H-L-2

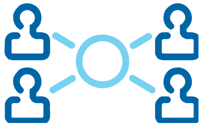
Introduction to Biomechanics

Prof. Dr. ir. Richard Goossens
Dr. Y. Song (Wolf)
Faculty of Industrial Design Engineering
Delft University of Technology

Aim

- **Knowledge** — To develop a basic understanding of biomechanics and its applications in product designs

- **Insight** — To demonstrate that such a system might be modeled so as to provide useful data for designs



- **Communication** — To communicate with experts in their professional languages

Contents

- Biomechanics & Design
- Musculoskeletal system
- Body mass segments
- Case study in biomechanics
- Models of human perception

Biomechanics

Biomechanics

Biomechanics is the study of the structure and function of biological systems by means of the methods of mechanics.

- Humans
- Animals
- Plants
- Organs and
- Cells

Biomechanics contributes to industrial design

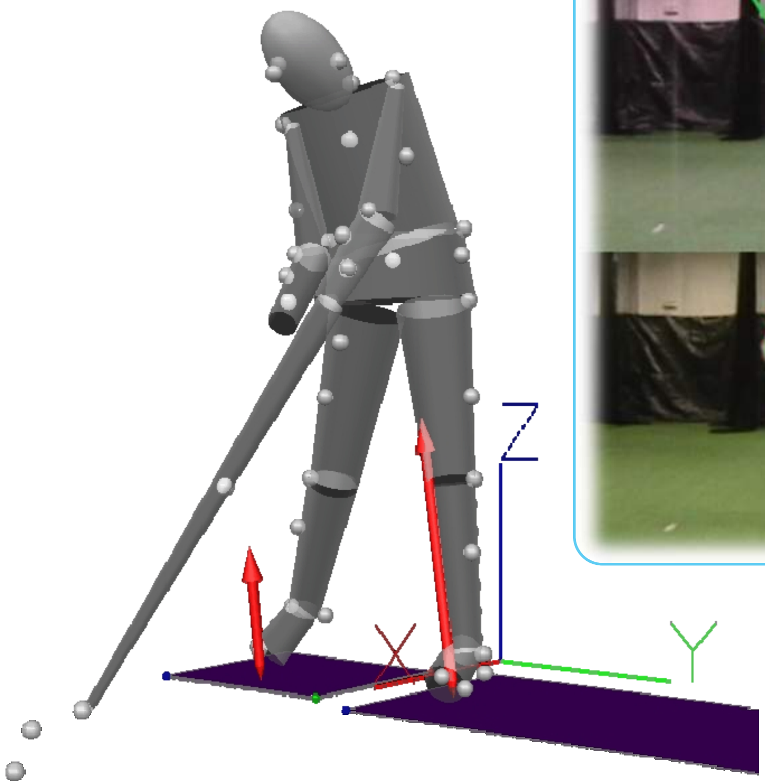
Medisign, TUDelft

Ergonomics office chair

Vacuum gripper for surgeons,
By Durandus Vonck, TUDelft

Courtesy of http://mdmpr.com/blog/open-day-at-the-ast-physiotherapy-rehabilitation-centre/, http://www.ergonomics.co.uk/bma_ergonomic_chairs.html

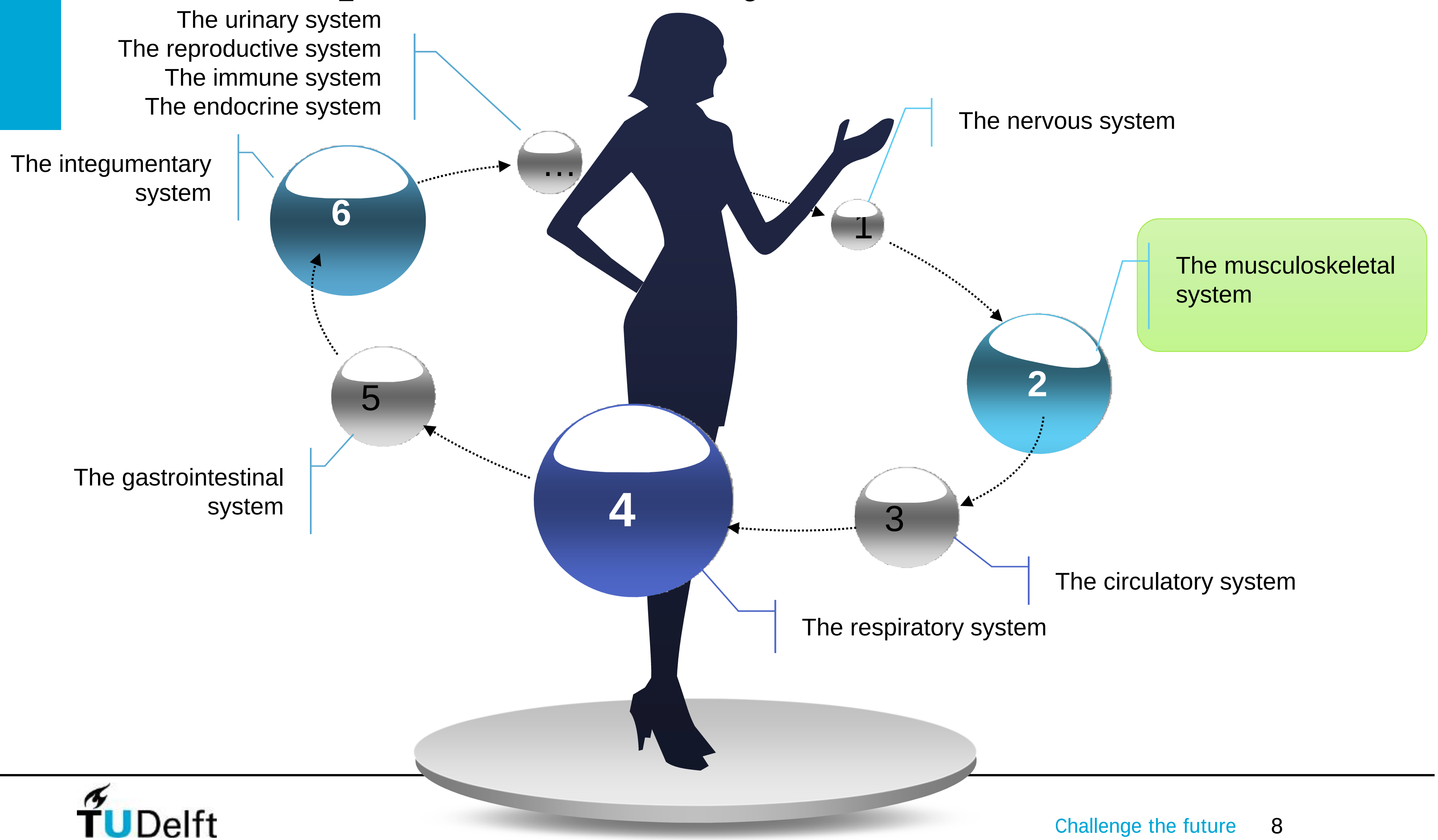
Improving performance from both equipment and user point of views



Courtesy of http://www.ecu.edu/cs-hhp/exss/SMotion.cfm

Understanding ourselves

Repeat: Human systems



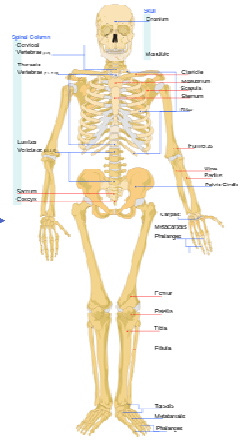
Anatomy of musculoskeletal system
Skeletal system

Musculoskeletal system

Musculoskeletal system

A musculoskeletal system is

a system that gives animals and humans the ability to move using the muscular and skeletal systems.



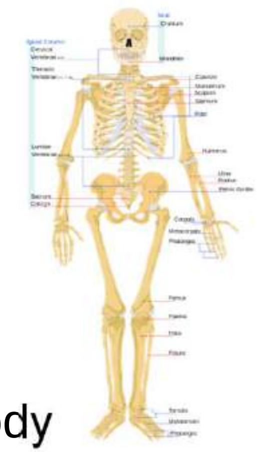
It provides the

- Form
- Support
- Stability and
- Movement

to the body

Courtesy of http://en.wikipedia.org/wiki/Human_musculoskeletal_system

The Skeletal System



The Skeletal System

Bones – skeleton

Joints

Cartilages

Ligaments - bone to bone

Tendon - bone to muscle

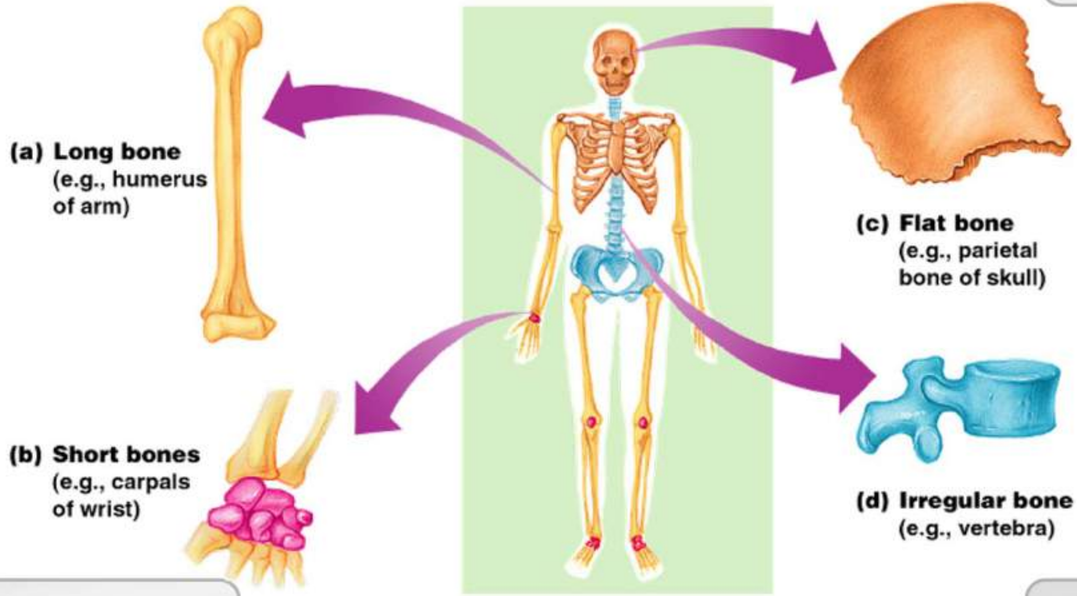
- Support of the body
- Protection of soft organs
- Movement due to attached skeletal muscles
- Storage of minerals and fats
- Blood cell formation

Courtesy of Essentials Of Human Anatomy Physiology 8th Edition, Pearson Education, Inc. publishing as Benjamin Cummings

Classification of Bones on the Basis of Shape

Bones are longer than they are wide (arms, legs)

Flat , curved (skull, Sternum)



Usually square in shape, cube like (wrist, ankle)

Irregular- odd shapes (vertebrae, pelvis)

Bones of the Human Body

206

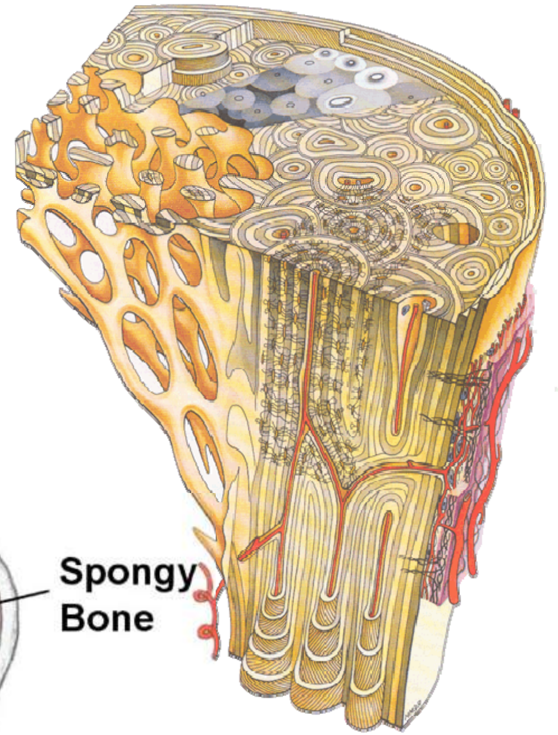
The skeleton has 206 bones

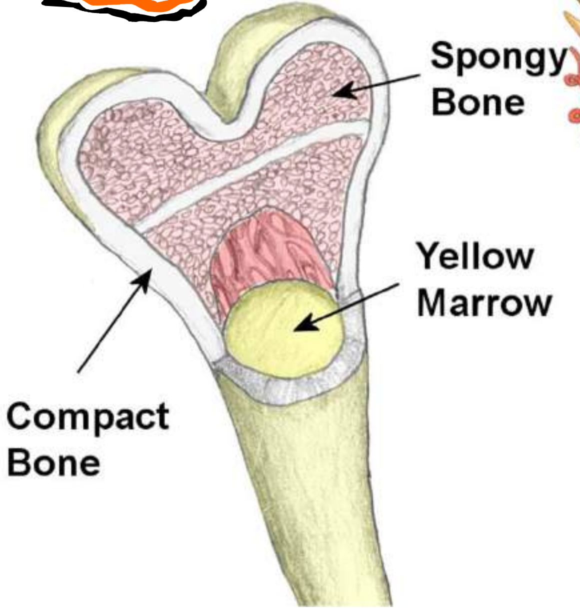
2

Two basic types of bone tissue

Compact bone
- Homogeneous

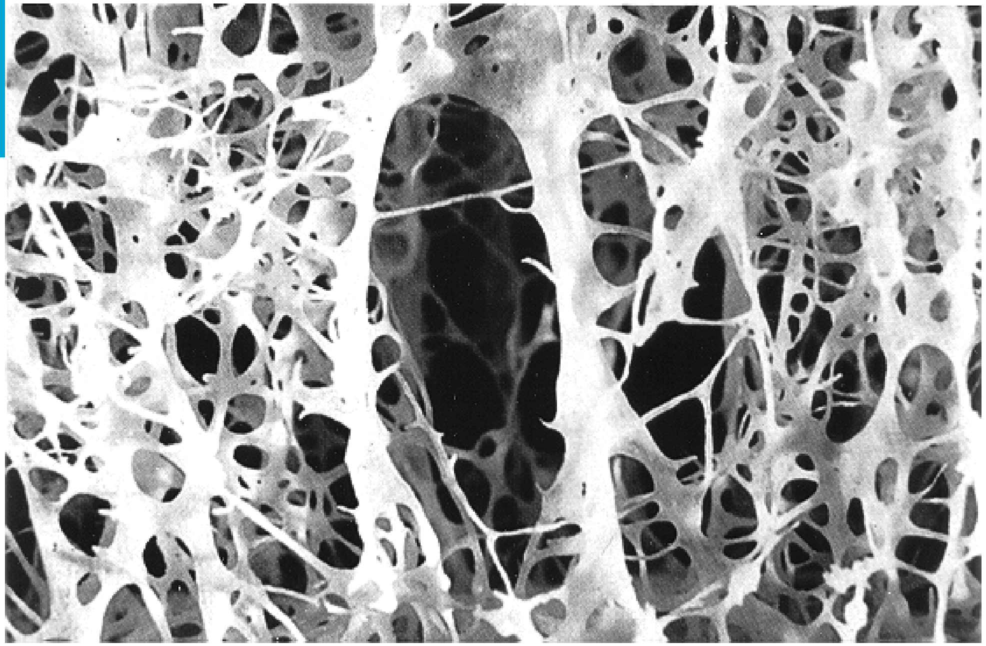
Spongy bone
- Small needle-like pieces of bone
- Many open spaces



