BIE 3134 BIOMECHANICS

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What is Biomechanics?

Bio+Mechanics=Biomechanics ☺

Biomechanics is mechanics applied with living systems

What is Biomechanics?

- Biomechanics is an exciting and fascinating specialty with the goal of better understanding the musculoskeletal system to enable the development of methods to prevent problems or to improve treatment of patients.

Biomechanics aims to explain the mechanics of life and living. From molecules to organisms, everything must obey the laws of mechanics.

—Y.C. Fung (1990)

What is Biomechanics?

- Biomechanics is the development, extension,and application of mechanics for the purposes of understanding better the influence of applied loads on the structure, properties, and function of living things and the structures with which they interact.

What is Biomechanics?

- Biomechanics has increasingly become an interdisciplinary field where

engineers,

physicists,

computer scientists,

biologists,

and material scientists work together to support

physicians,

sports scientists,

ergonomists,

and physiotherapists and many other professionals.

Principal Areas of Biomechanics

1- Performance : Walking, sitting, standing, reaching, throwing, kicking, and carrying objects, operating vehicles or tools, and sport mechanics. Internal movement and behavior such as blood flow, fluid circulation, heart and muscle mechanics, and skeletal joint kinematics.

Principal Areas of Biomechanics

2- Injury : Failure and damage of biosystems as in broken bones, torn muscles, ligaments, and tendons, and organ impairment, evaluation of tissue properties, studies of accidents and the design of protective devices.

Principal Areas of Biomechanics

3- Rehabilitation : Recovery from injury and disease. Rehabilitation thus includes all applications of mechanics in the health care industries encompassing such areas as design of corrective and assist devices, development of implants, design of diagnostic devices, and tissue healing mechanics.

Some Topics on Biomechanics

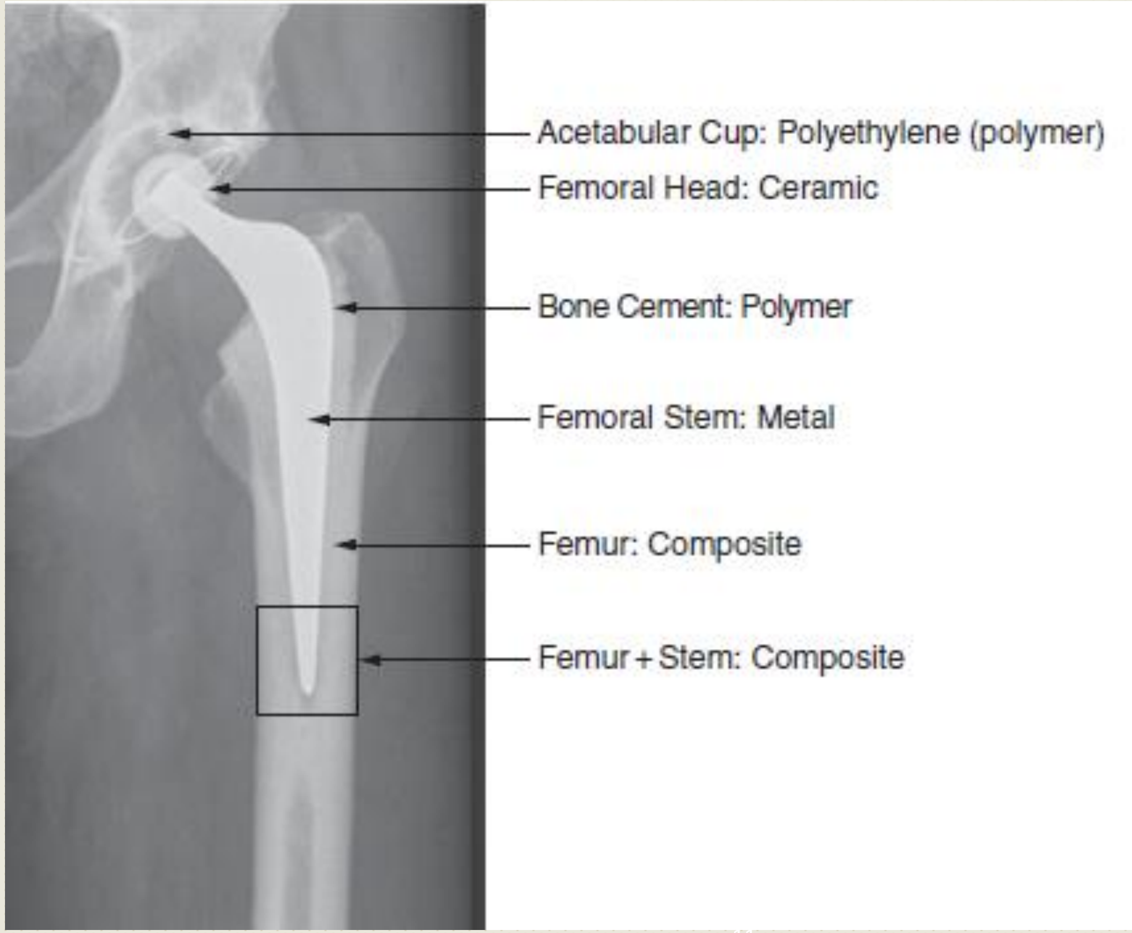
- Mechanics of Hard Tissue
- Musculoskeletal Soft Tissue Mechanics
- Joint-Articulating Surface Motion
- Joint Lubrication
- Analysis of Gait
- Mechanics of Head/Neck
- Biomechanics of Chest and Abdomen Impact
- Cardiac Biomechanics
- Heart Valve Dynamics
- Arterial Macrocirculatory Hemodynamics

Some Topics on Biomechanics (ctd.)

- Mechanics of Blood Vessels
- The Venous System
- Mechanics, Molecular Transport, and Regulation in the Microcirculation
- Mechanics and Deformability of Hematocytes
- Mechanics of Tissue/Lymphatic Transport
- Modeling in Cellular Biomechanics
- Cochlear Mechanics
- Vestibular Mechanics
- Exercise Physiology
- Factors Affecting Mechanical Work in Humans

Examples of Biomechanics Area

- Total hip replacement



What is Biomechanics?

Since biomechanics can be defined as mechanics ; this question can also be answered by answering the question

WHAT IS MECHANICS?

What is Mechanics?

- Mechanics deals with static (equlibrium) and movement behaviours of a matter which is effected by force.

or

- Study of what happens to a “thing” (the technical name is “BODY”) when FORCES are applied to it.

What is Mechanics?

From a historical perspective or viewpoint :

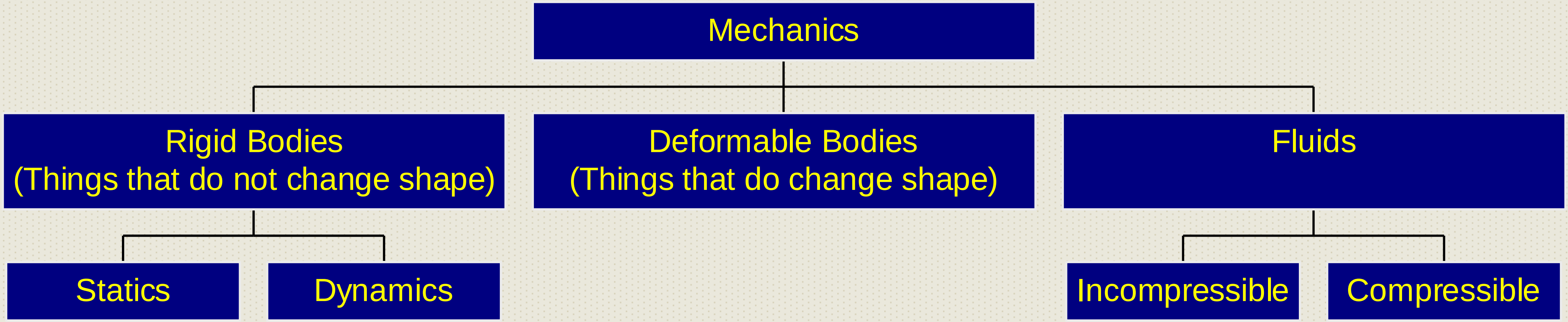
- Mechanics is the oldest of all physical sciences, dating back to the times of Archimedes (287–212 BC).

- The most prominent contributors are;

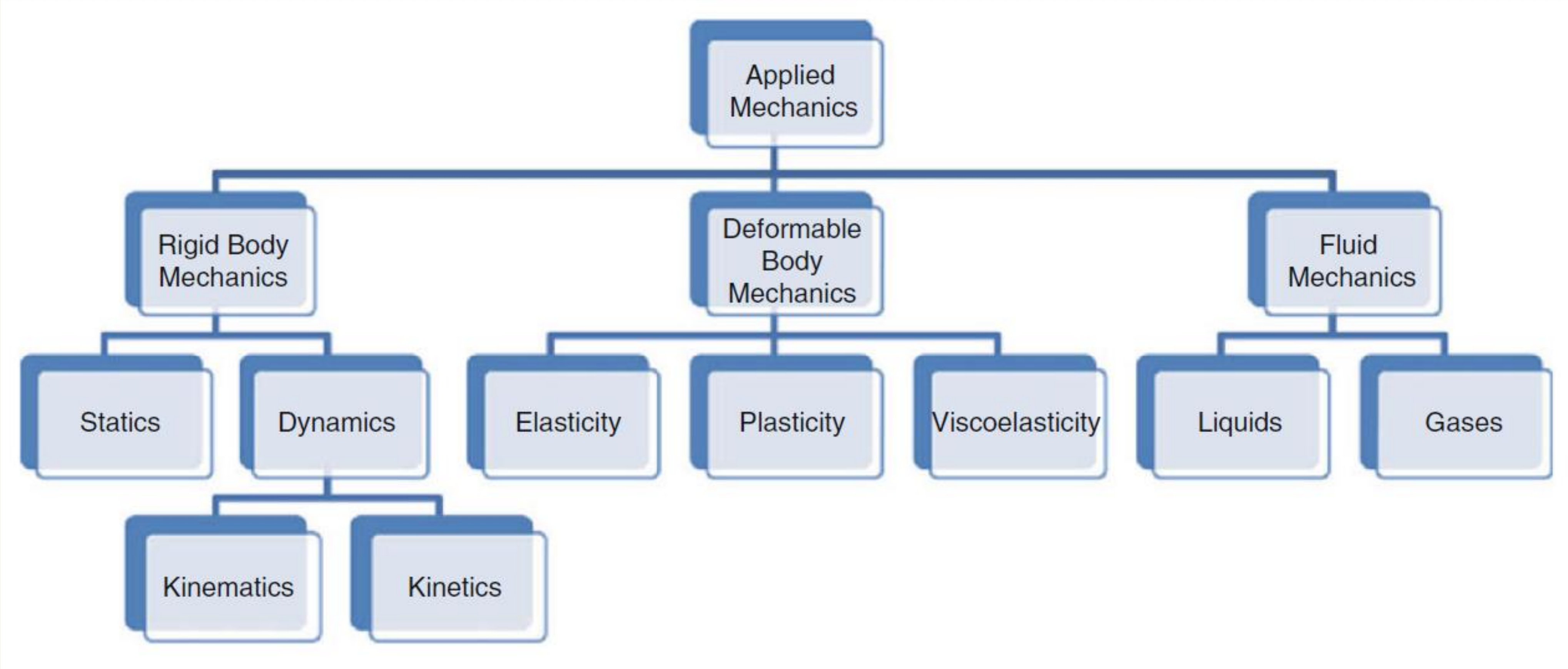
Galileo (1564–1642) made the first fundamental analyses and experiments in dynamics.

Newton (1642–1727) were to this field. Galileo, and Newton formulated the laws of motion and gravity.

Classification of Mechanics



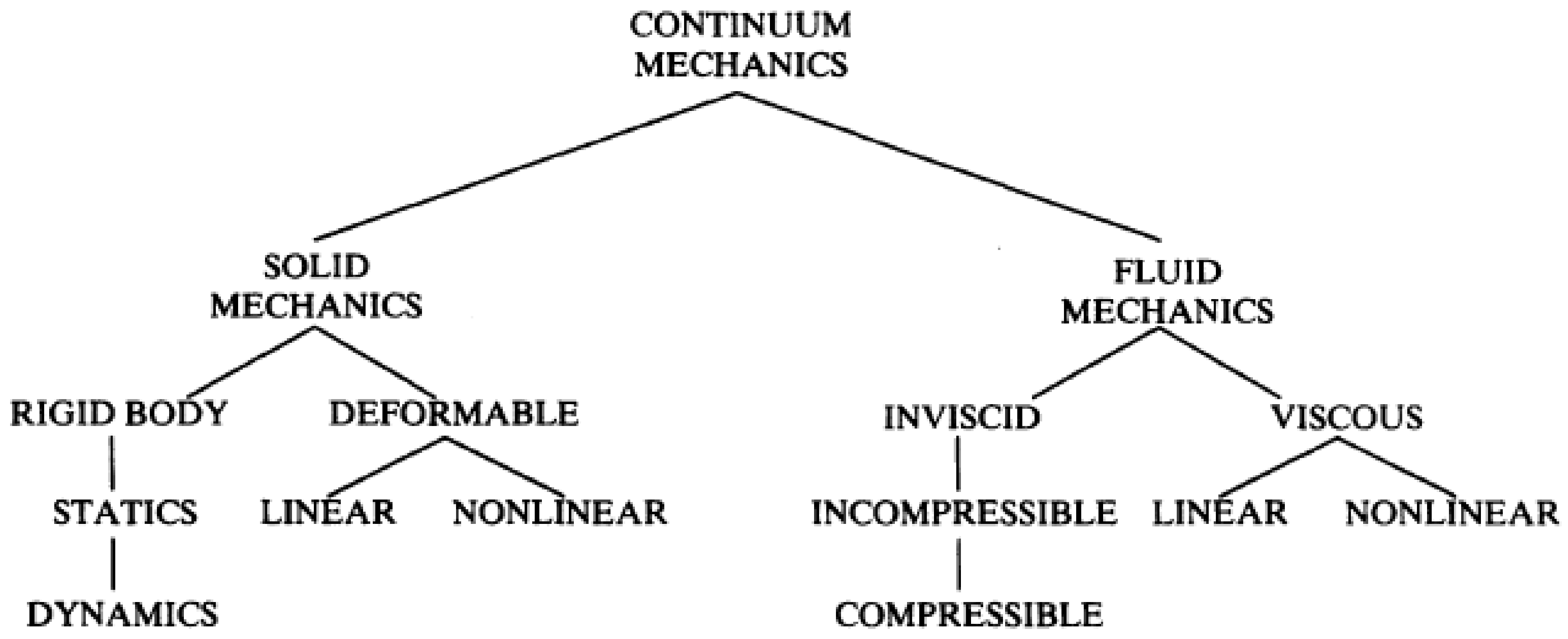
Classification of Mechanics (in detail)



There are five basic areas of study in mechanics:

1. Discrete mechanics,
2. Continuum mechanics,
3. Statistical mechanics,
4. Quantum mechanics,
5. Relativistic mechanics.

Continuum Mechanics



Continuum Biomechanics

Every continuum biomechanics problem can be addressed via the five fundamental postulates of continuum mechanics by specifying three things :

1. The geometry (i.e., the domain of interest),
2. The constitutive relations (i.e., how the material responds to applied loads under conditions of interest), and
3. The applied loads (or associated boundary conditions).

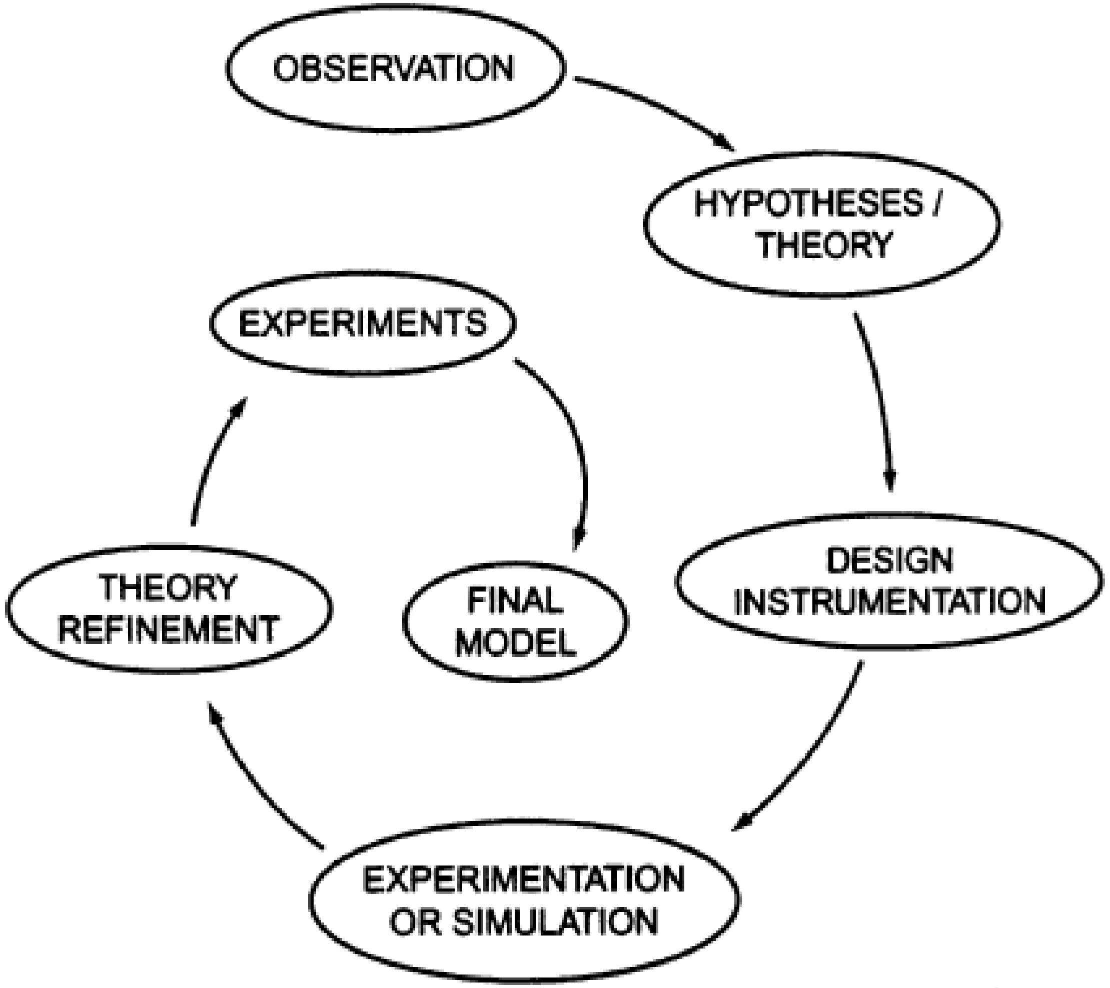
Continuum Biomechanics

A constitutive relation is but a mathematical descriptor of particular behaviors exhibited by a material under conditions of interest; it is not a descriptor of a material per se.

There are five steps in every constitutive formulation:

1. Delineate general characteristic behaviors.
2. Establish an appropriate theoretical framework.
3. Identify specific functional forms of the constitutive relation.
4. Calculate the values of the material parameters.
5. Evaluate the predictive capability of the final constitutive relation.

General Scientific Approach



Dimensions and Units

Four fundamental physical quantities (or dimensions).

- Length
- Mass
- Time
- Force

We will work with one unit system in Biomechanics:

- International System (SI)

Dimensions and Units

Quantity	Length	Time	Mass	Force
SI Units	meter	second	kilogram	newton*
	m	s	kg	N $\left(\frac{kg \cdot m}{s^2}\right)$

- **Spatial :** Relating to or with respect to the three-dimensional world.
- **Temporal :** Relating to or with respect to time.

Dimensions and Units

	Exponential Form	Prefix	SI Symbol
Multiple			
1 000 000 000	10^9	giga	G
1 000 000	10^6	mega	M
1 000	10^3	kilo	k
Submultiple			
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n

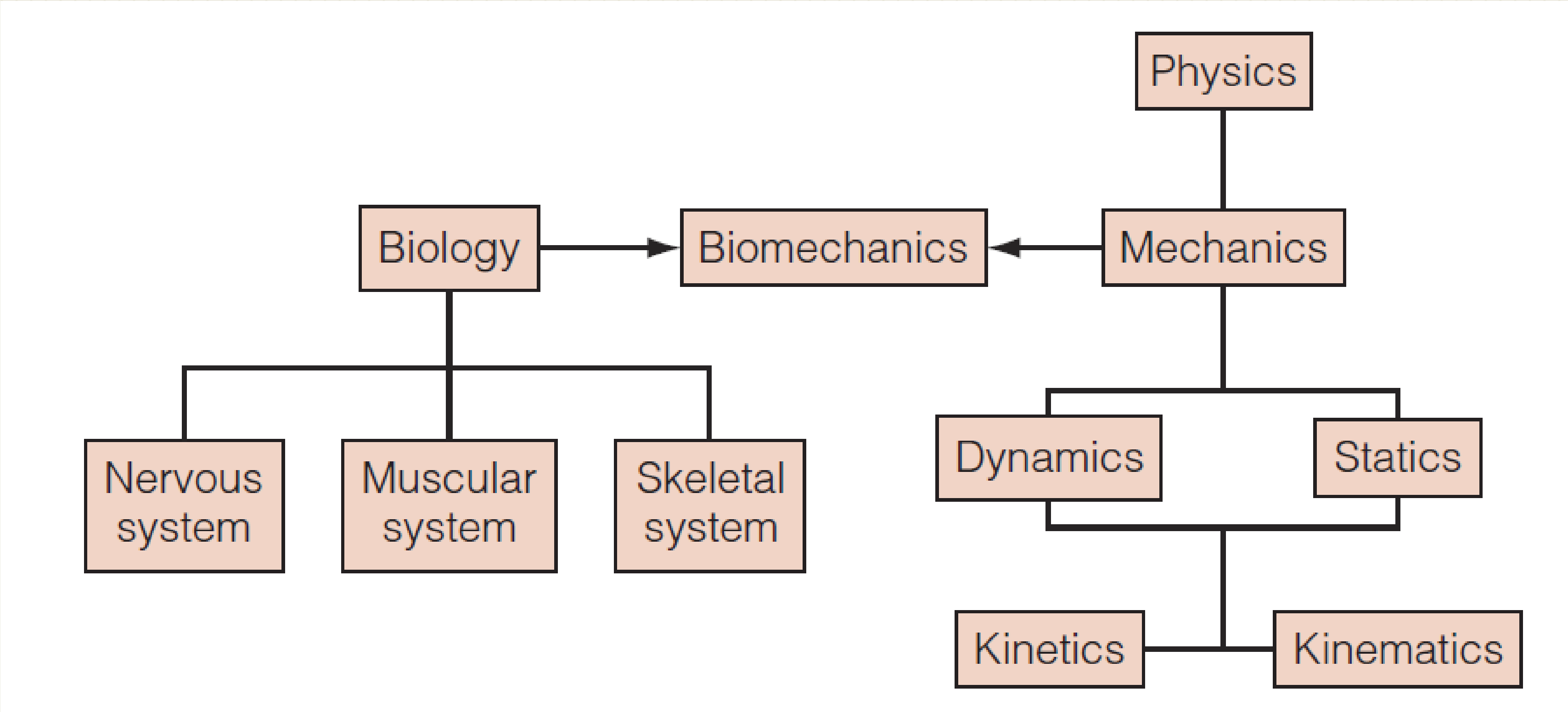
How to solve problems? (Tips)

1. **Interpret:** Read carefully and determine what is given and what is to be found/ delivered. Ask, if not clear. If necessary, make assumptions and indicate them.
2. **Plan:** Think about major steps (or a road map) that you will take to solve a given problem. Think of alternative/creative solutions and choose the best one.
3. **Execute:** Carry out your steps. Use appropriate diagrams and equations. Estimate your answers. Avoid simple calculation mistakes. Reflect on and then revise your work, if necessary.

