PROSTHETIC AND ARTIFICIAL LIMBS

Dr. Marwan Arbilei

UOT-BME

5th Level All Brunches

Contents

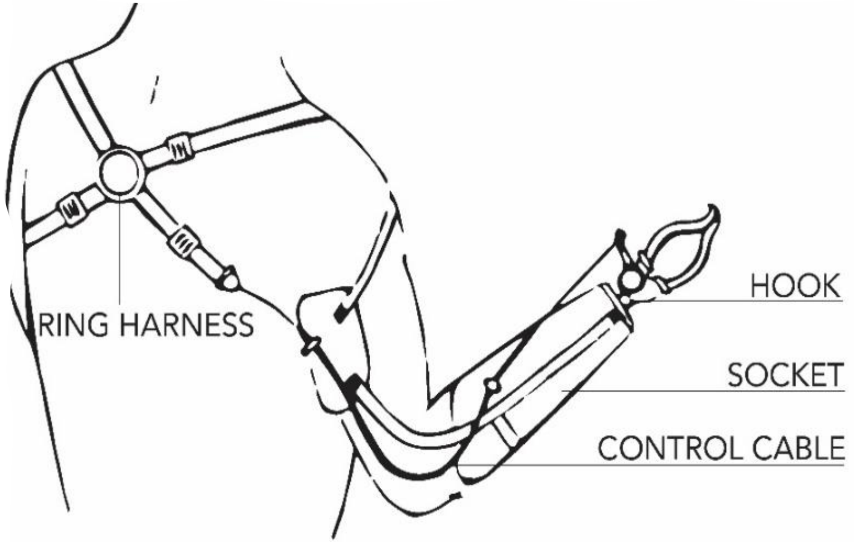
Types

Cosmetic prosthetics

- are light and cheap
- they have a very limited degree of movement and can only passively grip light objects.
- This type of prosthetics is designed for patients who wish to use their remaining limbs for all of the major functions.

Body-powered prosthetics

- allows muscles relative to the area to control the prosthetic arm through cables.
- it does allow for more degrees of freedom and allows the patient to physically feel the force.
- the body-powered prosthetic can only control one movement at a time and can quickly cause fatigue in the user.

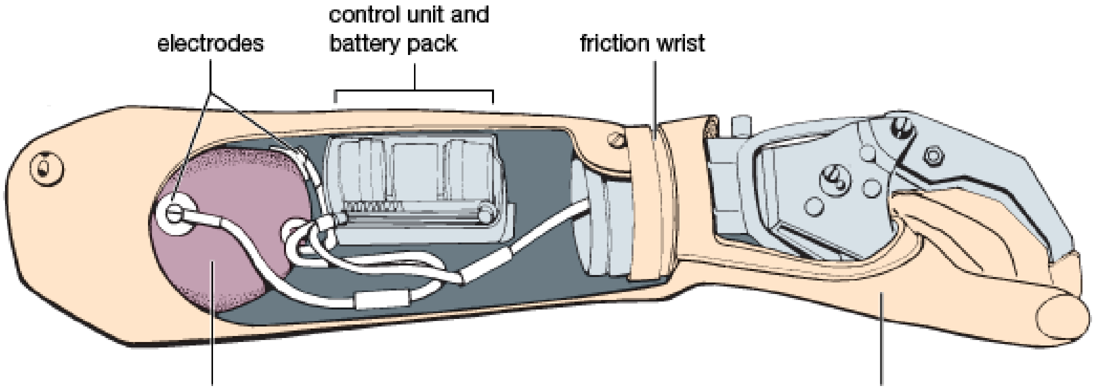


Types

Myoelectric externally powered prosthesis.

- picks up the electrical action potential in the residual muscles in the amputated limb.
- the prosthesis amplifies the signal using a battery and uses the electric signals to power the motors operating the respective part of the arm.
- myoelectric prosthesis allows for a much higher degree of freedom and does not require the patient to performed frequent strenuous muscle contractions.
- However, myoelectric prosthetics are generally heavier than the conventional types, and come at a much higher cost.

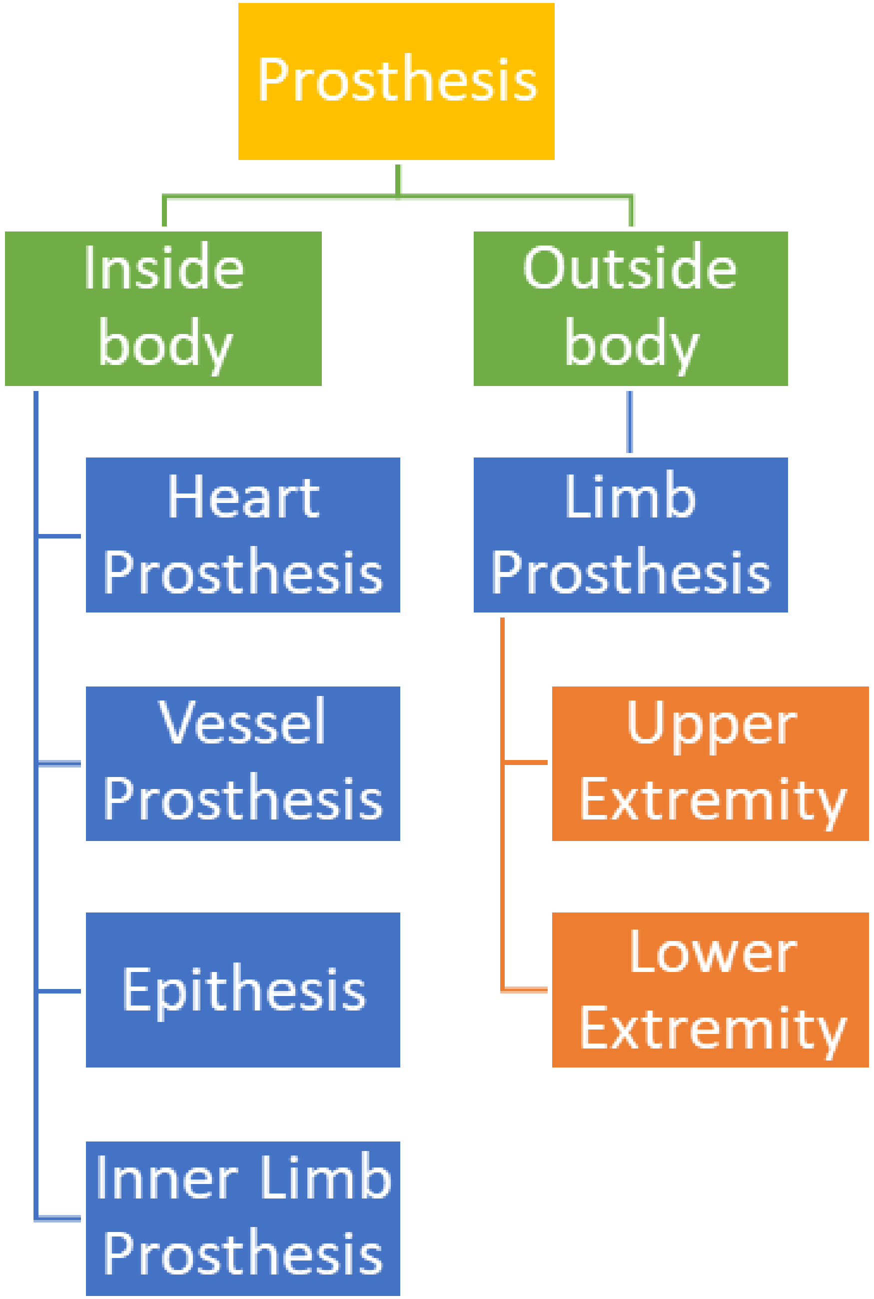
Parts of a below-elbow myoelectric prosthesis



Types based on location

Prosthetic limbs

- Trans radial (below the elbow)
- Trans humeral (above the elbow)
- Trans tibial (below the knee)
- Trans femoral (above the knee)



Designing

3 main parts of a conventional prosthetic limb

1. Pylon: Internal frame or skeleton of the prosthetic limb
   - Traditionally been formed of metal rods
   - Lighter carbon-fiber composites used in recent times

2. Socket: the portion of the prosthetic device that interfaces with the patient's limb stump or **residual limb**
   - transmits forces from the prosthetic limb to the patient's body
   - Soft linear is typically situated within the interior of the socket, to prevent irritation or damage to the skin and underlying tissues
   - Must be customized for the individual.
   - Nylon, fiberglass, Kevlar, polyesters, acrylics are commonly used materials