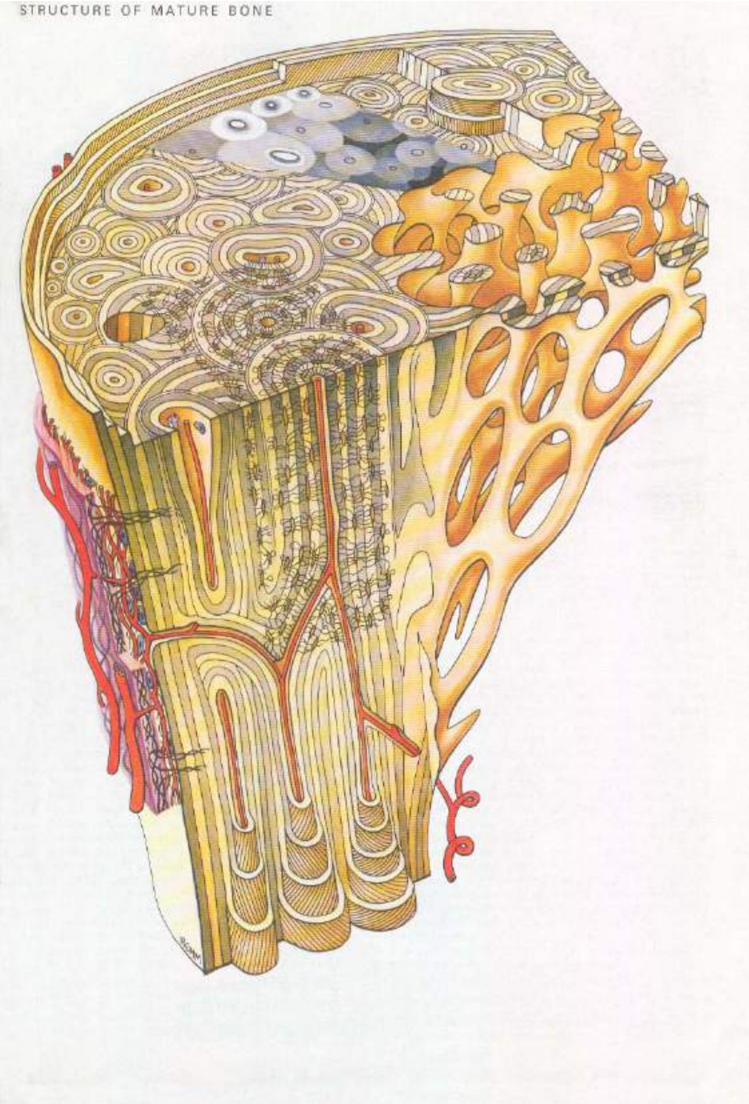


Courtesy of http://www.teachpe.com/anatomy/bone_structure.php

Spongy bone

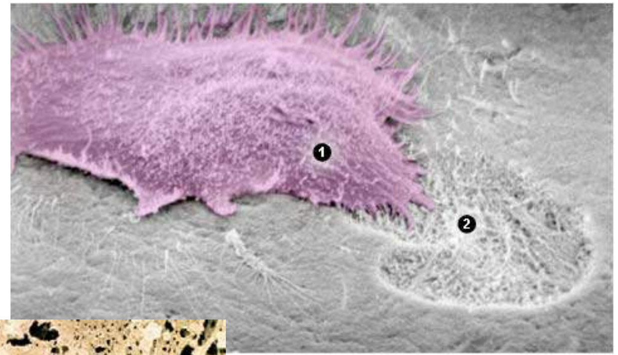


Inside bones



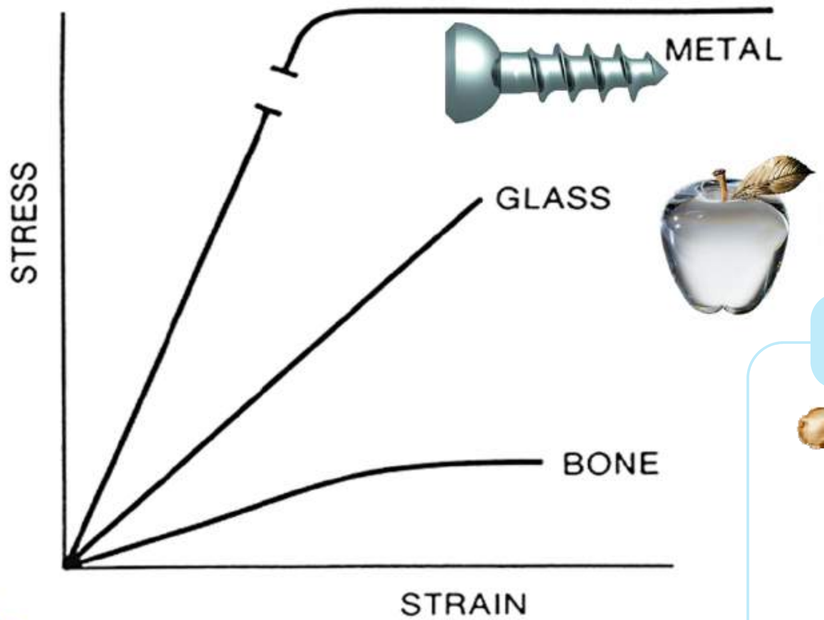
- Osteocytes

- Osteoclasts
- Osteoblasts

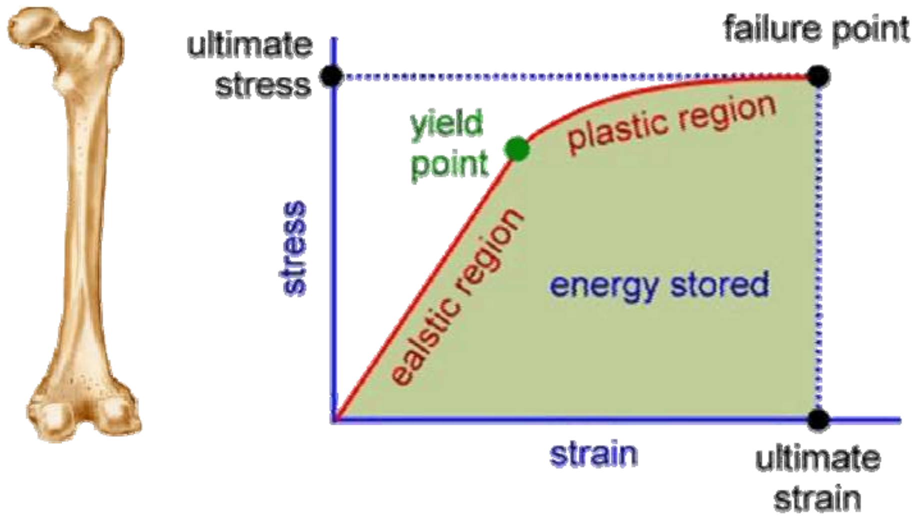


Mechanical properties of bones

Comparing to other materials

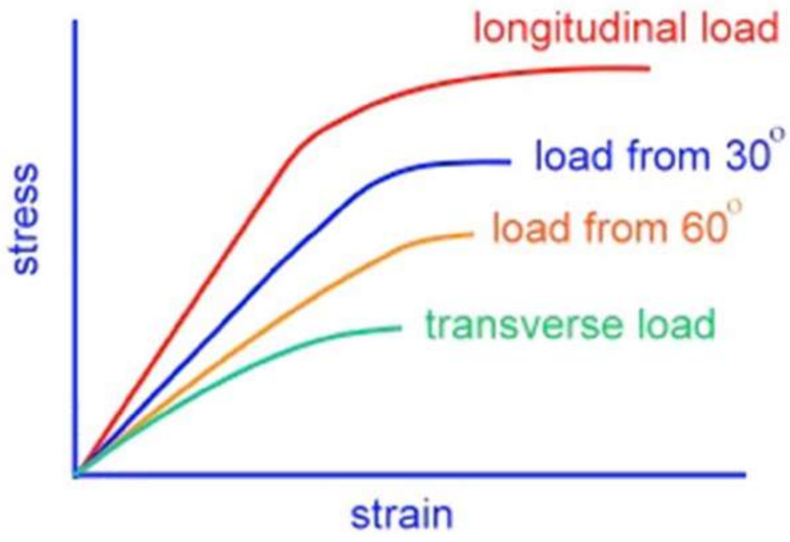


Stress-strain curve of the bone

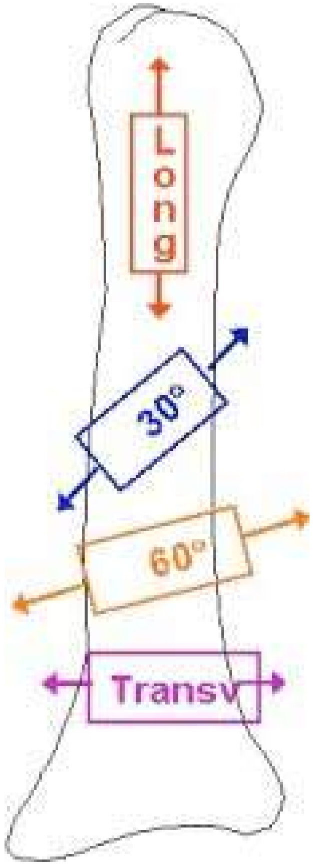


Courtesy of http://trendsupdates.com/golden-apple-by-steuben-glass-a-perfect-gift-for-christmas/, http://www.ztmedic.com/Content.aspx?news_prop=C200&id=31159

Anisotropic behavior of bone

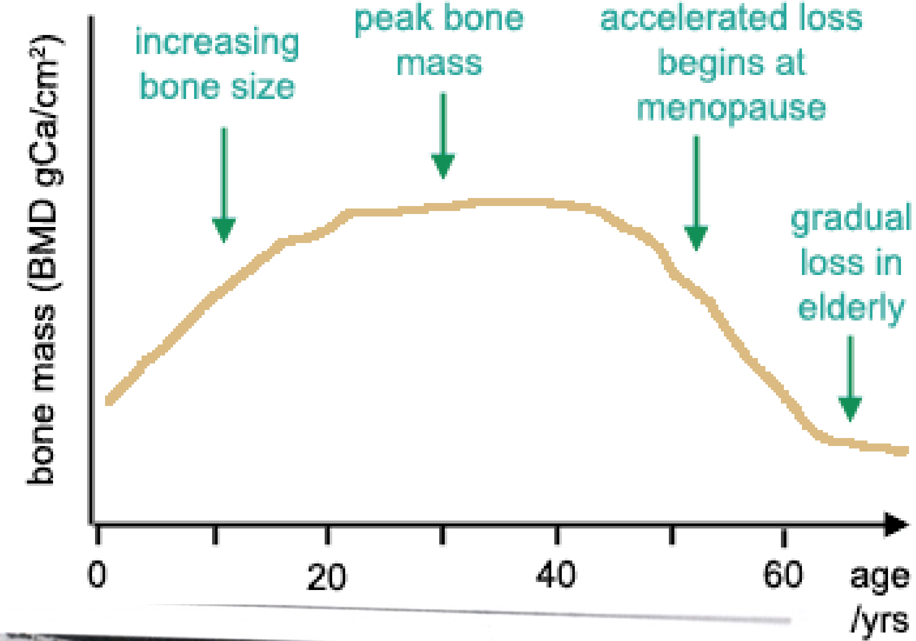


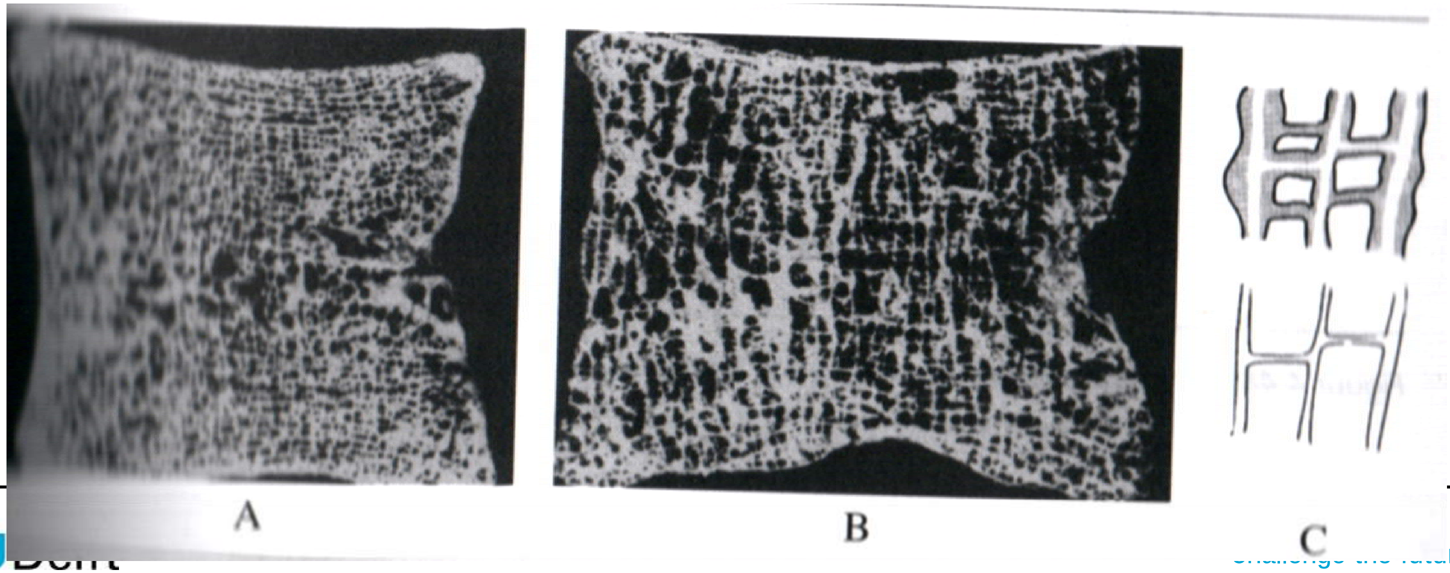
Anisotropic Behavior of the Bone



Some other aspects of bone

❖ Ageing





Bone fracture

Bone fracture is a break in a bone

Closed (simple) fracture

– break that does not penetrate the skin

Open (compound) fracture

– broken bone penetrates through the skin

Possible treatments

- **Conservative**
- **Surgical**

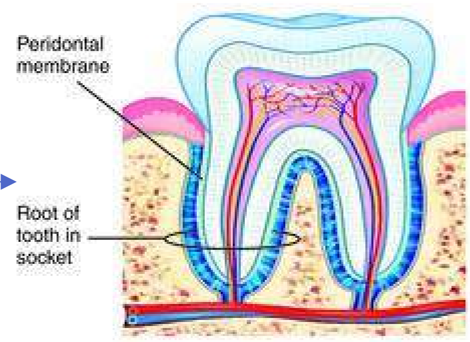
Courtesy of https://en.wikipedia.org/wiki/Bone_fracture

Joints – Anatomy

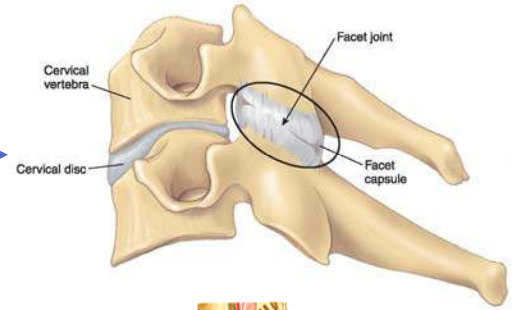
Joints

A joint, or articulation, is the place where two bones come together.

