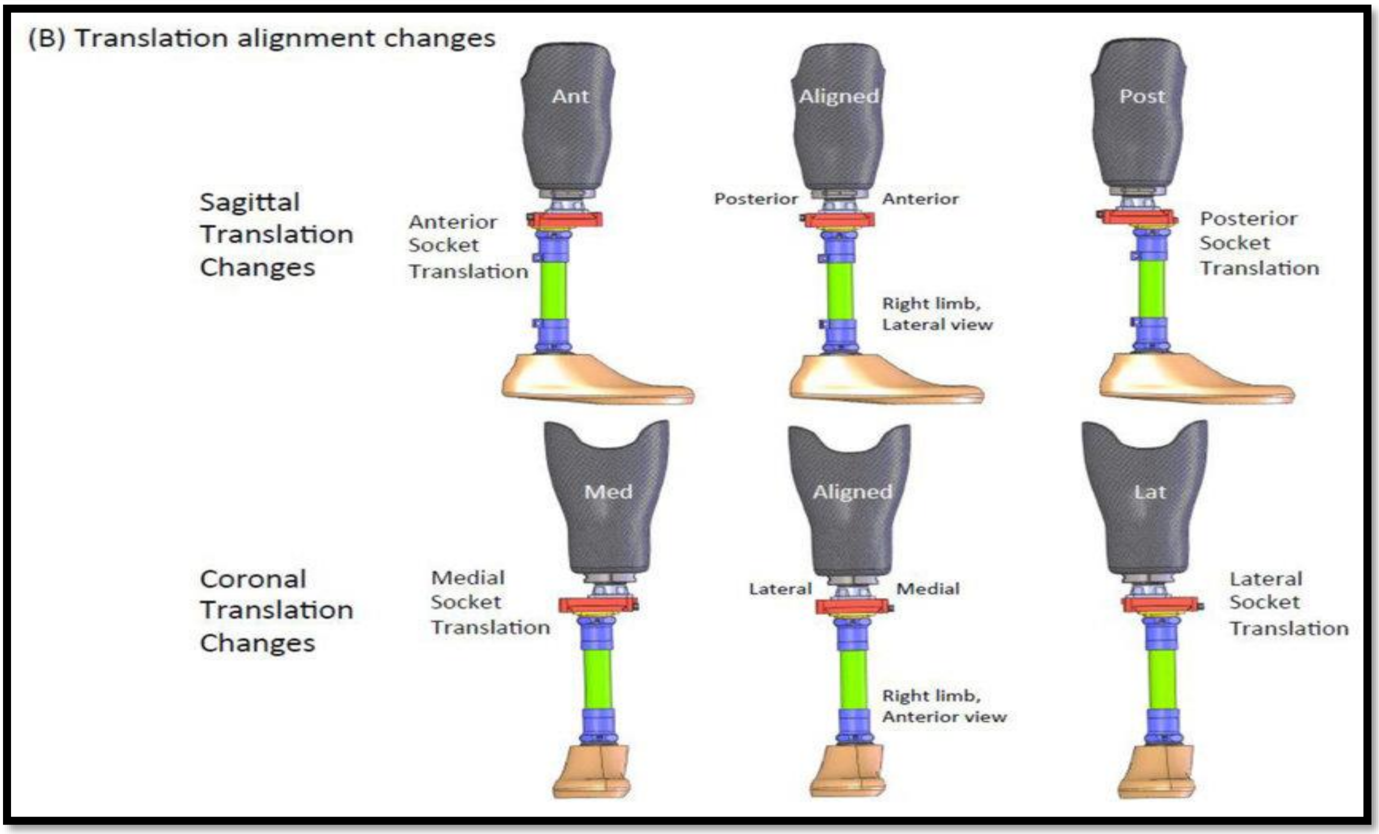
a-Tilting the socket: The socket and the foot are attached to each other so that the socket is flexed approximately (5 – 7) degrees. In order to expose appropriate areas of the anterior stump surface to weight bearing forces and to reduce forces tending to hyperextend the knee during the lateral half of stance phase. For very short stumps the flexion should be increased up till approximately 15 degree.

If the knee has flexion contracture the socket should be initially set up with that amount of flexion.

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

b- Shifting of the Socket: A plump line from anterior posterior of the socket will fall approximately 1/3 along the foot depending on the length of the feet while a plump line from the center of posterior wall will fall approximately 1 cm lateral on the center of heel and the line of the middle of the foot with line of the foot give a 5 degree angle as shown in figure.





There are two reference lines must be drown on the socket: -

i. Posterior reference line which is connecting the center point at posterior wall and the center point near the posterior distal end.

ii. Anterior-posterior center line which is connecting the mid-point between the patellar tendon and the posterior wall with the center point near the distal end.