3. Suspension system: mechanism that attaches the prosthetic to the body

Hardness system: straps, belts, suspension cuffs or sleeves

Gel liners (with locking mechanisms)

Suction suspension

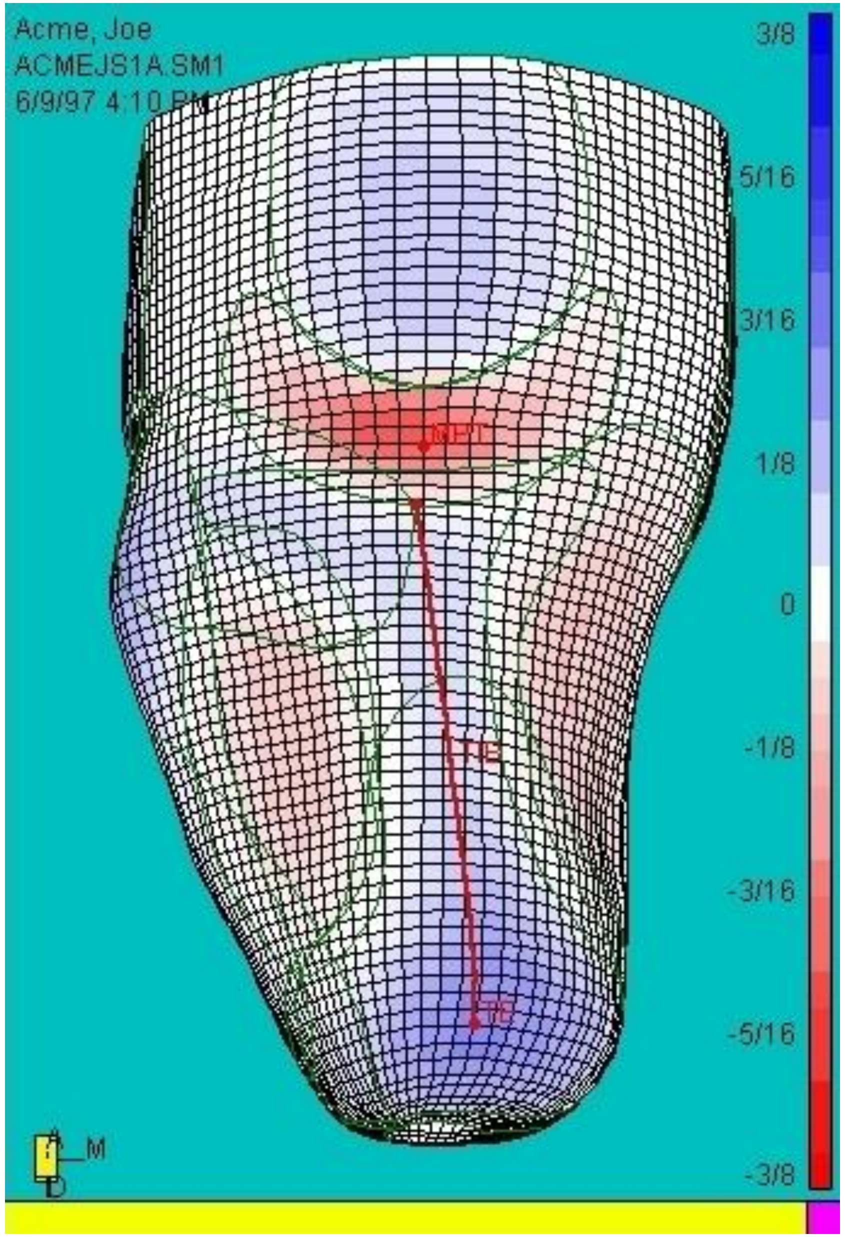
Designing

Customization

- Synthetic Skin
- Hydraulics
- High-impact exoskeleton
- Sensor
- Peripheral modification

Designing

❖ <u>3-D Modeling</u>



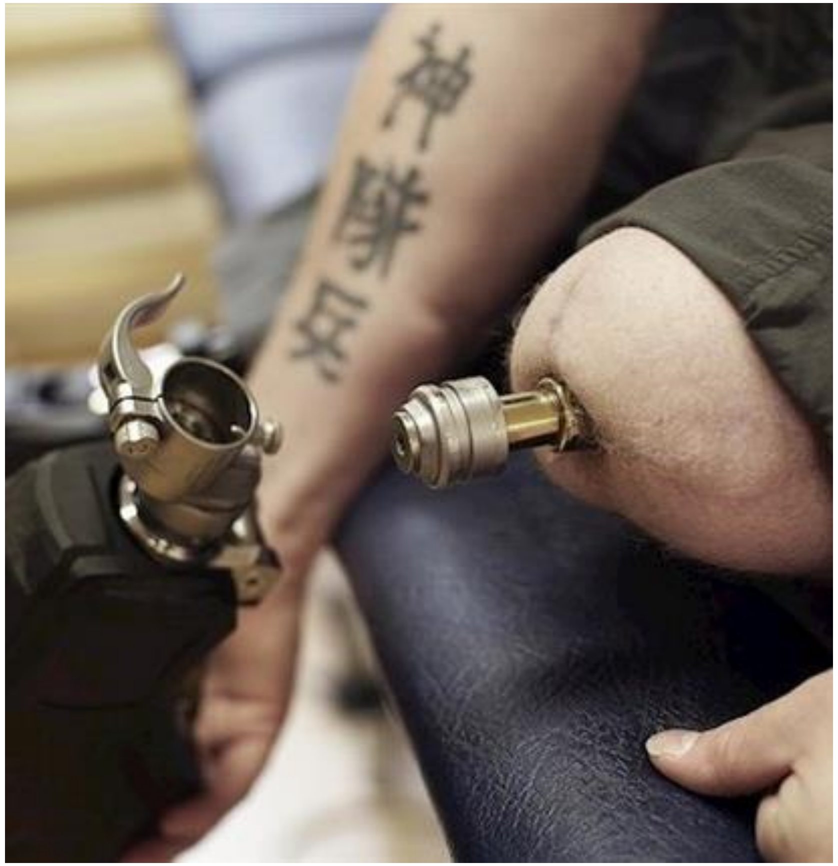
Osseointegration

- *"The direct structural and functional connection between living bone and the surface of a load-bearing artificial implant."* - Albrektsson et al. in 1981

- The implant contains pores into which osteoblasts and supporting connective tissues can migrate.

- Titanium implants have a tendency to fuse with bone
    - *Mechanism similar to bone fracture healing*

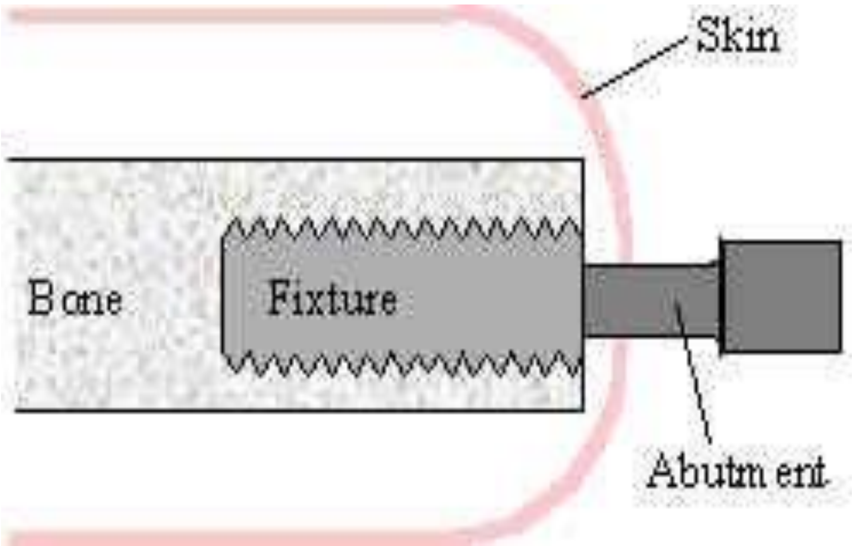
- Calcium phosphate coated implants are stabilized chemically with bone by the bonding to a cement line-like layer at the interface.