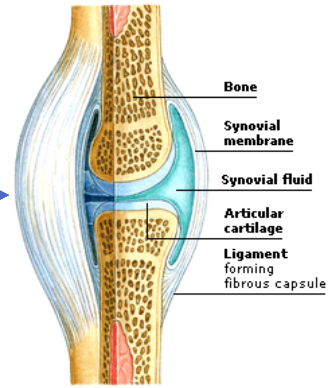
Fibrous – immovable:
- connect bones, no movement. (skull and pelvis).



Cartilaginous – slightly movable:
- bones are attached by cartilage, a little movement (spine or ribs).



Synovial – freely movable;
- Much more movement than cartilaginous joints. Cavities between bones are filled with synovial fluid. This fluid helps lubricate and protect the bones.

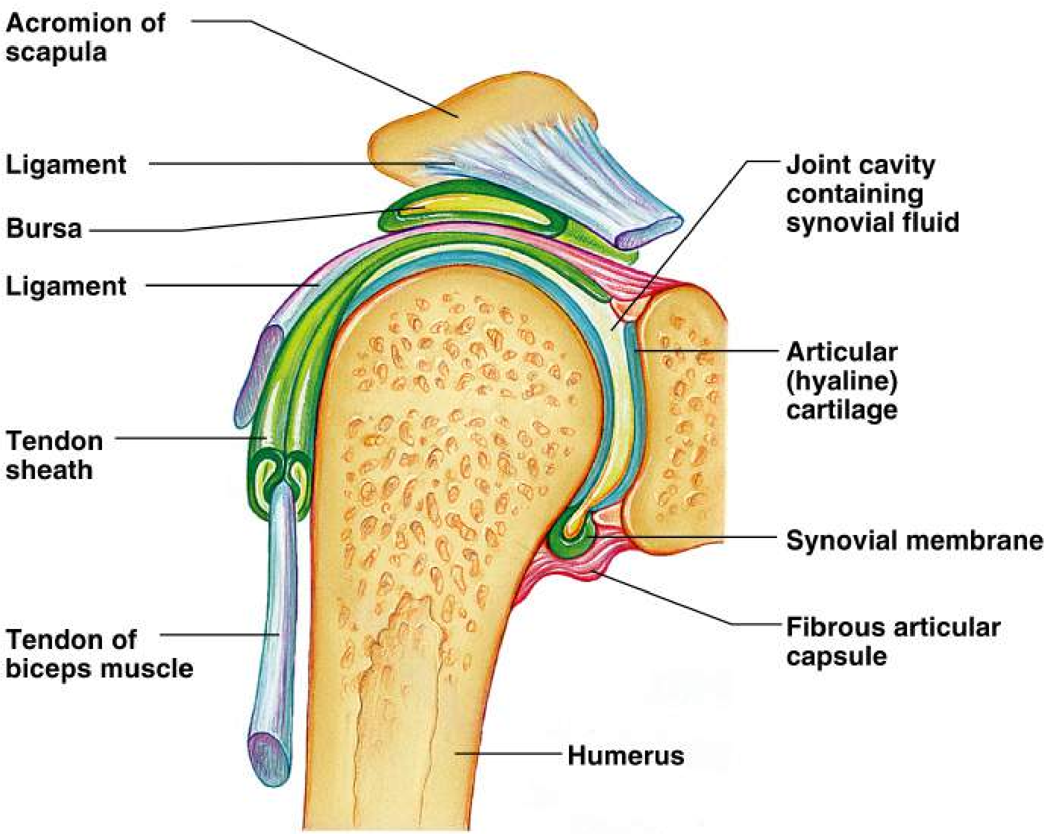


Courtesy of http://medical-dictionary.thefreedictionary.com/gomphoses, http://rozeklaw.com/wp-content/uploads/2013/03/facet-joint.jpg; http://www.m-a-i.in/joints.html

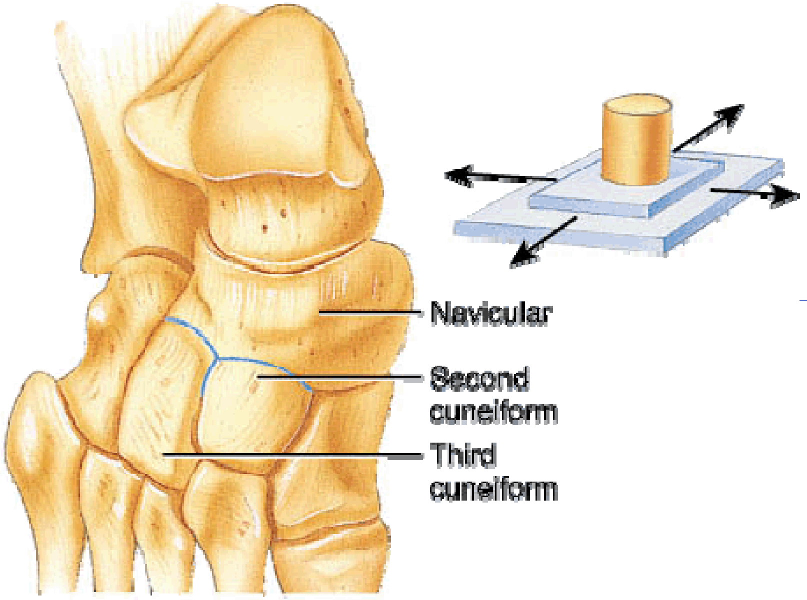
Inside the Synovial Joint

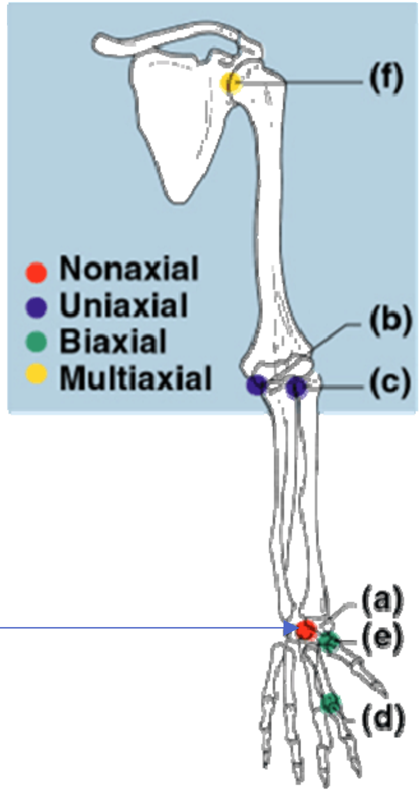
The Synovial Joint

The most common and most movable type of joint in the body of a mammal. As with most other joints, synovial joints achieve movement at the point of contact of the articulating bones.



Types of Synovial Joints



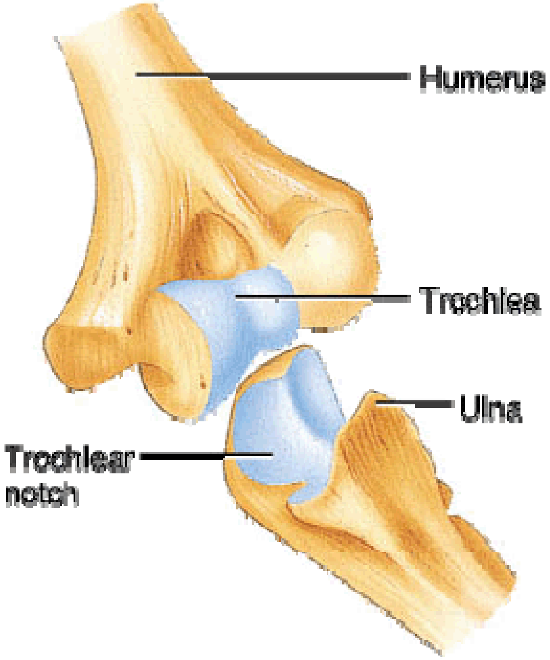


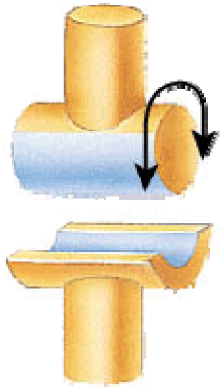
A: Plane joint

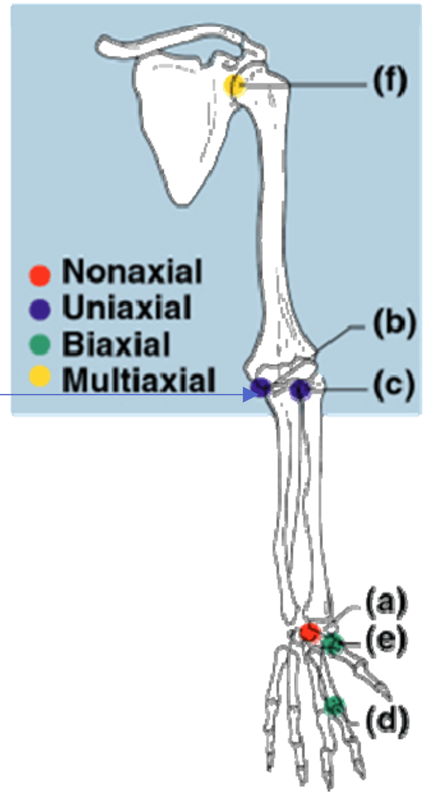
1. Nonaxial joint
2. Allows only gliding movement
3. Example: wrists, ankles, etc.

Courtesy of http://classroom.sdmesa.edu/eschmid/Chapter7-Zoo145.htm, **http://en.wikipedia.org/wiki/Plane_joint**