In bench alignment, the socket, foot and adjustable shank are attached to each other so that: -

A) The socket is flexed approximately 5 degrees in order to expose appropriate of the anterior stump surface to weight bearing forces from the socket and reduce forces tending to hyperextend the knee during the lateral half of stance phase.

B) A plumb line from the anterior posterior center of the socket will fall slightly ahead of the breast of the heel of shoe. Shorting the anterior length of the foot further reduce forces tending to hyperextend the knee during the lateral half of the stance phase.

C) A plumb line from the center of posterior brim will fall a proximately (1-1.3) cm lateral to the center of the heel. This socket foot relationship creates a force couple which tends to rotate the socket around the stump during the middle of stance phase with resulting increased compression of tissue medio proximally (a pressure-tolerant area) and decreased compression later proximally (a pressure- sensitive area).

D) For very short stumps the flexion of socket should be increased up till 15 degrees.

E) The socket is placed in adduction or abduction to correspond with what has been recorded during patient assessment.

2- Static Alignment

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

A) Put the leg on the patient and assess the fit. It mean no major gaps at the socket and stump, and the patient should have no discomfort. Check the patellar pocket in order to ensure that the stump fits into socket. The prosthetic should keep in mind that the amputee will be expected to walk with a flexed knee with weight bearing over the middle third of the foot in mid stance.

B) Ask the patient to stand and if he can comfortably, assess the fit and height of the leg. Make sure the patient putting his weight and does not flexed hip.

C) Check for the correct length of the prosthesis and toe out. The amputee should be standing with equal weight on both legs and feet approximately 10 cm apart at the heels, the toe out should be the same as normal leg. Keeping in mind that external rotation of the amputee side from the hip is possible. Both feet should be level and the pylon tube vertical.

D) To check height and check the level by using three anatomical references points: -

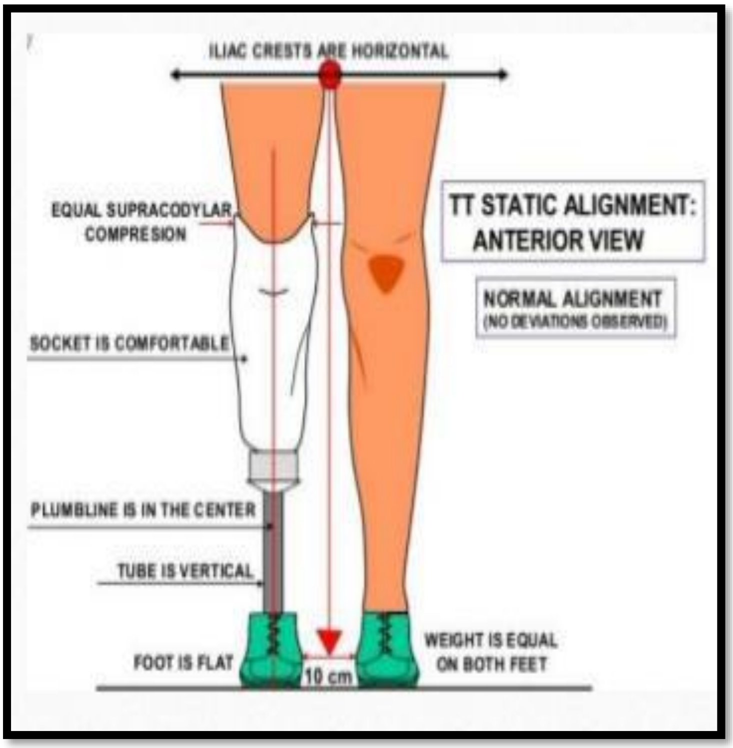
i- The iliac crest.

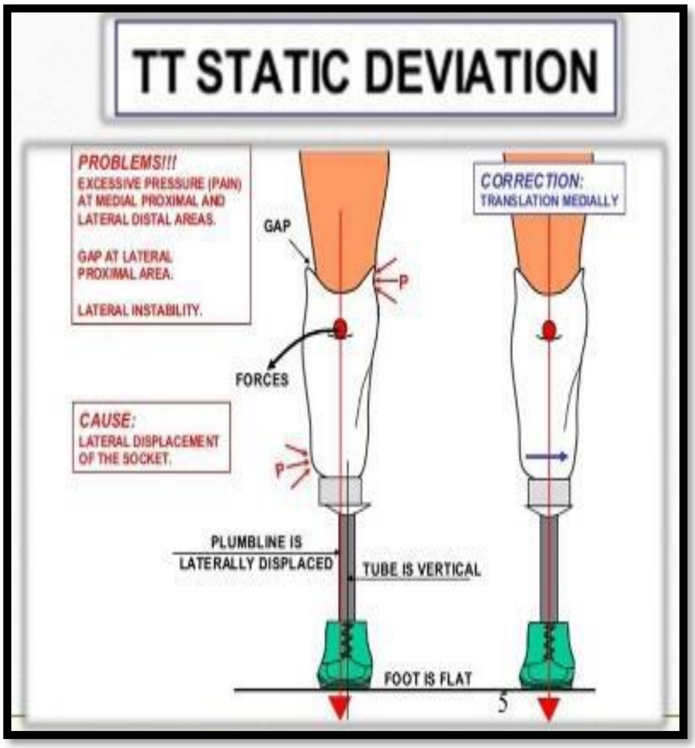
ii- The anterior-superior iliac spine.