Scalars and Vectors

	Scalars	**Vectors**
Examples:	Mass, Volume	Force, Velocity
Characteristics:	It has a magnitude (positive or negative)	It has a magnitude and direction
Addition rule:	Simple arithmetic	Parallelogram law
Special Notation:	None	Bold font, a line, an arrow or a “carrot”

Biomechanics to biology and physics (mechanics)



From a Cell to ....

Cell : The fundamental, structural, and functional unit of living organisms.

Cell → Cellulea “little rooms.” (Latin)

This terminology was coined by Hooke (1635-1703) who was perhaps the first to describe a cellular structure.

Biomechanics and Related Areas

- **Kinesiology :** Multidisciplinary study of human motion, including the anatomical, biomechanical, cultural, motor, pedagogical, physiological, psychological, and sociological aspects of motion.
- **Ergonomics :** Discipline concerned with human-machine interaction. Ergonomists use many biomechanical techniques in analyzing the work environment.

Anthropometry

Anthropometry is the discipline that studies measurements of the body and body segments in terms of height, weight, volume, length, breadth, proportion, inertia, and other properties related to shape, mass, and mass distribution. Anthropometrics basically describe the shape of the system.

- **Body mass index** (BMI) : Ratio of body mass to height used to describe stature. *Kg/m2*
- **Ponderal index** (PI) : Ratio used to describe stature. *Kg/m3*
- **Crural index** (CI) : (length of tibia / length of femur) x 100

kg kilograms of body mass

m height in meters

Anatomy

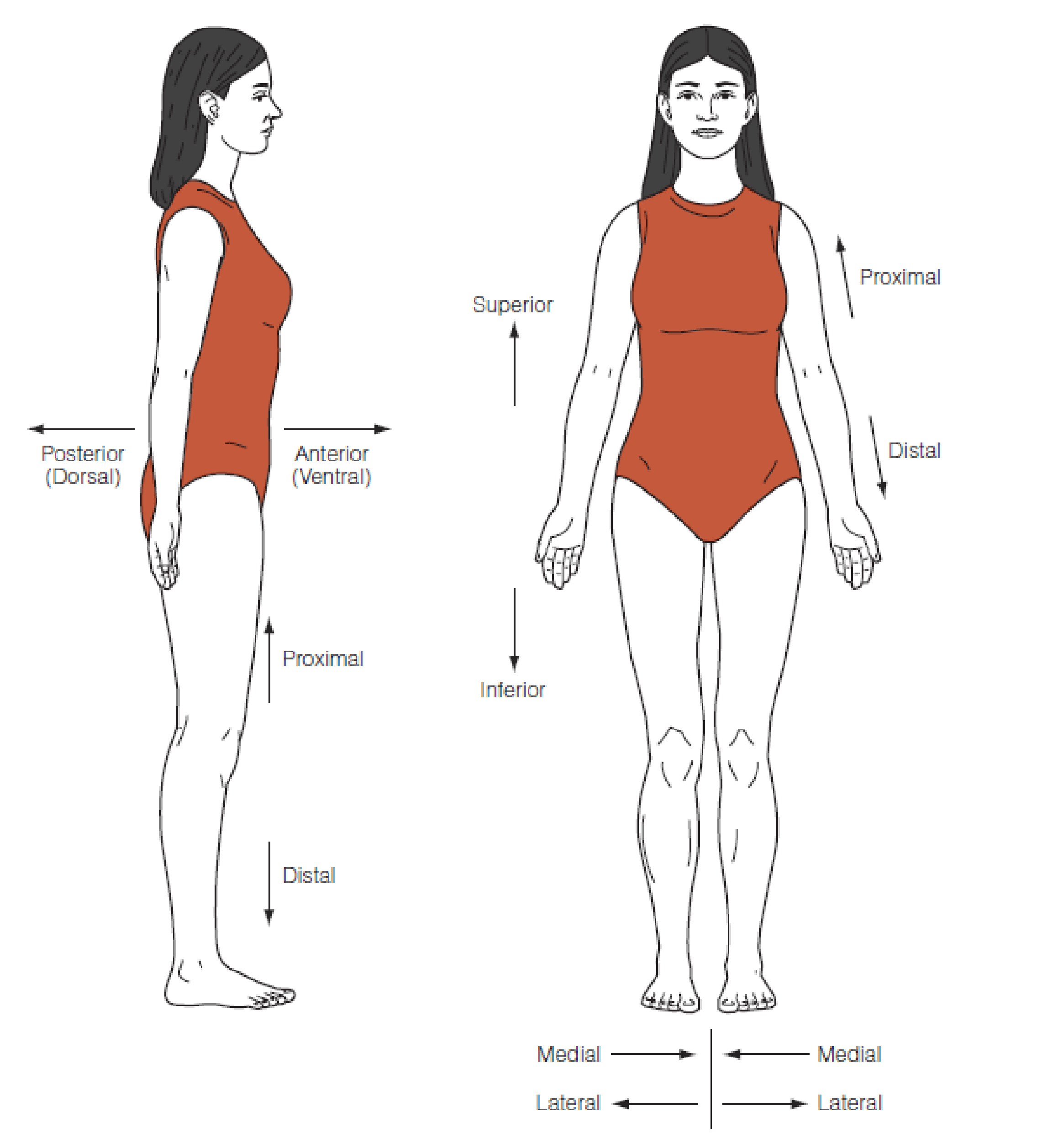
Terminology;

- To describe motion of the human body with consistency, researchers must have a common reference system and use consistent terminology. Much of the vocabulary used in biomechanics (and in most other movement-related disciplines) is derived from the field of anatomy.

Anatomical position

Reference position defined by standing erect with all joints extended, feet parallel, palms facing forward, and fingers together

The anatomical reference position with directions indicated.



Directional Terms

- ***Superior*** and ***inferior*** are used to describe being toward or closer to the head and feet, respectively. For example, the knee is superior relative to the ankle, but inferior to the hip. Cephalo or cranial may be used instead of superior, and caudal is sometimes used in place of inferior.
- ***Anterior*** means toward the front of the body, and posterior refers to being toward the rear of the body. The pectoralis muscles are anterior to the heart. Alternative terms for anterior and posterior are ventral and caudal, respectively.

Directional Terms

- ***Medial* and *lateral*** indicate position or movement toward and away from the midline of the body, respectively. One of the quadriceps muscles iscloser to the midline, and one is farther away from the midline: thus, the names *vastus medialis* and *vastus lateralis*.

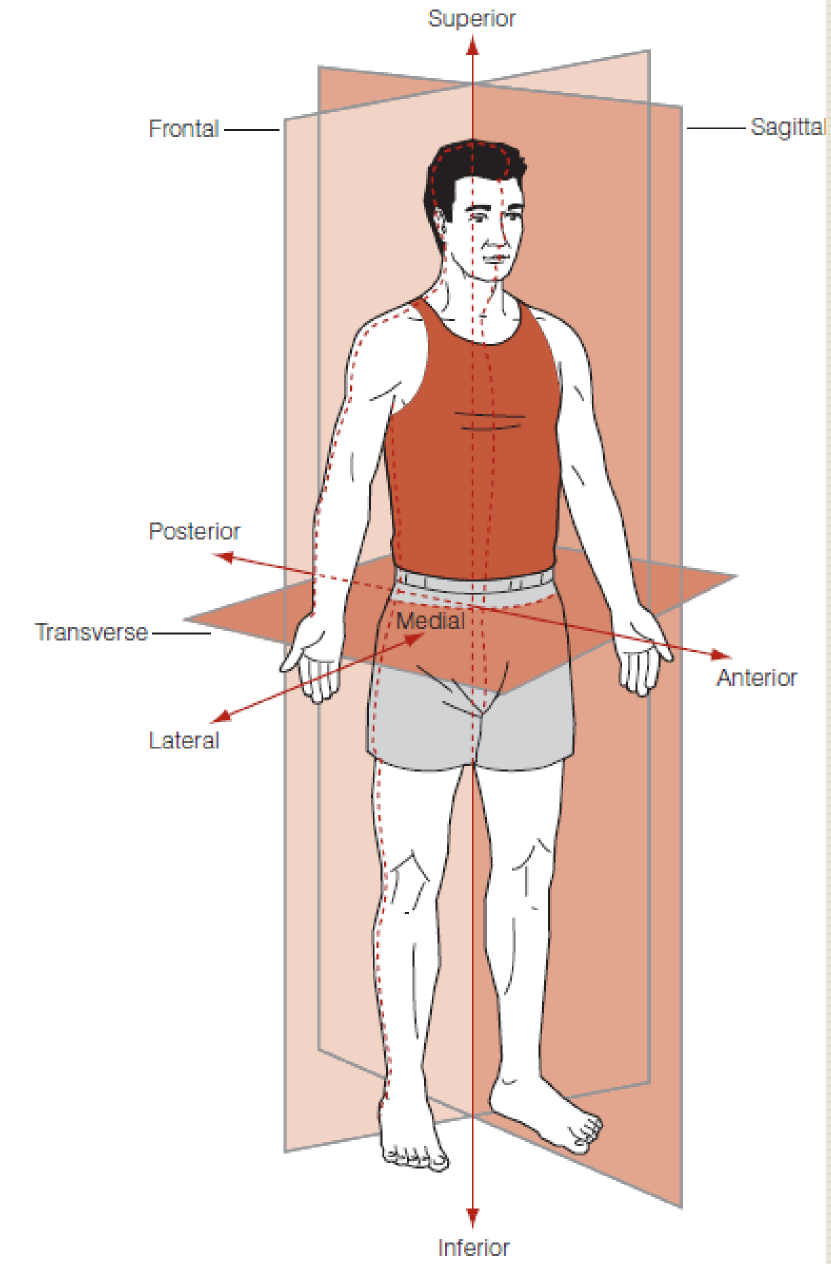
- ***Proximal*** means closer to the attachment of a limb to the body, and *distal* indicates having a position farther from the attachment of the limb to the body. The carpals are proximal to the phalanges.

- ***Superficial*** and ***deep*** describe relative proximity to the surface of the body. The gastrocnemius is superficial to the soleus.

Planes of system motion

Cardinal plane Plane that passes directly through the midline of the body. Includes :

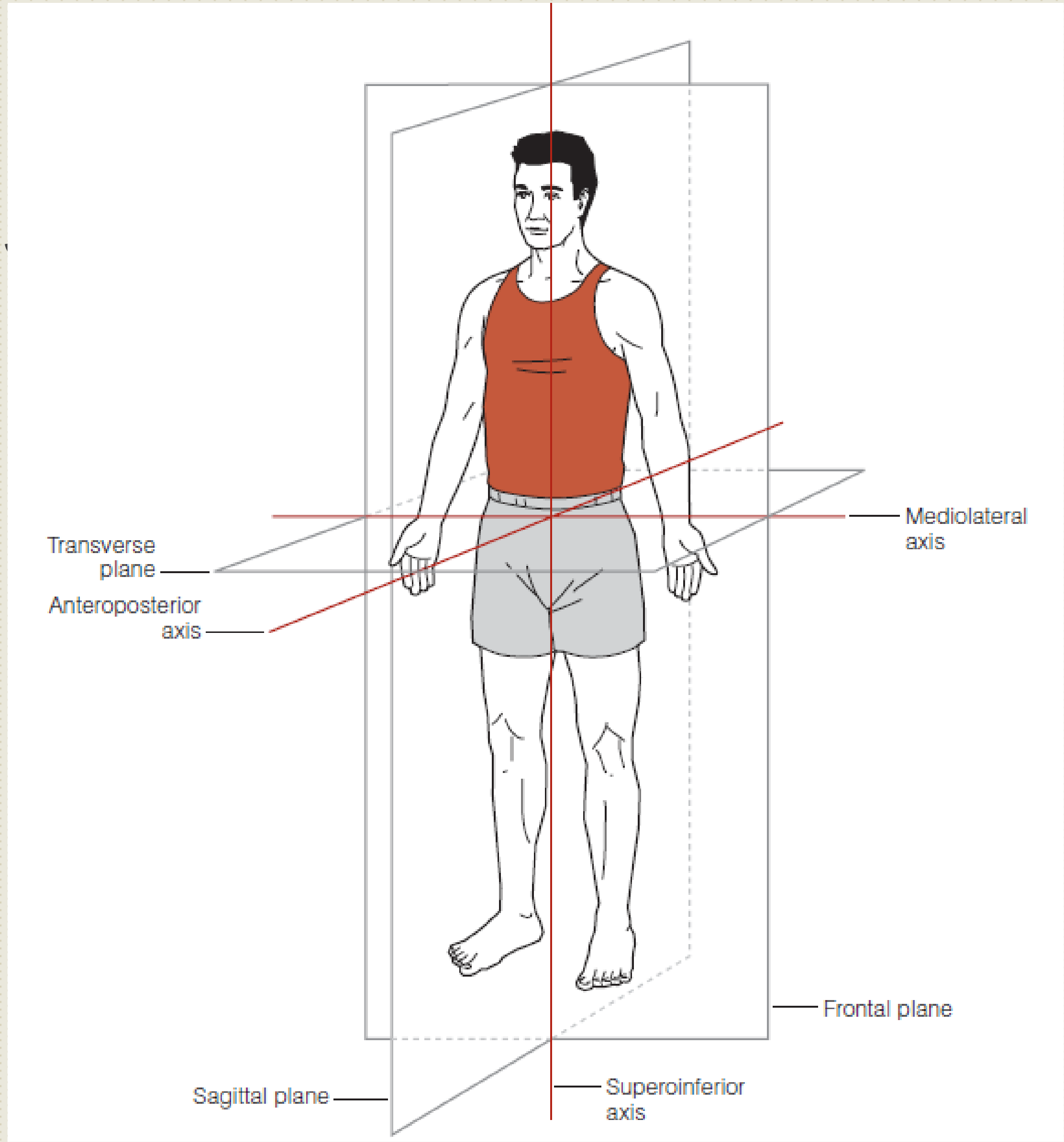
- **Sagittal plane** Vertical plane dividing the body into right and left halves.
- **Frontal plane** Vertical plane dividing the body into anterior and posterior halves.
- **Transverse plane** Horizontal plane dividing the body into superior and inferior halves.



Axes of system motion

A segmental movement describes a plane (*planar* motion) that rotates around a theoretical axis (*axial* motion). as there are three cardinal planes, there are three axes of rotation:

- *mediolateral*
- *anteroposterior*
- *superoinferior*



Axes of system motion

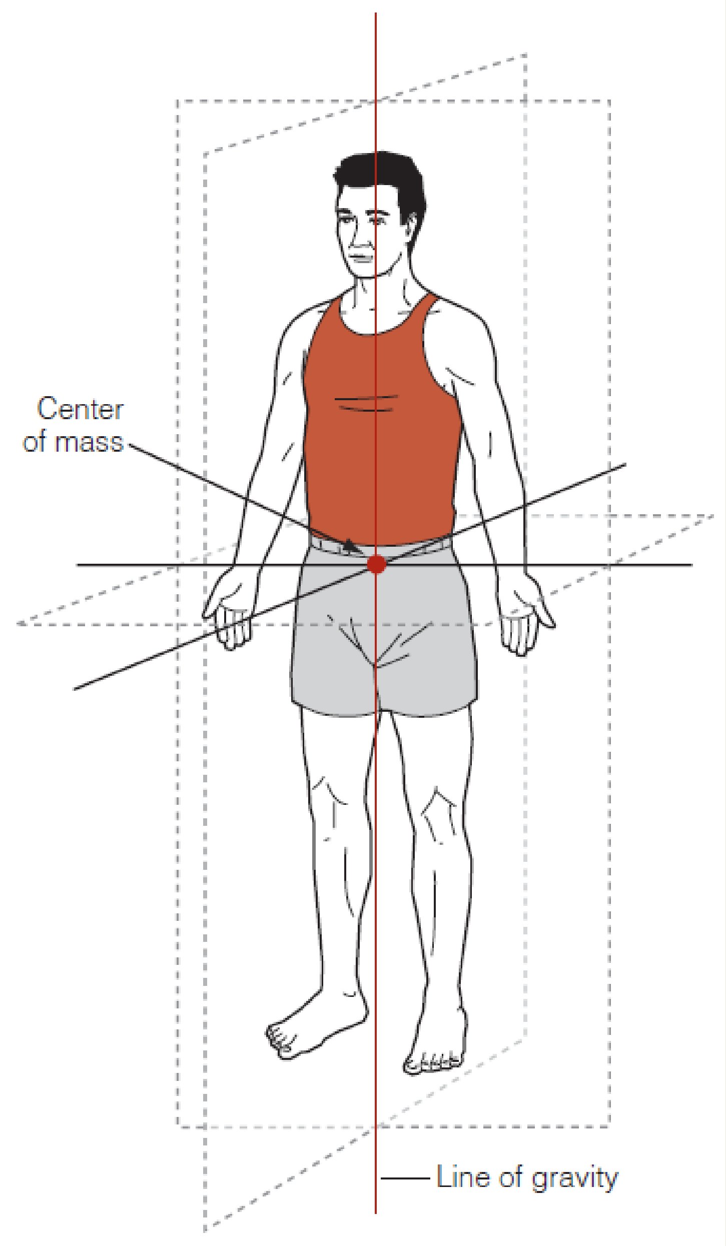
- **Mediolateral axis** Axis that passes horizontally side-to-side and is perpendicular to the sagittal plane.

- **Anteroposterior axis** Axis that runs horizontally from front to back and is perpendicular to the frontal plane of motion.

- **Superoinferior axis** Axis that passes up and down and is perpendicular to the transverse plane.

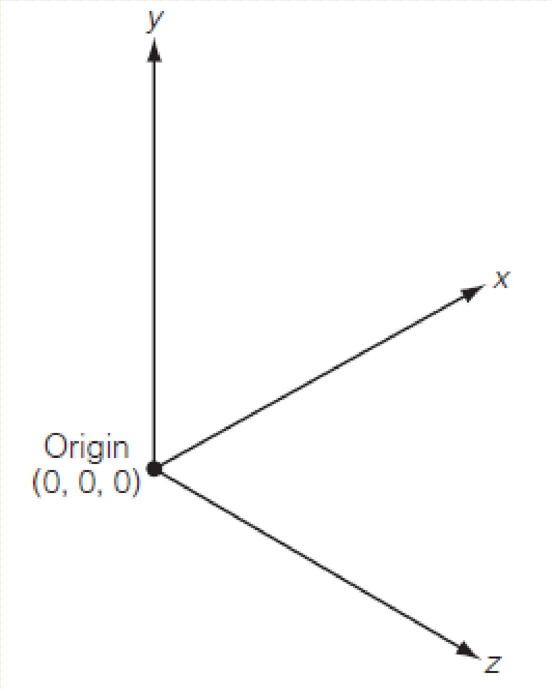
Planes, Axes, and the Center of Gravity

- The cardinal planes divide the body into equal mass halves. Axes are formed by the intersections of two planes. Because the cardinal planes bisect the body, they must also pass through the **center of mass.**
- Gravitational pull is concentrated at the center of mass. So at least in the vertical axis, the center of mass can be considered synonymous with the **center of gravity.**



Spatial Frames Of Reference

- To fully describe motion of the body system and its segments, we must be able to specifically define its position or location in space. This goal is achieved by establishing one or more frame of reference within a **Cartesian** or **rectangular coordinate system**. An **origin** and two or three orthogonal axes (each passing through the origin and defining one spatial dimension) are used to define a Cartesian coordinate frame of reference.