Types of Synovial Joints



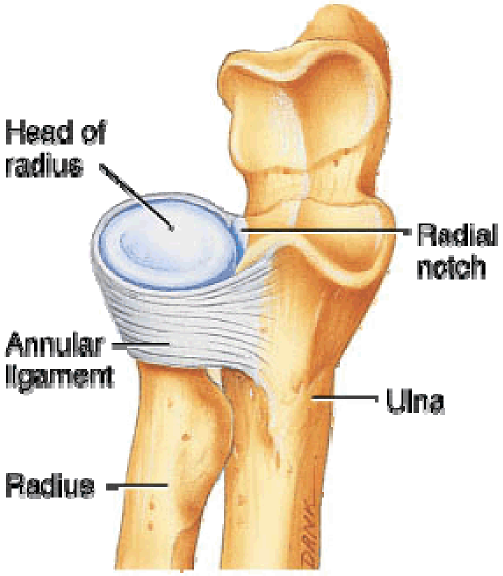


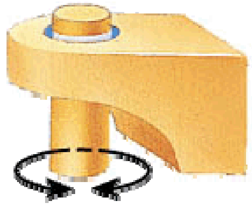


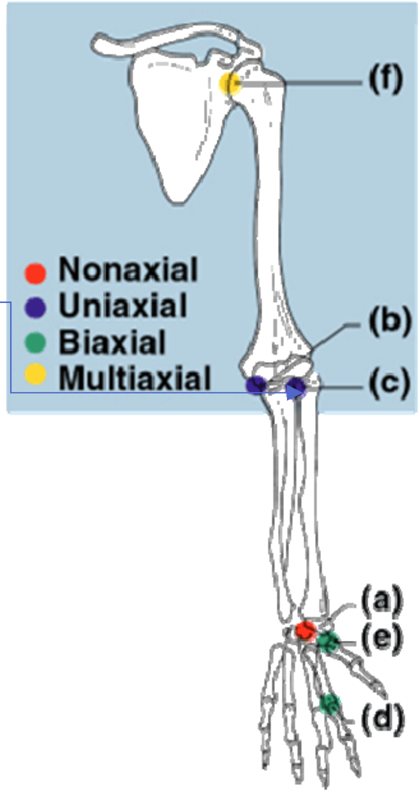
B: Hinge joint

1. Uniaxial joint
2. Allows rotation;
3. Examples: elbow and knee joints.

Types of Synovial Joints



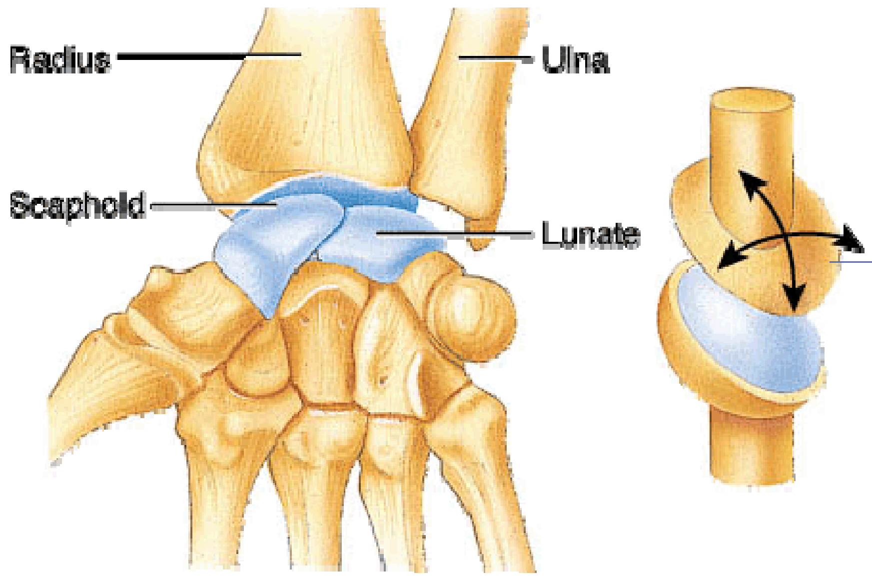


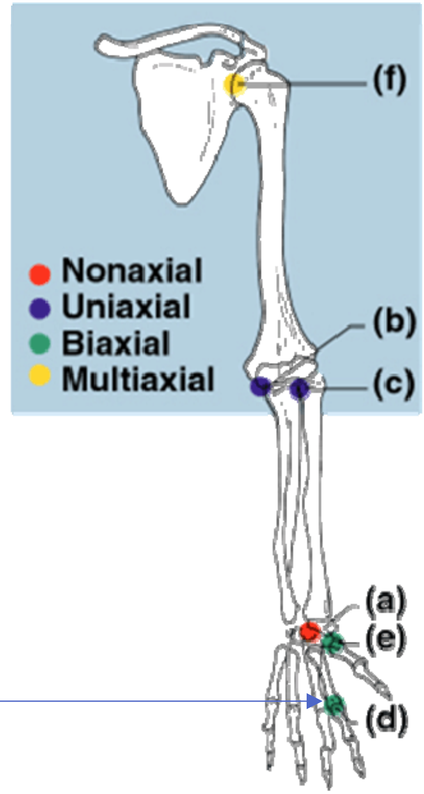


C: Pivot joint

1. Uniaxial joint
2. Allows rotation;
3. Examples: elbow and ankle joints.

Types of Synovial Joints

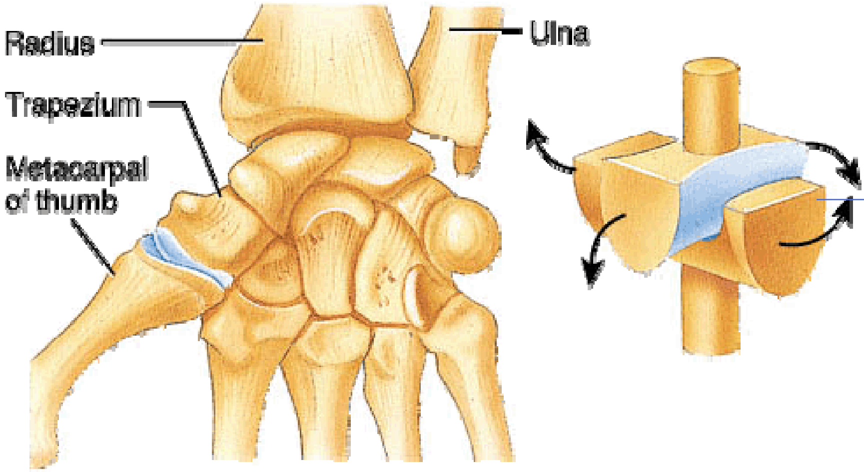


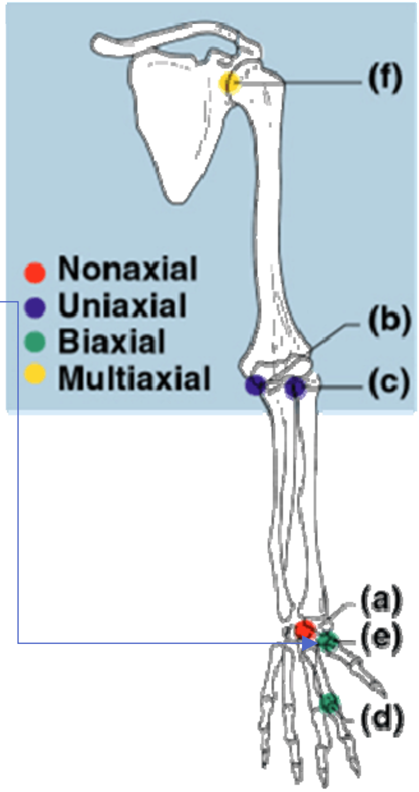


d: Condyloid joint

1. Biaxial
2. Allows movement in two planes
3. Examples: Wrist joint, etc.

Types of Synovial Joints

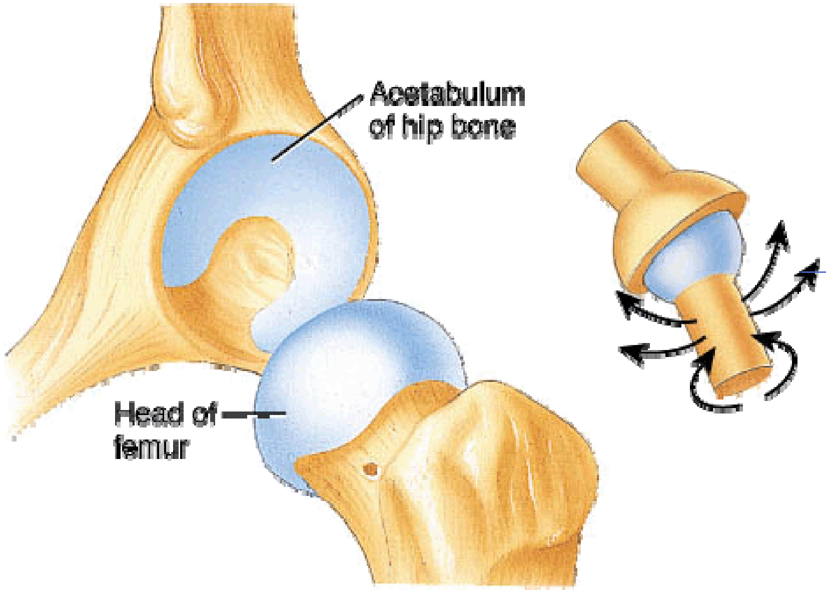


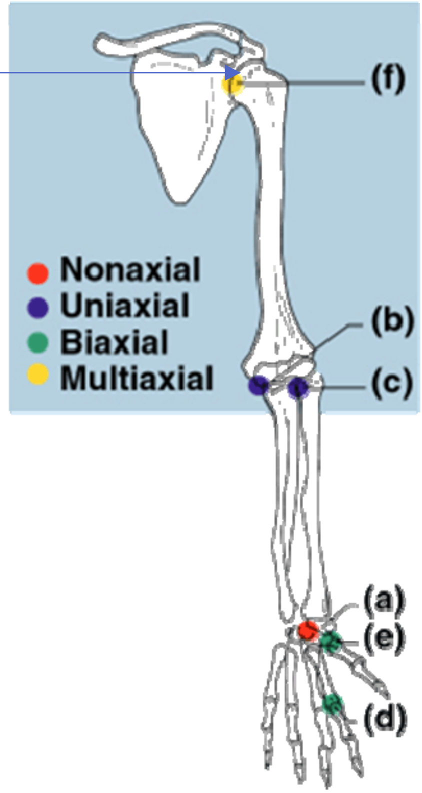


e: Saddle joint

1. Biaxial
2. Allow movement in the sagittal and frontal planes
3. Example: Carpometacarpal joint

Types of Synovial Joints





f: Ball and Socket joint

1. Multiaxial
2. Rotation
3. Examples: Shoulder joint, Hips joint

Ligament and tendon

Tendon

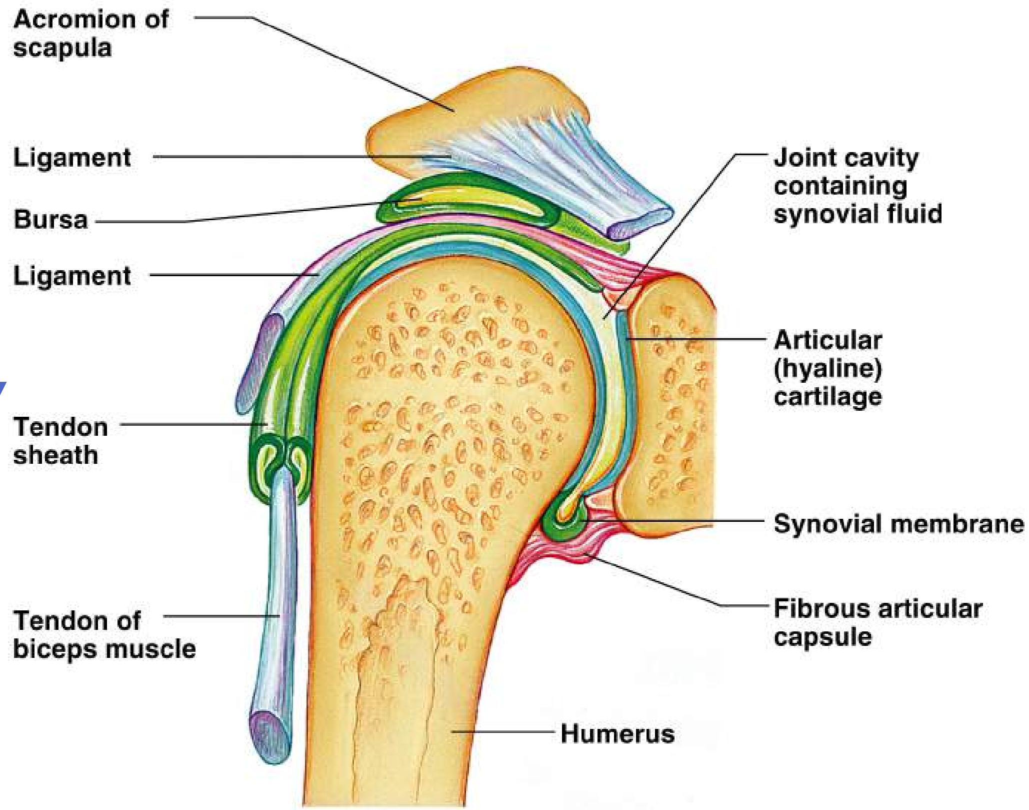
- ❑ Band of fibrous connective tissue
- ❑ Connects muscle to bone and is capable of withstanding tension

Function

-Transfer muscle force

-Transfer energy from one joint to another (through biarticular muscle)

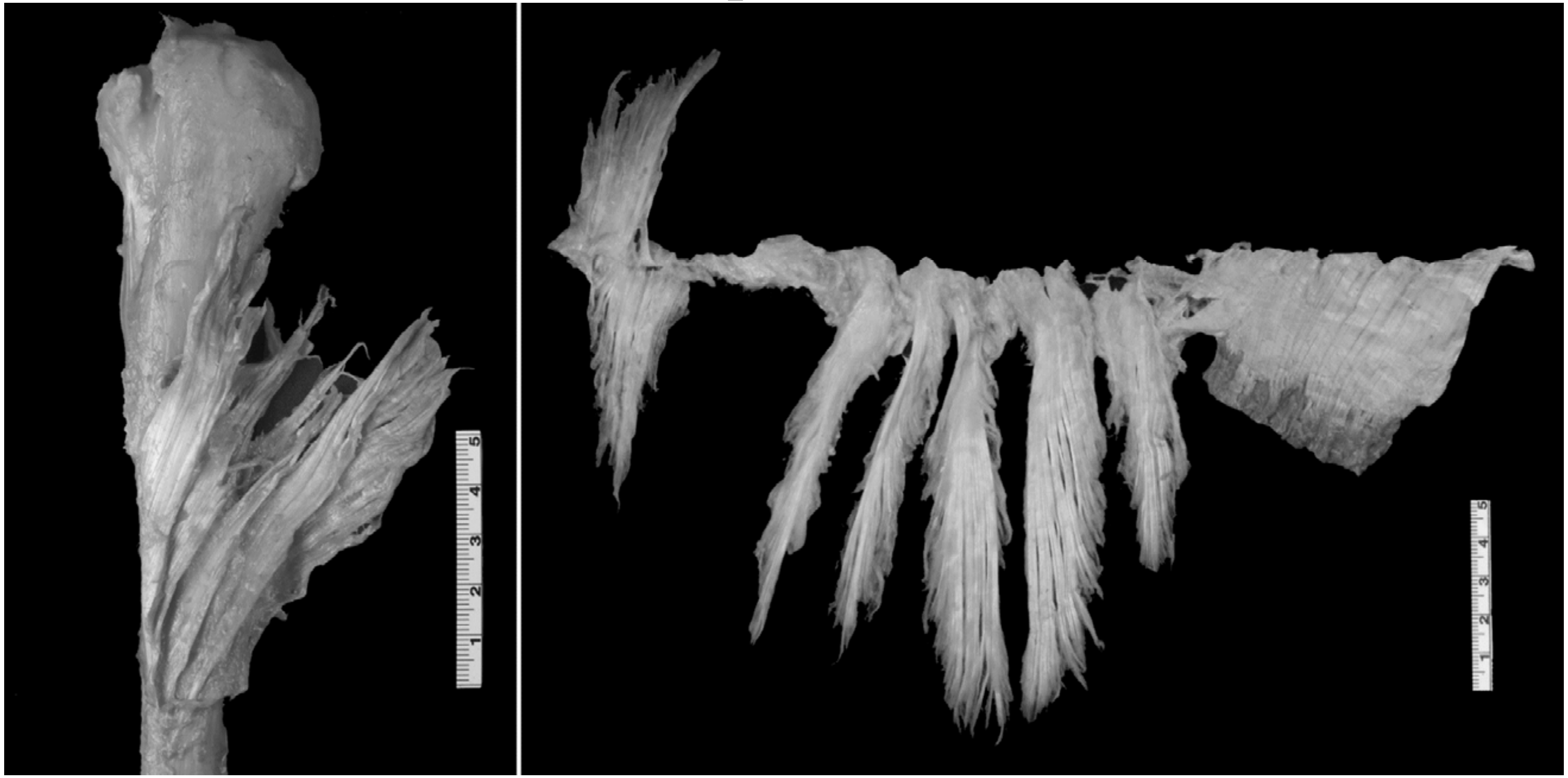
-Store and release energy for
- Efficient locomotion
- Increased power output
- Increased contraction velocity



