Trans-Femoral Prosthetics

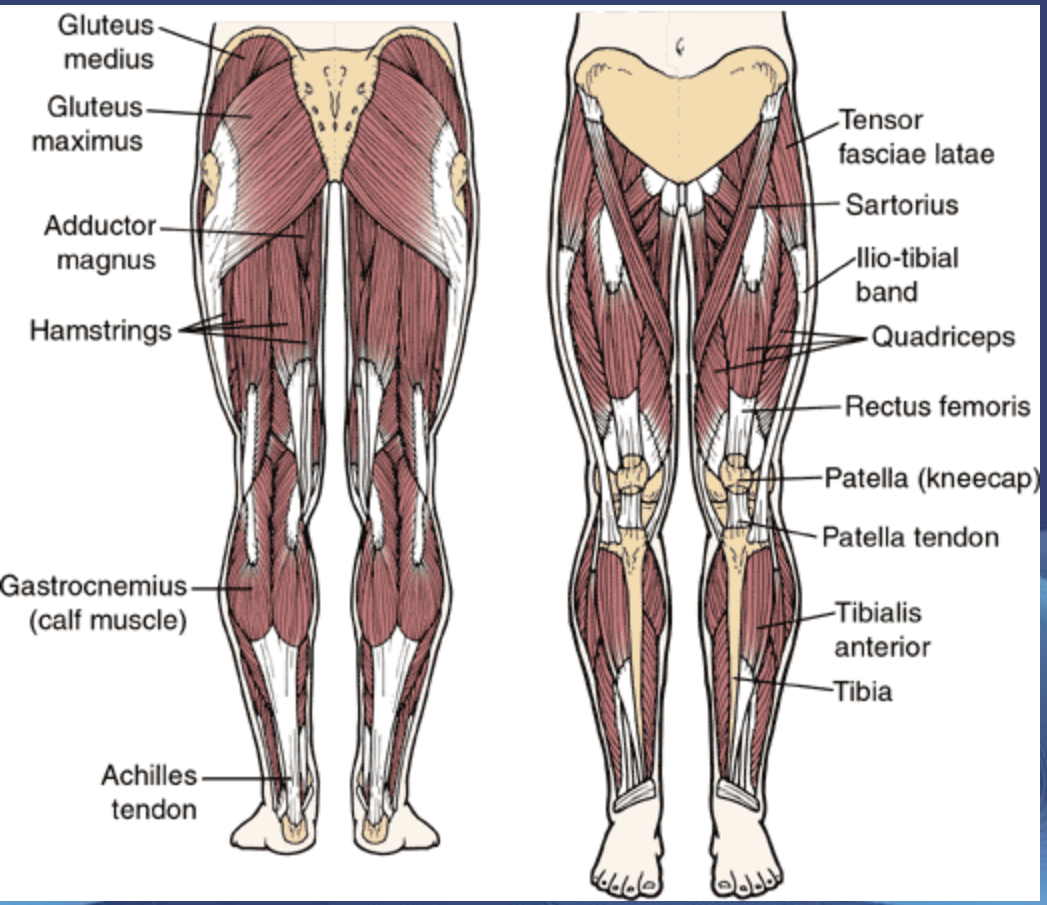
Shameem Bhatti Ashwin Ayyaswamy

Prosthetics

- Anatomy and basic mechanics of the leg
- Historical prosthetic and major innovations
- Today's products
- Future innovations

Anatomy of the Leg

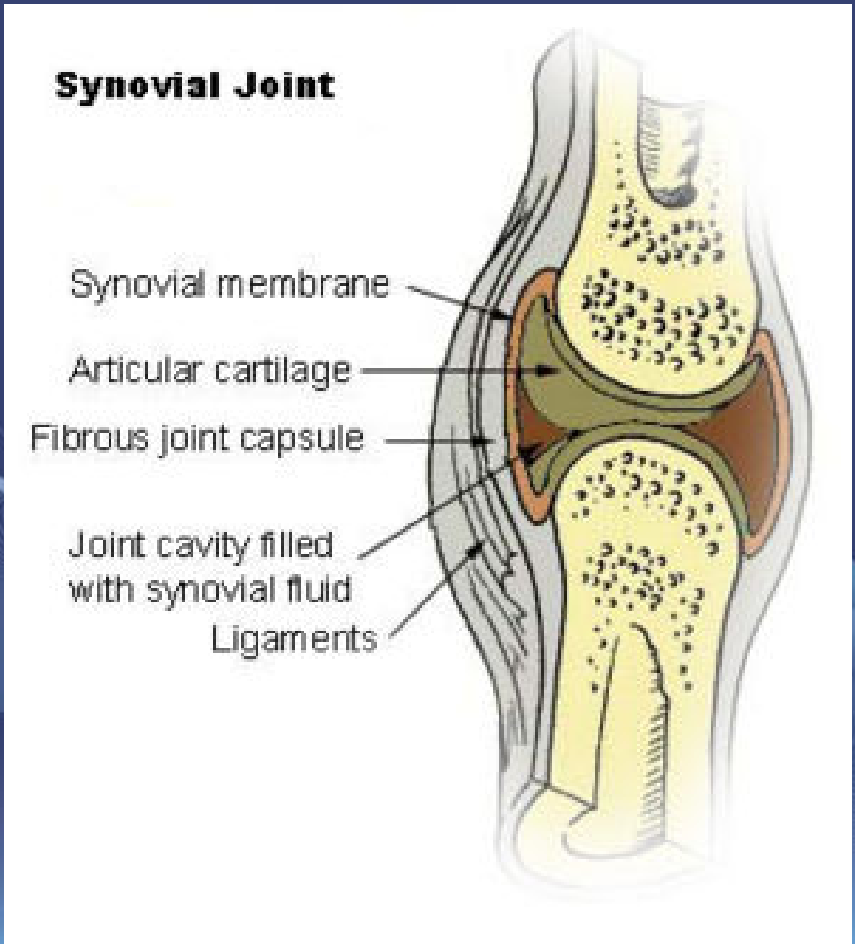
Muscular Control
(movement)