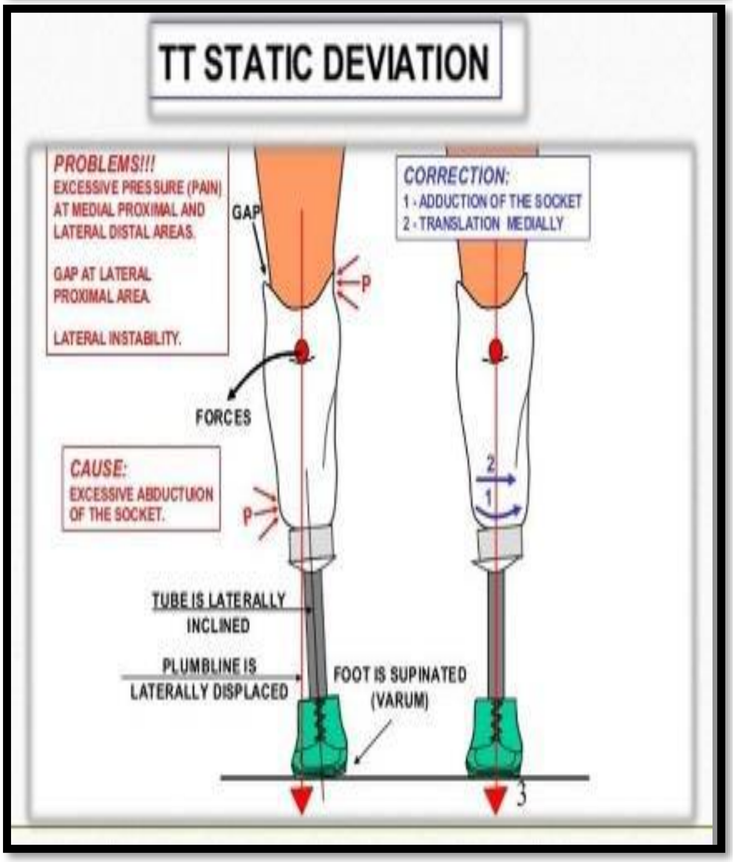
Iii- The posterior-superior iliac spine.

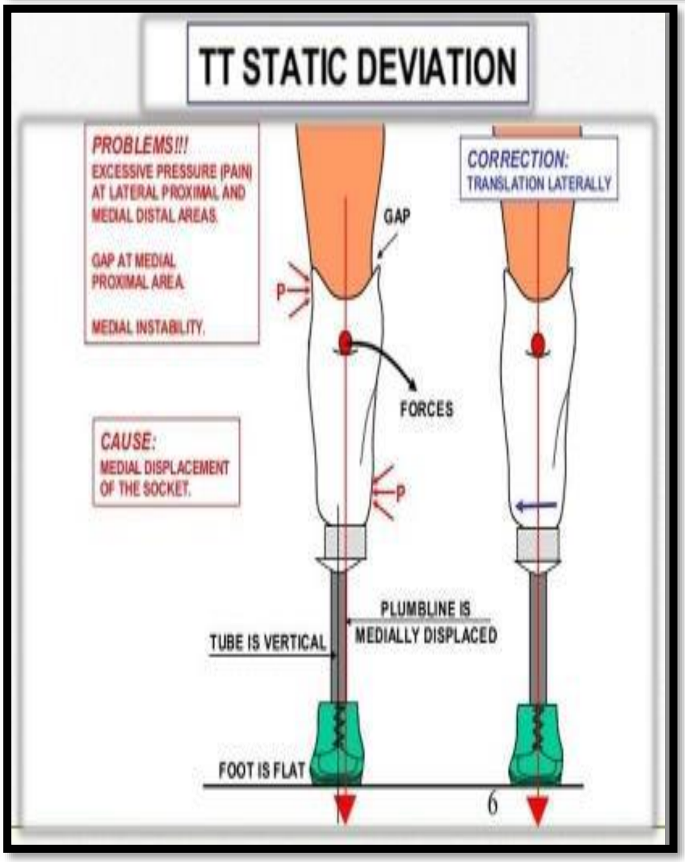
E) Check the initial tilt of the socket, if the heel is off the floor, give more flexion to the socket.