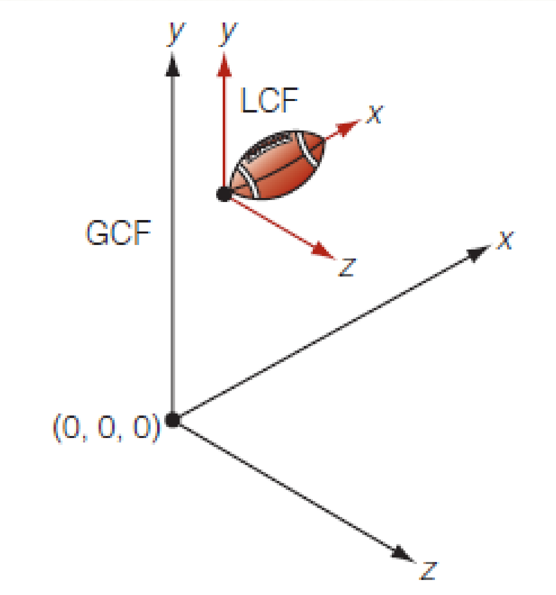
Global Reference Frame

- Fixed axes relative to the system, one of which is parallel to the ground, define the reference frame. This type of reference frame is called *global* (also absolute, fixed, stationary, and inertial or Newtonian). A **global reference frame** allows the position of any single point to be specified with respect to the defined origin. In other words, this frame is used to describe movement of the *entire* system as a whole relative to the start.

- However, to clearly describe the orientation of the entire system or the individual segments of the system (as opposed to defining the system as a single point moving in space), we must construct another reference frame within our global frame that moves with the system.

Local Reference Frame

- Second frame of reference is called **local** (also anatomical, cardinal, moving, relative, segmental, and somatic) and has an origin and axes attached to the body. The origin of the local reference frame is established at the center of mass of the system or a system segment. The axes are orthogonal, have the same handedness as the global frame, and are aligned with those of the global frame when the system is in the anatomical position



Definitions

- **Center of mass** The point that represents the average location of a system’s mass.
- **Center of gravity** The point at which the force of gravity seems to be concentrated.
- **Line of gravity** A vertical line representing gravity that passes though a system’s center of mass.
- **Cartesian or rectangular coordinate system** A frame of reference defi ned by an origin and two or three orthogonal axes, each passing through the origin and defining one spatial dimension.
- **Origin (O)** A stationary point in the environment, from which all measurements are made.

Definitions

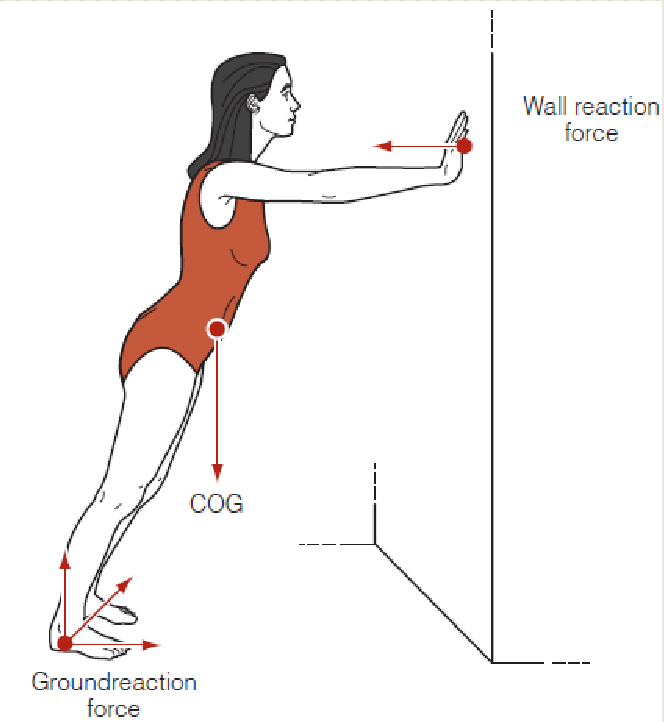
- The center of mass (or center of gravity) of the system is at the intersection of the three cardinal planes. All forces can be represented with a line that possesses specific characteristics. Gravity can be represented with a line called the **line of gravity** that passes through the center of mass.

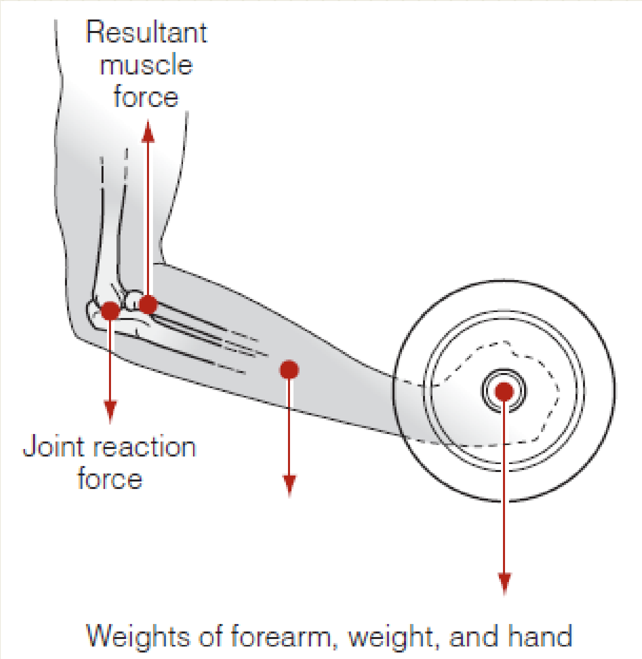
Definitions

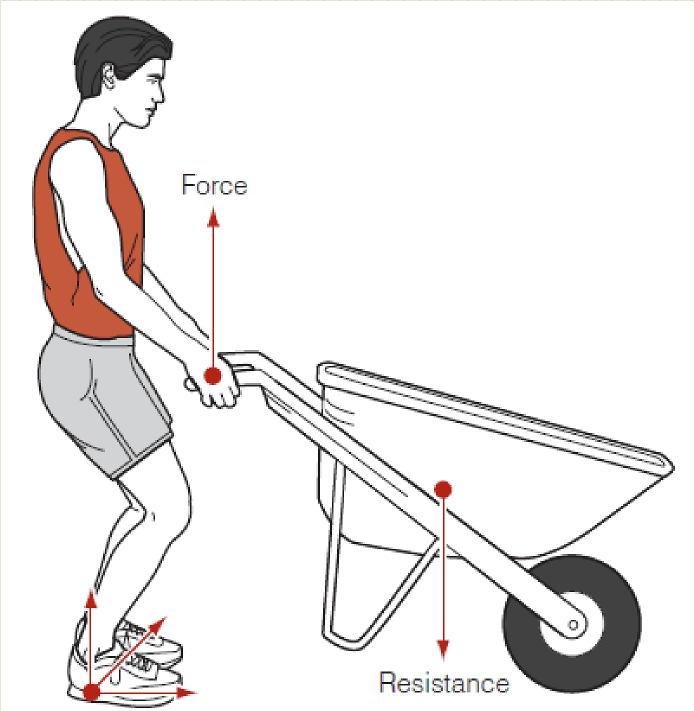
- **Roll** Rotation of a system around the *x* axis.
- **Yaw** Rotation of a system around the *y* axis.
- **Pitch** Rotation of a system around the *z* axis.
- **Degrees of freedom (DOF)** The number of independent ways in which a system can move.

Free Body Diagram

- A **free-body diagram** is a simplified representation of the system *free* of the movement environment. The center of mass must be presented because it is the point at which the force of gravity is concentrated. Points of contact with the environment are important because these are areas where the system is acted upon by external forces.

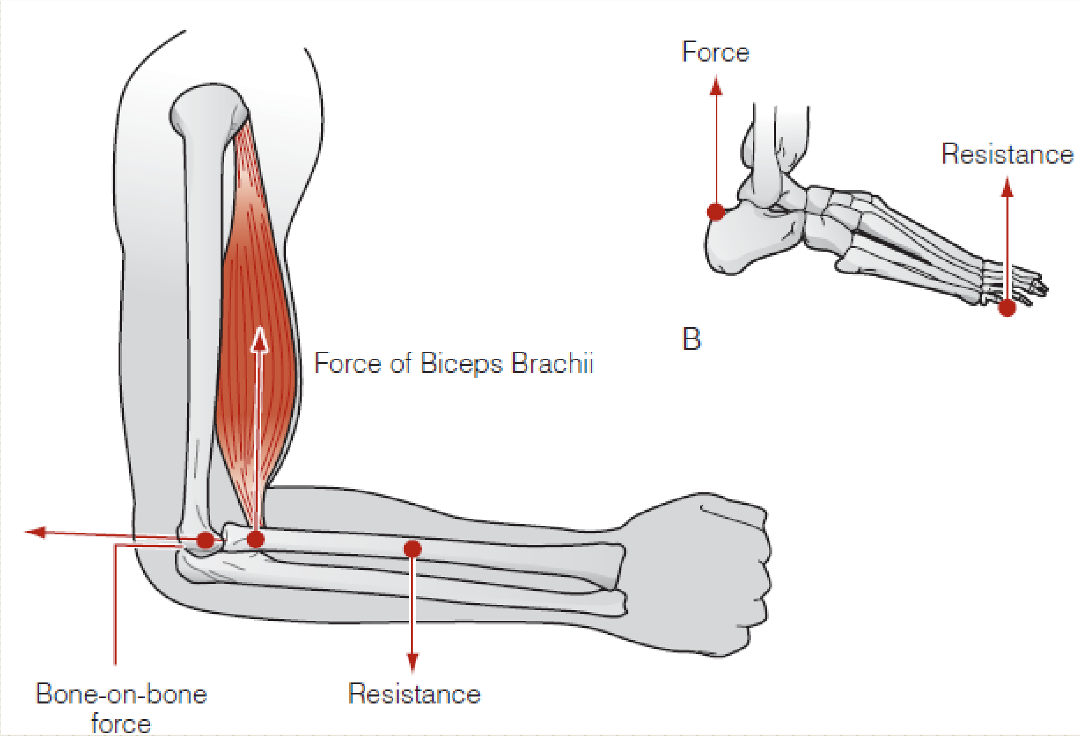


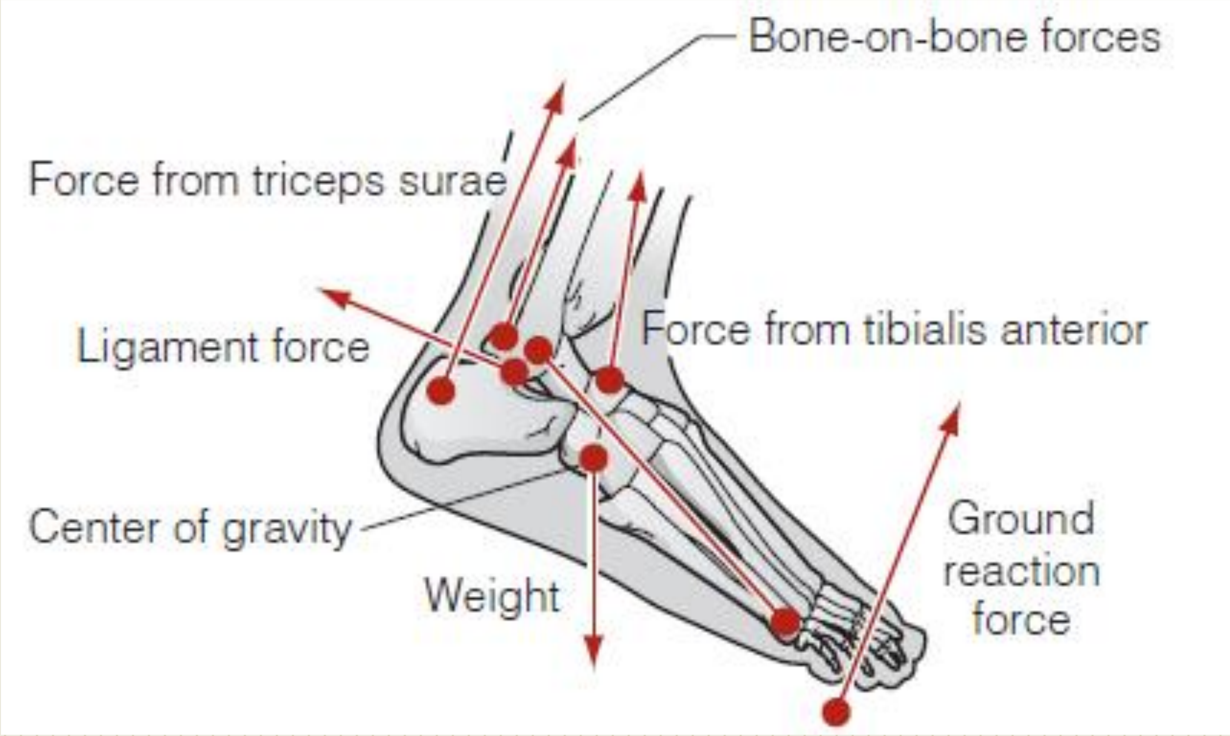




Free Body Diagram

- In situations in which a joint (segmental link) in the body is the system of interest, internal forces such as muscle forces and forces at the link itself (joint reaction forces) are usually represented along with the center of mass and environmental contact points (external forces).



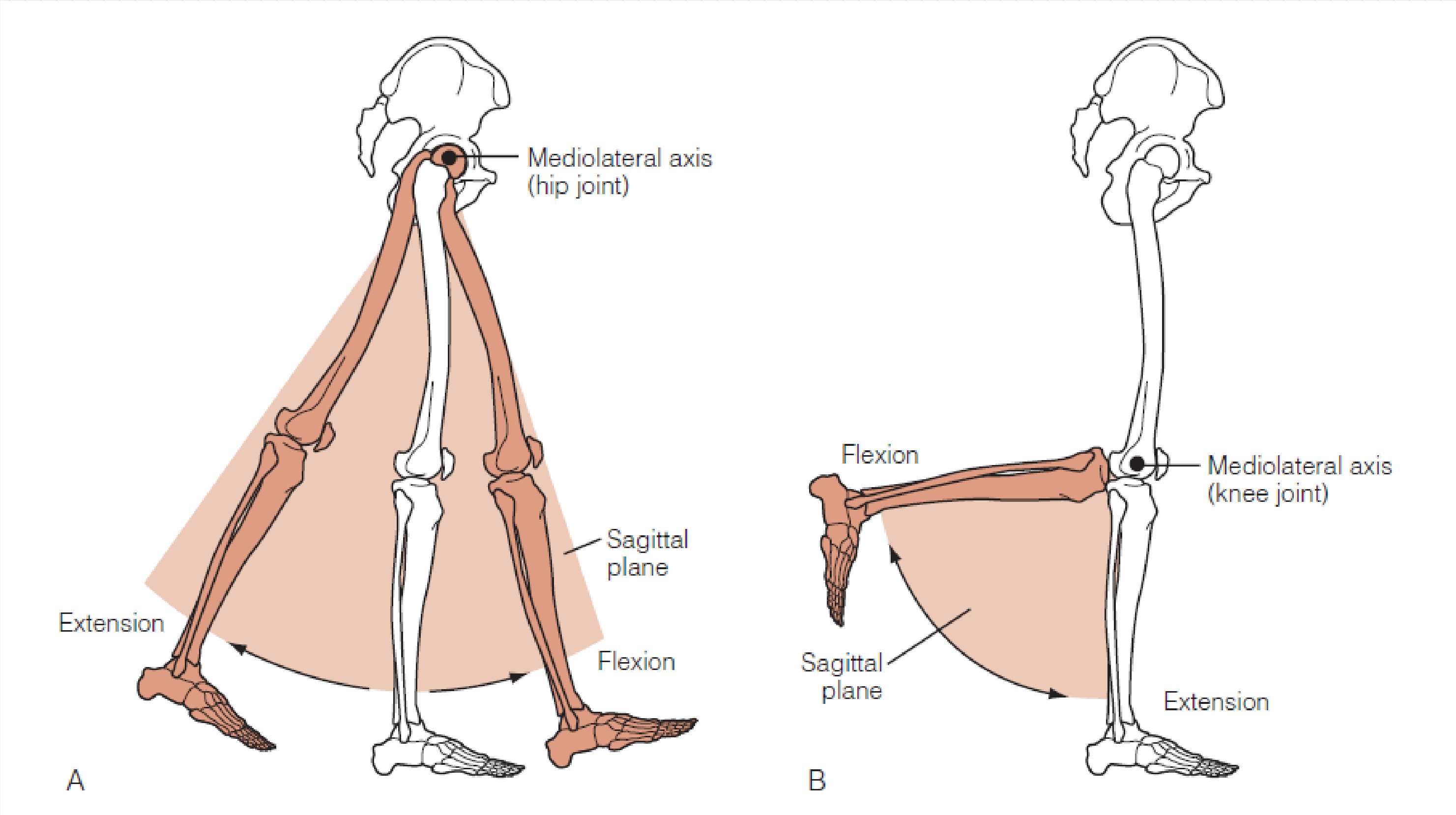


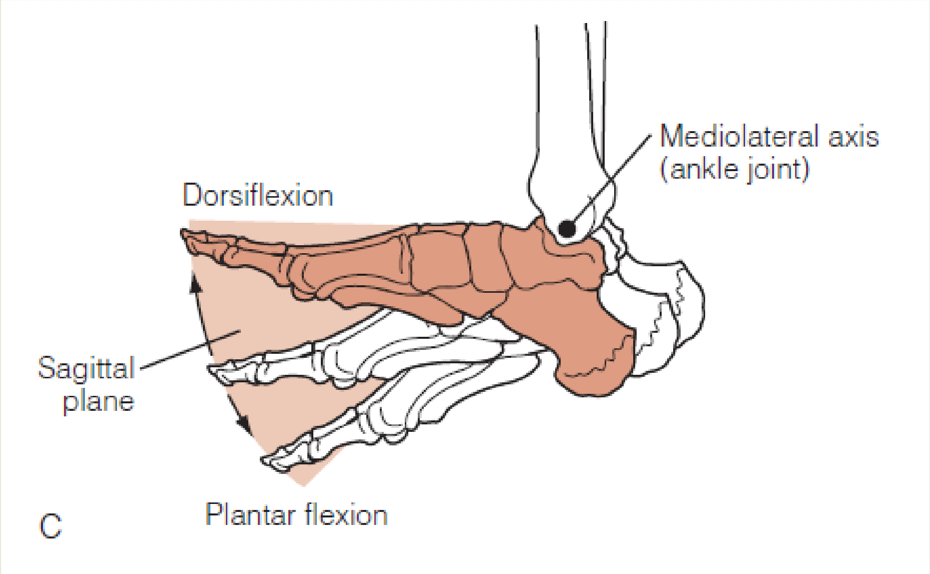
Motions in Sagittal Planes

Most body segmental links (joints) possess degrees of freedom in the sagittal plane: ankle (talocrural), elbow, hip, interphalangeal, intervertebral, knee, shoulder (glenohumeral), and wrist.

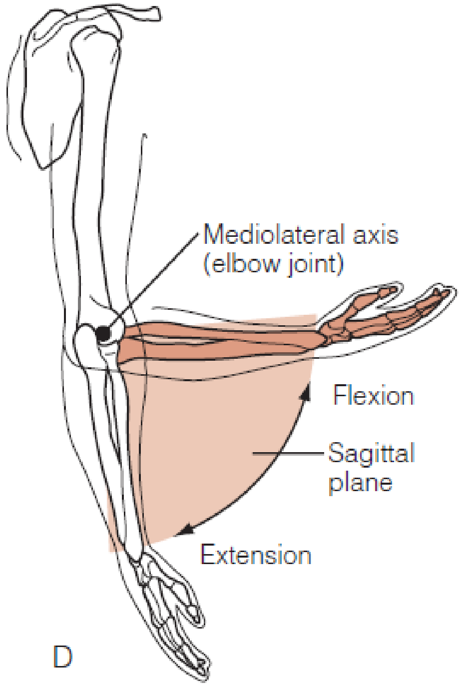
- **Flexion :** Segmental motion in a sagittal plane, around a mediolateral axis, and away from the anatomical position.
- **Extension :** Returns a segment to the anatomical position in a sagittal plane around a mediolateral axis and is described as increasing the angle at the joint.