Connections

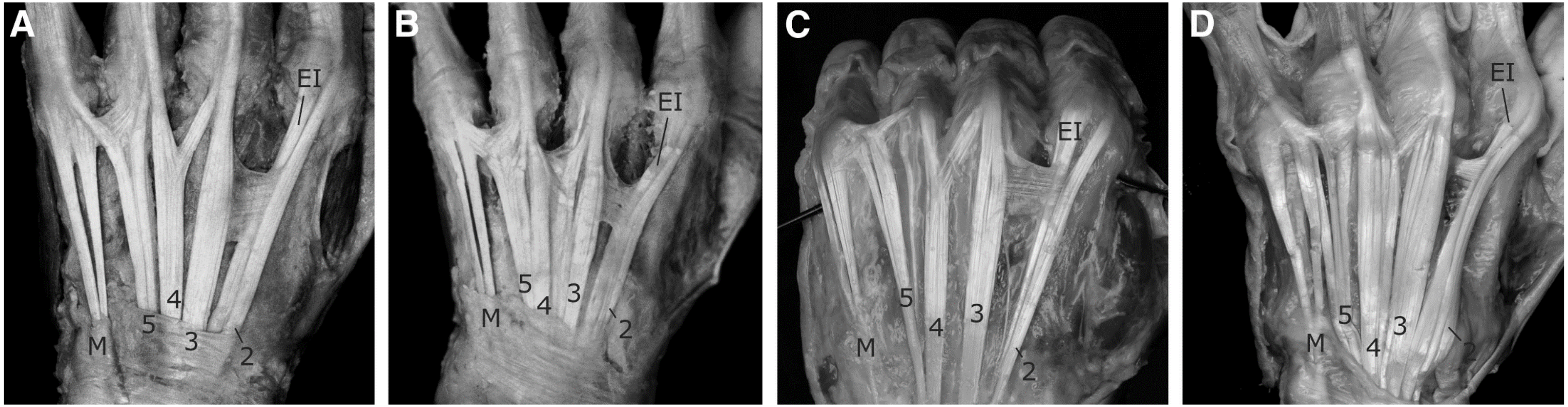
Strong tendon weak muscle

tendon sheets - aponeursoses



Deltiod muscle to humerus and claivicula

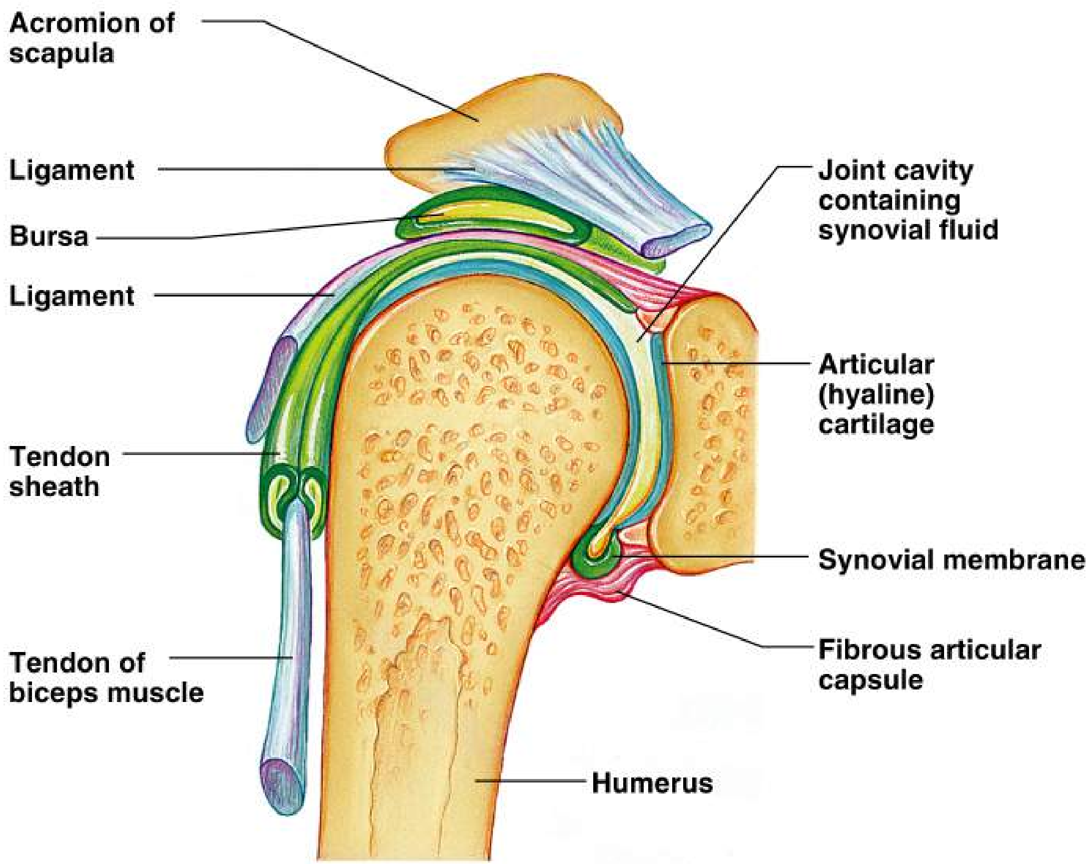
Connections



Ligament and tendon

Ligament

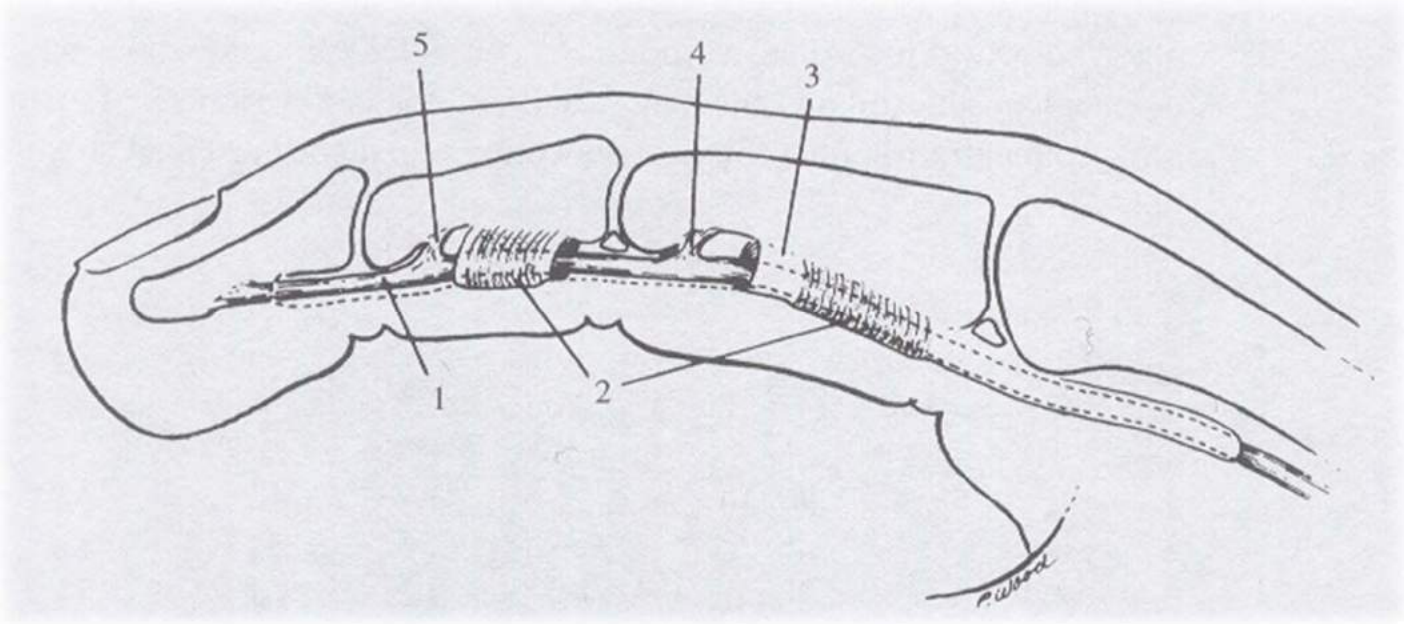
- ❑ The fibrous tissue
- ❑ Connects bones to other bones



Function

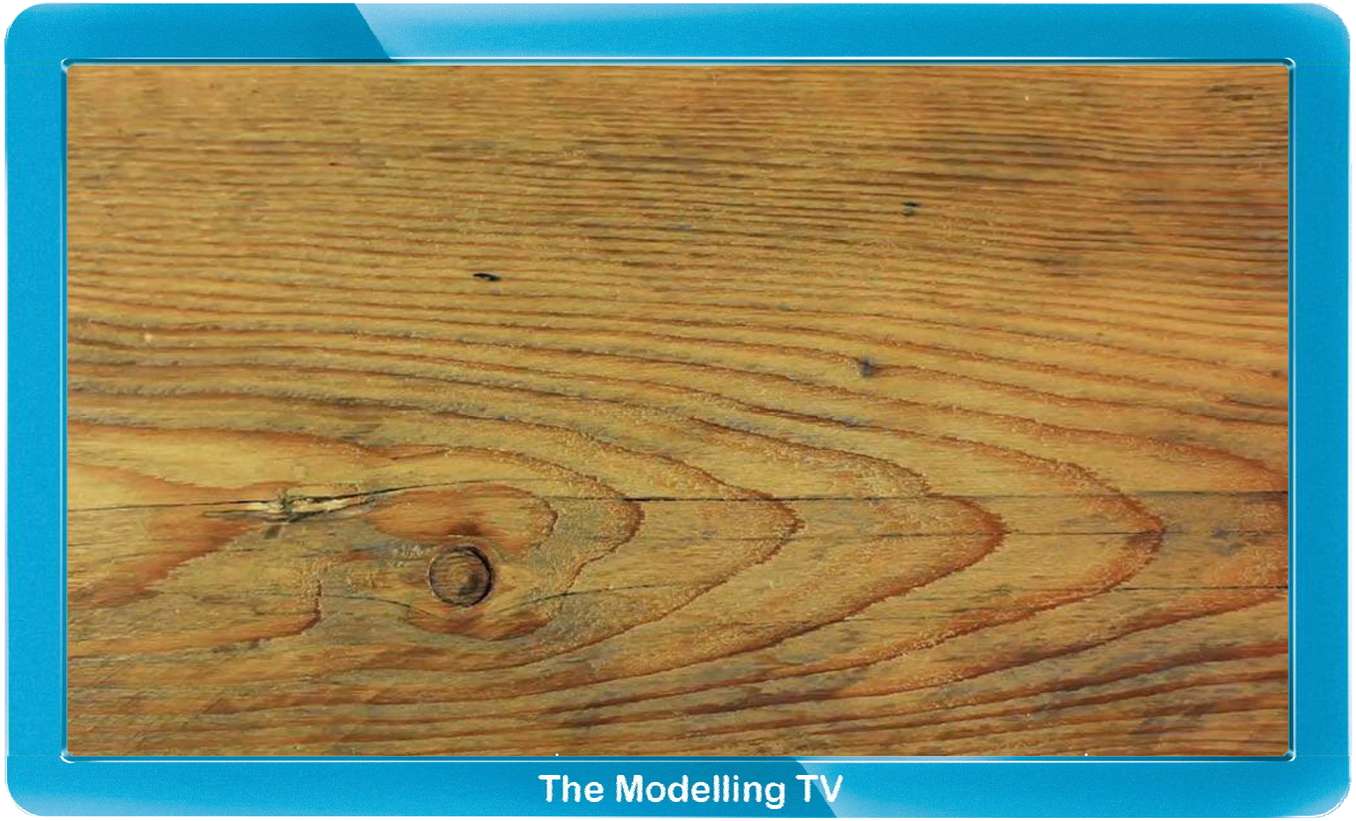
- Prevent joint dislocation
- Limit joint excursion
- Guide joint motion
- Constrain tendon paths

Ligament in the finger



Ligament in the leg

Applications: Exo-L



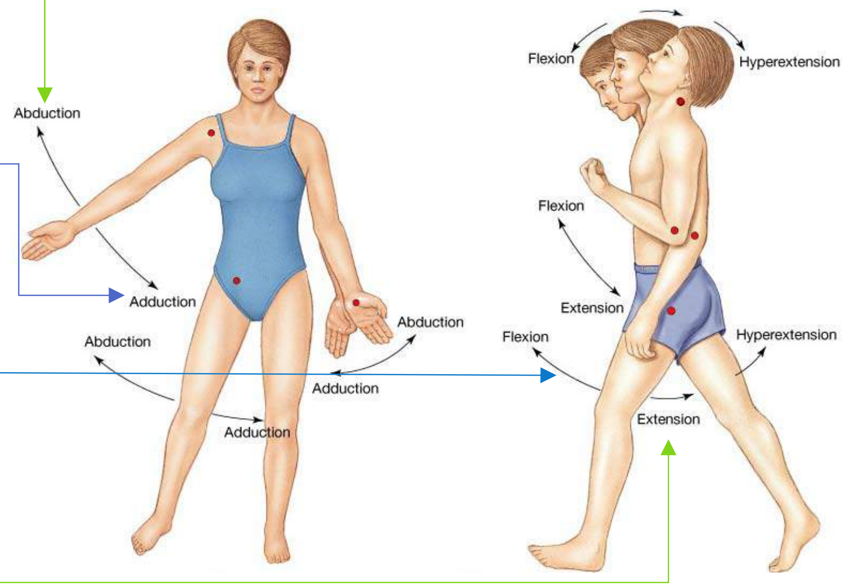
Types of movements

Abduction
- movement away from longitudinal axis

Adduction
- movement toward longitudinal axis

Flexion
- reduces angle of articulating elements in anterior-posterior plane

Extension
-increases angle of elements in anterior-posterior plane



Courtesy of **http://droualb.faculty.mjc.edu/Lecture%20Notes/Unit%202/chapter_8_articulations%20with%20figures.htm, http://encyclopedia.lubopitko-bg.com/Joints_Articulations.html**

Anatomy of musculoskeletal system

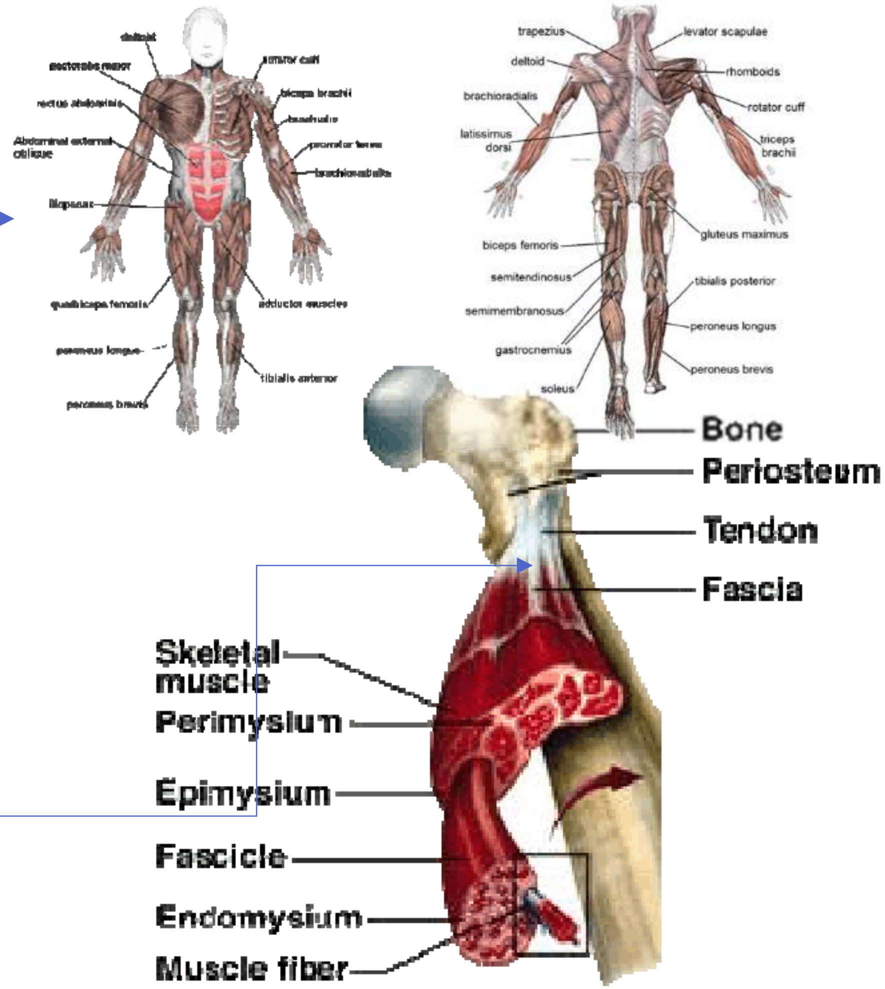
Muscle

Classification of Bones on the Basis of Shape

The muscle

- The human body is comprised of 324 muscles
- Muscle makes up 30-35% (in women) and 42-47% (in men) of body mass.
- There are three types of muscles

Muscles are attached to bones by tendons.