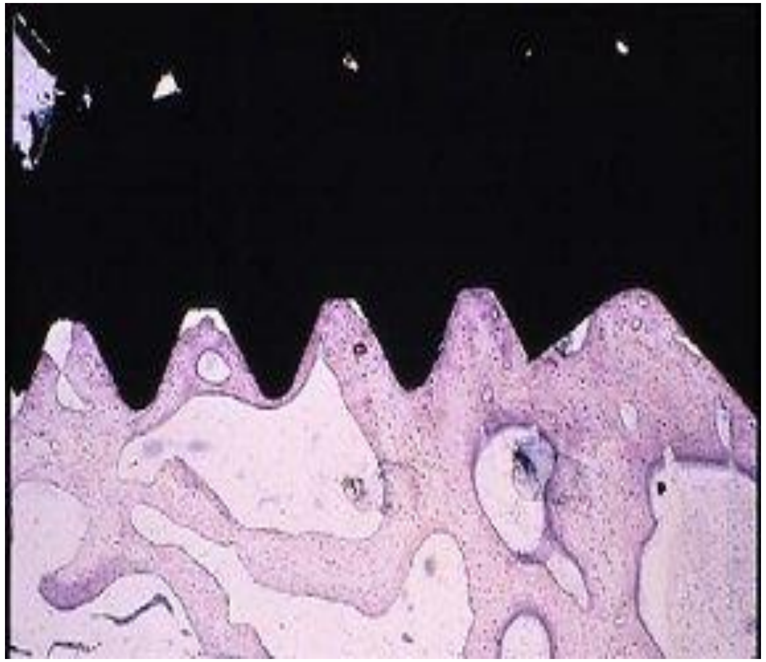
Uses Titanium implants – *biocompatible*

Less friction for soft tissues – *socket not needed*

High initial mechanical stability - *action of the screws against the bone*



The abutment is connected in the second stage surgery. With the twist of an Allen key, the limb can be attached to the abutment.

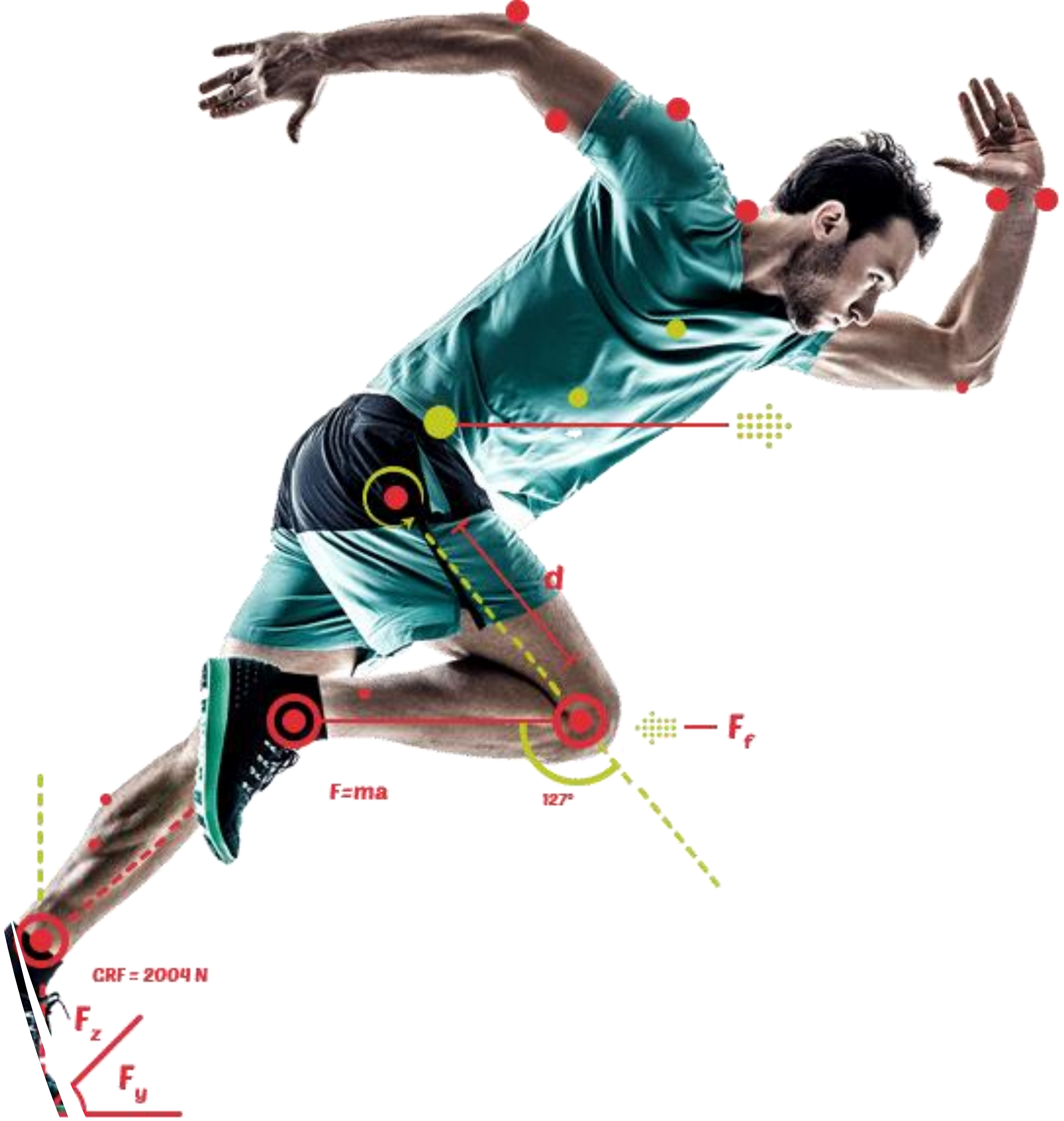


Section showing bone cells in contact with threaded titanium. (image: Prof. P.I Branemark of Gothenburg Sweden)

- Healing time is required, typically months, before full integration
- Implant failure due to prolonged adverse stimuli
- ➢ High failure rate for torsional overload
- Fibrous encapsulation due to micro-cracks

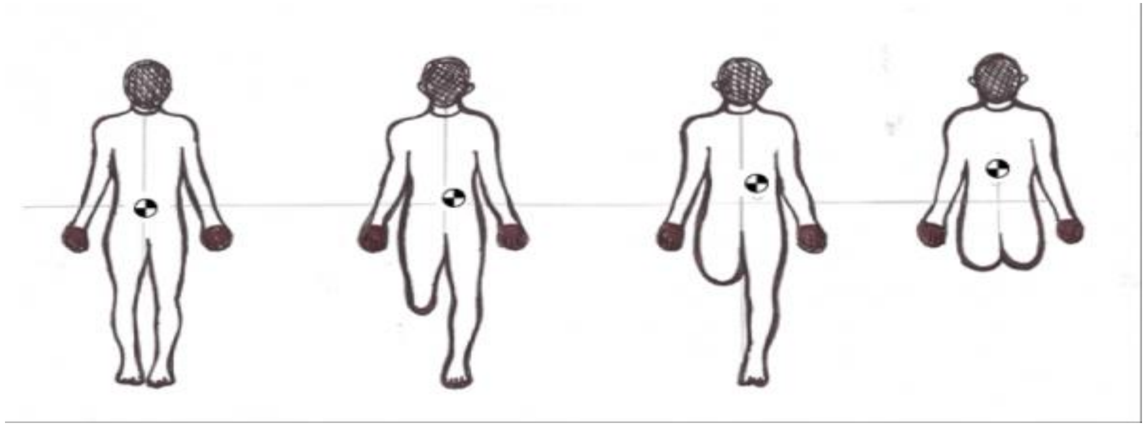
Importance in Biomechanics

- In terms of reaction forces, the effects are more pronounced on the legs than on the arms
- When analyzing general stance and locomotion, the lower limbs are obviously more involved
- Some important biomechanical aspects involve:

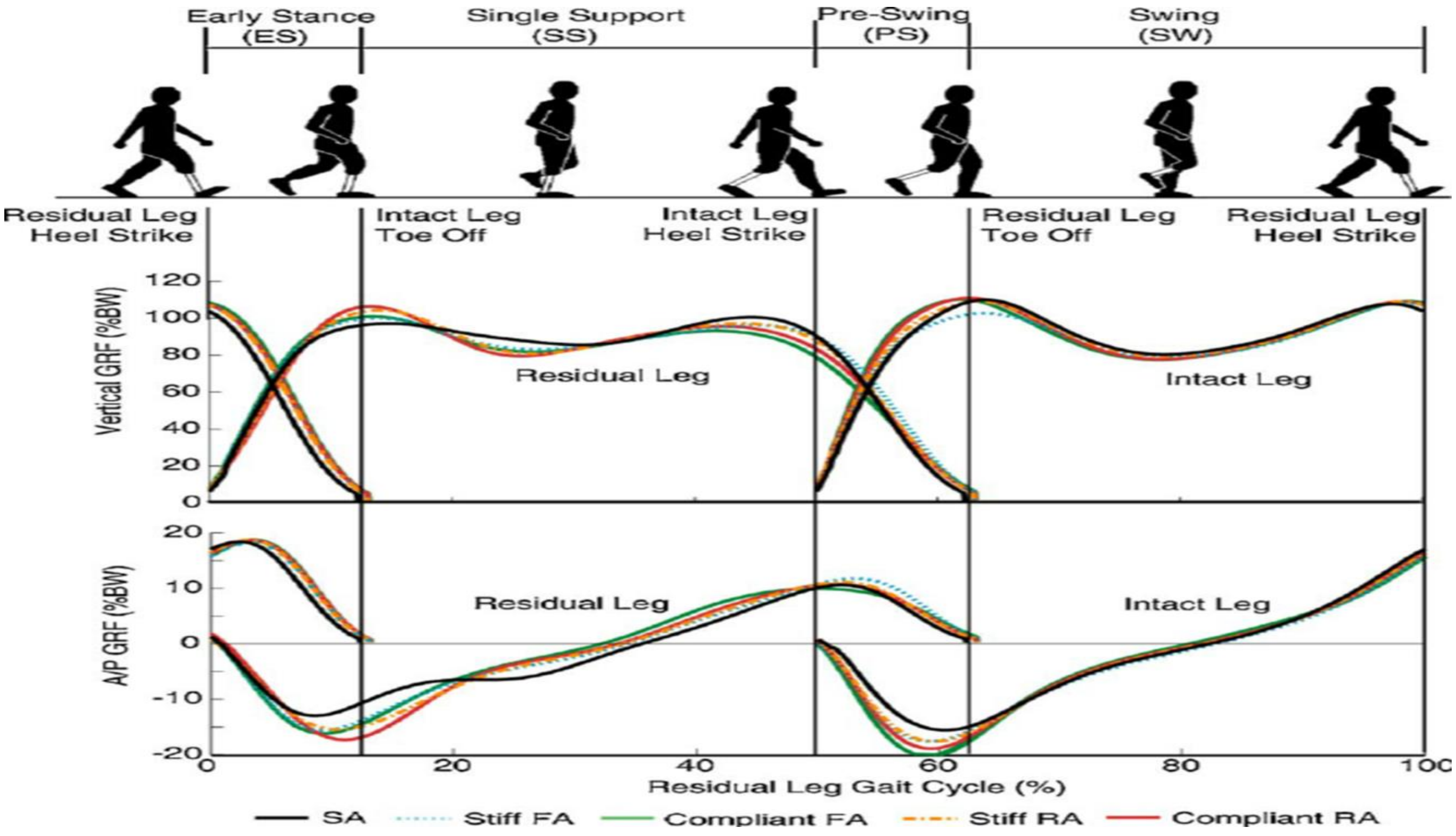


Weight Bearing

- In an amputee, because some mass is excised, the center of the mass of the person changes
- Spine needs body mass symmetry (static stability)
- At the same time, the stump needs low inertia prosthesis (dynamic stability)
- The prosthetic should be strong enough to support the body on its own, yet compliant enough to
- handle Ground Force Reactions (GFR)



Centre of mass for different amputee situations



Ground Force Reactions (GFR) during regular walking gait: intact leg vs ESAR leg

Gait Involvement

Take for example, the Langrangian equation of motion for the shank during swing phase:

$$\theta'' = -\frac{Wr}{I_0}\,[\,Y''\cos\theta + (Z'' + g)\sin\theta]$$

where,

g = Acceleration due to gravity

I_0 = Moment of inertia of the shank and foot at the centre of the knee joint about hinge axis

W = Total mass (shank + foot + variable mass M)
r = Distance of centre of gravity (of shank and foot) from the centre of the knee joint
y, z = Cartesian co-ordinates, y-horizontal, z-vertical
Y, Z = Displacements of the knee along y (forward) and z (upward) directions
Y”, Z” = Accelerations of the knee along y and z directions

θ = The flexion-extension angle of the shank with respect to the vertical, positive in anti-clockwise direction

θ” = Angular acceleration of the shank.

Gait Involvement

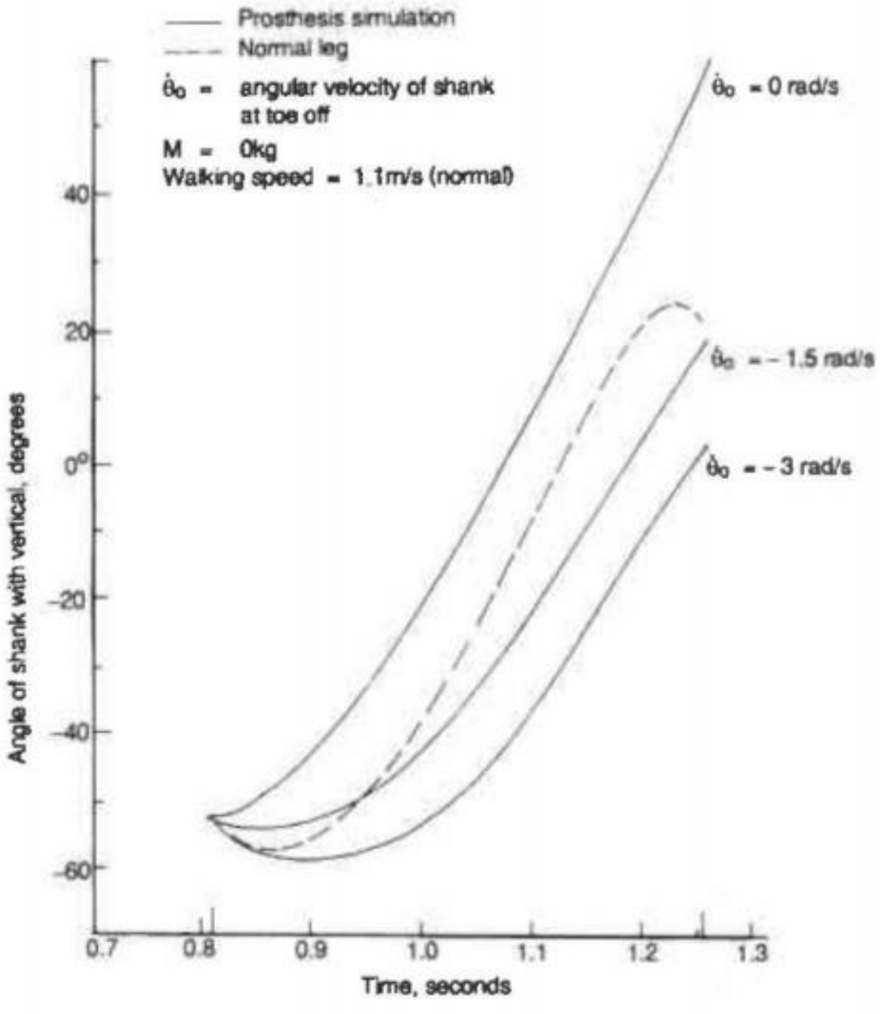


Fig. 4. Effect of position of centre of gravity of prosthesis shown by shifting the point mass M along the shank axis.