- Quadriceps
  - Extension of the leg
- Adductors
  - Lateral movement
- Hamstrings
  - Flexion of the leg
- Calf (Gastrocnemius)
  - Torque on the ankle
  - Plantar flexion
- Tibialis Anterior
  - Torque on the ankle
  - Dorsal flexion

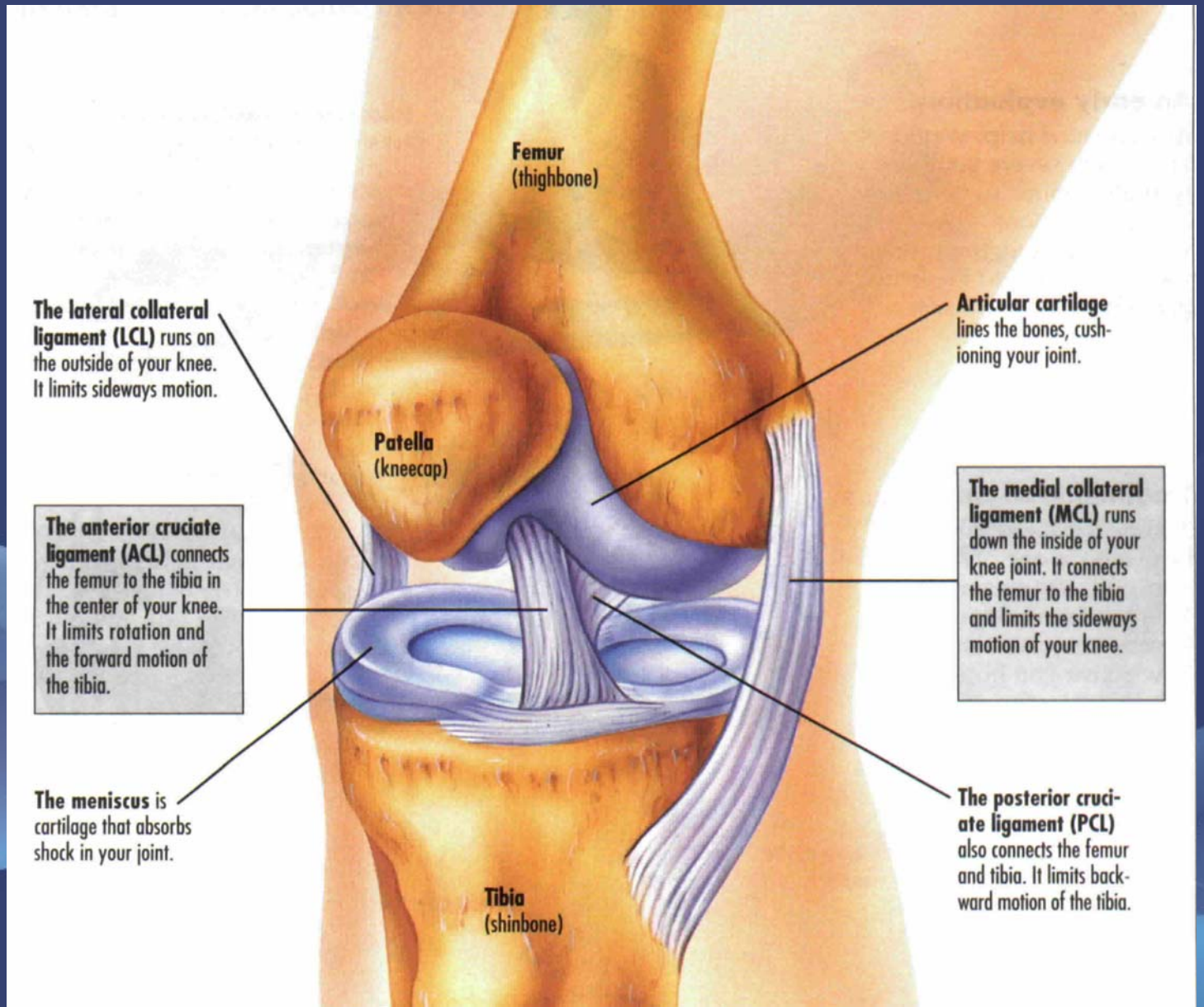
Joint Structure

(Synovial)