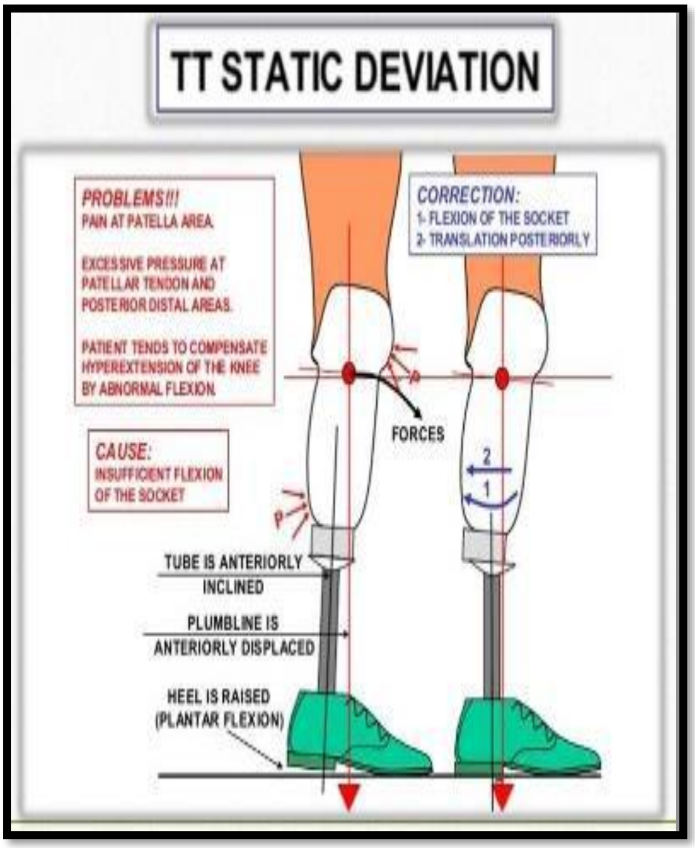
If the front part of the foot is not touching the floor, give more extension to the socket. If too much pressure on lateral upper side of the socket; the socket must be more abducted. If too much pressure on medial proximal edge of the socket; the socket must be more adducted.