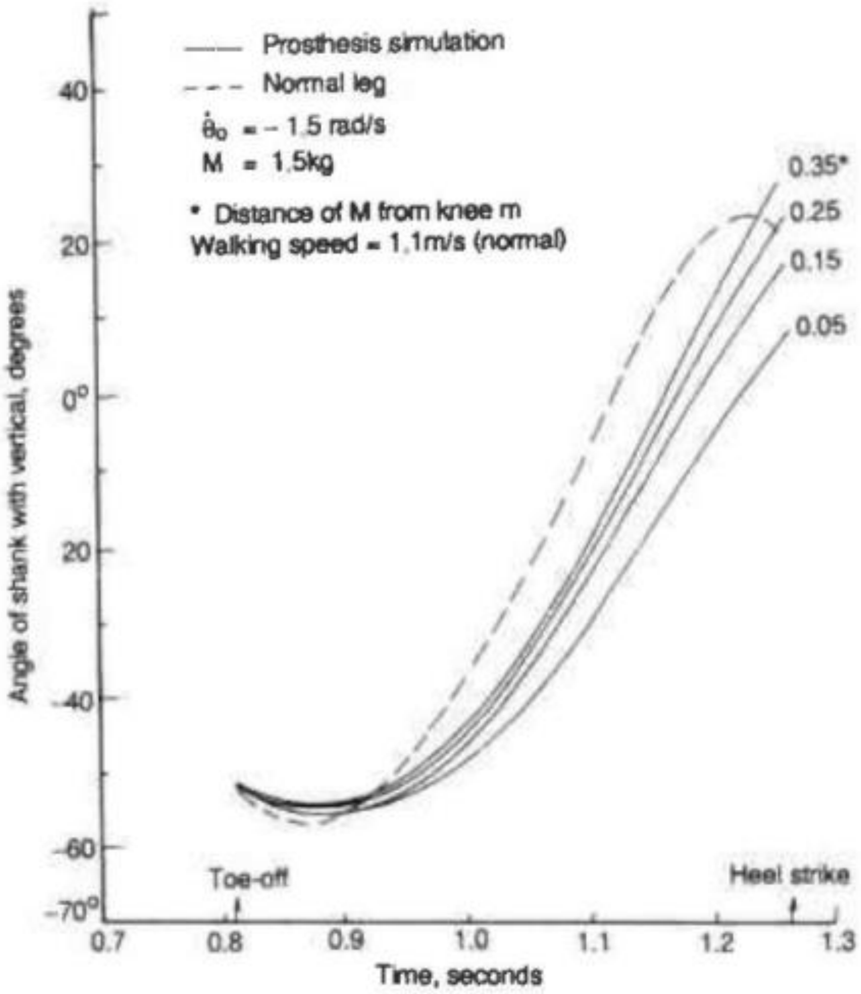


Fig. 3. Effect of angular velocity at toe-off on motion of shank.

Gait Involvement

- The shank motion is naturally very sensitive to the value of angular velocity and instantaneous values of vertical acceleration of the shank at toe-off
- <u>This is why low inertia prosthetics are desired</u>

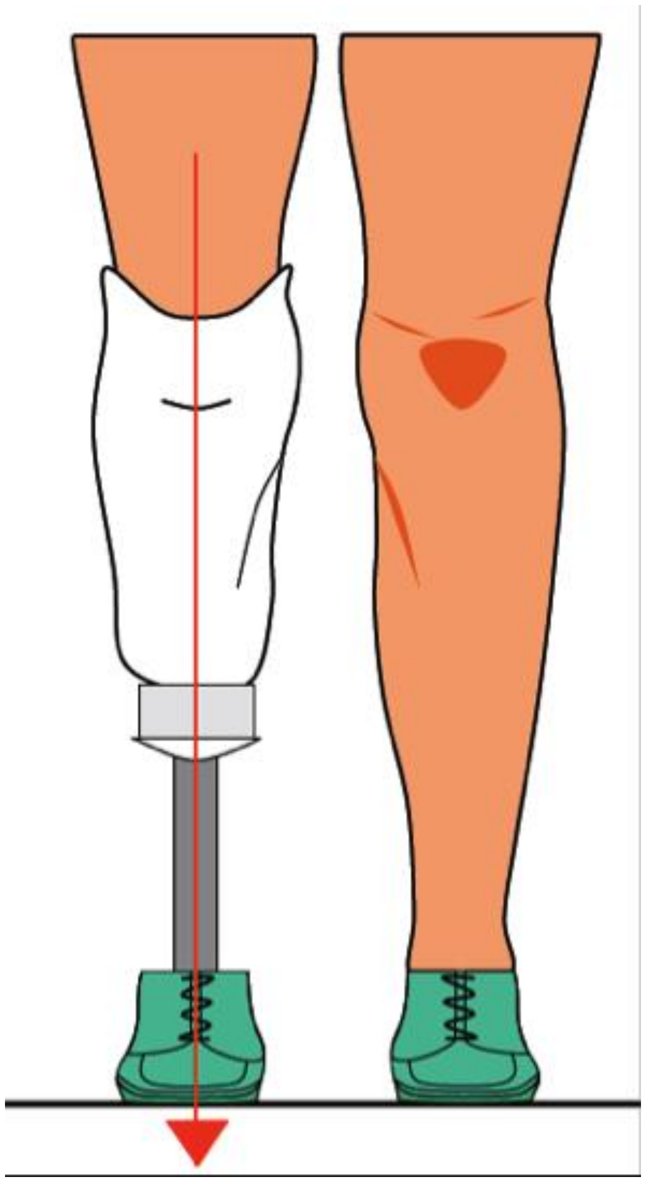
- Within these parameters, their “normal” gait can only be obtained if walking speeds are kept around 1.1 m/s to 1.2 m/s
- <u>This is why people with prosthetic limbs prefer to walk slower</u>

- Also, movement for trans tibial patients is easier than for trans femoral ones
- <u>This is because retaining the knee reduces extra metabolic cost from the hip</u>

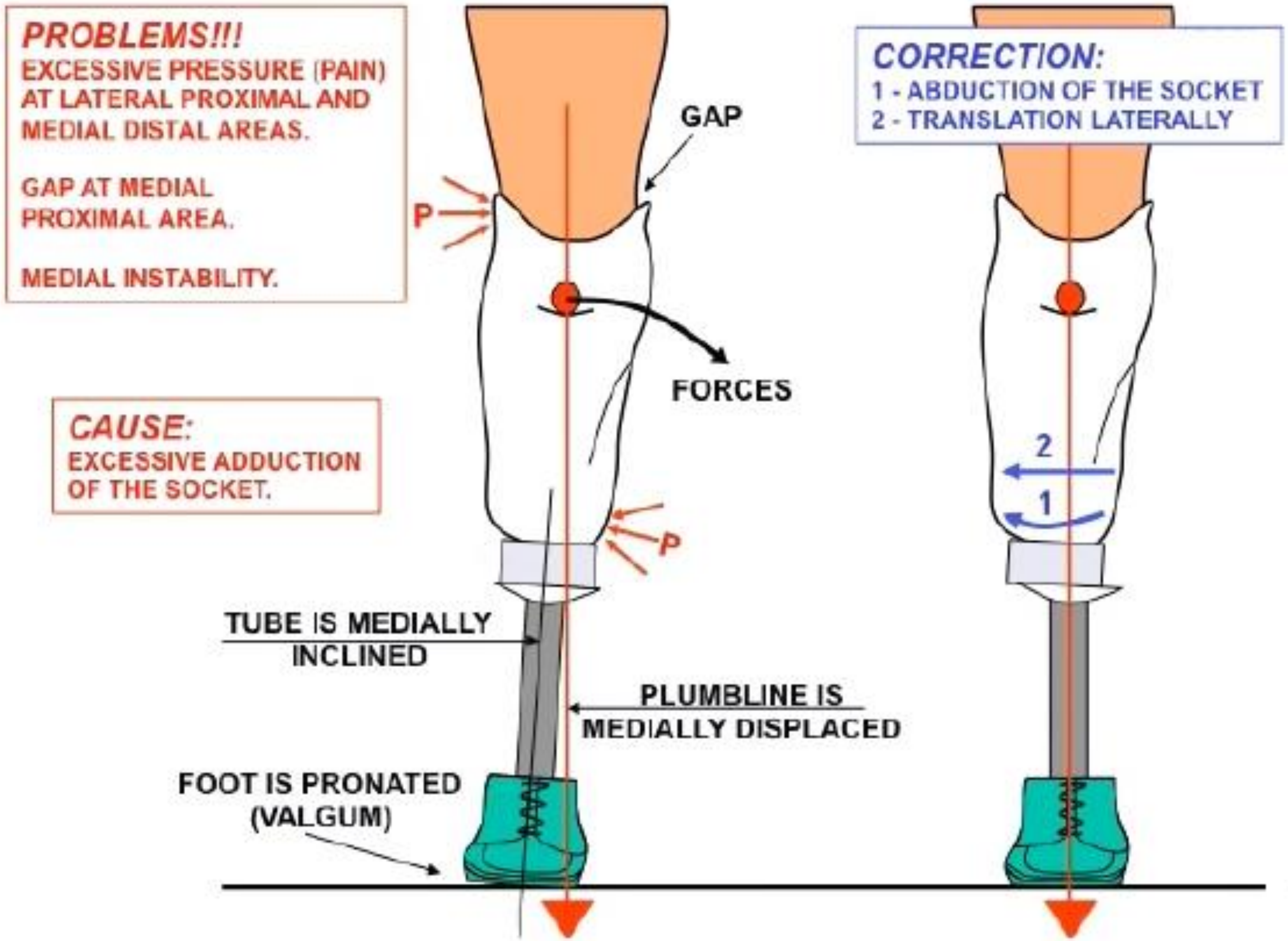
- *For a normal leg, much of the deviation is normalized by strong muscles*