Courtesy of http://en.wikipedia.org/wiki/Human_musculoskeletal_system

Classification of Bones on the Basis of Shape

The muscle

- The human body is comprised of 324 muscles
- Muscle makes up 30-35% (in women) and 42-47% (in men) of body mass.
- There are three types of muscles

- Produce movement or tension
- Generate heat
- Muscle cells are excitable

Classification of Bones on the Basis of Shape

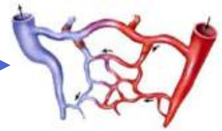
The muscle

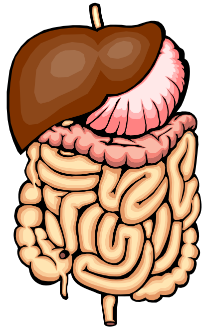
- The human body is comprised of 324 muscles
- Muscle makes up 30-35% (in women) and 42-47% (in men) of body mass.
- There are three types of muscles

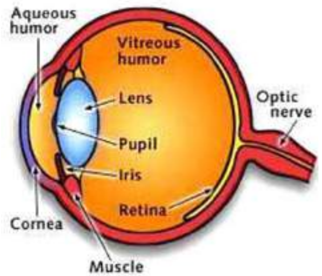
Skeletal (Striated) Muscle

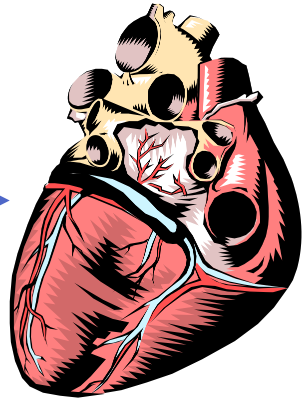
Smooth Muscle

Cardiac Muscle

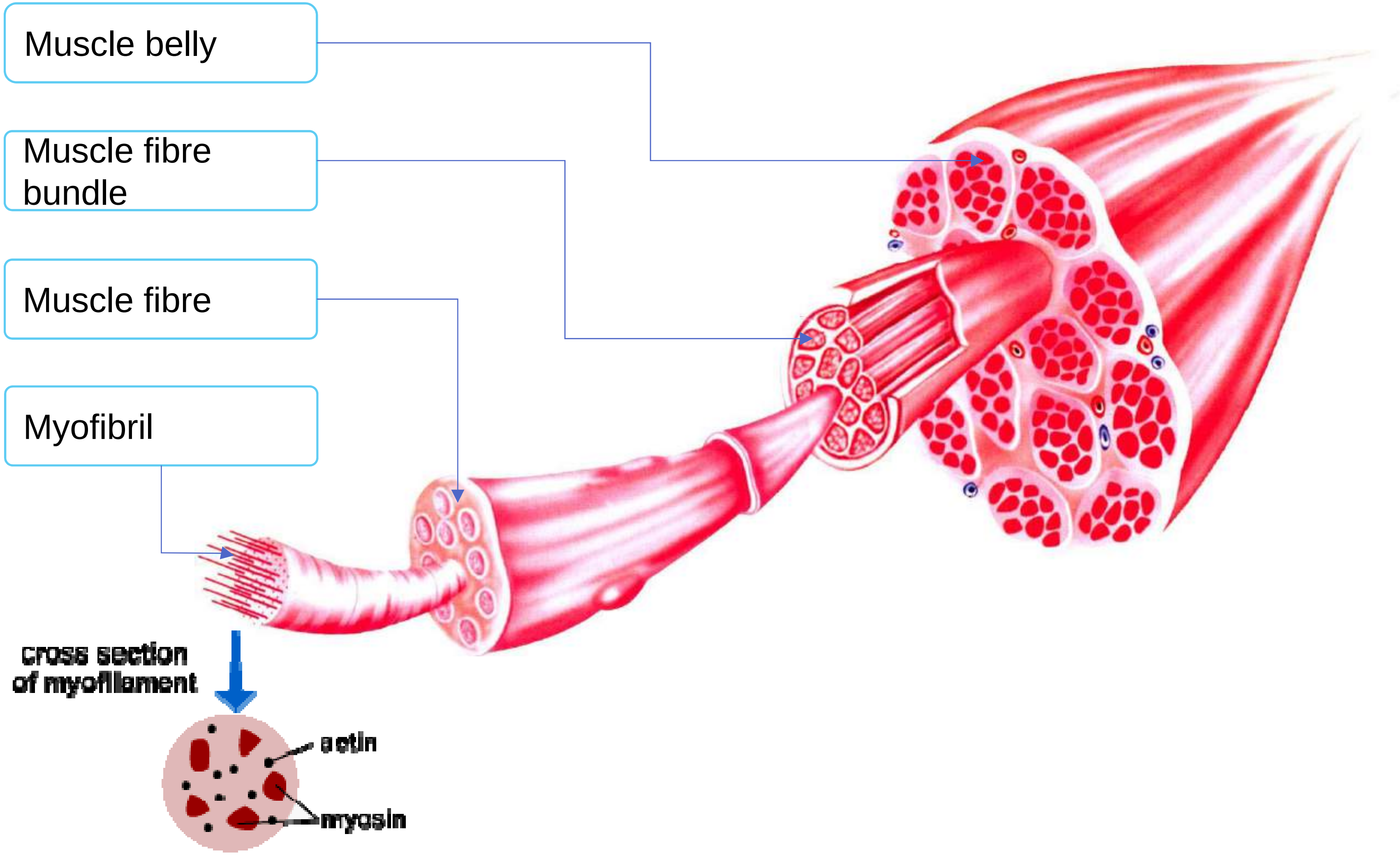








Components of skeletal muscle



Muscle properties

Muscle

Contractility

- Ability of a muscle to shorten with force

Extensibility

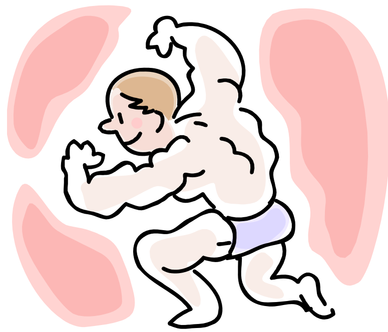
- Muscle can be stretched to its normal resting length and beyond to a limited degree

Excitability

- Capacity of muscle to respond to a stimulus

Elasticity

- Ability of muscle to recoil to original resting length after stretched



Types of Muscle Contraction

Concentric contraction

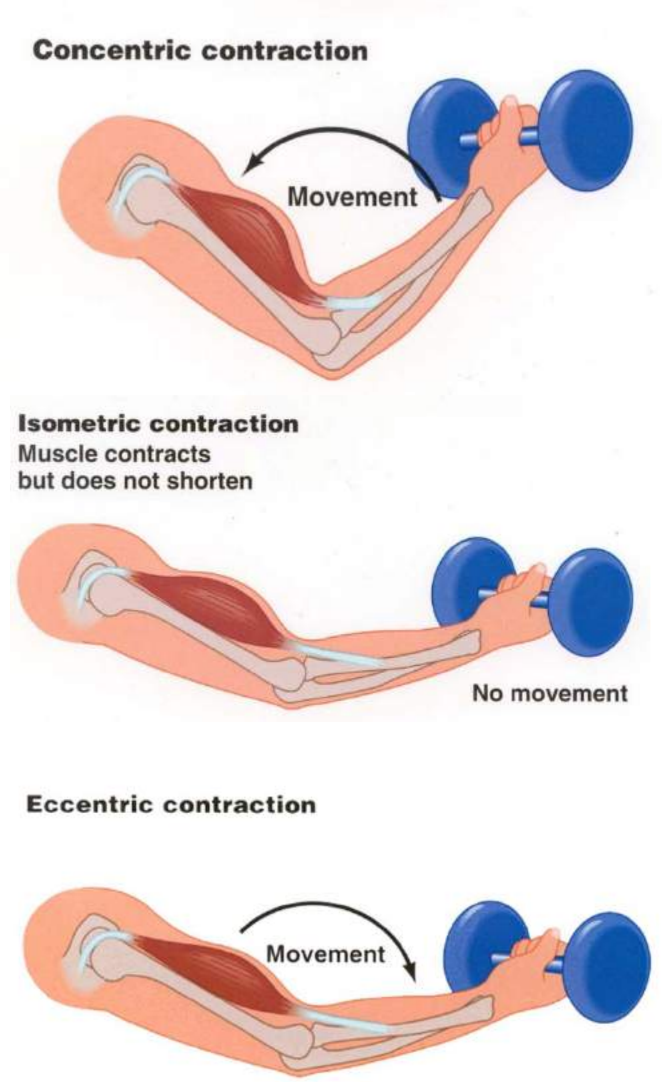
- Length of muscle shortens
- Muscle force is greater than the resistance

Static or Isometric contraction

- No change in muscle length
- Muscle force is equal to the resistance

Eccentric contraction

- Muscle lengthens
- Muscle force is less than the resistance

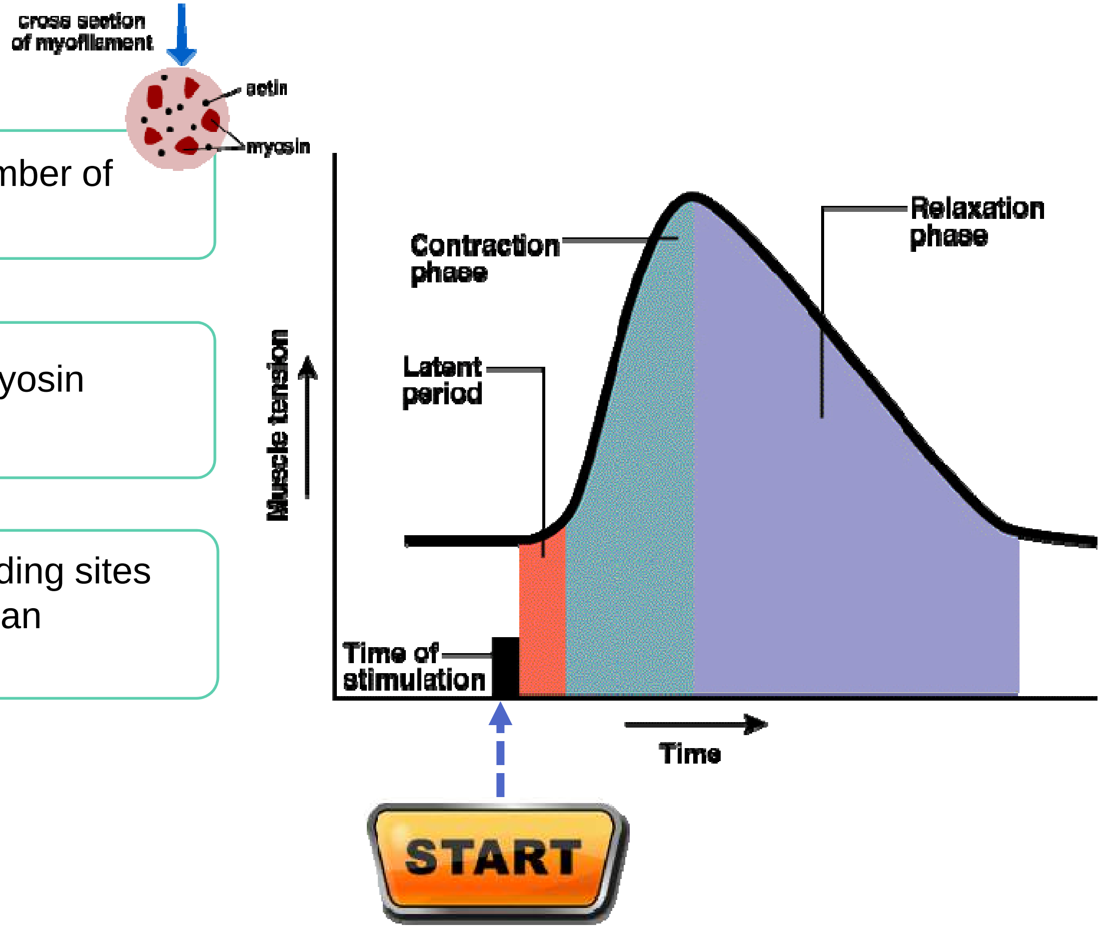


Muscle Contraction: twitch

Active muscle force is proportional to number of active actin/myosin binding sites.