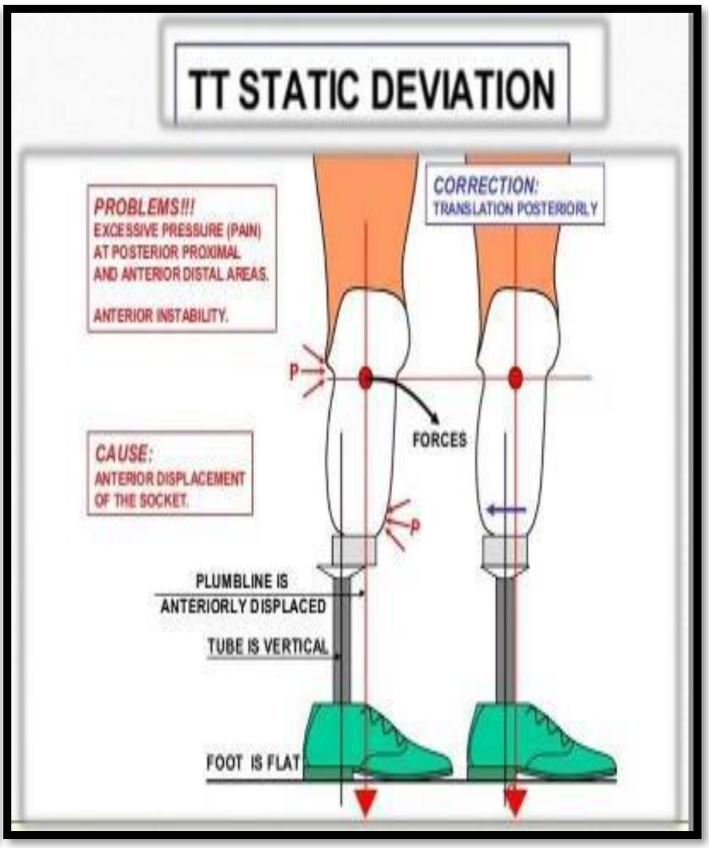


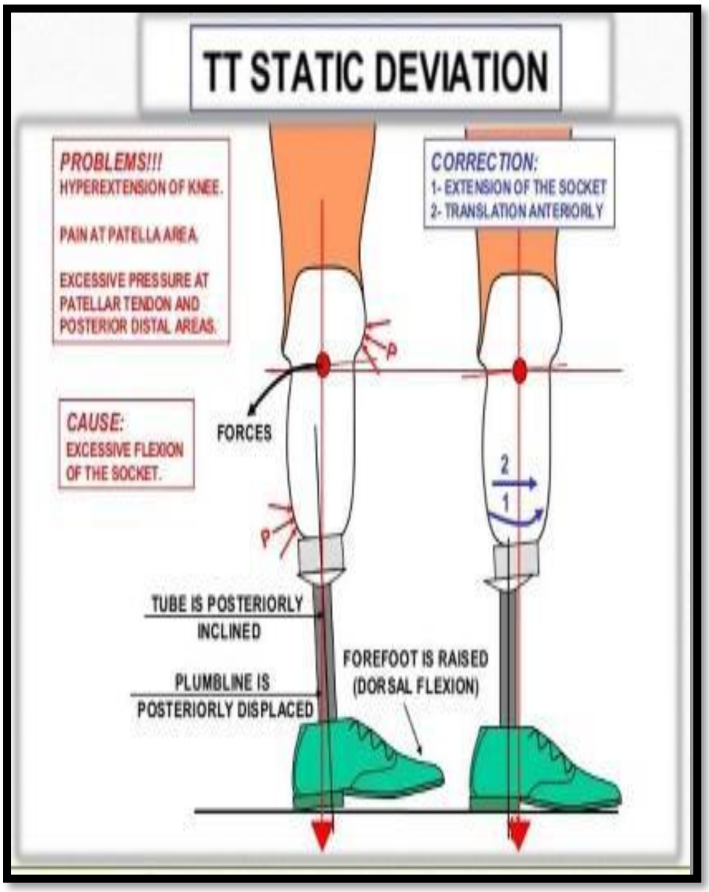







TT STATIC DEVIATION
PROBLEMS!!!
PAIN AT PATELLA AREA.
EXCESSIVE PRESSURE AT PATELLAR TENDON AND POSTERIOR DISTAL AREAS.
PATIENT TENDS TO COMPENSATE HYPEREXTENSION OF THE KNEE BY ABNORMAL FLEXION.
CORRECTION:
1- FLEXION OF THE SOCKET
2- TRANSLATION POSTERIORLY
P
FORCES
2
1
CAUSE:
INSUFFICIENT FLEXION OF THE SOCKET
TUBE IS ANTERIORLY INCLINED
PLUMBLINE IS ANTERIORLY DISPLACED
HEEL IS RAISED (PLANTAR FLEXION)


TT STATIC DEVIATION
PROBLEMS!!!
EXCESSIVE PRESSURE (PAIN) AT POSTERIOR PROXIMAL AND ANTERIOR DISTAL AREAS.
ANTERIOR INSTABILITY.
CORRECTION:
TRANSLATION POSTERIORLY
P
FORCES
CAUSE:
ANTERIOR DISPLACEMENT OF THE SOCKET.
PLUMBLINE IS ANTERIORLY DISPLACED
TUBE IS VERTICAL
FOOT IS FLAT


TT STATIC DEVIATION
PROBLEMS!!!
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CORRECTION:
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2- TRANSLATION ANTERIORLY
P
CAUSE:
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FORCES
2
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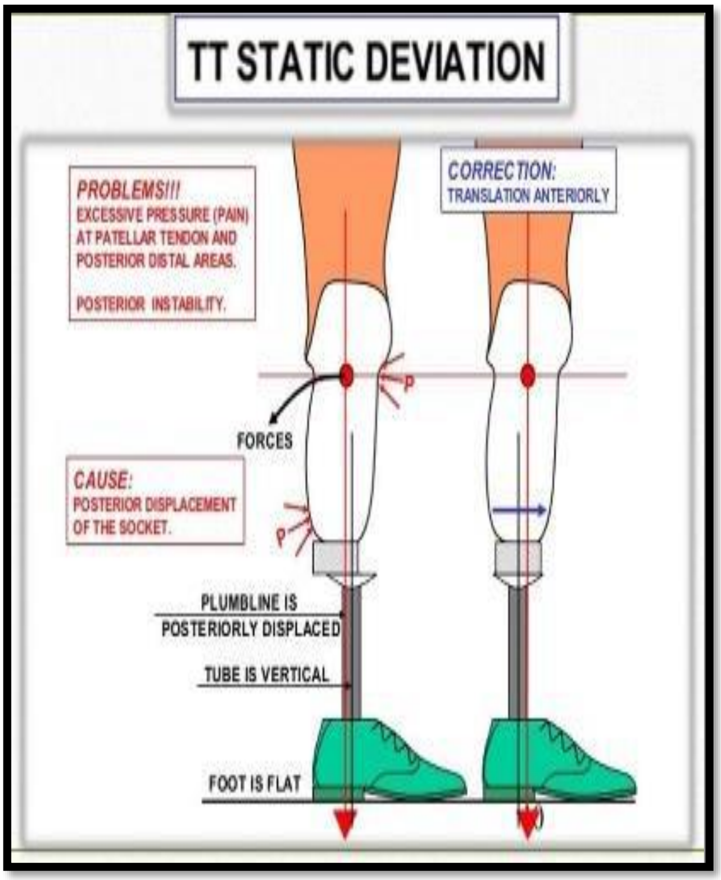
TUBE IS POSTERIORLY INCLINED
PLUMBLINE IS POSTERIORLY DISPLACED
FOREFOOT IS RAISED (DORSAL FLEXION)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P
FORCES
CAUSE:
POSTERIOR DISPLACEMENT OF THE SOCKET.
PLUMBLINE IS POSTERIORLY DISPLACED
TUBE IS VERTICAL
FOOT IS FLAT