Stabilization

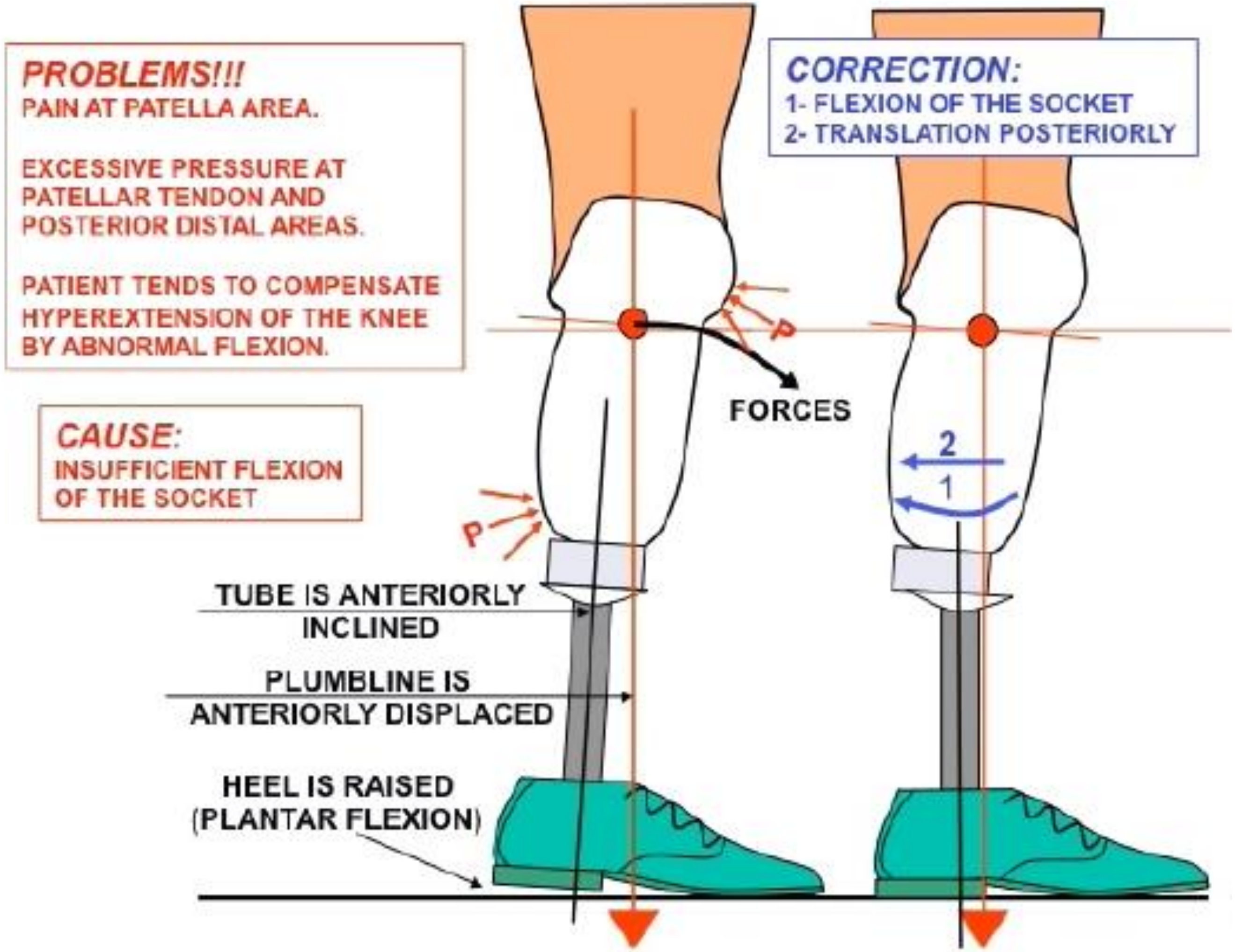
- *People with amputations have a lack of direct muscle*
- *control over some joints.*
- Stabilization from torque isn't as straightforward
- The leg bears the same weight as the other foot
- It fits comfortably
- It maintains static equilibrium
- It looks stable….



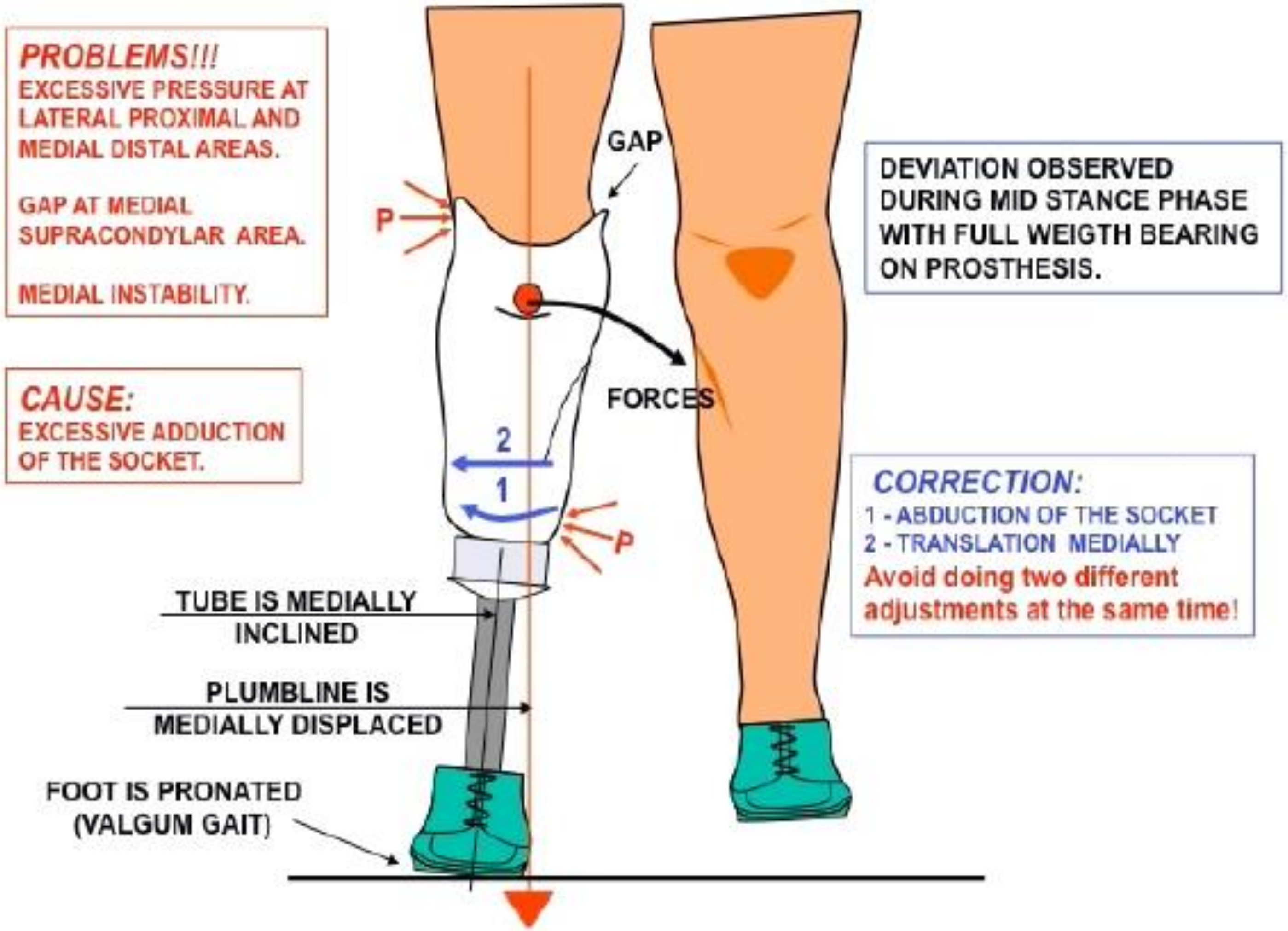
But is it ?