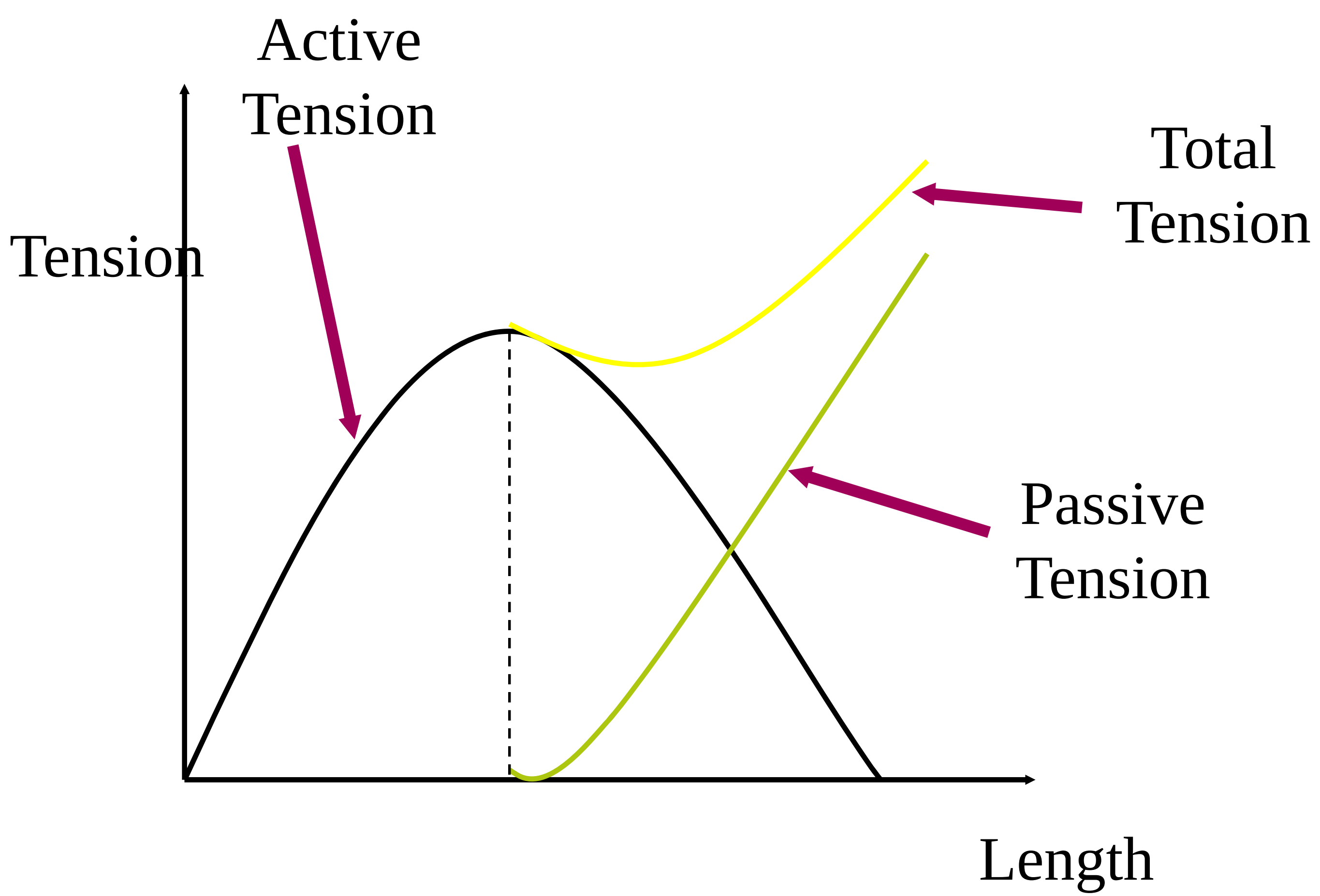
The number of sites available for actin/myosin binding depends on the muscle's length.

The greatest number of actin-myosin binding sites are available when the muscle fiber is at an intermediate length



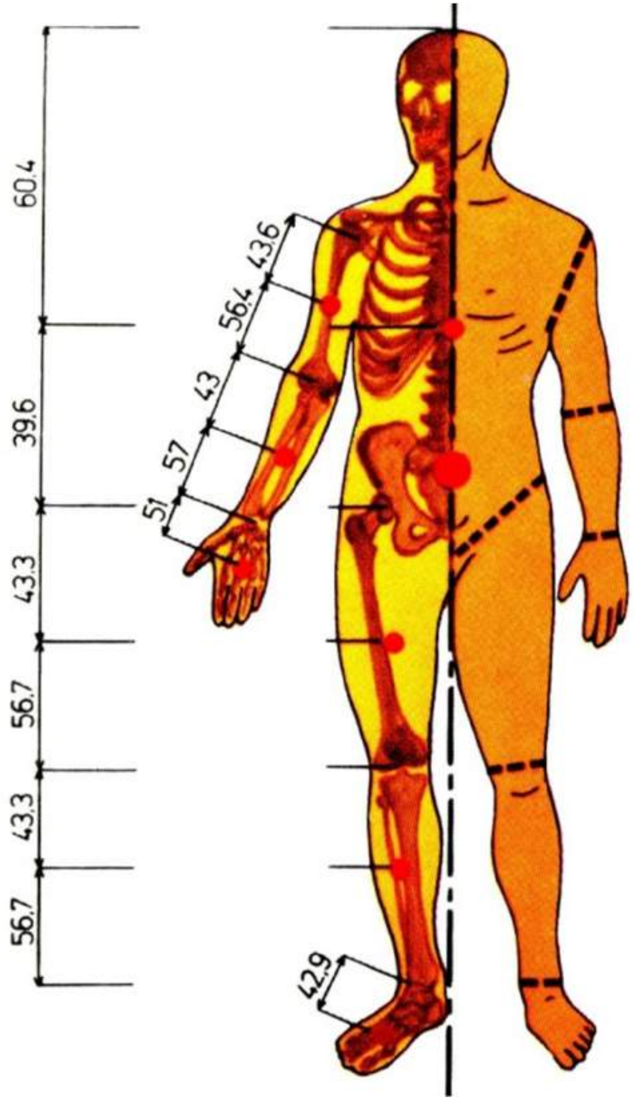
Courtesy of http://faculty.weber.edu/nokazaki/Human_Biology/Chp%206-muscular-system.htm

Length vs. Tension Curve

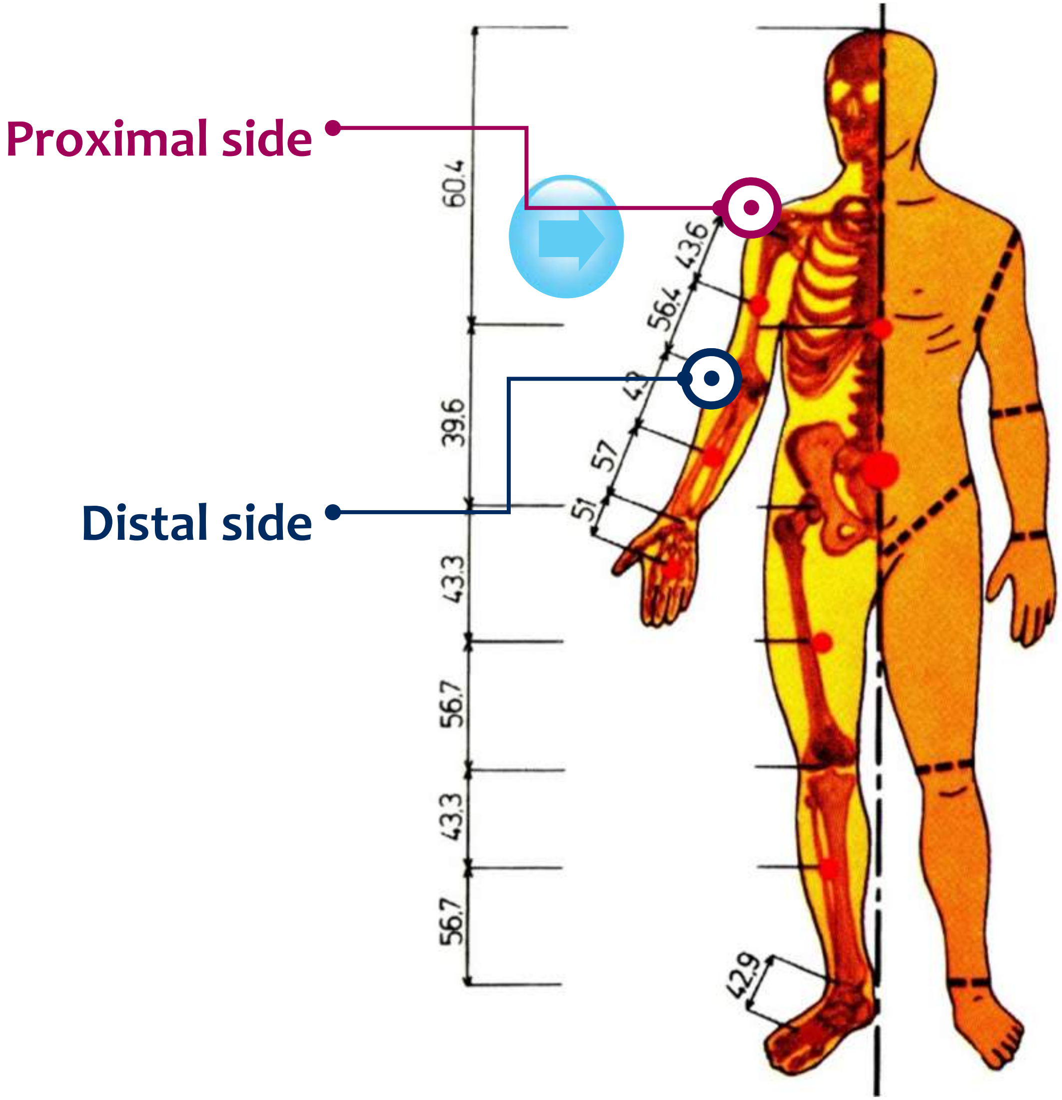


Mass segment of human body

Centre of gravity (c.g.) of body segments



Centre of gravity (c.g.) of body segments



Mass of body segment

Following Biomechanics and Motor Control of Human Movement

Segment	Segment / Total Body Weight	Centre of Mass / Segment length	Centre of Mass / Segment length
		Proximal	Distal
Hand	0.006	0.506	0.494
Forearm	0.016	0.43	0.57
Upper arm	0.028	0.436	0.564
F'arm+hand	0.022	0.682	0.318
Upper limb	0.05	0.53	0.47
Foot	0.0145	0.5	0.5
Shank	0.0465	0.433	0.567
Thigh	0.1	0.433	0.567
Foot + shank	0.061	0.606	0.394
Lower Limb	0.161	0.447	0.553
Head, neck, trunk	0.578	0.66	0.34
Head, neck, arms, trunk	0.678	0.626	0.374
Head and neck	0.081		

Ref. http://books.google.nl/books?id=_bFHL08IWfwC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=snippet&q=mass%20segment&f=false

Mass of body segment

by Zatsiorskji and Selujanov (1979), based on athlete's data

Mass of the segment (kg)

Mass (**kg**)

$$m_i = B_0 + B_1 m + B_2 H$$

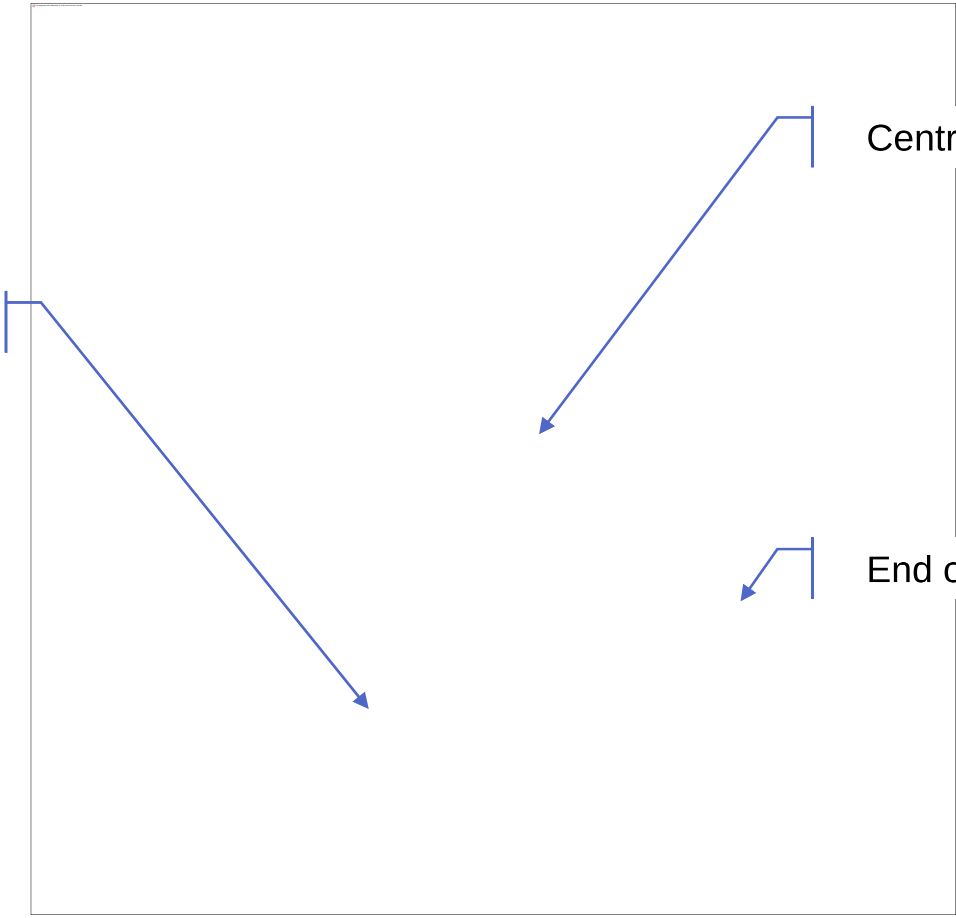
Height (**cm**)

Coefficient

Segment name	B_0[kg]	B_1	B_2[kg/cm]
Head+neck	1.296	0.0171	0.0143
Hand	-0.1165	0.0036	0.00175
Forearm	0.3185	0.01445	-0.00114
Upperarm	0.25	0.03012	-0.0027
Leg	-0.829	0.0077	0.0073
Shank	-1.592	0.03616	0.0121
Thigh	-2.649	0.1463	0.0137
Trunk			
Upper part of the trunk	8.2144	0.1862	-0.0584
Middle part of the trunk	7.181	0.2234	-0.0663
Lower part of the trunk	-7.498	0.0976	0.04896

Courtesy of http://biomech.ftvs.cuni.cz/pbpk/kompendium/biomechanika/geometrie_hmotnost_en.php

Case study: Mass segments of a child throws a ball



Case studies

Case study: Yoga elastic band

Yoga elastic band

Consider using an elastic yoga band in the yoga lesson:

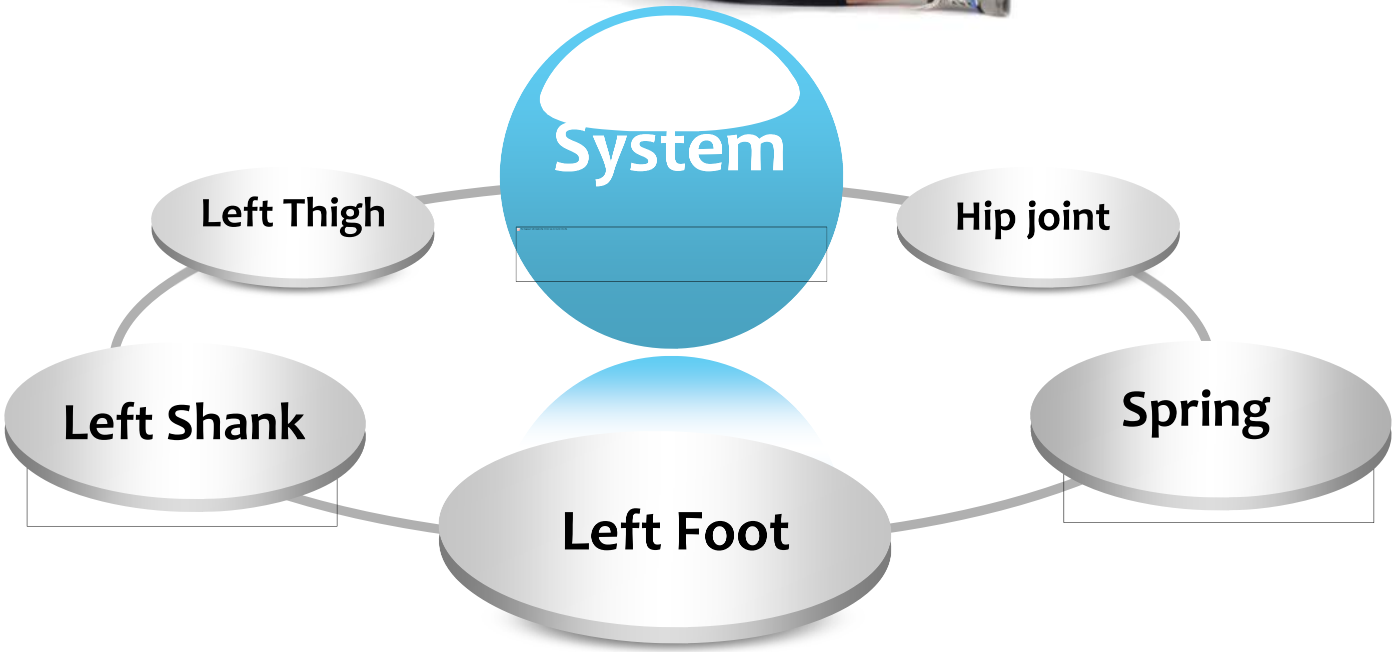
What is the angular velocity of her leg if she applies a 32 Nm torque on her hips joint?