Motions in Sagittal Planes





Motions in Sagittal Planes



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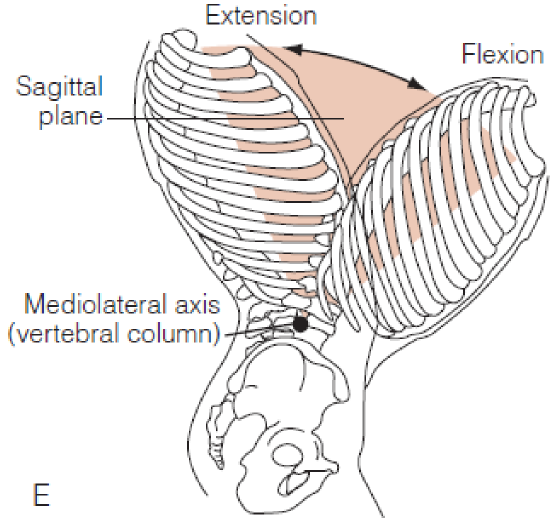

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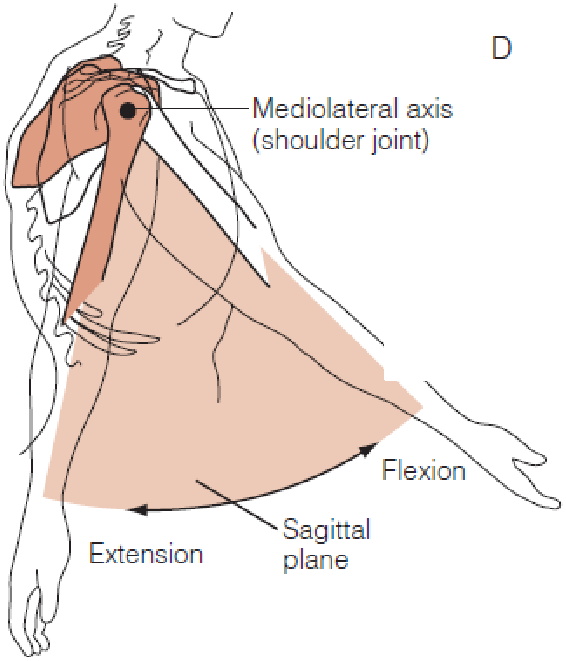

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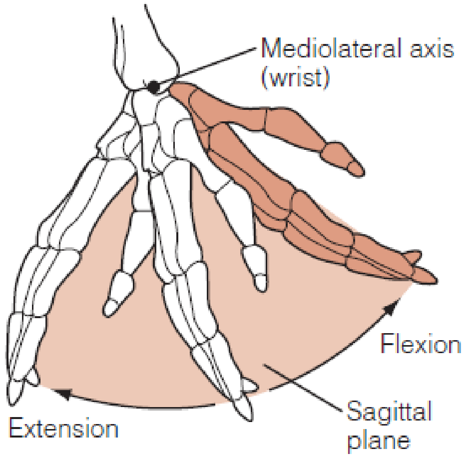

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Motions in Frontal Planes

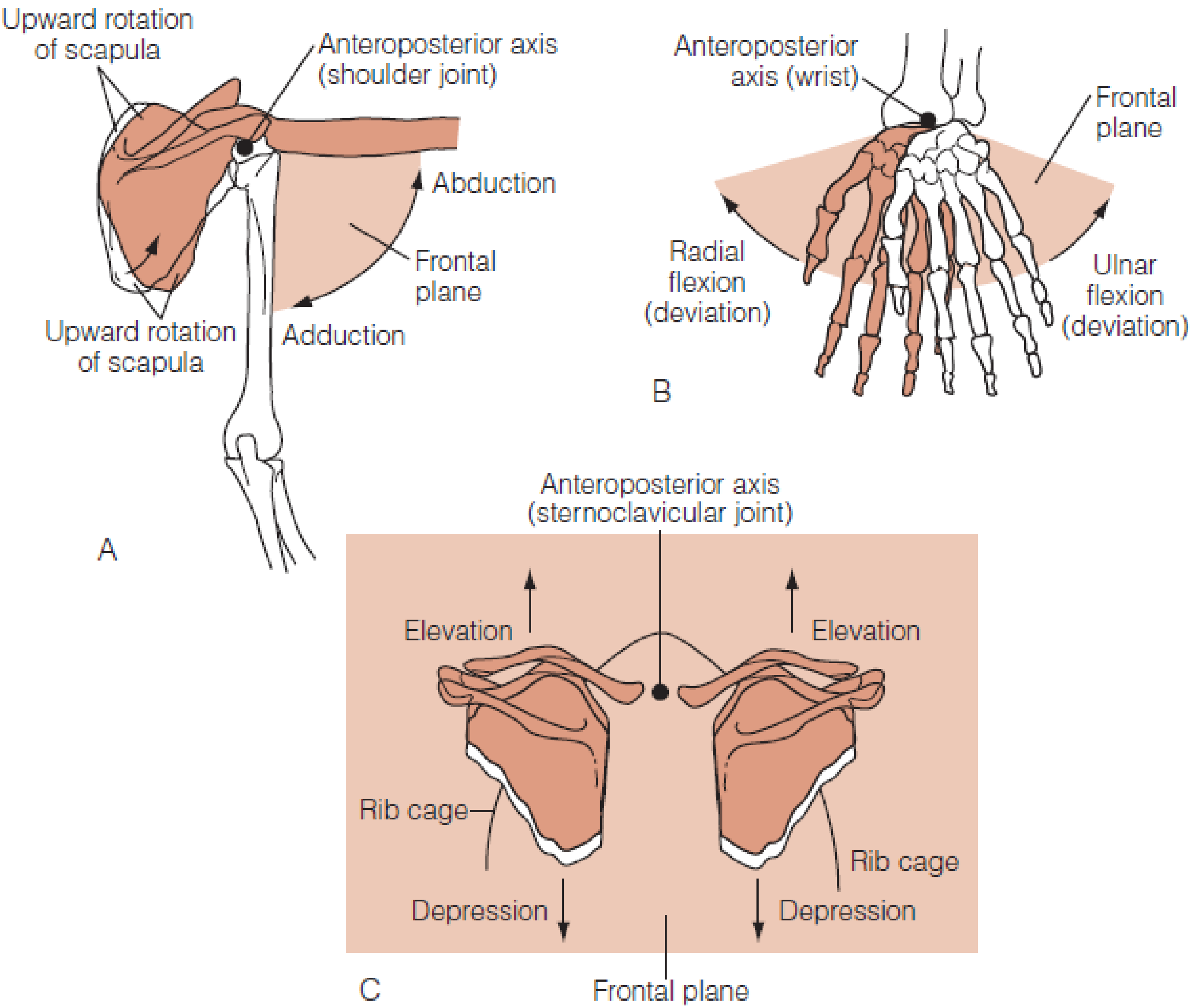
- Body segmental links that are capable of frontal plane motion (around an anteroposterior axis) are the foot (subtalar and transverse tarsal joints), hip, intervertebral, metacarpophalangeal, shoulder, and wrist.

- **Lateral flexion :** Motion of the axial skeleton (at the intervertebral joints) in the frontal plane around an anteroposterior axis.
- **Abduction :** Motion in a frontal plane and around an anteroposterior axis that moves the segment away from the anatomical position.
- **Adduction :** Frontal plane motion that returns the segment to the anatomical position.

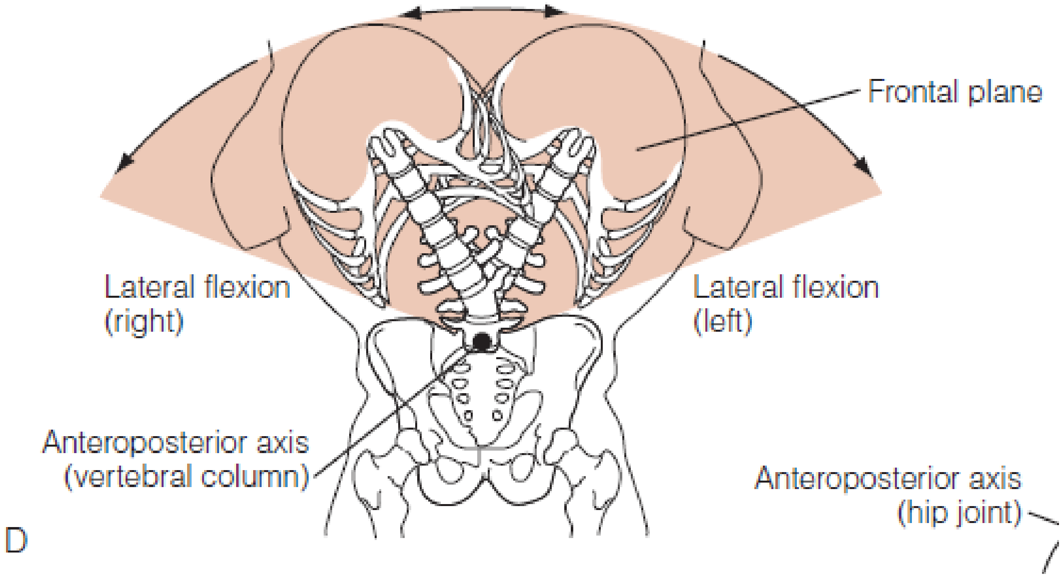
Motions in Frontal Planes

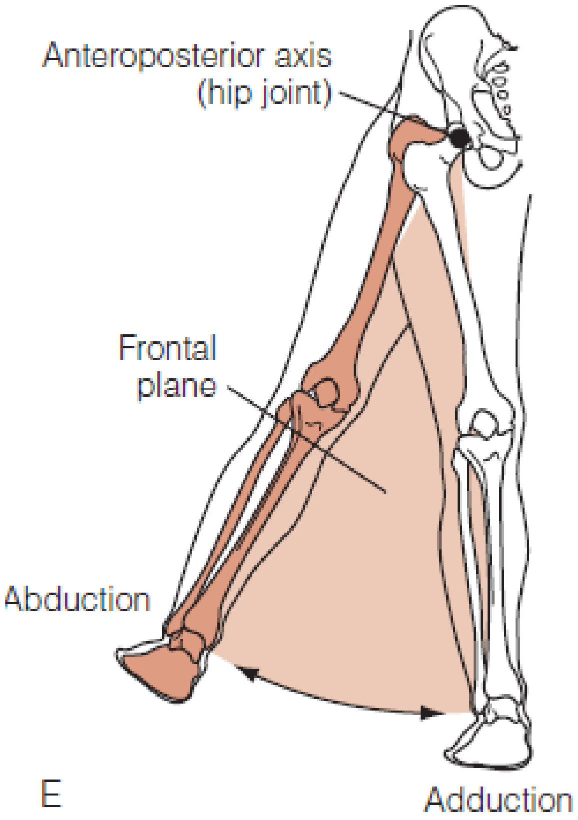
- **Eversion :** Frontal plane motion around an anteroposterior axis such that the sole of the foot rotates outward or laterally.
- **Inversion :** Frontal plane motion around an anteroposterior axis such that the sole of the foot rotates inward or medially.
- **Deviation :** Frontal plane motion around an anteroposterior axis at the wrist.

Motions in Frontal Planes



Motions in Frontal Planes

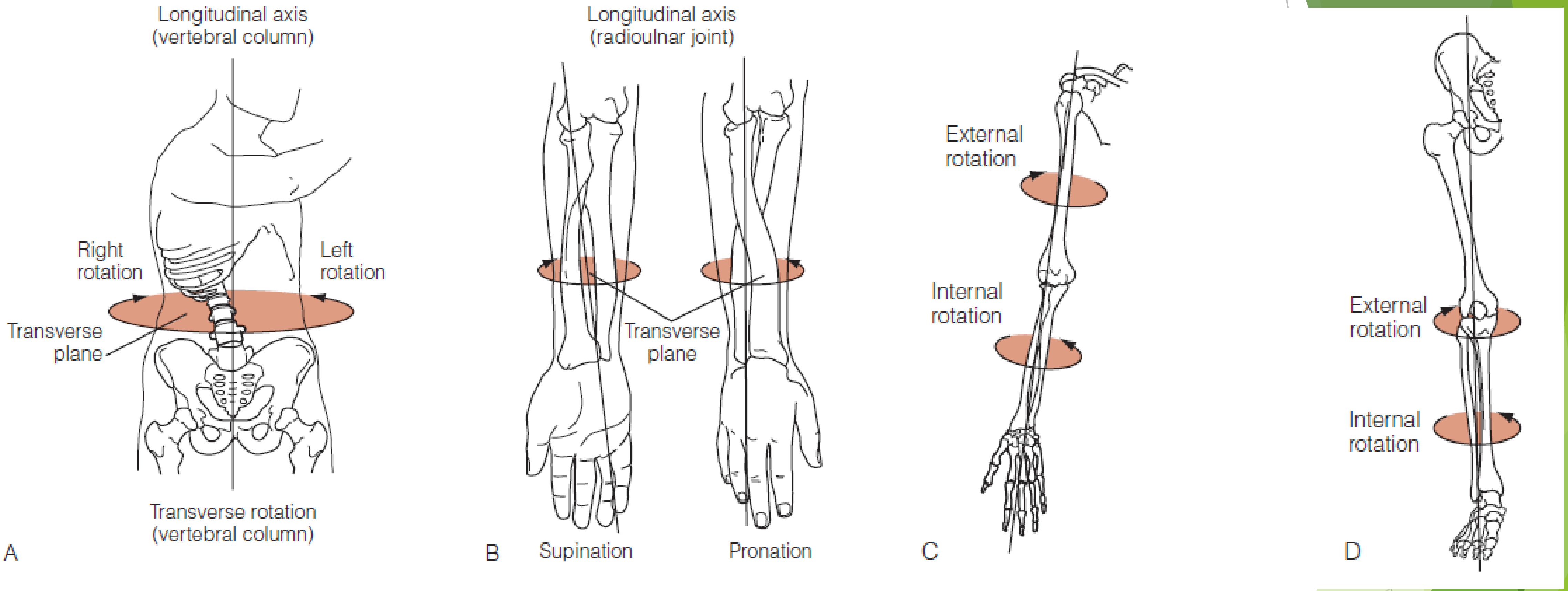




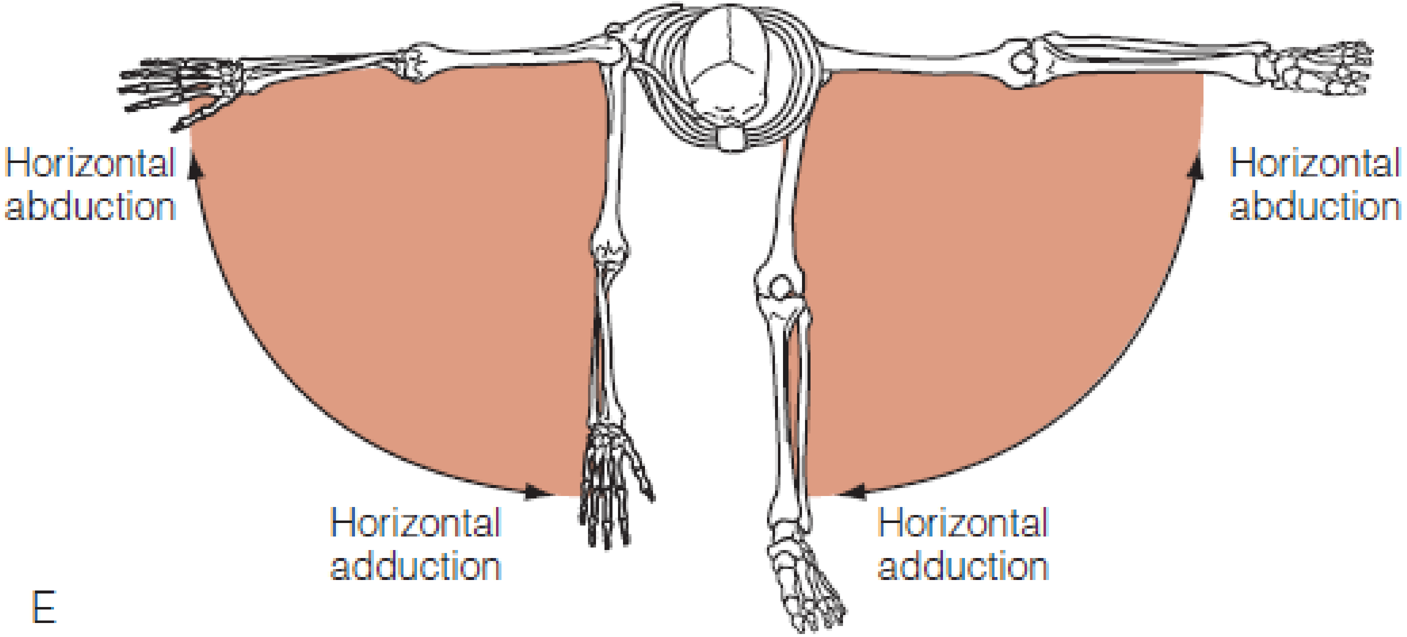
Motions in Transverse Planes

- Skeletal segmental links with DOF in the transverse plane (around a superoinferior axis) directly from the anatomical position are the hip, intervertebral, shoulder, and radioulnar
- **Pronation :** Rotation at the radioulnar joint around a superoinferior axis that causes the palm to turn toward the body (medially and posteriorly).
- **Supination :** Transverse plane motion that returns the radioulnar joint toward the anatomical position (palm moves anteriorly).

Motions in Transverse Planes



Motions in Transverse Planes

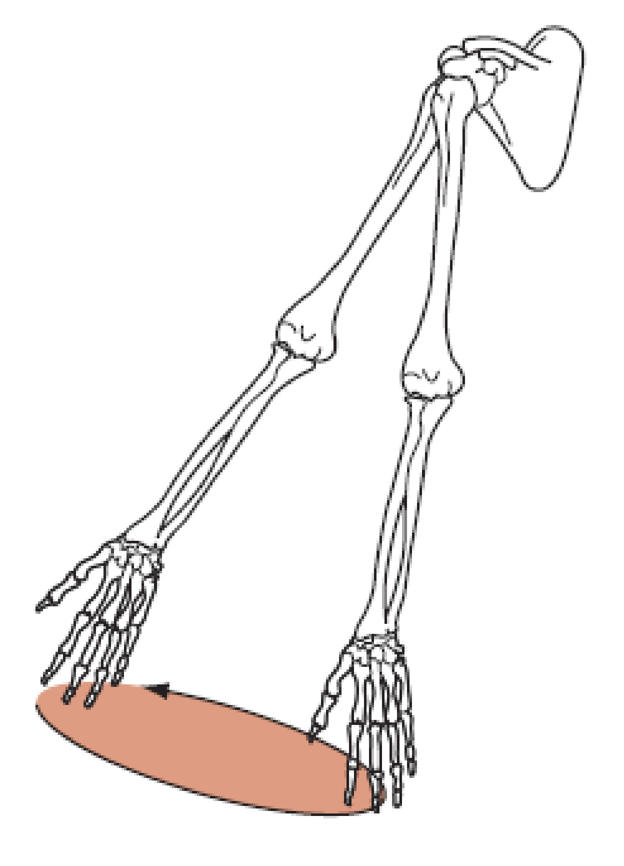


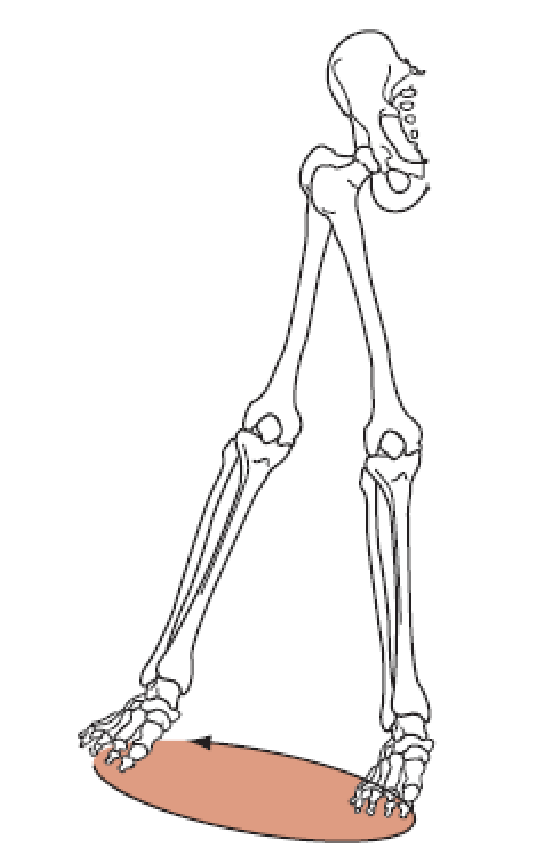
Motions in Oblique and Multiple Planes

- Some segmental link motions do not fi t into the cardinal planes and axes described. Planes and axes can be oblique. Therefore, if a segment is moved into an oblique plane before the motion of interest occurs, the segmental link motion is also oblique or diagonal (e.g., oblique abduction). In addition, movements can occur in more than one plane of motion, and some motions occur in planes but not around axes.

Motions in Oblique and Multiple Planes

- One segmental link motion that occurs in more than one plane (around more than one axis) is called ‘**circumduction**’





Using Terminology

Discussions of planes, axes, directions, and segmental motions:

- As can be seen, the cardinal planes (sagittal, frontal, and transverse) and axes (mediolateral, anteroposterior, superoinferior) are very useful for the description of musculoskeletal movement *from the anatomical position*.
- As the anatomical position is a constant starting reference point, it is accompanied by cardinal axes (and planes) that are always the same. However, natural motion does not often begin in the anatomical position.

Using Terminology

- We need the ability to establish frames of reference outside of the body and independent of the anatomical position.

- We need to define multiple frames of reference. Cartesian coordinate frames of reference are very versatile. The *x*, *y*, and *z* are not only *axes* that can be used in place of the cardinal axes but also form a frame of reference in terms of *planes* and *directions* of motion of both individual segments and the entire system.

Movement

- **Motion :** A change in position with respect to both spatial and temporal frames of reference.
- **Force :** Something that possesses the capability to cause a change in motion or shape of the system.
- **Relative motion :** The motion of one object with respect to a reference object.
- **Translation :** Motion along one of the x, y, or z axes; linear motion.
- **Rotation :** Motion around a fixed axis and therefore in a circular path; angular motion.

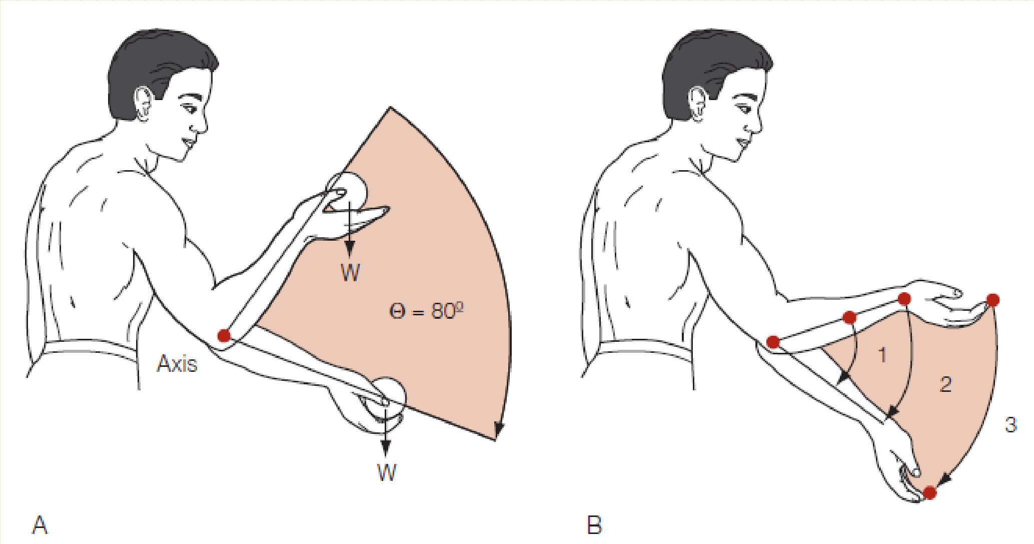
Movement

Translation :

- The linear path of a system in translation can be straight or curved. If the path of the system is a straight line (i.e., no change occurs in direction of motion), the motion is termed '***rectilinear translation***'.
- **'Curvilinear translation'** is the same as rectilinear in terms of the points on the system moving together, but in this case the path of the representative point is curved (in an arc) instead of straight (i.e., direction of system motion is changing).