Dynamic Alignment

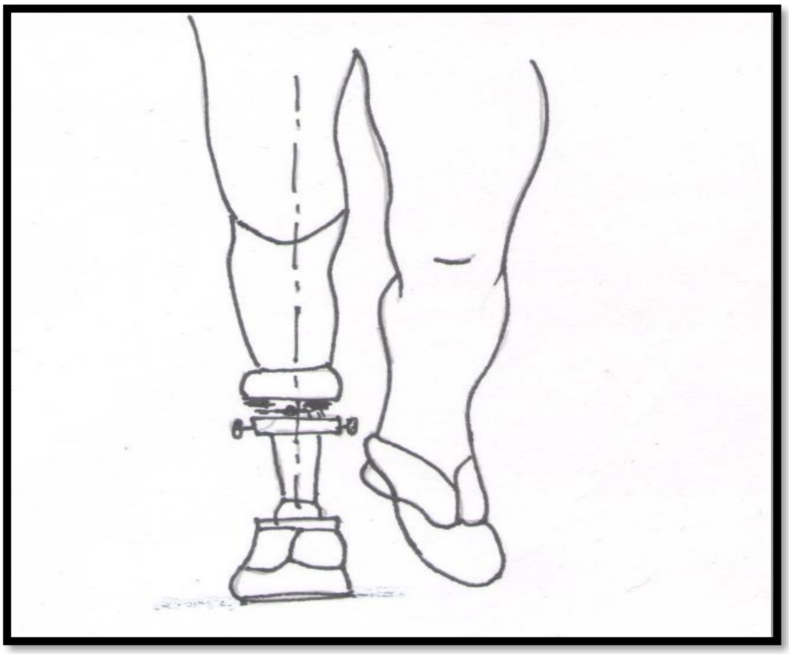
1- Mediolateral Alignment:-

A- Check toe out of prosthesis foot and line of progression. Compare with sound leg during walking.

B- Foot or sole of shoe must flat on the floor.

C- Check the lateral or medial shift of other motion at the proximal border of socket. The socket should remain stable at midstance. Equal compression of tissue at medial and lateral proximal brim. It is shown in figure.

Mediolateral

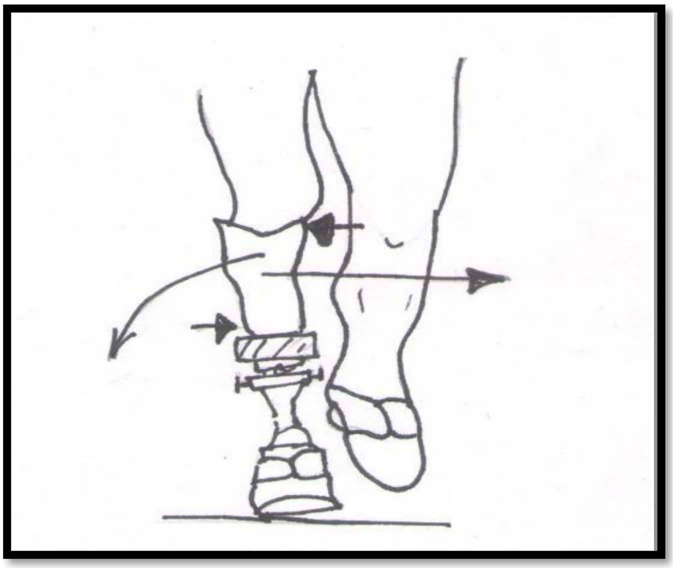


Mediolateral Alignment

1.1 Mediolateral tilt adjustment:-

If the sole of the shoe is not flat on the floor during mid-stance. A tilt adjustment is indicated. To confirm check the pylon tubing for vertical position.

If the medial border of shoe is not contact with the floor, the pylon tubing lean laterally. It notice the lateral proximal will gape and the medial proximal brim may show excessive bulging of tissue and the amputee may complain of pressure at the distal cut end of the fibula shaft as shown in figure.