PROBLEMS!!!
EXCESSIVE PRESSURE (PAIN) AT LATERAL PROXIMAL AND MEDIAL DISTAL AREAS.
GAP AT MEDIAL PROXIMAL AREA.
MEDIAL INSTABILITY.
CAUSE:
EXCESSIVE ADDUCTION OF THE SOCKET.
P
GAP
FORCES
P
TUBE IS MEDIALLY INCLINED
PLUMBLINE IS MEDIALLY DISPLACED
FOOT IS PRONATED (VALGUM)
CORRECTION:
1 - ABDUCTION OF THE SOCKET
2 - TRANSLATION LATERALLY
2
1

OR

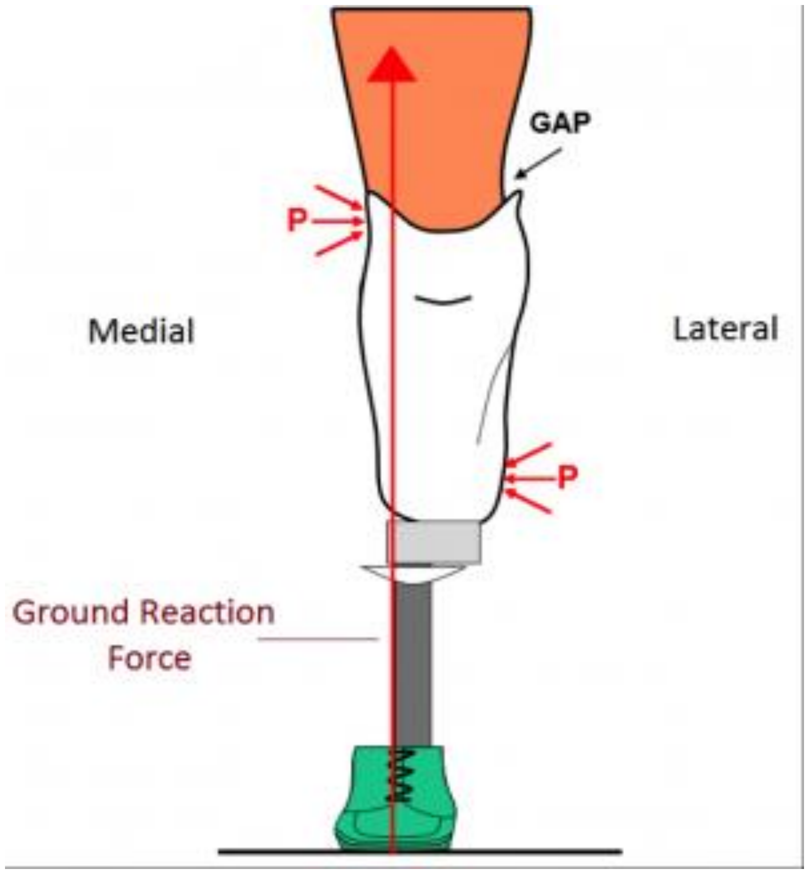

PROBLEMS!!!
PAIN AT PATELLA AREA.
EXCESSIVE PRESSURE AT PATELLAR TENDON AND POSTERIOR DISTAL AREAS.
PATIENT TENDS TO COMPENSATE HYPEREXTENSION OF THE KNEE BY ABNORMAL FLEXION.
CAUSE:
INSUFFICIENT FLEXION OF THE SOCKET
CORRECTION:
1- FLEXION OF THE SOCKET
2- TRANSLATION POSTERIORLY
P
P
FORCES
2
1
TUBE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

One more example



Therefore

- Stabilization is a challenge for prosthetists
- Designs may sometimes look eschew
- But are made to accommodate the various ‘pitfalls’
- Non-countered pressure points P are adjusted to be handled by compliant soft tissues



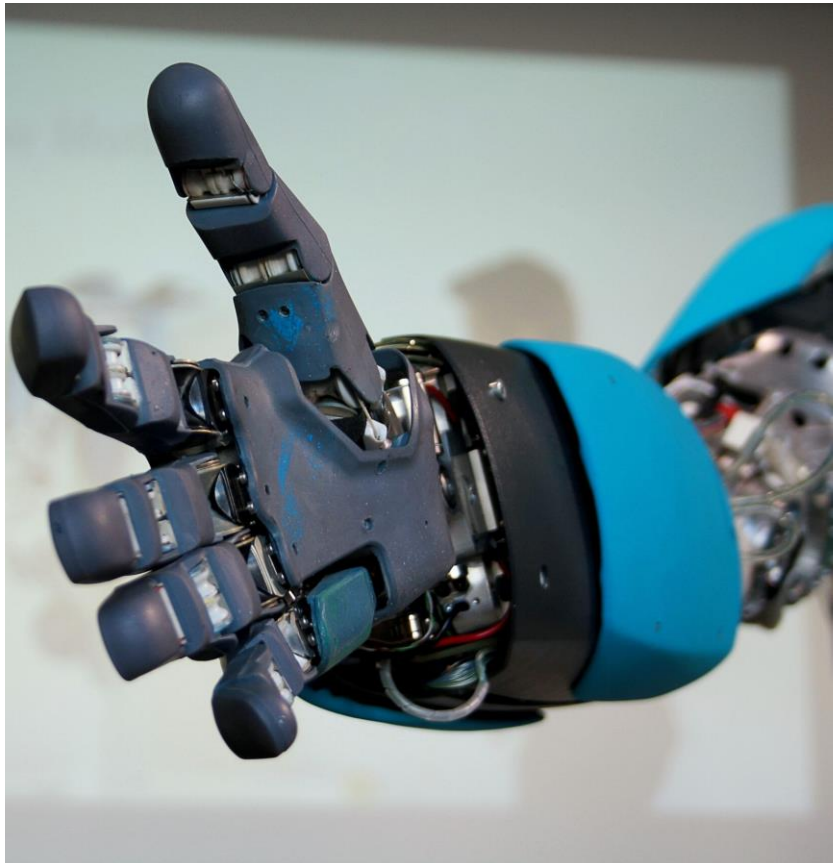
The socket torque causes pressure in specific parts of the prosthetic socket in a predictable way. This torque is resisted by soft tissue compression

Bionics

- In medicine, bionics means the replacement or enhancement of organs or other body parts by mechanical versions

- Bionic implants differ from mere prostheses by mimicking the original function very closely, or even surpassing it

➢ *Bionics are "smart prosthetics"*



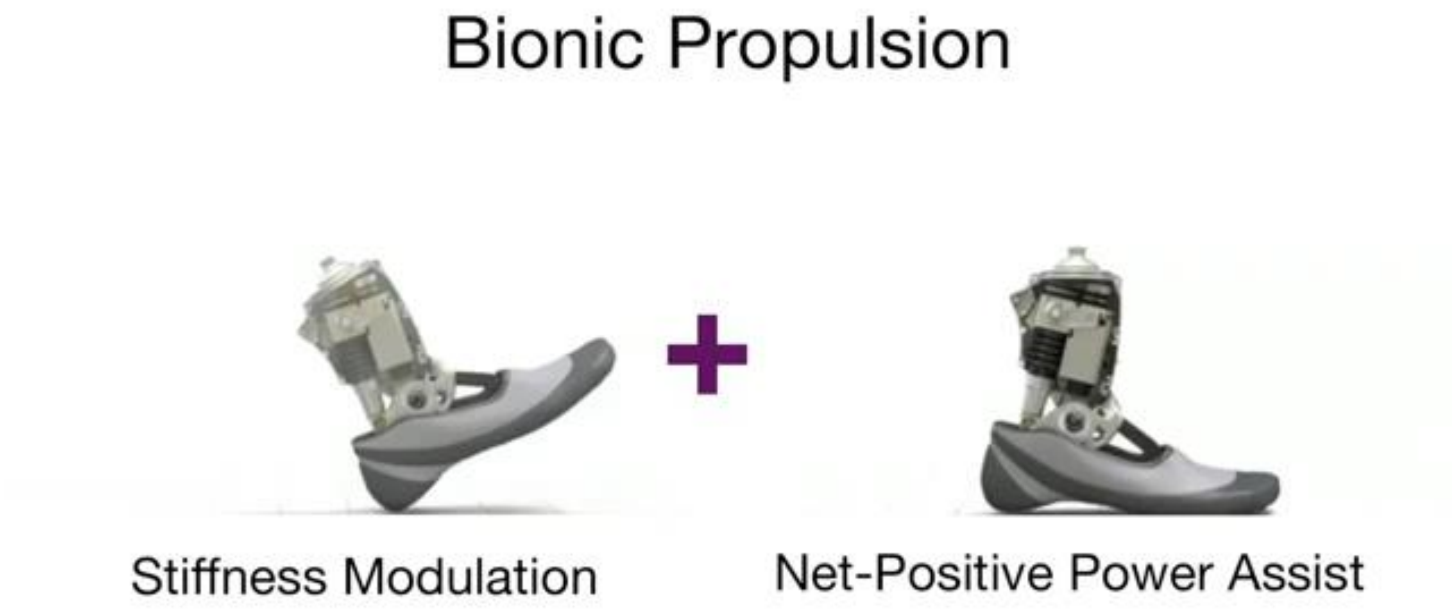
Interfacing

- **Mechanical**: *How they are attached to the body*
  - Stiffness-wise the attachment has to mirror the body tissues
  - Use of synthetic skin and tissues might remedy this need
  - Electrostatics effect on stiffness is under research