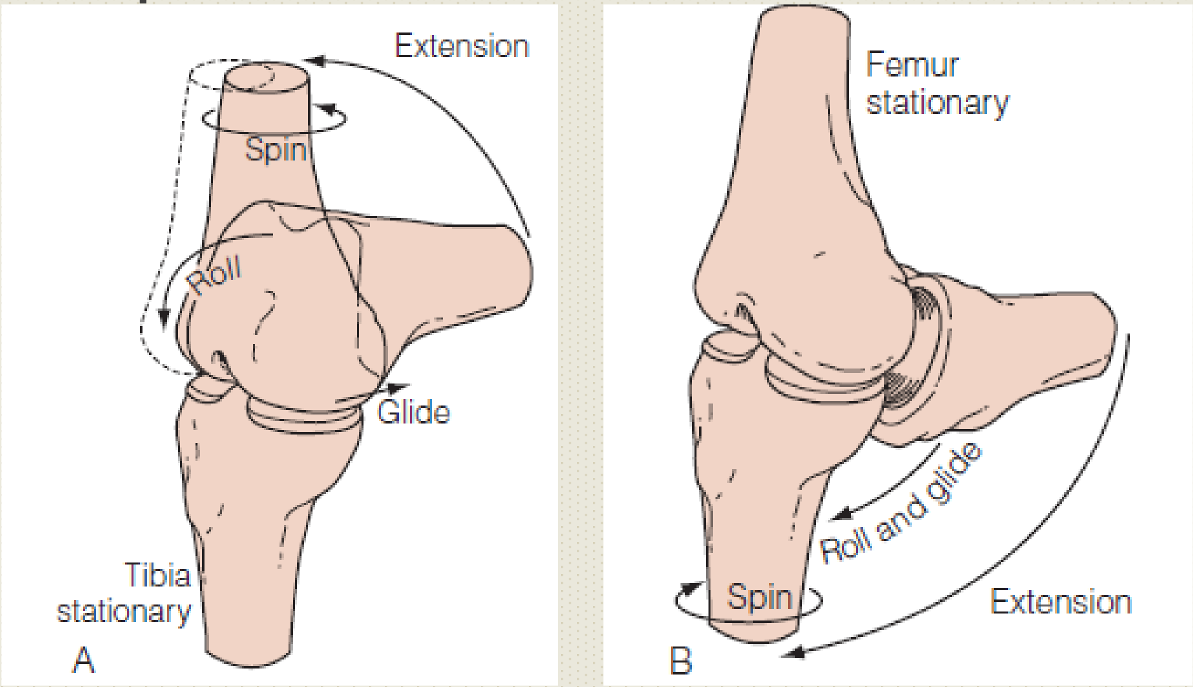
Movement

- Because the path of motion of one point on a rotating system or system segment describes a circle (and therefore the location of one segment relative to another forms an angle), rotation is also called ‘**angular motion’**. In the case of rotation, all points on the rotating segment have the same *angular displacement* (; the Greek letter theta), measured in degrees or radians. Each of the points on a rotating segment has a different curvilinear displacement depending upon its distance from the axis of rotation, called the ‘**radius of rotation’**



Movement

- **Spin :** Occurs if all points on one articulating surface come in contact with one point on another articulating surface.
- **Glide :** Sliding or pure translation in which a point on one surface glides or skids over many points of an opposing surface.
- **Roll :** A combination of rotation and translation in which each point on a surface contacts a unique location on the other surface.



Movement

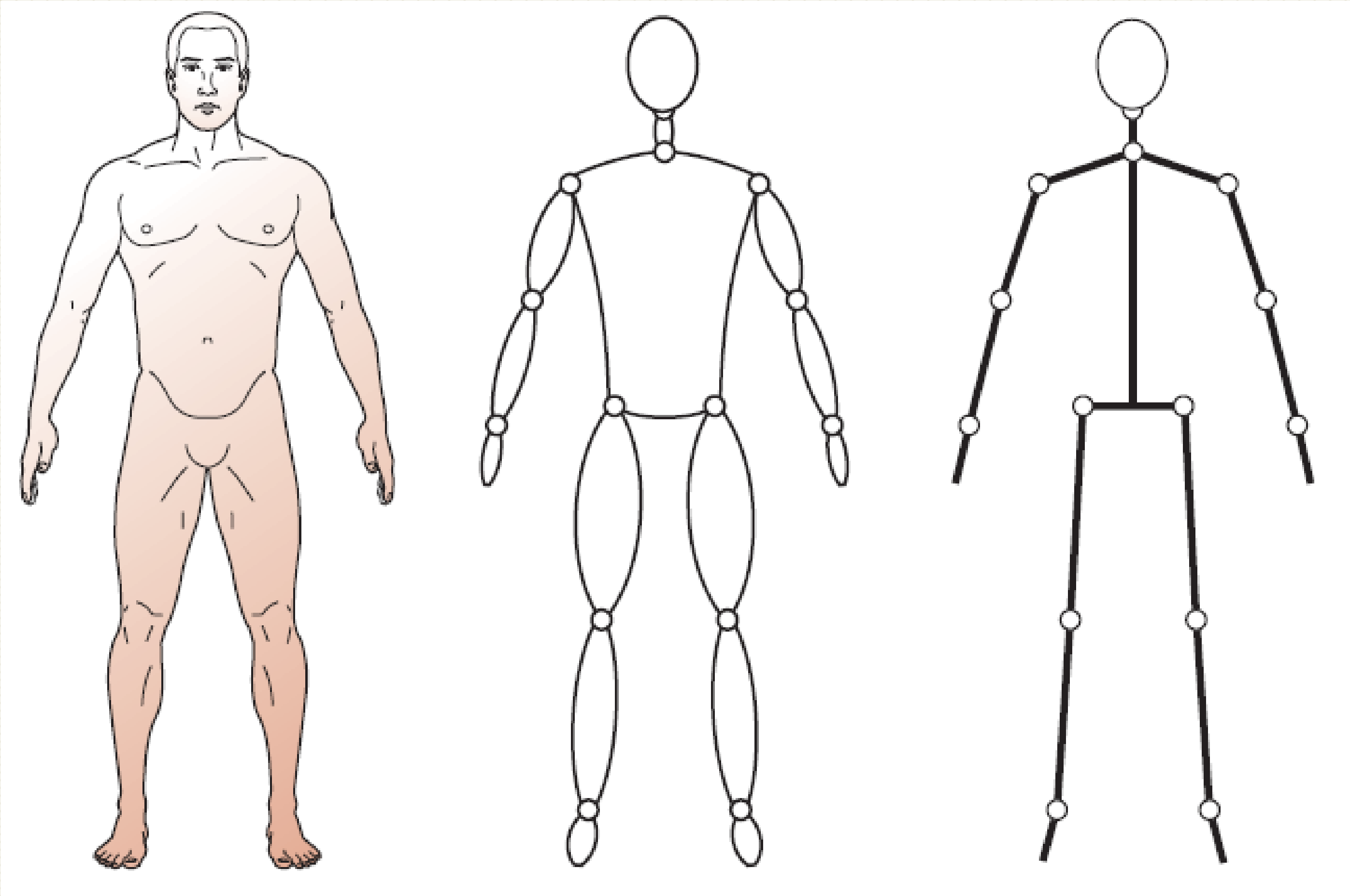
- In trying to describe motion of the system, using simplified models (such as the free-body diagrams referred to earlier) is sometimes helpful. Thus far in the process of defining the system and describing its movements, we have modeled the human body system as having multiple segments connected at links (joints).
- At the basic structural and movement levels, a ‘**kinetic chain’** is simply a system of linked rigid bodies subject to force application. Because all of the segments in the chain are linked together, motion at one link in the chain affects force transfer and therefore motion at one or more other links in the chain.

Movement

- **Kinetic chain :** System of linked rigid bodies subject to force application.
- **Serial or simple kinetic chain :** Kinetic chain in which each segment participates in no more than two linkages.
- **Complex kinetic (kinematic) chain :** Kinetic chain in which a segment is linked to more than two other segments.
- **Mobility :** The total degrees of freedom of a kinetic chain.

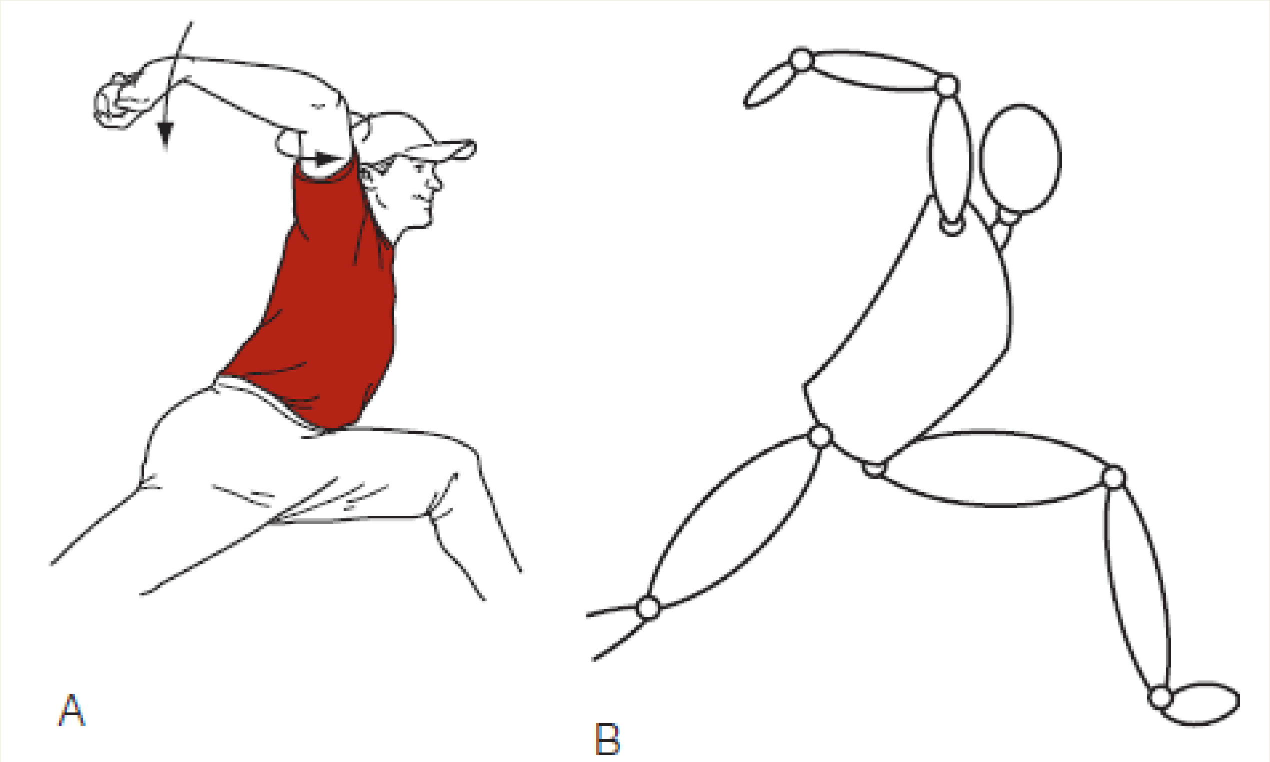
Movement

- Complex kinetic chain



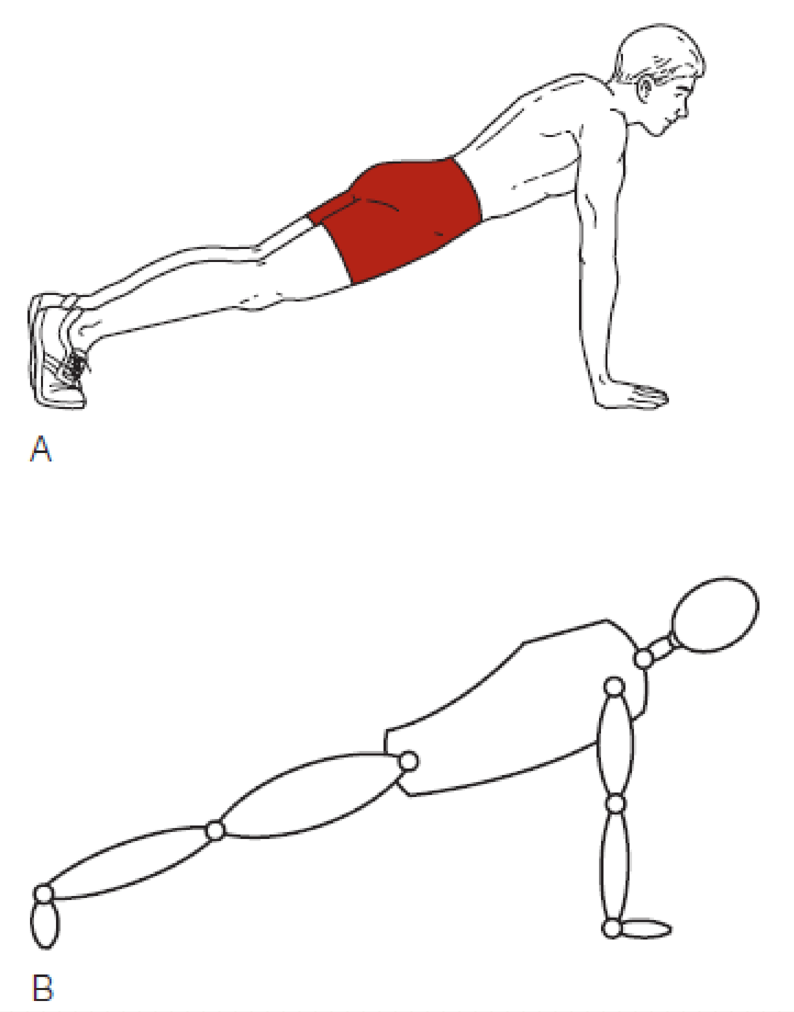
Movement

- **Open kinetic chain :** Kinetic chain in which motion can occur at one link in the chain without cooperative motion at other links.



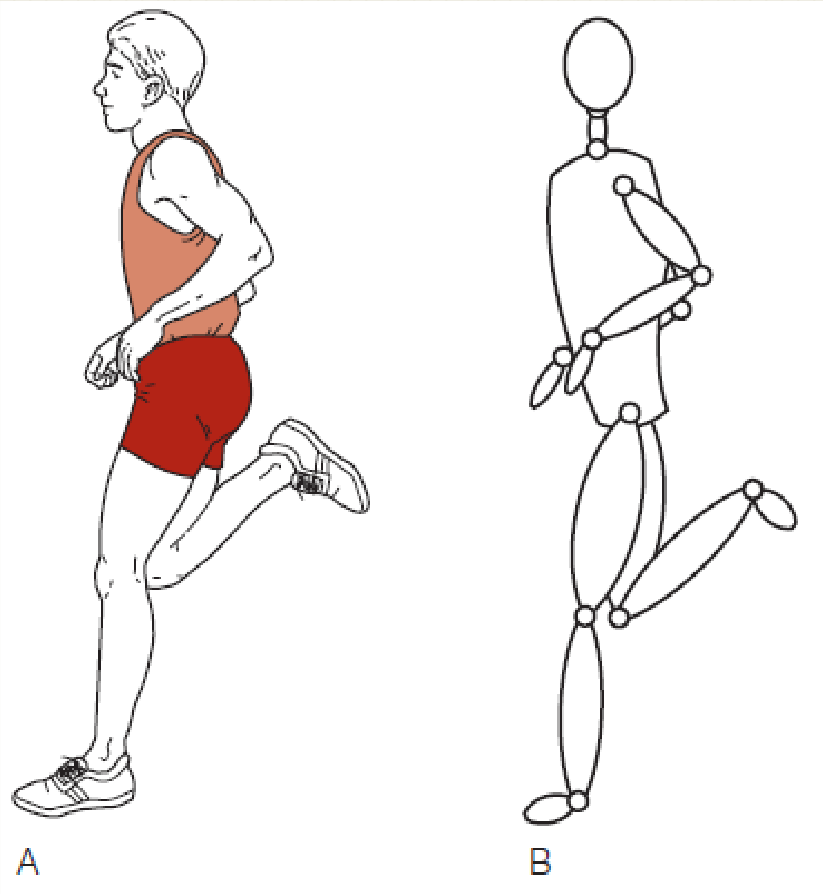
Movement

- **Closed kinetic chain :** Kinetic chain in which motion at one link is only possible with cooperative movement at other links.



Movement

- **Functional kinetic chain** A complex kinetic chain in which some links are involved in open chain motion and others are engaged in closed chain motion.



Movement

- **Functional Anatomy :** Skeletal muscles produce force required to move the joints through their many degrees of freedom. We usually represent muscle force with one vector, when in reality multiple muscles are responsible for the action at a given joint.

Motions in Transverse Planes

- In trying to describe motion of the system, using simplified models (such as the free-body diagrams referred to earlier) is sometimes helpful. Thus far in the process of defining the system and describing its movements, we have modeled the human body system as having multiple segments connected at links (joints).
- At the basic structural and movement levels, a '**kinetic chain**' is simply a system of linked rigid bodies subject to force application. Because all of the segments in the chain are linked together, motion at one link in the chain affects force transfer and therefore motion at one or more other links in the chain.

Motion of the System

Motion can be described in **qualitative** or **quantitative** terms. Quantitative and qualitative methods should be viewed not as competing, but rather as complementary, tools used to analyze movement

- **Qualitative Motion Analysis :** describes how the human body "looks" upon visual inspection as it performs skills, including its position in space, the position of body parts relative to each other, and in some cases the position of segments of body parts in relation to each other.
- **Quantitative Motion Analysis :** also helps one develop the ability to visually analyze motion to very quickly isolate the various factors affecting the performance. However, a more specific analysis is often needed. In other words, we sometimes need to quantify the movement. Quantitative analysis may stem from the simple need for deeper understanding of why the system moves the way that it does.

Qualitative Motion Analysis

<u>Composite approach</u> : Qualitative analysis approach that views the whole body as a system that progresses through stages or phases as it refines movement patterns.

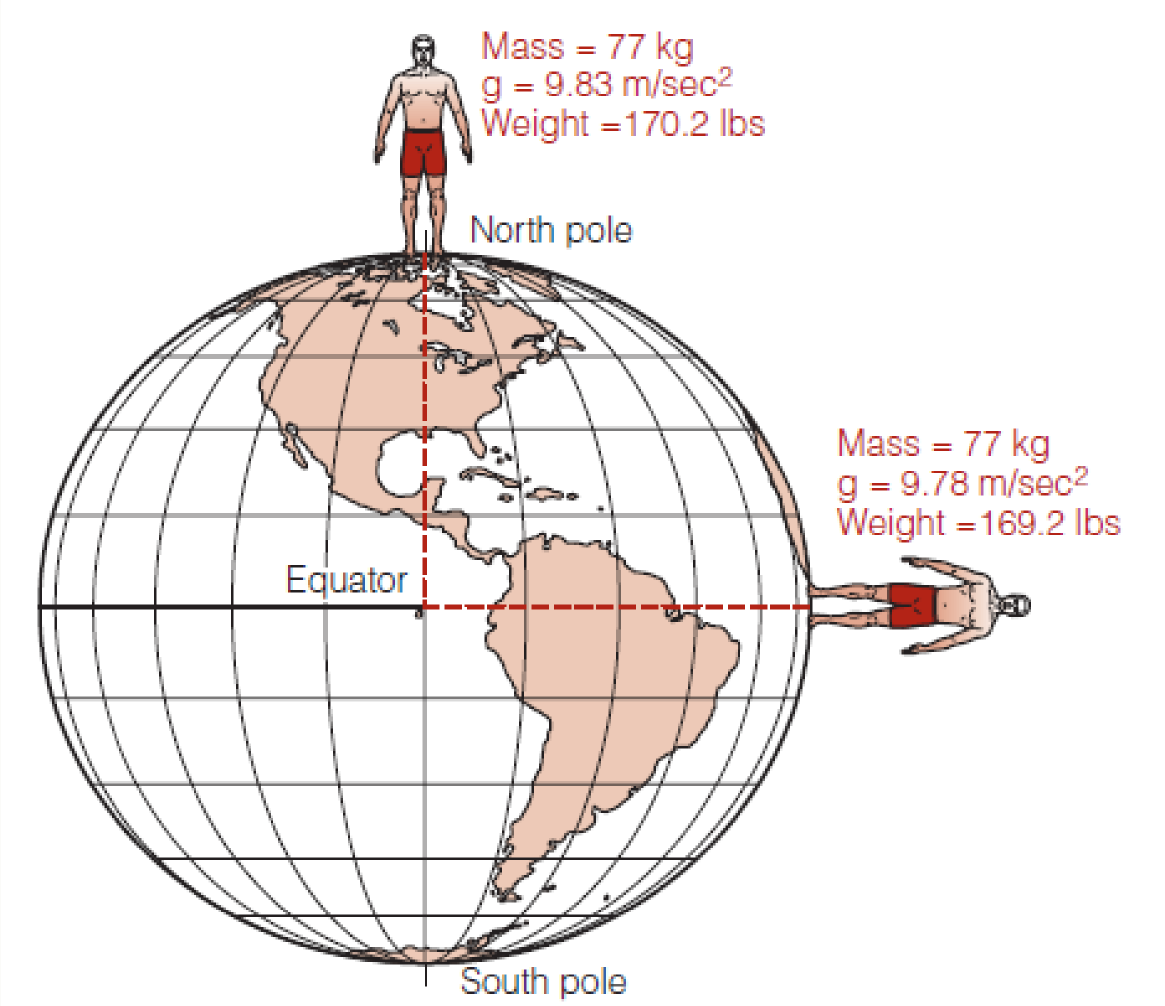
<u>Component approach</u> : Qualitative analysis approach that views the body in component sections, with each section progressing through more refined steps toward mature movement patterns.