Mediolateral tilt adjustment

TO CORRECT:-

a- Lateral tilt of the socket which will bring the medial border of the shoe to the floor and pylon vertical. The tilt does correct the foot position but at the same time shift the weight line further laterally.

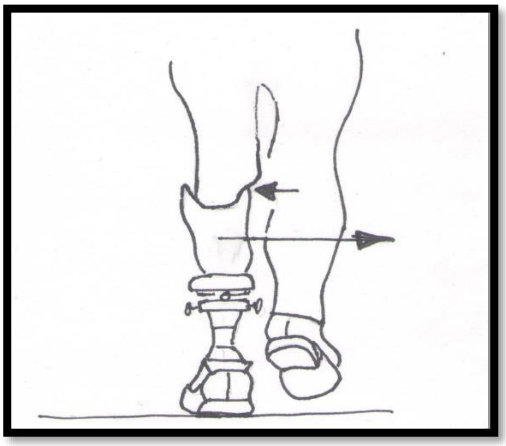
b- Shift socket medially.

1.2 Mediolateral shift adjustment:-

1.2.1 Observe and adjust the width of the walking base

If the socket over the foot was shifted too laterally, the foot or sole of shoe will most likely flat on the floor and the pylon tubing vertical.

The amputee may complain of abnormal pressure at the medial proximal brim, and the socket in lateral motion causing gaping at lateral proximal brim. Often the patient feel insecure because of the narrow walking base. As shown in figure.



The socket too lateral over the foot

TO CORRECT:-

1- Shift the socket medially.

2- Do not tilt the socket.

the patient feels secure but the t Ly, too medial shifted if the socket was -Note: walking pattern could be awkward (the patient is walking like a duck) because the foot would be too laterally from the center of gravity (CG). The amputee must bring his CG over foot by tilting or shifting the hip.

2 - Anteroposterior Alignment: -

2.1 Observe the amputee walking left to right

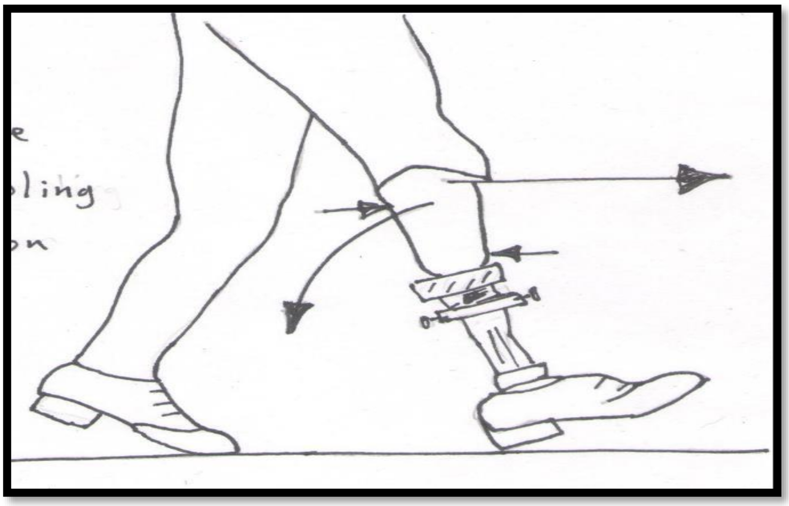
Sufficient distance from the amputee is of importance to observe fully the gait cycle and possible shortcoming.

The stance phase should be smooth and even from heel contact to toe off, voluntarily controlled by the amputee's residual limb and knee.

The knee should be not lack stability, but at the same time, excessive effort should not be required to control stability or to flex the knee at the end of stance phase. The prosthetic foot should be of proper size, exact heel heights compared to the shoe worn by the amputee, and heel wedge or planter flexion bumper of the proper firmness according to the weight and function of the individual amputee.

2.2 Anteroposterior tilt and shift adjustment: -

2.2.1 If at heel strike the amputee cannot control knee flexion, causing rapid and premature knee flexion, the prosthetic forefoot will contact the floor prematurely. The amputee will complain of pain at the distal anterior aspect of tibia and posterior proximal brim. He feels and seems to be precipitated (يندفع) forward immediately after heel strike as illustrated in figure.