We choose:

- Her height is 170cm;
- Her mass is 60 kg;
- She is a Dutch;
- The spring constant of the elastic band is 100N/m
- Every part of her body is fixed except the hip joint;
- The elastic band is fixed around the ankle

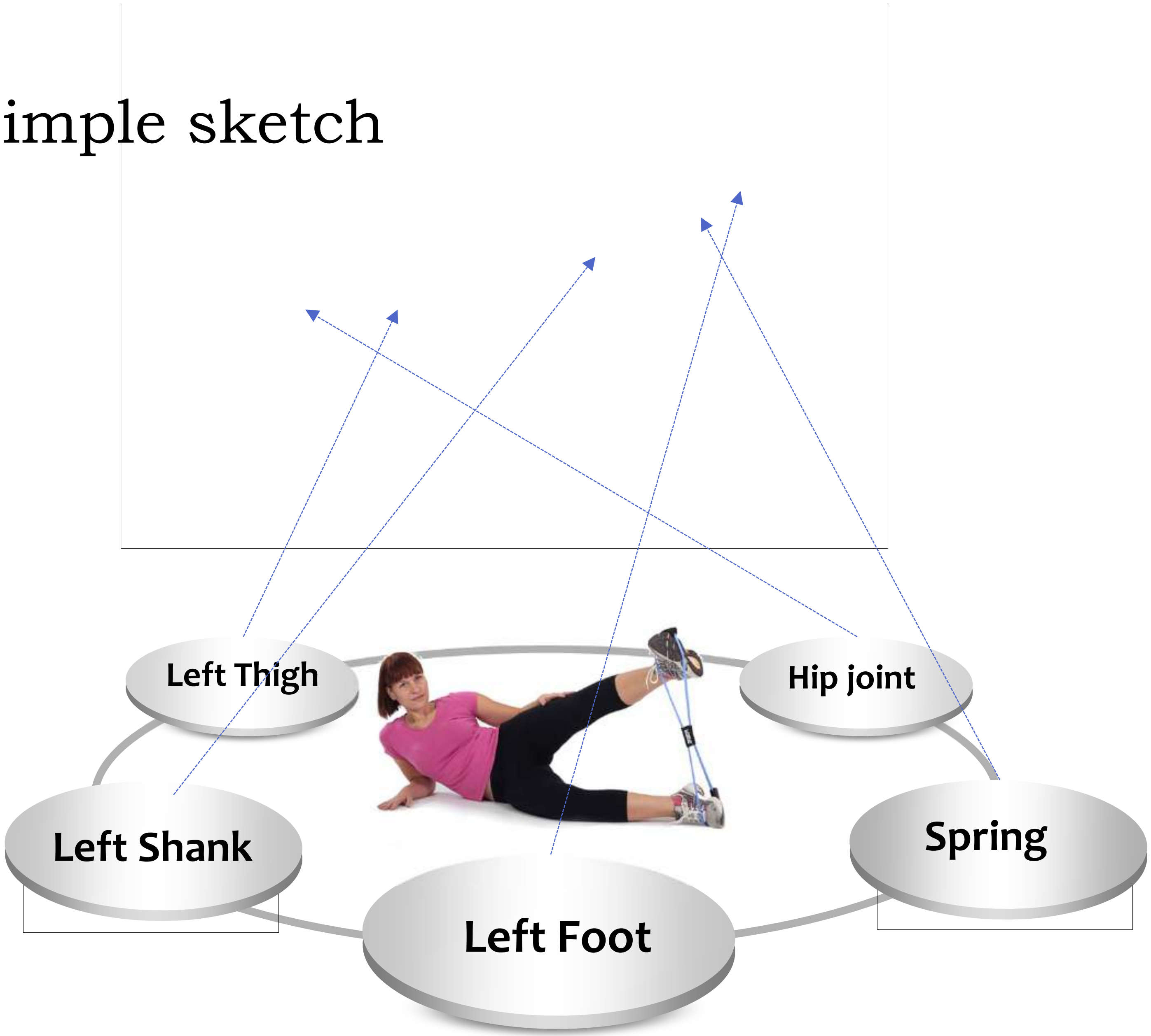
Courtesy of http://www.physio-pedia.com/Musculoskeletal_Physiotherapy_Courses

System & components



Courtesy of http://www.physio-pedia.com/Musculoskeletal_Physiotherapy_Courses

A simple sketch



Courtesy of http://www.physio-pedia.com/Musculoskeletal_Physiotherapy_Courses

Explore geometric relations

$$\alpha = \frac{\pi}{2} - \theta(t) + \tan^{-1}\frac{L5 - L5\cos\theta(t)}{L1 + L5\sin\theta(t)}$$

$$L8 = \sqrt{(L5 - L5\cos(\theta(t))^2 + (L1 + L5\sin(\theta(t))^2}$$

Courtesy of http://www.physio-pedia.com/Musculoskeletal_Physiotherapy_Courses

Modelling

Mass of the thigh, shank and foot

Inertia force

$$(-m_{thigh}L2^2 - m_{shank}L4^2 - m_{foot}L6^2)\frac{d^2\theta(t)}{dt^2}$$

Gravity of the thigh, shank and foot

Resist to the movement

$$(-m_{thigh}gL2 - m_{shank}L4 - m_{foot}gL6)cos\theta(t)$$

Spring

Resist to the movement

$$-\mathrm{k}(L8 - L1)\mathrm{L5sin}\alpha$$

User

Trigger the movement

$$M_{user}$$

$$\sum M = 0$$

Establish relations

3D human model based on Dined data

To be introduced in H-L-3 lecture

Establish relations

Anthropometric model

Parameters for the model

Body mass segments

		Proximal	Distal
Hand	0.006	0.506	0.494
Forearm	0.016	0.43	0.57
Upper arm	0.028	0.436	0.564
F'arm+hand	0.022	0.682	0.318
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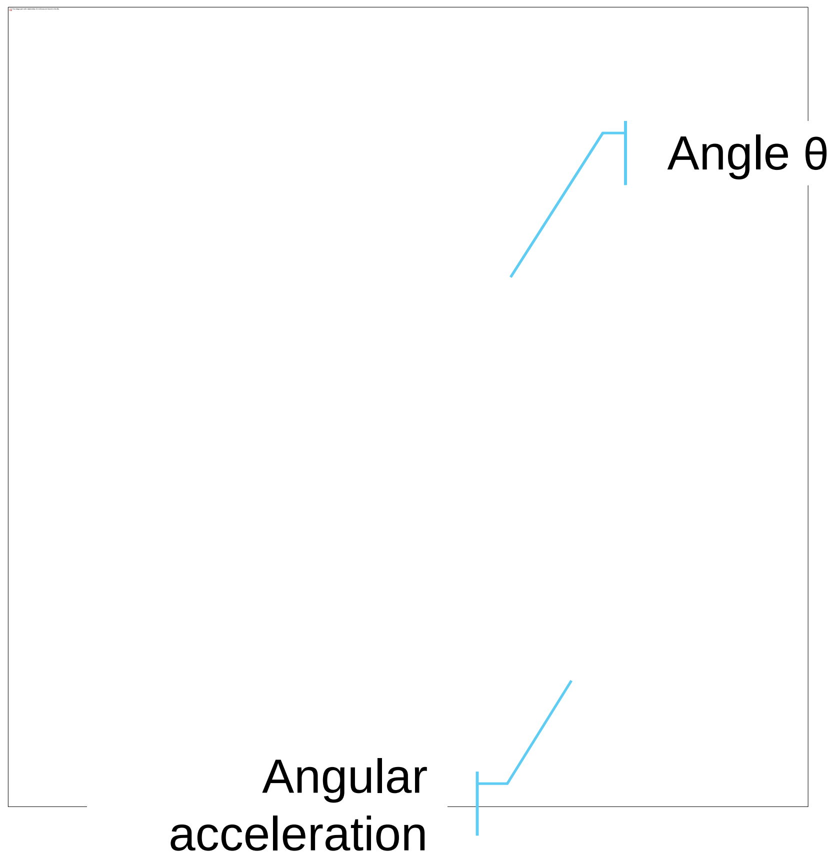
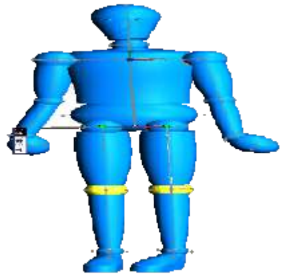
Establish relations



From objective perceptions to subjective perceptions

The human: Two worlds



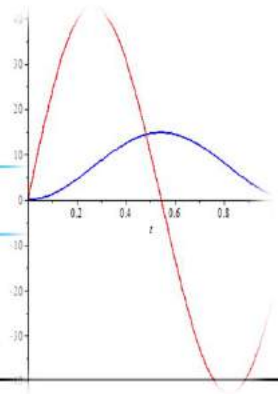
Objective perceptions: physical world

- Units
- Additive
- cognitive process

Subjective perceptions: introspection

- Units?
- rules?
- sensory process

Same?



Just noticeable difference

Just noticeable difference

The smallest detectable difference between a starting and secondary level of a particular sensory stimulus

- **Test methods:**

Simple up-down method (Boff 1932)

Weber's Law:
It states that the ratio of the increment threshold to the background intensity is a constant

Constant
To be determined by experiment

$$k_w = \frac{\Delta I}{I}$$

Increment

Background intensity

Weber’s law & Fechner’s law

Weber's Law:

$$k_w = \frac{\Delta I}{I}$$

subjective, perceived, psychological intensity

$$Response = \log(I)$$

Physical intensity

Mathematically, Webers’ law and Fechner’s law are equivalent

Steven’s power law

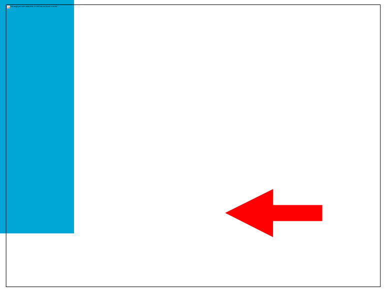
$$\psi(I) = kI^{a}$$

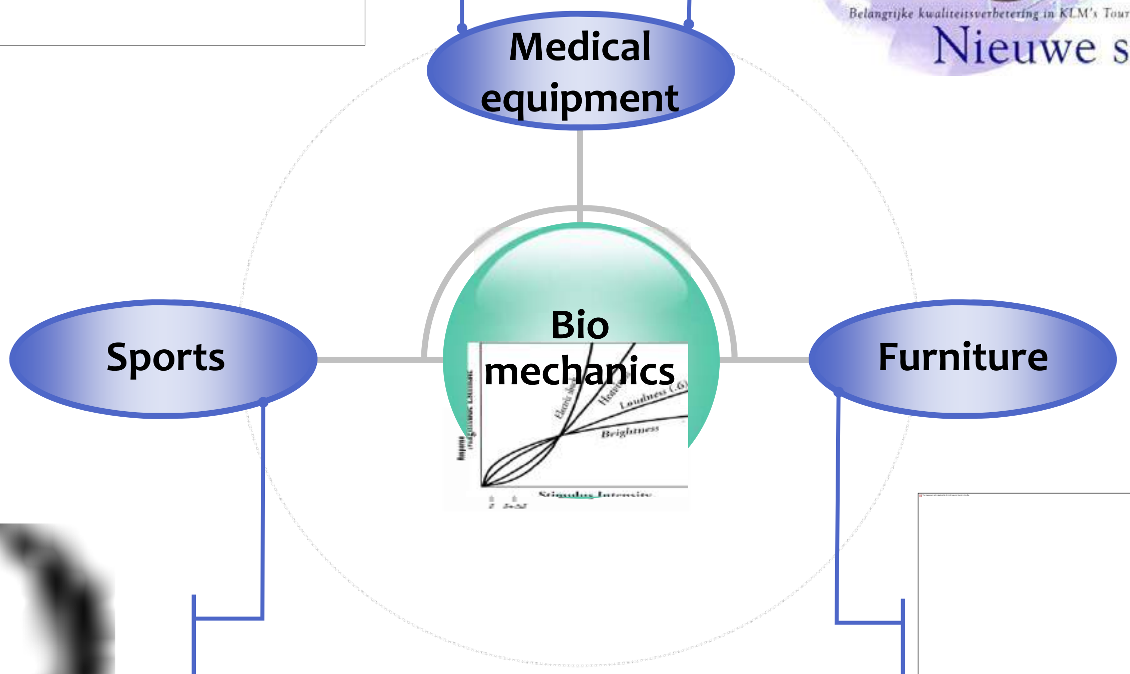
- $\psi(I)$: Subjective magnitude
- k: Constant: depends on the type of stimulation & Units
- a: Constant: depends on the type of stimulation
- I: Magnitude of the physical stimulus

Types	Exponent
Loudness	0.67
Vibration	0.95
Brightness	0.33
Smell	0.6
Cold	1
Discomfort, cold	1.7
Discomfort, warm	0.7
Muscle force	1.7
Electric shock	3.5
…	…

Industrial design applications

Industrial design applications





Courtesy of www.nike.com, http://www.aaop.ca/community/, http://gymflow100.com/common-cardio-machine-workout-mistakes/

Thank You

Prof. Dr. ir. Richard Goossens
Dr. Wolf Y. Song
Faculty of Industrial Design Engineering
Delft University of Technology