- Most common joint in the body
- Enclosed in a membrane which secretes synovial fluid into the joint cavity, which nourishes and lubricates
- Bones cushioned by articular cartilage which allows for movement of the joint
- Types of synovial joints:
  - condyloid
  - ball and socket
  - saddle
  - hinge
  - pivot
  - gliding

Knee Joint

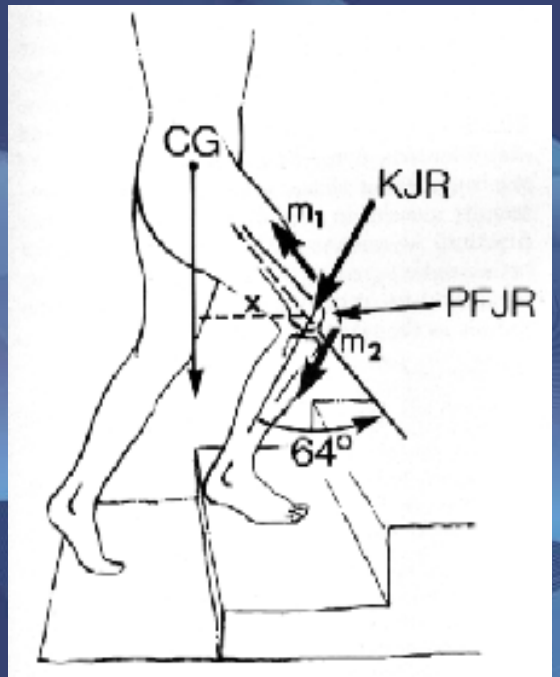

Femur
(thighbone)
The lateral collateral ligament (LCL) runs on the outside of your knee. It limits sideways motion.
Articular cartilage lines the bones, cushioning your joint.
Patella
(kneecap)
The anterior cruciate ligament (ACL) connects the femur to the tibia in the center of your knee. It limits rotation and the forward motion of the tibia.
The medial collateral ligament (MCL) runs down the inside of your knee joint. It connects the femur to the tibia and limits the sideways motion of your knee.
The meniscus is cartilage that absorbs shock in your joint.
The posterior cruciate ligament (PCL) also connects the femur and tibia. It limits backward motion of the tibia.
Tibia
(shinbone)

Knee Joint

- The knee functions as a self maintaining, joint and loading zone. The purpose of which is to accept and transfer bio-mechanical loads between the femur, tibia, patella, and fibula, and allow flexion and extension of the lower leg.
- Synovial complex condyloid joint
  - condyloid joint is where the two bone surfaces fit together in a odd shape
  - One surface is convex - the femur
  - One surface is concave - the meniscus

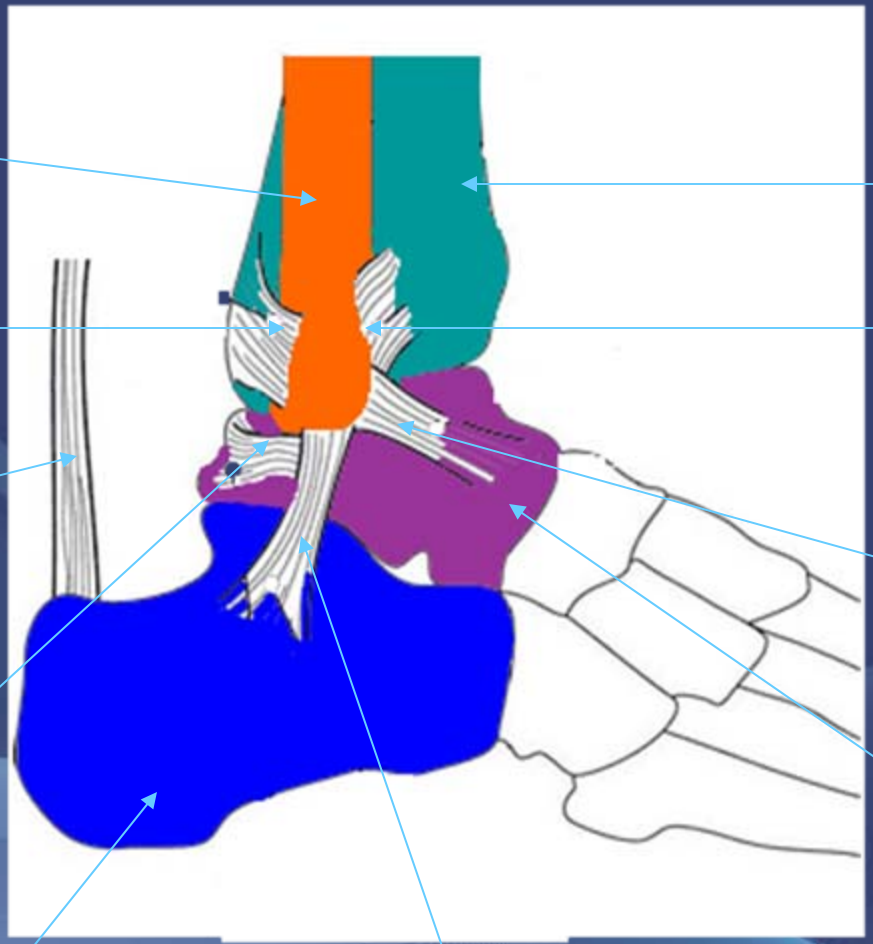
Knee Mechanics

- Loading shock energy is primarily dissipated in the knee
- Typical knee range of motion is 150° of flexion