Heel strike cannot controlling knee flexion

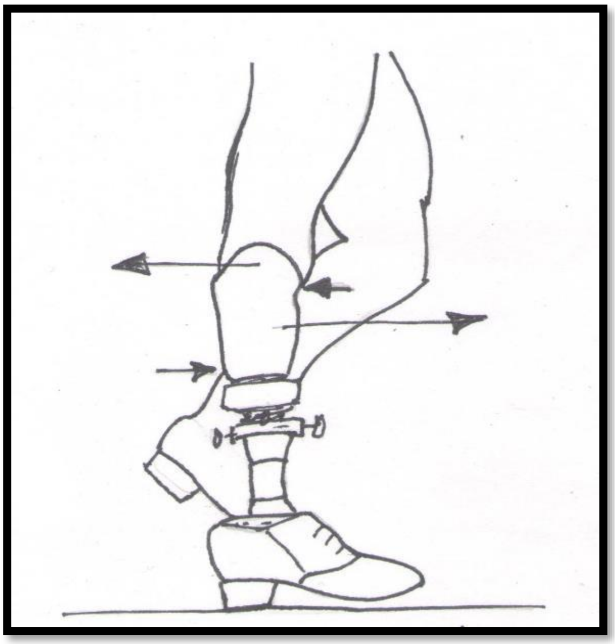
CAUSE:-

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

TO CORRECT:-

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

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

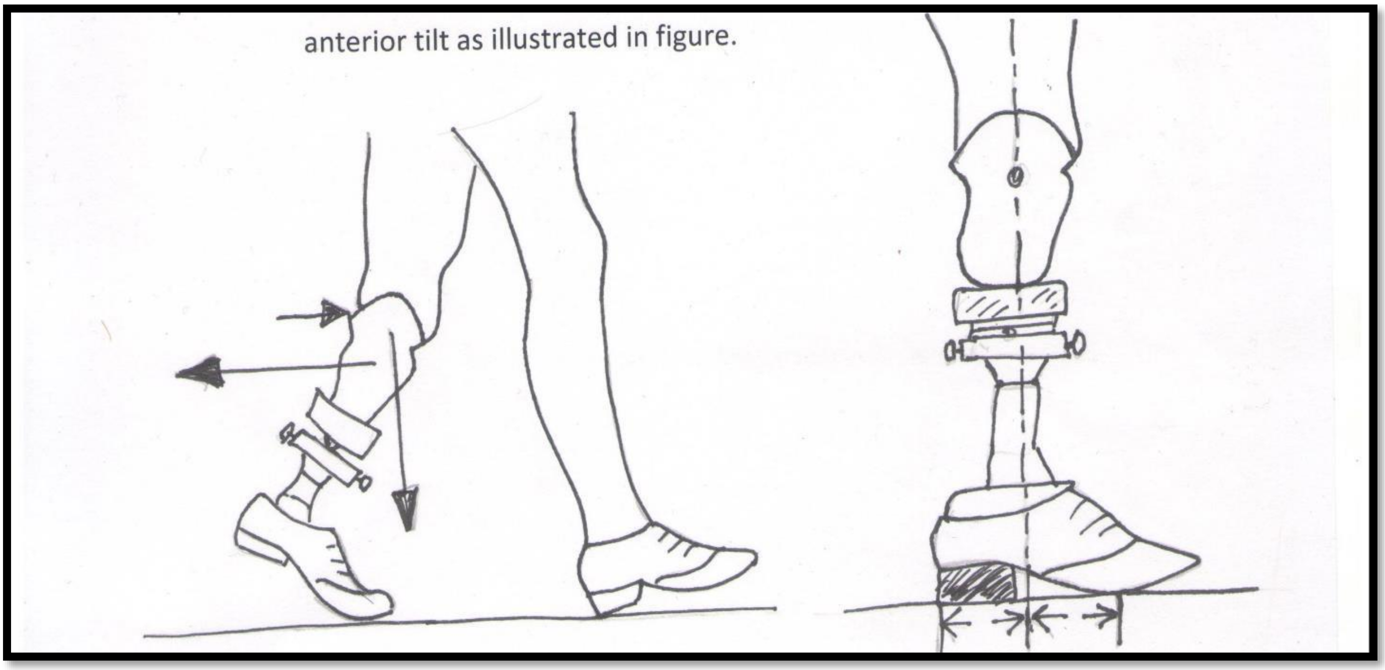


Knee forced hyperextension

TO CORRECT: -

Shift the socket anterior over the foot or make a firmer heel cushion. If the same symptoms at the socket are apparent, but the prosthetic foot is in contact with front only, the heel is off the floor and the pylon is vertical, an anterior tilt is the indication.

2.2.3 If at time of toe off, a sudden drop off takes place, giving the appearance of the amputee walking downhill with his prosthesis and there is excessive pressure usually at the posterior proximal brim, the socket been either placed too far anteriorly, or there is excessive anterior tilt as illustrated in figure.



Excessive pressure at posterior proximal brim

Centering the socket at P.T level

TO CORRECT:-

a- Shift the socket posteriorly over the support surface of the prosthetic foot. (centering the socket at PT level, midway between heel edge and rolling foot, as shown in figure is a good indicator).(1/3, 2/3).

b- Tilt socket posteriorly and reduce socket flexion.

When the alignment is correct and the patient is happy, check the stump for a new damage and then prepare the prosthesis to be finished. Check and mark the .trim lines and cosmetic measure