Quantitative Motion Analysis

- **Scalar quantity :** A quantity that can be fully specified simply with a single numerical magnitude of appropriate units.
- **Mass :** The quantity of matter of which a body is composed.
- **Inertia :** A body's resistance to having its state of motion changed by application of a force.
- **Vector quantity :** A quantity that can only be fully specified with a magnitude of appropriate units and a precise direction. (Direction : Sense or way in which a force is applied; represented by the tip of a vector. Orientation : The alignment or inclination of the vector in relation to the cardinal directions. Point of application : The point or location at which a system receives an applied force; usually defined by the tail of the vector.)
- **Weight :** Measure of the force with which gravity pulls upon an object's mass.

Quantitative Motion Analysis

- Weight varies depending upon proximity to the center of the Earth, but mass does not.



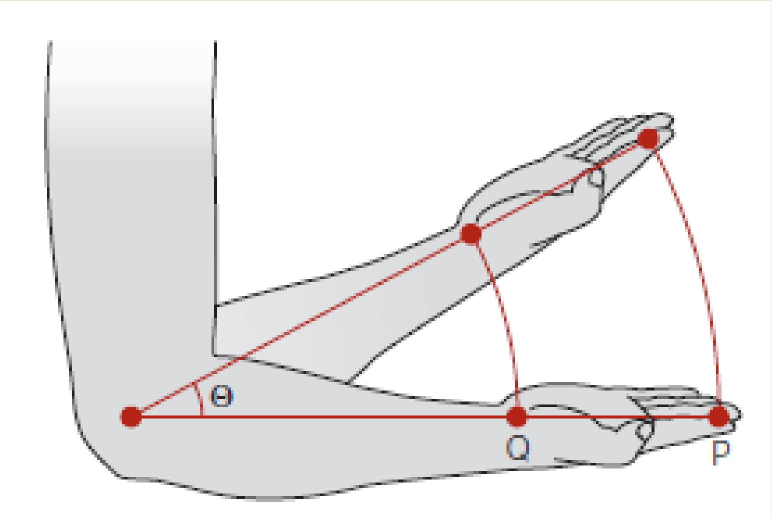
Quantitative Motion Analysis

- **Polar coordinate system** A coordinate system in which the location of the given point is defined by its distance (radius) r from the origin, and by the angle θ between the chosen reference axis and the line formed by connecting the given point to the origin.
- **Plane polar coordinates** Coordinates (r, θ) representing the location of a point within a polar coordinate system.

It is sometimes more convenient and necessary to define a polar coordinate system and locate a point in space using its plane polar coordinates. We must also be able to transform Cartesian coordinates into polar coordinates, and vice versa.

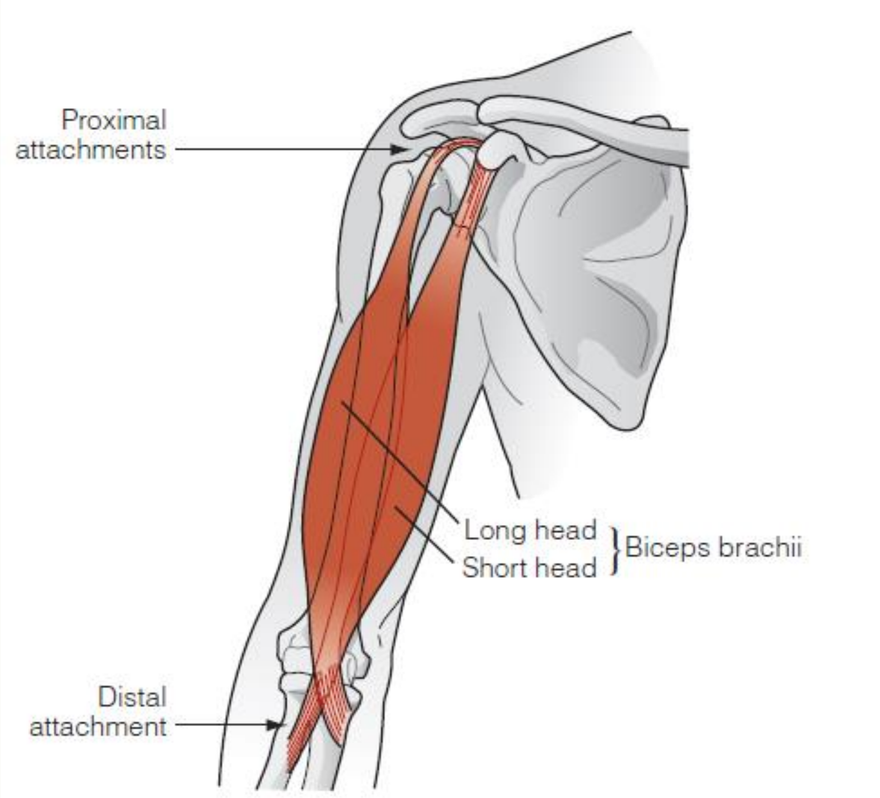
Quantitative Motion Analysis

- The points have the same angular displacement but two different curvilinear displacements.



Muscles and Motion

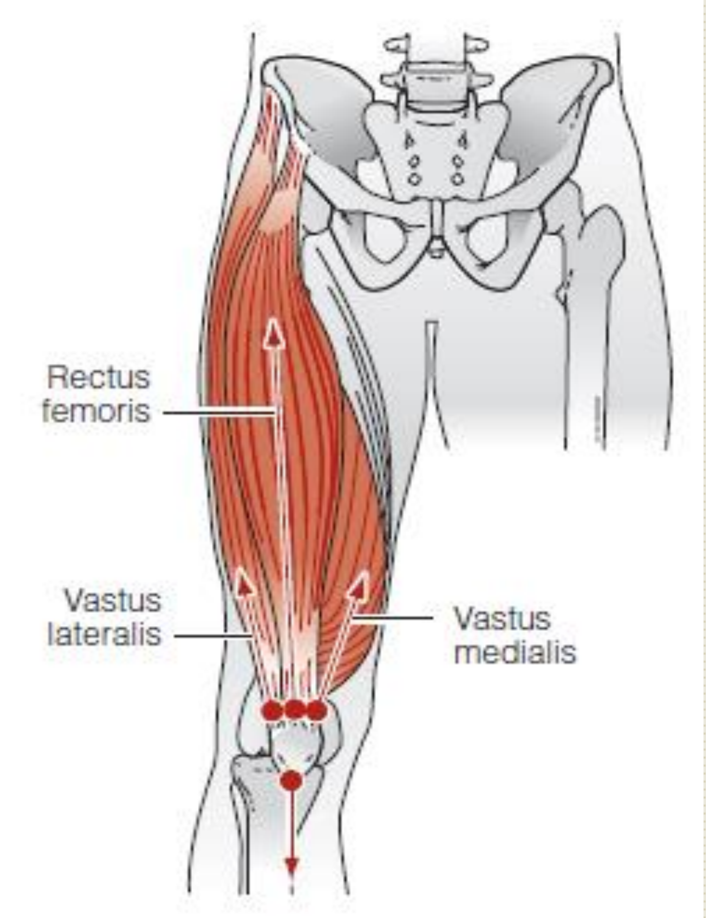
- Motions of the skeletal system are made possible through contraction of skeletal muscle.



- In general, a muscle has two points of attachment: a **proximal attachment** (sometimes called an origin) that tends to be at a relatively immoveable location, and a **distal attachment** (sometimes called an insertion) that tends to be on a relatively moveable segment. The two attachments of the muscle (and therefore two segments) are brought closer together during muscle contraction, with the less stable end being moved closer to the more stable.

Muscle force vectors.

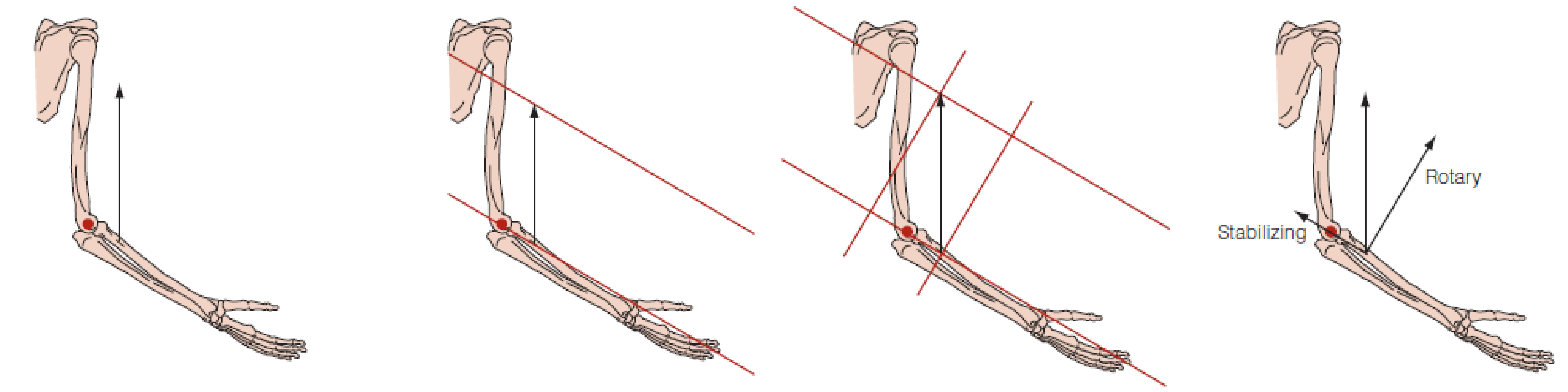
- As we mentioned before we usually represent muscle force with one vector, when in reality multiple muscles are responsible for the action at a given joint.



For example, the quadriceps femoris muscle (rectus femoris, vastus intermedius, vastus lateralis, and vastus medialis) produces four forces, with different lines of action simultaneously acting upon a common point of application (the tibial tuberosity through the patellar tendon). We have four muscle force vectors, with one resultant vector producing the final motion of the tibia relative to the femur

Muscle force vectors

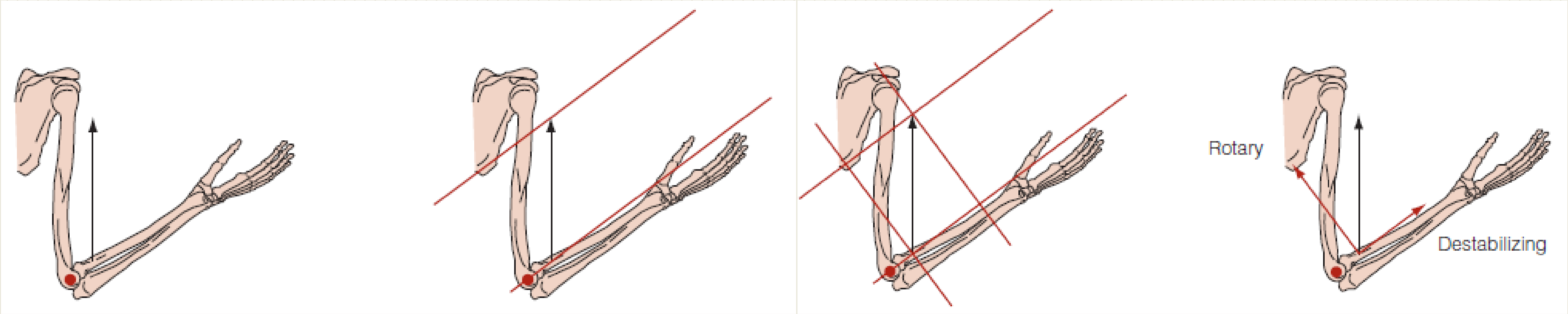
- A single force can have multiple directional effects (i.e., can be resolved into a vertical (perpendicular) component and a horizontal (parallel) component).
- A single muscle force vector can also be resolved to observe two different effects. To resolve muscle force vectors, we use a somatic reference system.



Muscle force vectors

- **Rotary component :** The vertical or perpendicular component of a muscle force vector representing the amount of force that would tend to cause joint rotation.
- **Stabilizing component :** The horizontal (parallel) component of a muscle force vector directed toward the joint, representing the amount of force that would tend to stabilize the joint.
- **Destabilizing component :** The horizontal (parallel) component of a muscle force vector directed away from the joint, representing the amount of force that would tend to destabilize the joint.

Muscle force vectors



Types of Forces

Field (non-contact) force: A force that acts at a distance without making contact with the object that it is affecting. There are the four types of field forces, and they are in order of strongest to weakest:

- **Strong nuclear force :** Force that occurs between subatomic particles, preventing the nucleus of an atom from exploding due to protons producing a repulsive electric force.
- **Electromagnetic force :** Force that occurs between electric charges.
- **Weak nuclear force :** Force that is a product of some radioactive decay processes.
- **Gravitational force :** Force that exists between bodies of mass.

Types of Forces

Contact forces : They are exactly what their name implies: the result of physical contact between two bodies.

For example:

- During jumping, the feet contact the ground to apply the force.
- If you hit a baseball with a bat, there is physical contact.

Types of Forces

- **External forces :** Forces that interact with the system from the outside.

- **Internal forces :** Forces that act within the defined system.

Only external forces can cause a change in the motion of a system (Newton's first law of motion), whereas internal forces can change only the shape of the system. If you jump from a diving platform, gravity changes your state of motion and pulls you toward Earth. In this example, the system is defined as the whole body. As a result, muscle forces in this case are internal (acting inside the system). Since the only forces that can change the state of motion of a system are external, muscle forces can change only the shape of the system in our example.

Types of Forces

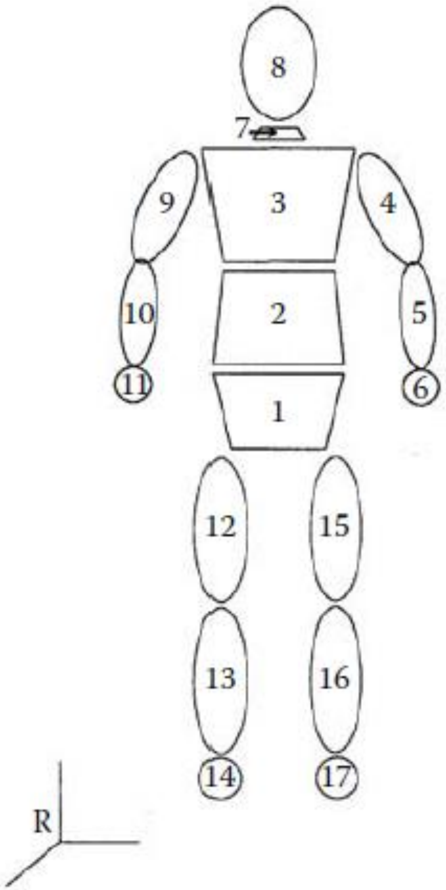
- **Action force :** The initially applied force.
- **Reaction force :** The simultaneous equal counterforce acting in the opposite direction to the action force.
- **Friction :** The force that resists the sliding of two objects in contact.
- **Normal force :** Force that acts downward on one surface and upward on another.
- **Ground reaction force :** An equal and oppositely directed normal force from the earth.

Force an Pressure

The terms pressure and force are sometimes used interchangeably. However, pressure is the magnitude of applied force acting over a given area (1 N/m2 = 1 Pa).

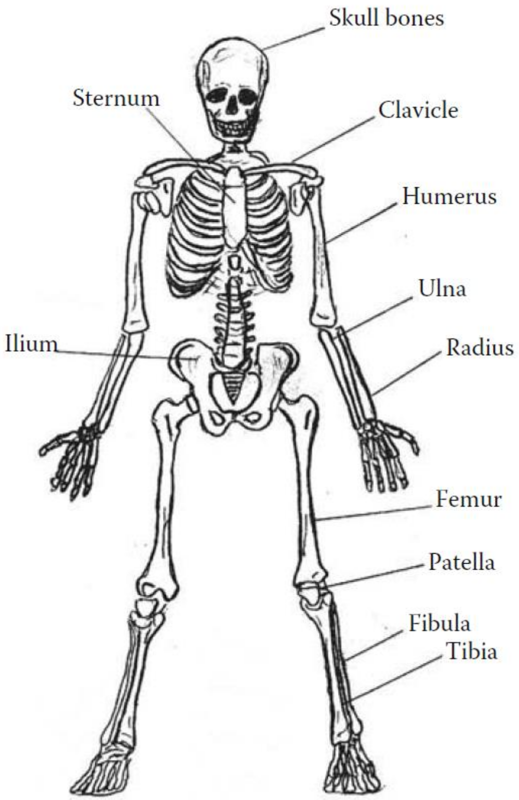
Pascal's law : Pressure applied to a fluid is transmitted undiminished to every point of a fluid and to the walls of the container.

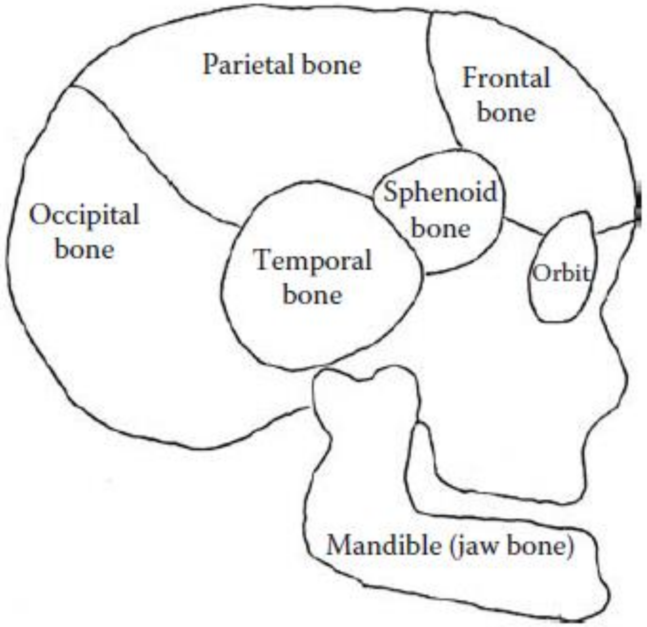
Human Frame Model

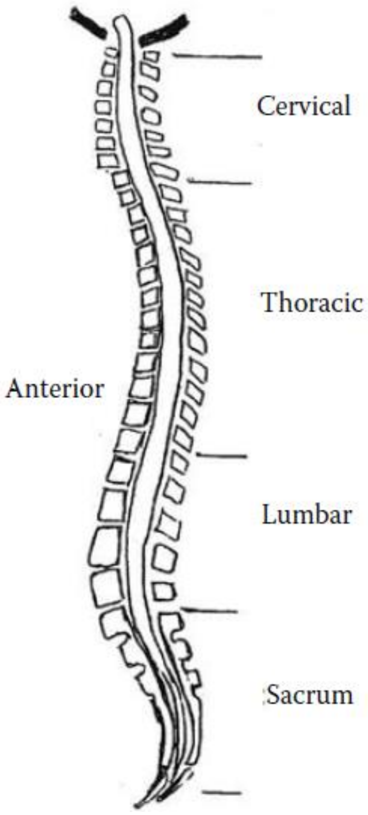


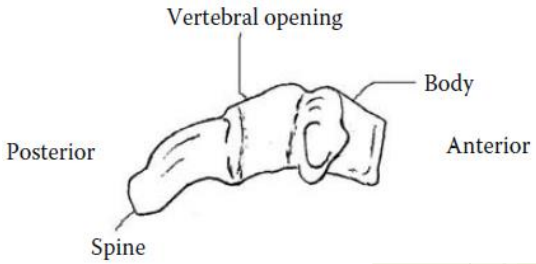
Segment Number	Segment Name
0	Inertial reference frame
1	Pelvis or lower-torso body
2	Midriff or mid-torso body
3	Chest or upper-torso body
4	Left upper arm
5	Left lower arm
6	Left hand
7	Neck
8	Head
9	Right upper arm
10	Right lower arm
11	Right hand
12	Right upper leg or right thigh
13	Right lower leg
14	Right foot
15	Left upper leg or left thigh
16	Left lower leg
17	Left foot