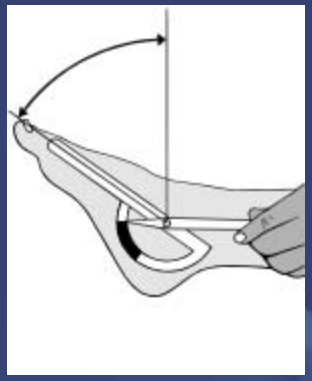
m1 = quadriceps force
m2 = patellar tendon tension
KJR = knee joint reaction
PFJR = patellofemoral joint reaction
CG = center of gravity
x = flexor lever arm.

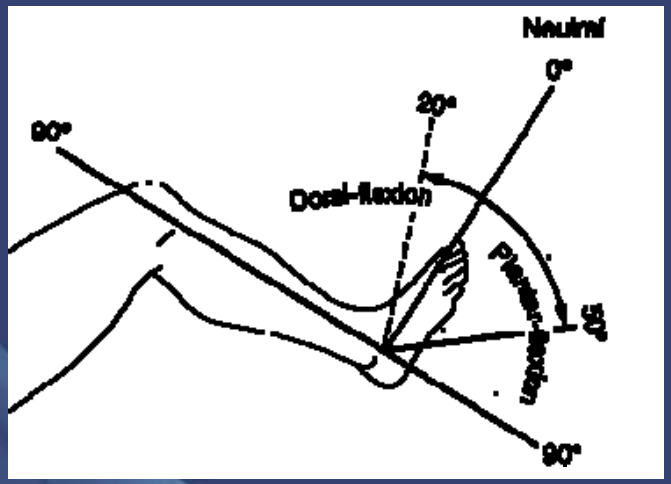
Anatomy of an Ankle

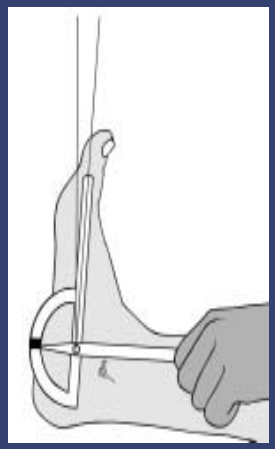


- Ligaments connect bone to bone
- Tendons connect muscle to bone

- The ankle, or talocrural joint, is a synovial hinge joint. That connects the distal end of the tibia and fibula to the proximal end of the talus.
- The ankle joint allow for plantar flexion and dorsiflexion.







Plantar Flexion

Toes point away from the body

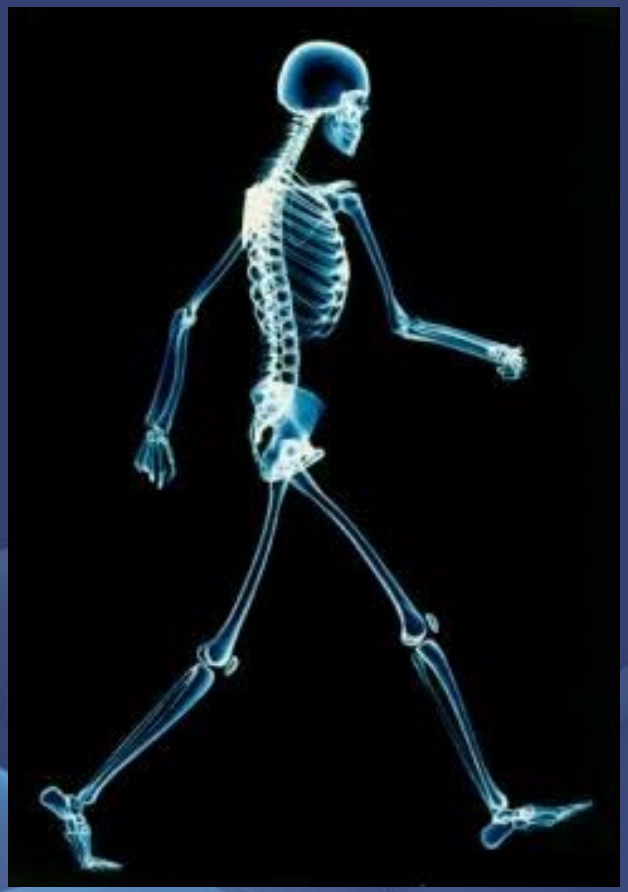
Dorsiflexion

Toes point towards the body

- Between the talus and the metatarsals the ankle allows for transverse rotation of up to 18 degrees this is due to the fact that the ankle has gliding synovial joints.