2. Dynamic

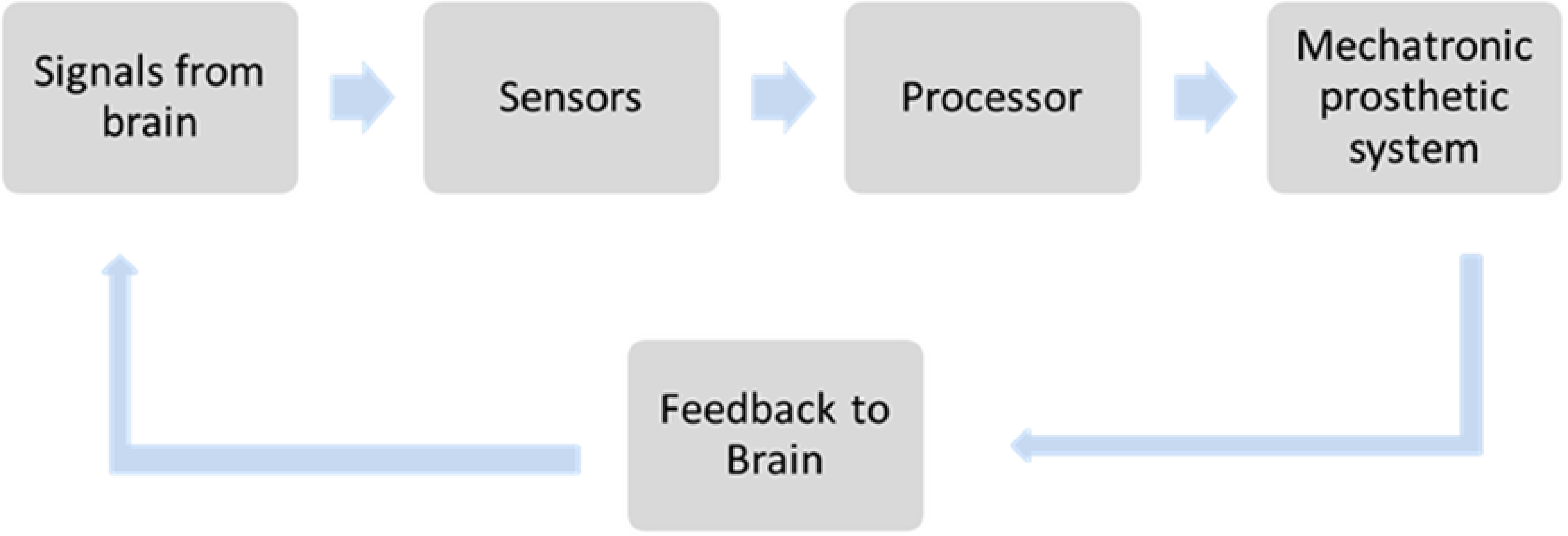
- *How they move like flesh and bone*
  - Passive prosthetics work well only to absorb shock, but have limited movement
  - Bionic ones seek to accommodate for the releasing energy as well
  - They provide more fluid motion and at the same time reduce fatigue

- *<animation>*



3. **Electrical**: *How they communicate with the nervous system*

- Movements are based on impulses during reflexes
- Sensors and microchips are modulated according to neural command



- Relaxation of residual limb → little power and torque on bionic limb
- Increased muscle power → increased torque
- Sensors from the bionics may send not only mechanical feedback but also sensory ones

Comparison: Bonics Vs Passive Prosthetic

Prosthesis Today

Prosthesis Today

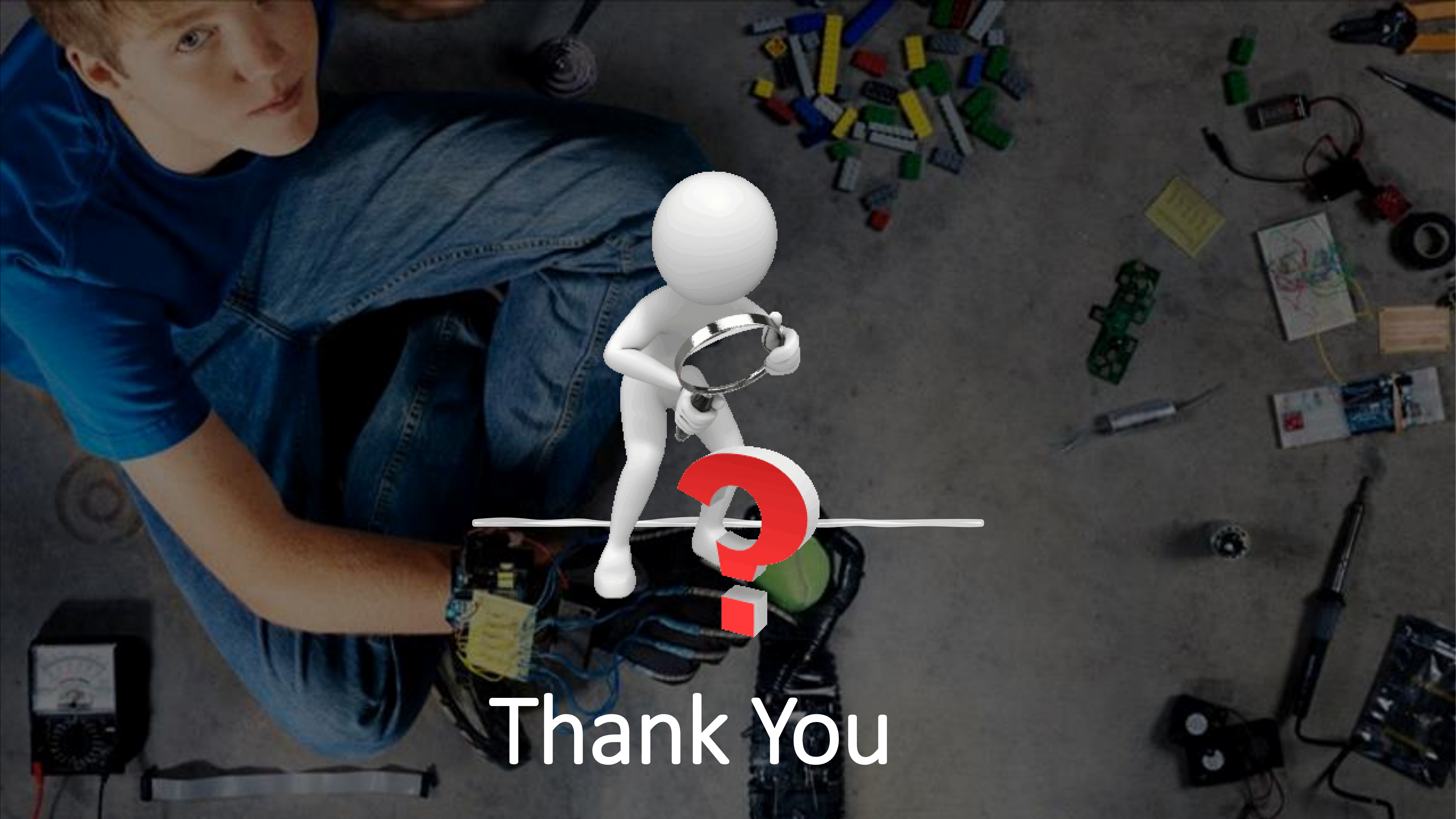
Hugh Herr, climbing with his prostheses. He can lengthen them, to give him a much greater reach than an ordinary human being. Photograph: / Andrew Kornylak/Aurora Photos/

General Limitations

- Difficulty in mass production
- Cost (customization + surgery)
- Comparative Inadaptability during movement
- ‘Overuse Syndrome’ on the intact limb
- No healing of artificial limb
- Limited warranty (~2-3 years by most companies)
- *They are also louder*

Future Alternatives and Research

- Limb Transplant
- Tissue Engineering
- 3-D Printing
- Stumble Recovery
- Sensory Feedback
- Robotic Limbs
- Thought-controlled Prosthetics


Thank You