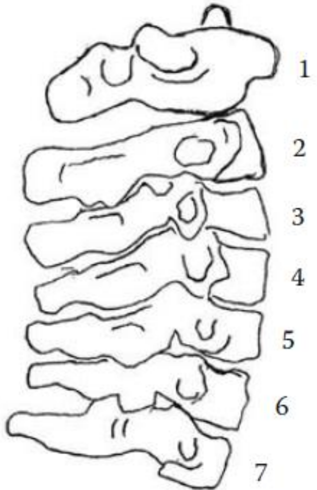
Human Skeleton



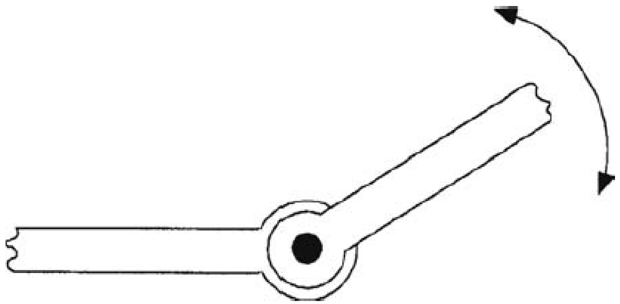


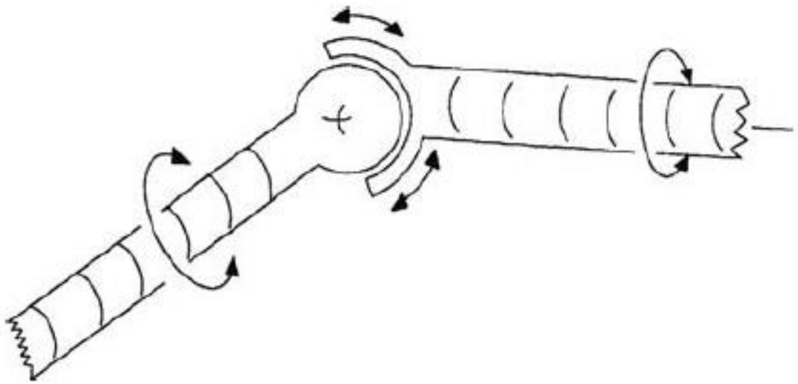


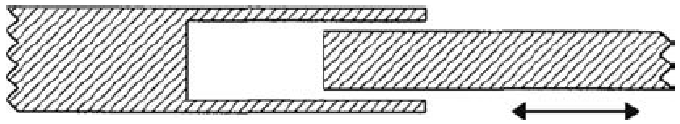




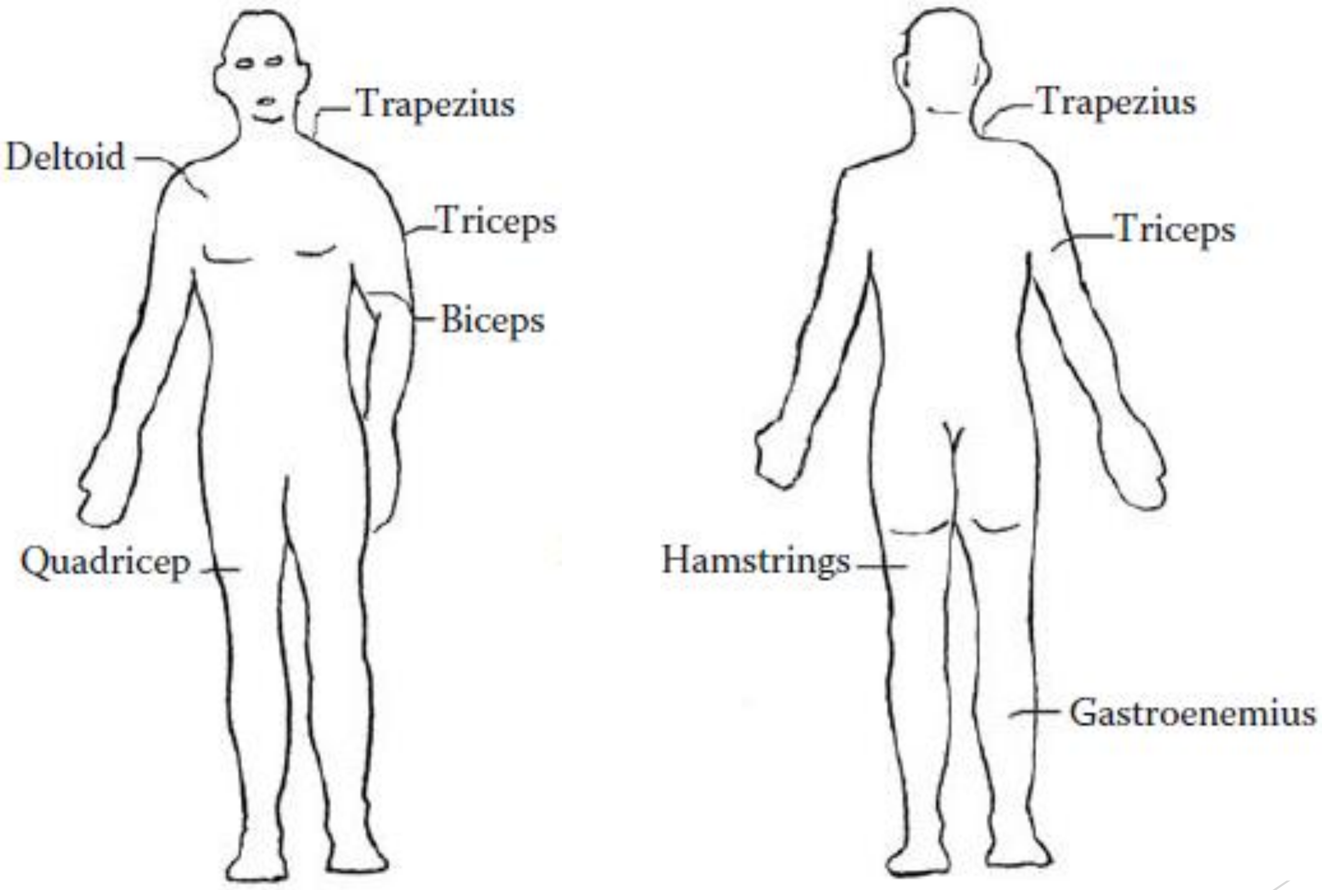
Major Joints



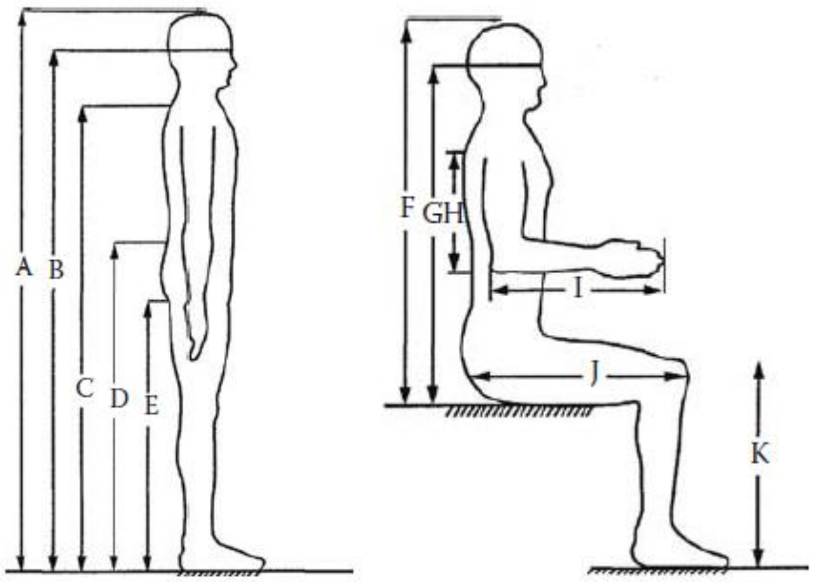




Major Muscle Groups



Anthropometric Data

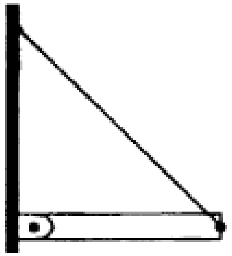
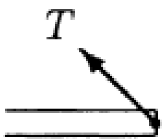
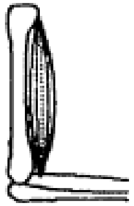
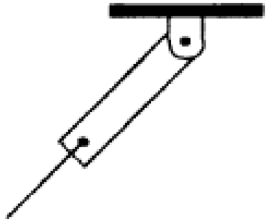
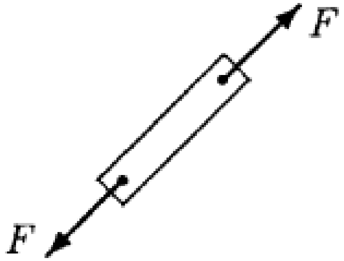
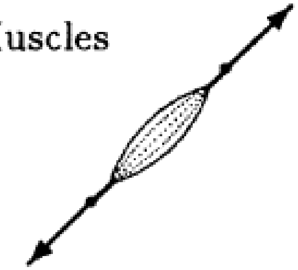


A. Stature
B. Eye height (standing)
C. Mid shoulder height
D. Waist height
E. Buttocks height

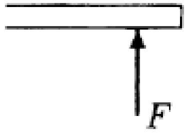
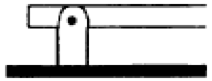
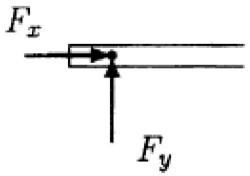
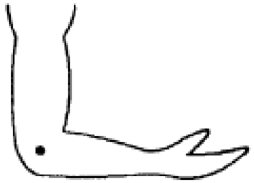
F. Sitting height
G. Eye height (sitting)
H. Upper arm length
I. Lower arm/hand length
J. Upper leg length
K. Lower leg length

Name	Figure Dimension	Male			Female		
		5th%	50th%	95th%	5th%	50th%	95th%
Stature	A	1.649	1.759	1.869	1.518	1.618	1.724
Eye height (standing)	B	1.545	1.644	1.748	1.427	1.520	1.630
Mid shoulder height	C	1.346	1.444	1.564	1.210	1.314	1.441
Waist height	D	0.993	1.102	1.168	0.907	0.985	1.107
Buttocks height	E	0.761	0.839	0.919	0.691	0.742	0.832
Sitting height	F	0.859	0.927	0.975	0.797	0.853	0.911
Eye height (sitting)	G	0.743	0.800	0.855	0.692	0.743	0.791
Upper arm length	H	0.333	0.361	0.389	0.306	0.332	0.358
Lower arm/hand length	I	0.451	0.483	0.517	0.396	0.428	0.458
Upper leg length	J	0.558	0.605	0.660	0.531	0.578	0.628
Lower leg length	K	0.506	0.553	0.599	0.461	0.502	0.546

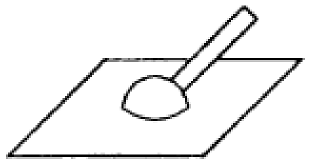
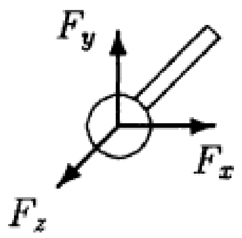
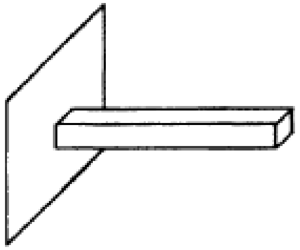
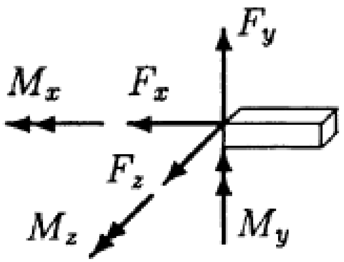
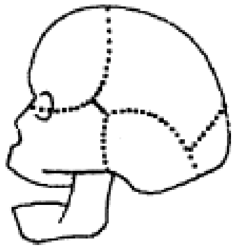
Supports (Joints)

TYPE OF SUPPORT OR JOINT	SAMPLE GRAPHICAL REPRESENTATIONS	REPRESENTATIONS FOR USE IN FREE-BODY DIAG.	BIOMECHANICS EXAMPLES	UNKNOWNS
Flexible members (cables, ropes)			Muscles, ligaments 	Magnitude of the tension in the cable or muscle
Two-force members			Muscles 	Force magnitude

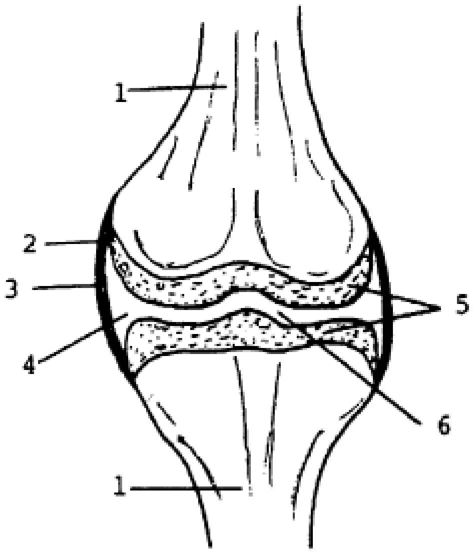
Supports (Joints)

Rollers and other simple supports (no friction)			Bone-to-bone contact 	Force magnitude
Hinge or pin connection			Elbow 	Magnitude and direction of force (force components)

Supports (Joints)

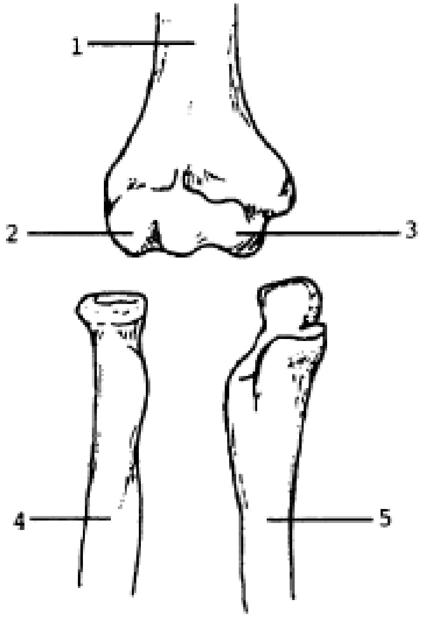
TYPE OF SUPPORT OR JOINT	SAMPLE GRAPHICAL REPRESENTATIONS	REPRESENTATIONS FOR USE IN FREE-BODY DIAG.	BIOMECHANICS EXAMPLES	UNKNOWNS
Ball-and-socket			Hip 	Magnitude and direction of force
Fixed, welded, or built-in			Skull 	Magnitude and direction of force and moment

Skeletal Joints

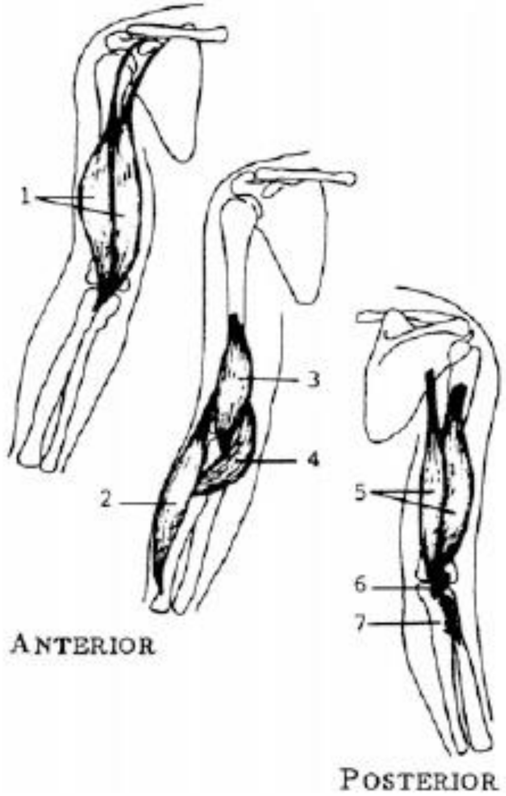


A diarthrodial joint: (1) Bone, (2) ligamentous capsule, (3, 4) synovial membrane and fluid, (5, 6) articular cartilage and cavity

Mechanics of Elbow

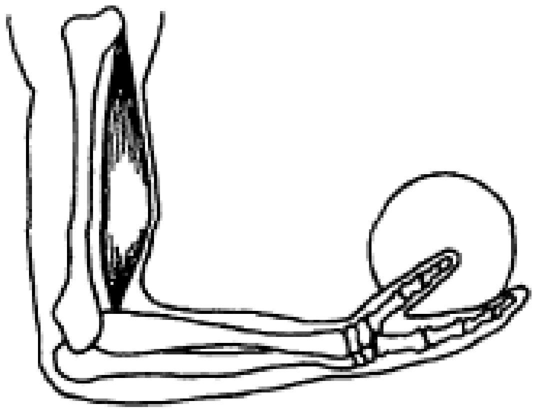


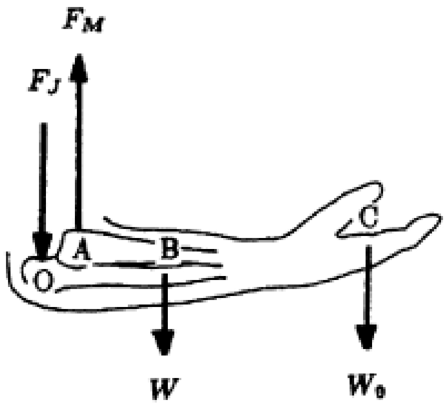
Bones of the elbow: (1) humerus, (2) capitulum, (3) trochlea, (4) radius, (5) ulna

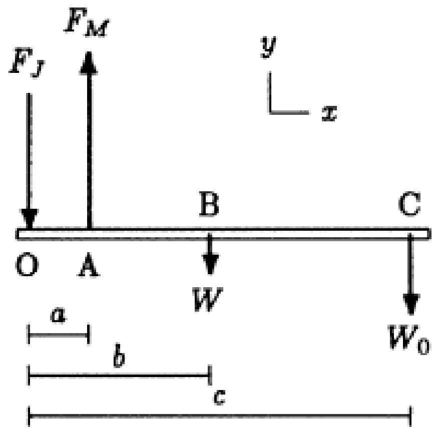


Muscles of the elbow: (1) biceps, (2) brachioradialis, (3) brachialis, (4) pronator teres, (5) triceps brachii, (6) anconeus, (7) supinator

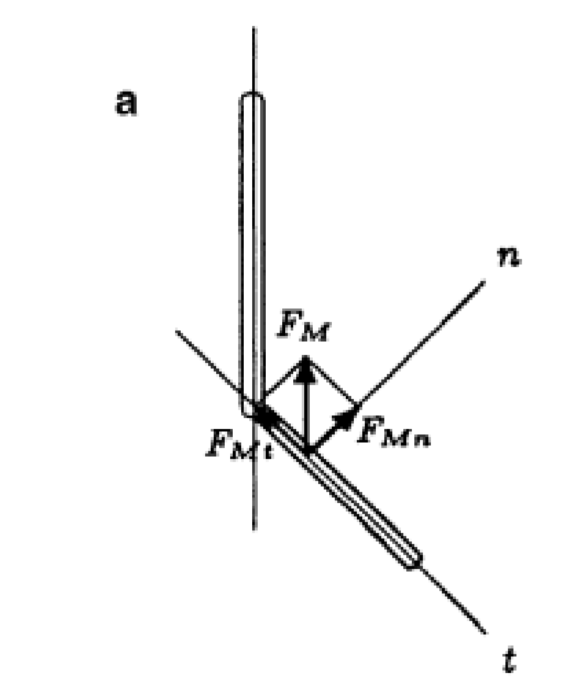
Example

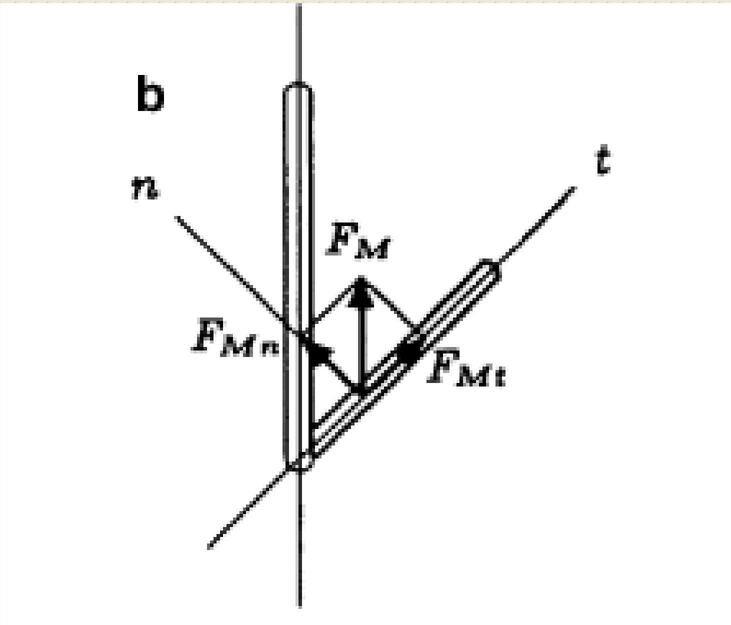






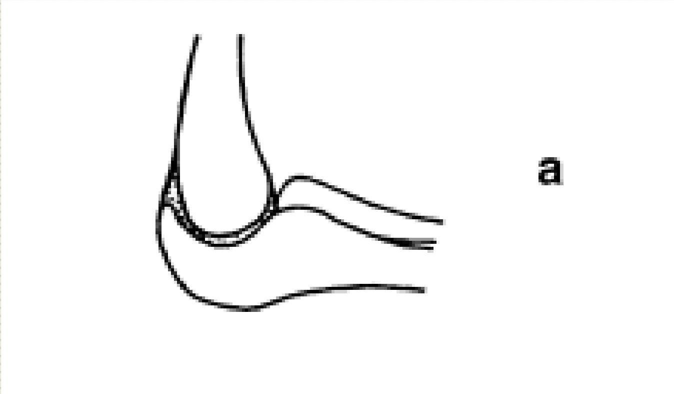
Rotational and stabilizing/sliding components of muscle force of elbow

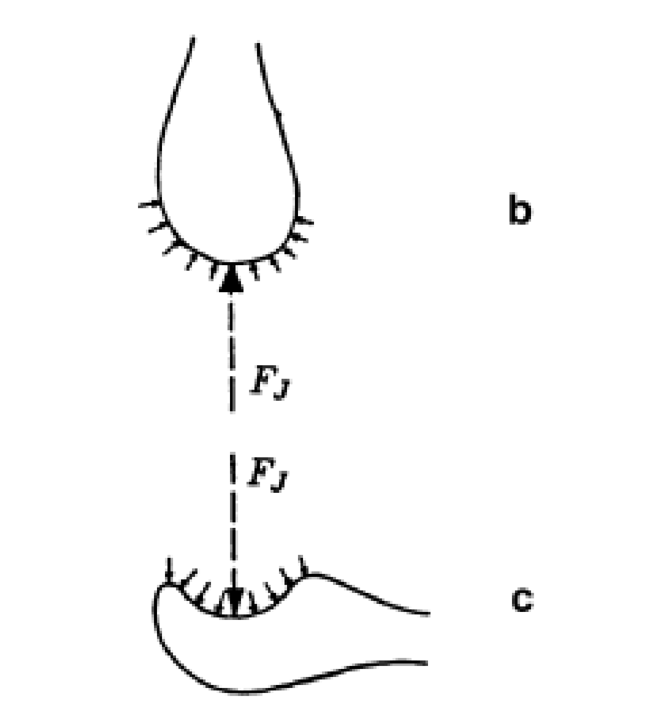




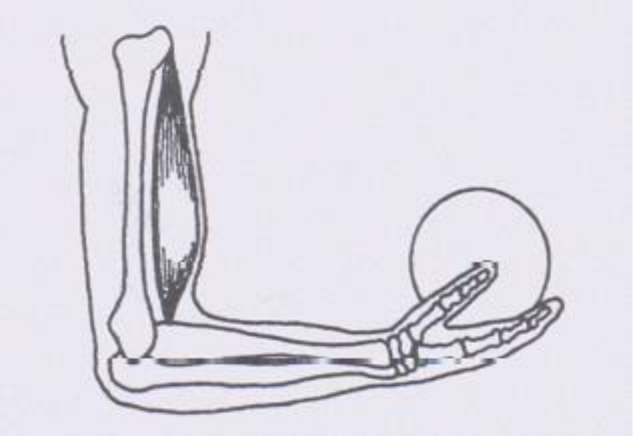
Rotational (F_{Mn}) and stabilizing or sliding (F_{Mt}) components of the muscle force