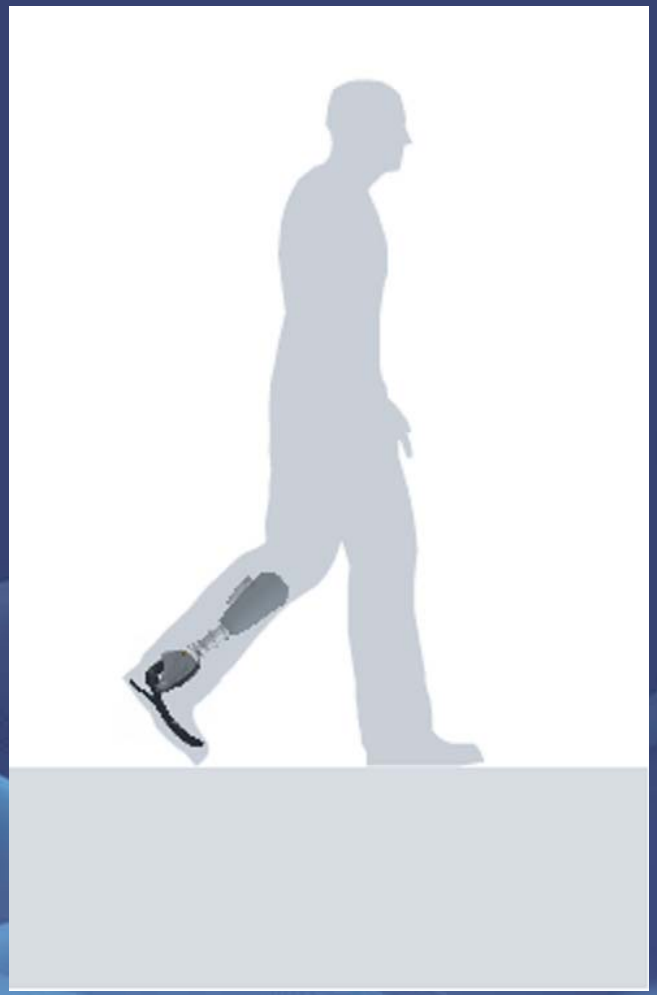
Gait

- Gait is the way the manner in which one walks
  - Weight placement
  - Heel strike or mid foot strike
  - Length of leg
  - Angle of foot
    - Transverse & Saggital angles
  - foot shape
- Gait varies from person to person
- In prosthetics, maintaining a natural gait is one of the main goals

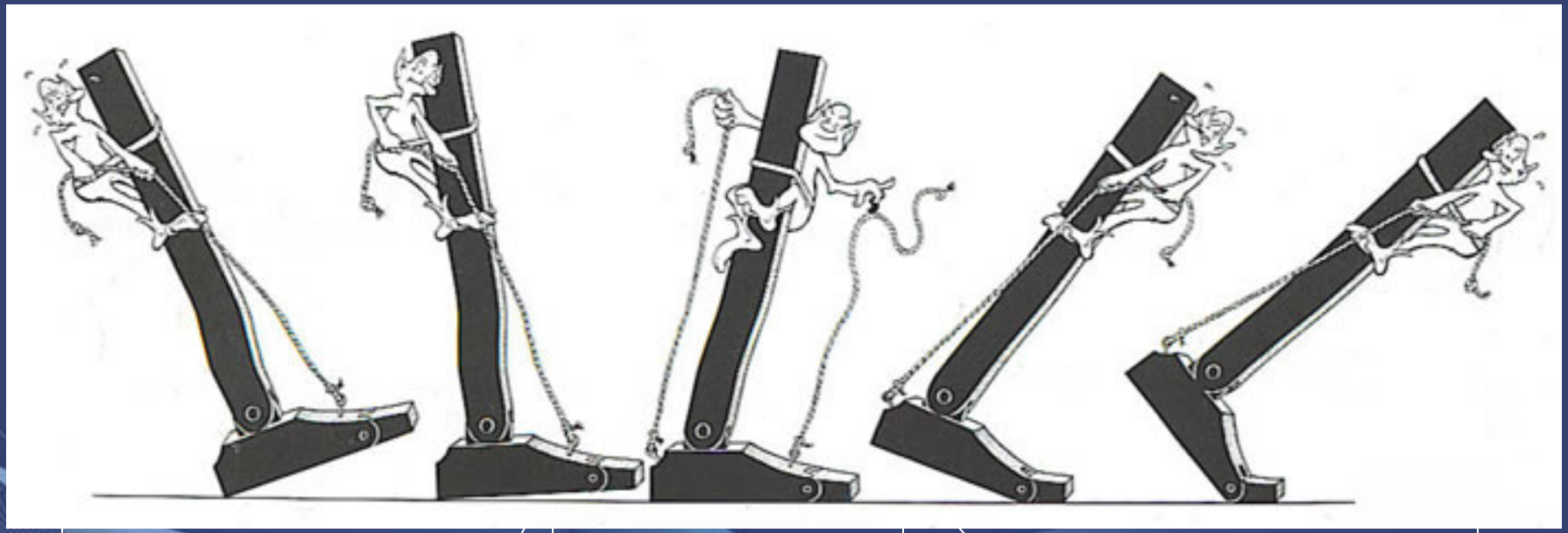


Power Analysis of Gait

- Walking requires a substantial amount of power to be generated by the leg
- Three main areas of power production and absorption in the leg are the ankles, knees and hip.
- Amputees lose power at their ankles because they lack toes and an ankle to push off.
- We utilise our plantar flexor muscles to propel ourselves forward and then catch ourselves on the other heel.
- The main source of difference in power production between normal and amputee gait exists at the hip.
- Due to the lack of ankles the amputee has to use the hip to "pull" the prosthetic leg in the correct direction.



Walking Gait Phases



Swing phase:
Heel applies force to the ground

Stance phase:
The foot is on the ground.

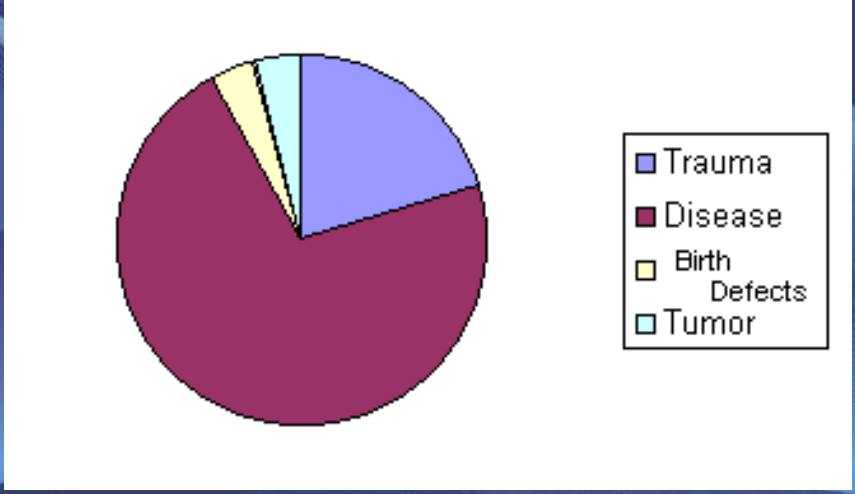
Propulsive force:
Due mainly to ankle joint torque.

Amputation Statistics

Some Statistics:

- There are currently over ten million amputees in the world.
- More than 250,000 persons lose a limb each year.[1]
- In the US alone over 3000 people will lose an appendage within the week that is more than 18 people per hour! [2]

Causes of Amputations:



Most amputations are due to :

- vascular diseases which limit circulation
- diabetes which slows down the healing process

The Perfect Prosthetic

- A prosthesis is any device that is an artificial substitute for a body part.
- The perfect prosthetic would act as a complete leg replacement
- Mimic the action of the leg muscles
- Allow for greater balance control

History of Prosthetic Innovations

- In 1696, a Dutch surgeon introduces the first non-locking below knee prosthesis.
- Before this blacksmiths in the middle ages made lower limbs out of metal for knights.
- The first prosthesis to have an articulating foot (this was achieved using cat gut) was the Anglesey Leg built by James Potts in the 1800s.
- Up until 1946 lower limb prosthetics were attached to the stump using straps or clamps, now by using suction prosthetics could be held in place in a comfortable way.
- This led to the beginning of custom built prosthetics.

Today's Products

- Direct Bone Anchorage
- Ossür
  - Running foot
- Otto Bock
  - C-Leg
  - Jaipur Foot

Direct Bone Anchorage

Many people who use above knee prosthesis have reported a range of problems and difficulties in using the prosthesis with a prosthetic socket.

A Swedish study shows that 72% of users report problems with heat and sweating in the socket and 62% report problems with chafing of the stump by the socket.

Direct bone anchorage means that the prosthetic is attached without a socket. The method is based on the process of osseointegration.

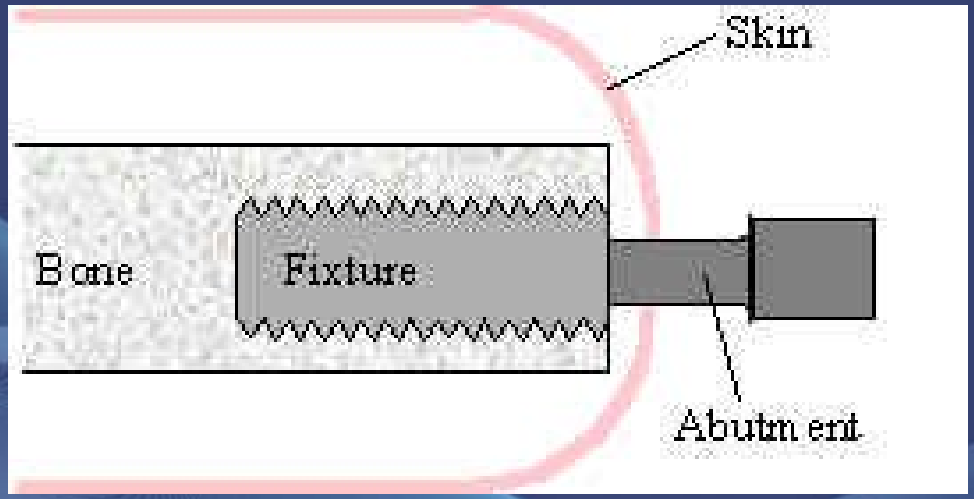
Surgically implanting a Titanium coated screw to the femur allows the bone to grow and attach itself to the screw.

An analogy of how this works is if you had a piece of nail in wood and the wood grew around the nail then it would be very difficult to remove the nail.

As Titanium is a highly biocompatible material it integrates with the bone quite easily. When tests were done using stainless steel the fixtures fell out after a few years.

The surgery for implantation is two fold, first the titanium bolt is placed in the remaining part of the femur and then the bone is allowed to heal.

Then after 6 months the abutment is added this penetrates the skin and is visible on the outside.



When drilling the bone the surgeons have to be careful not to cause the bone to heat up above 42 degrees C. As at this temperature the cells in the bone will die. This problem is overcome by drilling slowly and cooling profusely.

One of the main advantages of direct bone attachment is the fact that the muscles on the stump can control the prosthetic.

This allows for a sense of space, the person can tell when the prosthetic is in the air or when it hits the ground and can even tell the difference between carpeted floor and tile.

The direct bone attachment can be used for upper limb prosthetics too.

Research is currently being done on the use of direct bone attachment in sports.

Ossür: Running Foot

- The 'Cheetah' foot
  - designed to emulate the characteristic of the cheetah leg
- Flexible foot stores energy through elastic deformation
- Releases energy in a motion that produces a force similar to the action of the calf muscle

Marlon Shirley

- World's fastest man on prosthetics
- World Record holder
  - 100m – 11.08s
  - 200m – 22.67s
  - Long jump – 6.78m
- 6 time world champion
  - 100m and long jump
- U.S. Olympic Spirit Award
- Abandoned by his birth mother at 3, he lost his leg when he fell under a lawnmower at his orphanage at 5
- In High school he was able to compete against able bodied student successful

YouTube break

Otto Bock: C-Leg

Otto Bock: C-Leg

- Microprocessor controlled hydraulic unit
  - Dynamically adapts to all gait speeds in real time
- Complex sensory array
  - Knee position sensor
  - Strain gauges throughout the main shaft
  - Sensors sample data 50 times a second from:
    - Ankle moment above the foot
    - The knee angle
    - Speed of knee rotation
- Advantages of the constantly readjusting hydraulic control
  - loading while the knee joint is under flexion is possible
  - The device will instantaneously recognize the gait phase the user is in

Anatomy of a C-Leg

- Pyramid adapter
  - Connects to the prosthetic socket
- Electronics
  - Microprocessor performs measurements and controls processes
- Knee Angle sensor
  - Measures flexion angle and angular speed of the joint
- Hydraulic Cylinder
  - Linear hydraulic cylinder controls motion of the C-leg
  - Generates appropriate levels of movement resistance for flexion and extension during stance and swing phases
- Tube Adapter w/ Moment Sensor
  - Strain gauge measures the flexion moments in the ankle area and transmit the resulting signals to the microprocessor

C-Leg: Case Study

Andrew Lourake

Air Force Two Pilot

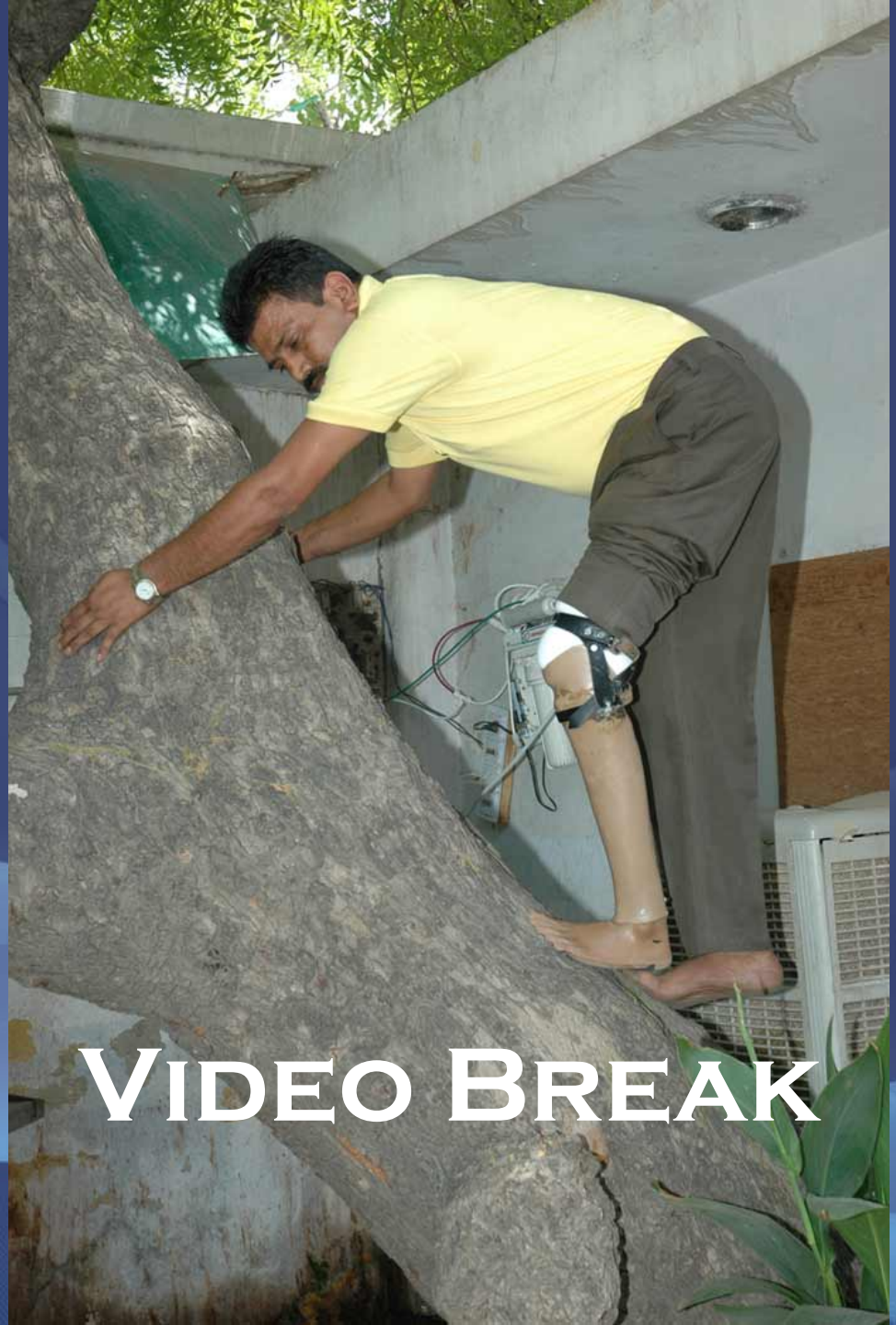
- A motorcycle accident, a broken leg, and a persistent infection. After 18 operations, only two alternatives remained; losing the leg, or losing the dream job as a US Air Force pilot.
- He was able to gain full status as an air force pilot responsible for the lives of passengers
- The C-leg allowed him to overcome the potential dangers to an amputee
  - Walking through the plane in a turbulent situation where the plane could sway and drop without warning
  - Reach the emergency exits in a crash situation

Jaipur Foot

- The Jaipur foot an organization that has developed a cost effective prosthetic for those living in poverty
- In India, it is estimated that 10 million people suffer a locomotion disability, almost all of these people live well below the poverty line
- This organization is truly amazing they work tirelessly making hundreds of prosthetics in war torn zones from Afghanistan to Rwanda

Jaipur Foot

- Very light and allows for an amazing amount of mobility
- Extremely low price: CAD $35
- The Jaipur foot allows users to run, climb trees and even pedal bicycles
- The foot is designed to be used barefoot and it emulate the reflexive properties of a regular foot
- The foot was designed by the *Indian space research organization* and is made of a polyurethane compound



Video Break

Future Innovations

Artificial Muscles in prosthetics

- Today's foot prosthetics use a spring system to return energy.
- This means that regardless of surface the stiffness of the spring remains the same.
- The prosthetic cannot adapt to changing surfaces nor to changes in the intention of the patient while walking.
- Due to these restrictions, amputees can't retrieve their original natural gait pattern.

- Tomorrow's prosthetics will use pleated pneumatic artificial muscles.
- Pneumatic artificial muscles are contractile devices operated by pressurized air.
- When inflated, they bulge, shorten and thereby generate a contraction force.
- The force depends on the applied pressure and on the muscle's length.
- Because of the one-way force a paired or antagonistic set-up is needed in order to generate a restoring force or movement.

Sources

- Lauren L. Smith, Prosthetic Limb Development: A Historical Review, Discussions, Vol. 1 2006
- Van C. Mow, Basic Orthopaedic Biomechanics and Mechano-Biology, 3rd Edition
- Joseph Hamill, Kathleen Knutzen, Biomechanical Basis of Human Movement, 2nd Edition
- James Gamble, Human Walking
- http://www.nytimes.com/packages/html/science/20061003_FOOT_GRAPHIC/index.html
- http://www.time.com/time/reports/heroes/foot.html
- http://www-personal.umich.edu/~shc/prostheses.html
- http://www.abc.net.au/science/slab/leg/default.htm
- http://lucy.vub.ac.be/publications/Daerden_Lefeber_EJMEE.pdf
- http://www.jaipurfoot.org/default.asp
- http://www.youtube.com/watch?v=gnKd-94a3Pw
- http://www.ottobock.com/cps/rde/xchg/ob_com_en/hs.xsl/1913.html
- http://www.ottobock.com/cps/rde/xchg/ob_com_en/hs.xsl/7090.html
- http://www.ossur.com/pages/2759
- http://www.ossur.com/prosthetics/feet/sprintfeet
- http://en.wikipedia.org/wiki/Knee
- http://en.wikipedia.org/wiki/Synovial_joint