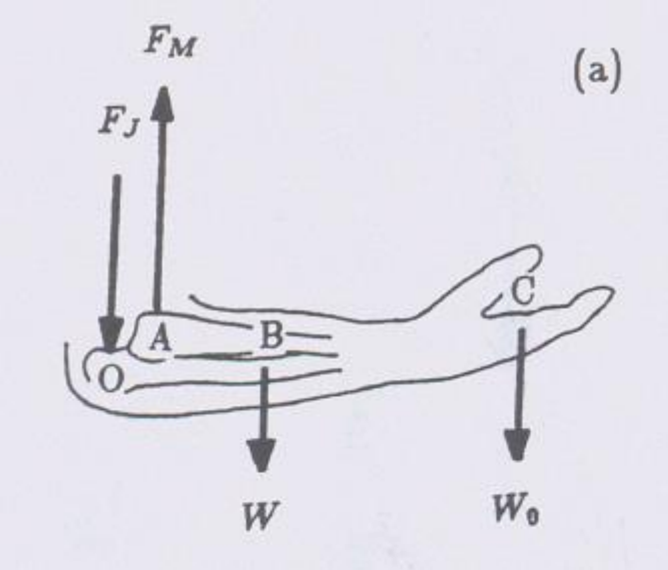
The joint reaction forces of elbow

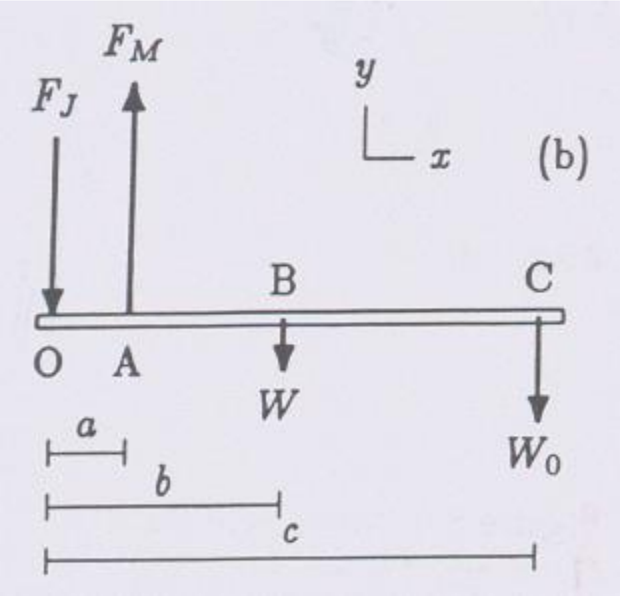




Mechanics of Elbow







$$\sum M_O = 0: \qquad F_M = \frac{1}{a}(b\,W + c\,W_0)$$

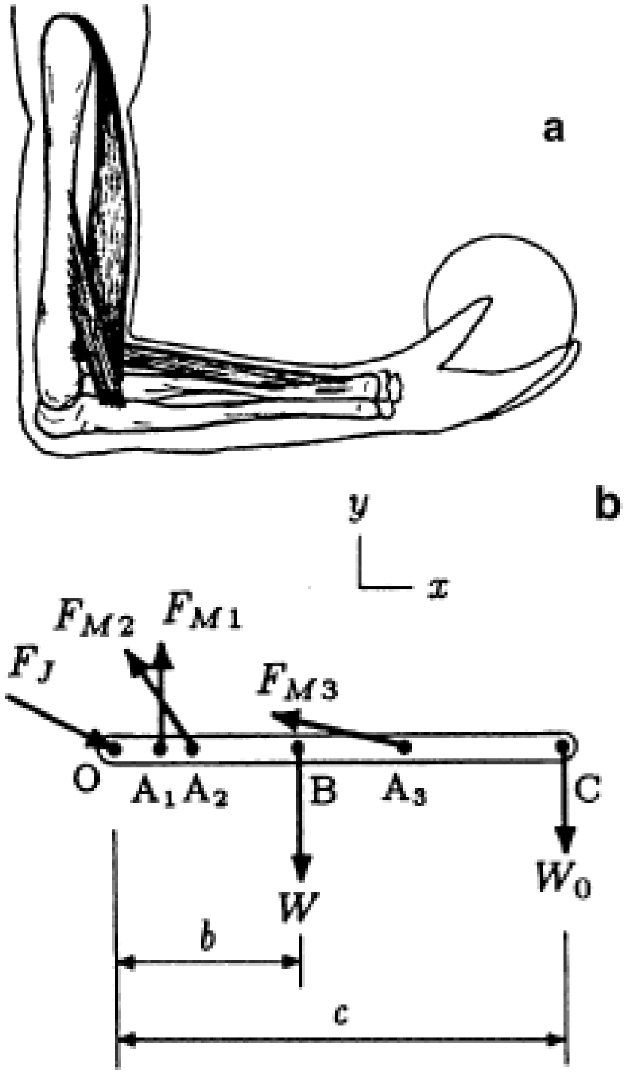
$$\sum F_y = 0: \qquad F_J = F_M - W - W_0$$

For given values of geometric parameters a, b, and c, and weights W and W_0, Eqs. (i) and (ii) can be solved for the magnitudes of the muscle and joint reaction forces. For example, assume that these parameters are given as follows: $a = 4$ cm, $b = 15$ cm, $c = 35$ cm, $W = 20$ N, and $W_0 = 80$ N. Then from Eqs. (i) and (ii):

$$F_M = \frac{1}{0.04}[(0.15)(20) + (0.35)(80)] = 775\text{ N} \quad (+y)$$

$$F_J = 775 - 20 - 80 = 675\text{ N} \quad (-y)$$

Mechanics of Elbow



$$\sum M_O = 0: \quad a_1 F_{M1} + a_2 F_{M2} + a_3 F_{M3} = b\,W + c\,W_0$$

$$\sum F_x = 0: \quad F_{Jx} = F_{M1x} + F_{M2x} + F_{M3x}$$

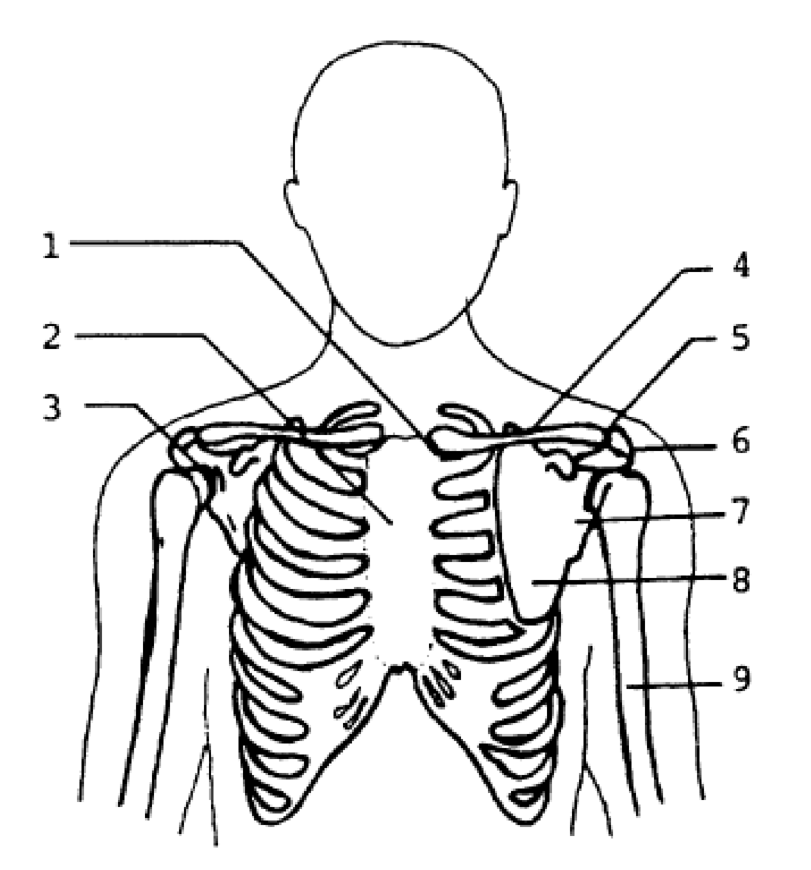
$$\sum F_y = 0: \quad F_{Jy} = F_{M1y} + F_{M2y} + F_{M3y} - W - W_0$$

$$F_{M2} = k_{21}\,F_{M1} \quad \text{with} \quad k_{21} = \frac{A_2}{A_1}$$

$$F_{M3} = k_{31}\,F_{M1} \quad \text{with} \quad k_{31} = \frac{A_3}{A_1}$$

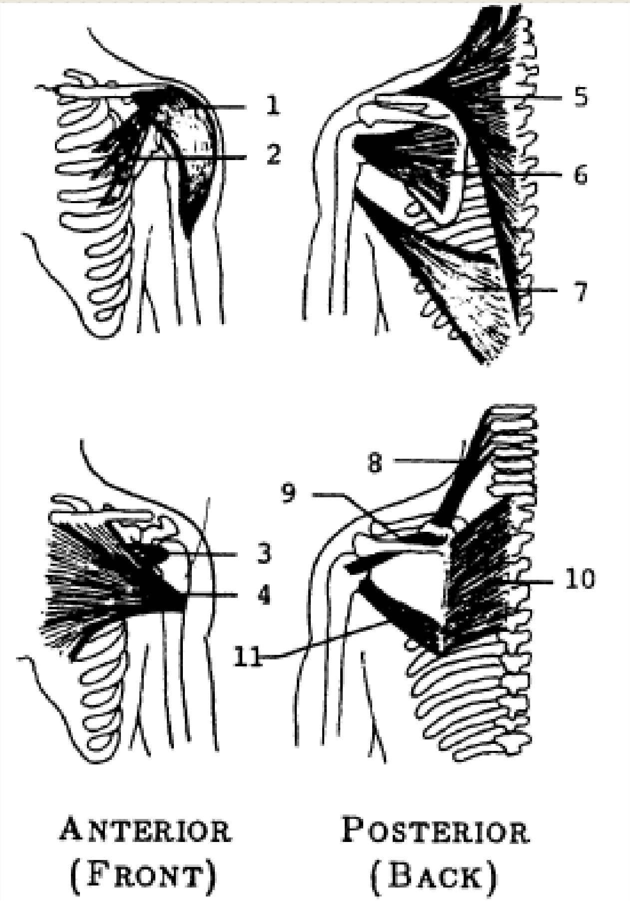
$$F_{M1} = \frac{b\,W + c\,W_0}{a_1 + a_2 k_{21} + a_3 k_{31}}$$

Mechanics of Shoulder



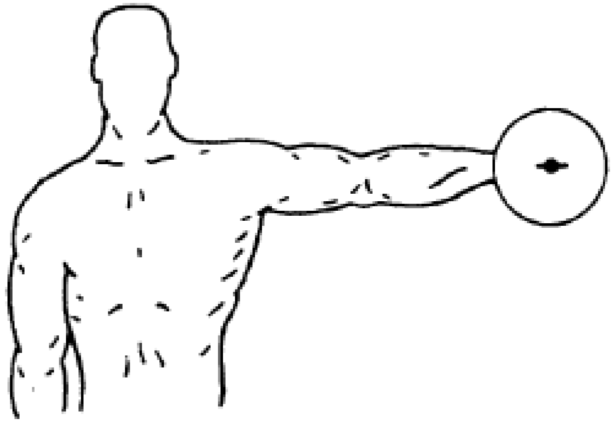
The shoulder:
(1) sternoclavicular joint, (2) sternum, (3) glenohumeral joint, (4) clavicle, (5) acromioclavicular joint, (6) acromion process, (7) glenoid fossa, (8) scapula, (9) humerus

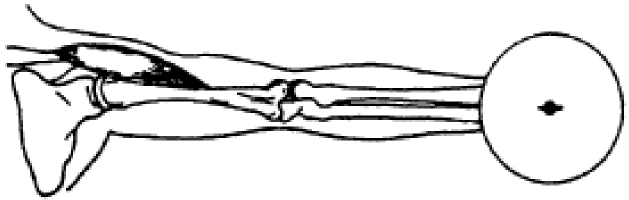
Mechanics of Shoulder

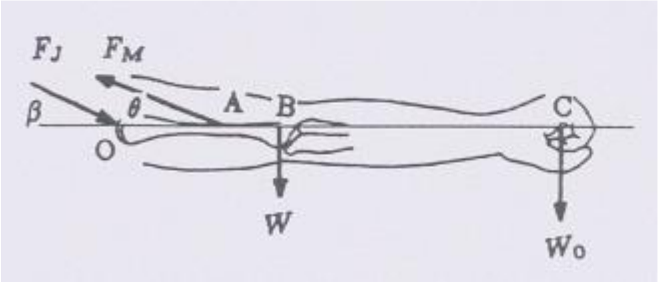


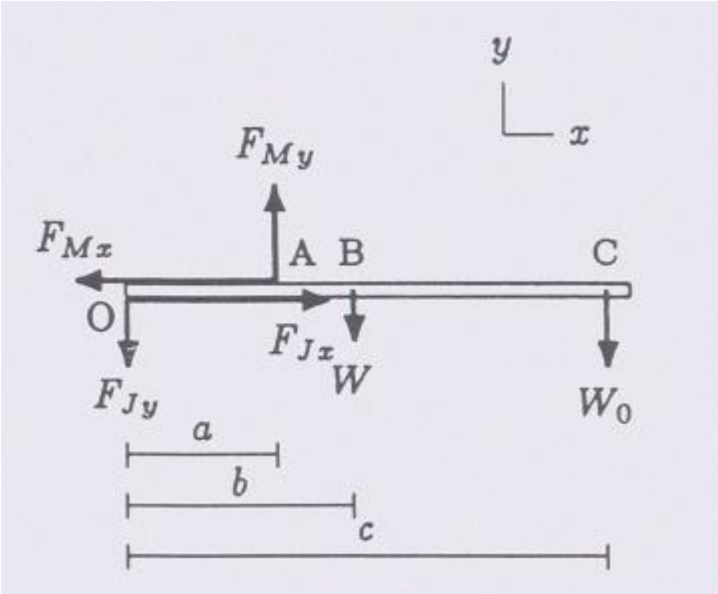
Shoulder muscles:
(1) deltoideus, (2) pectoralis minor, (3) subscapularis, (4) pectoralis major, (5) trapezius, (6) infraspinatus and teres minor, (7) latissimus dorsi, (8) levator scapulae, (9) supraspinatus, (10) rhomboideus, (11) teres major

Example









tion. The components of the muscle force are:

$$F_{Mx} = F_M \cos\theta \quad (-x)$$
$$F_{My} = F_M \sin\theta \quad (+y)$$

Components of the joint reaction force are:

$$F_{Jx} = F_J \cos\beta \quad (+x)$$
$$F_{Jy} = F_J \sin\beta \quad (-y)$$

$$\sum M_O = 0: \quad a\,F_{My} - b\,W - c\,W_0 = 0$$

$$F_{My} = \frac{1}{a}(b\,W + c\,W_0)$$

$$F_M = \frac{F_{My}}{\sin\theta}$$

$$F_{Mx} = F_M \cos\theta$$

$$\sum F_x = 0: \quad F_{Jx} = F_{Mx}$$

$$\sum F_y = 0: \quad F_{Jy} = F_{My} - W - W_0$$

$$F_J = \sqrt{(F_{Jx})^2 + (F_{Jy})^2}$$

$$\beta = \tan^{-1}\left(\frac{F_{Jy}}{F_{Jx}}\right)$$

Now consider that $a = 15$ cm, $b = 30$ cm, $c = 60$ cm, $\theta = 15°$, $W = 40$ N, and $W_0 = 60$ N. Then:

$$F_{My} = \frac{1}{0.15}[(0.30)(40) + (0.60)(60)] = 320\ N \quad (+y)$$

$$F_M = \frac{320}{\sin 15°} = 1236\ \text{N}$$

$$F_{Mx} = (1236)(\cos 15°) = 1194\ N \quad (-x)$$

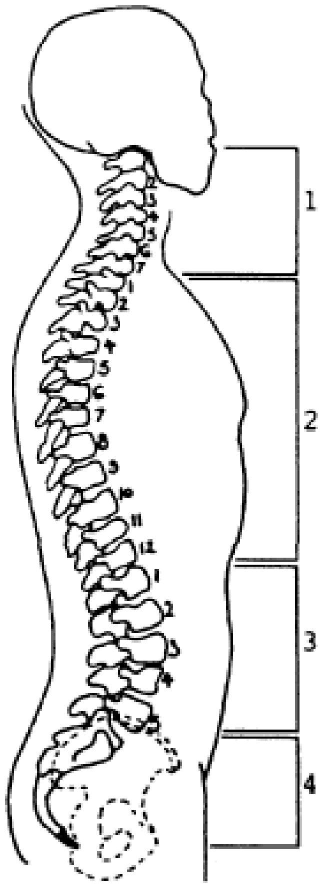
$$F_{Jx} = 1194\ \text{N} \quad (+x)$$

$$F_{Jy} = 320 - 40 - 60 = 220\ N \quad (-y)$$

$$F_J = \sqrt{(1194)^2 + (220)^2} = 1214\ \text{N}$$

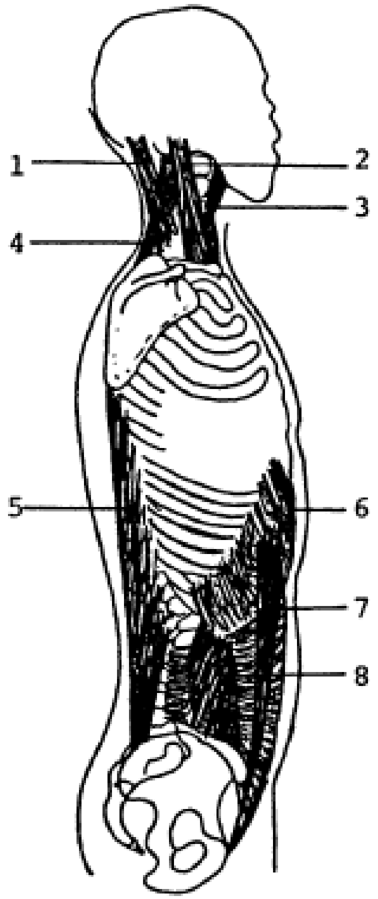
$$\beta = \tan^{-1}\left(\frac{220}{1194}\right) = 10°$$

Mechanics of Spinal Column



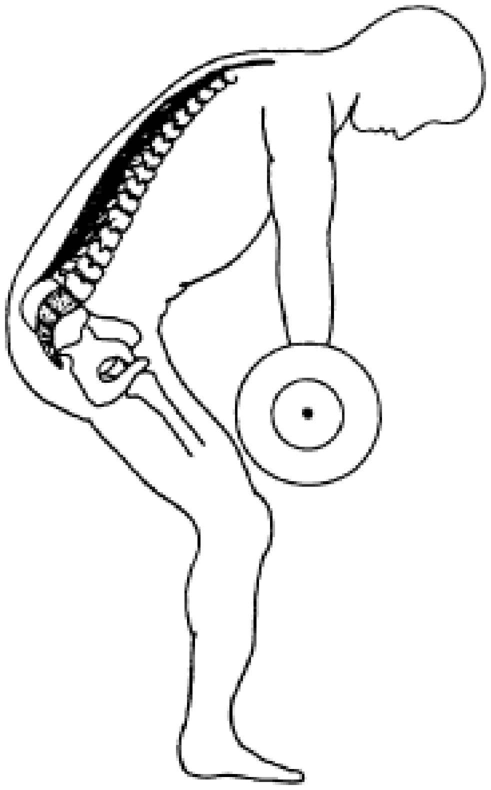
The spinal column:
(1) cervical vertebrae, (2) thoracic vertebrae, (3) lumbar vertebrae, (4) sacrum

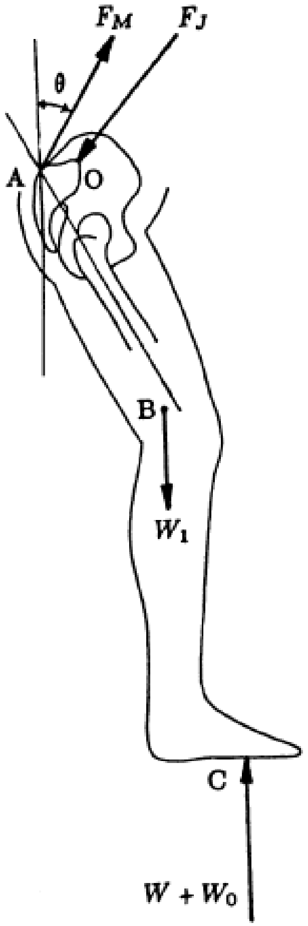
Mechanics of Spinal Column

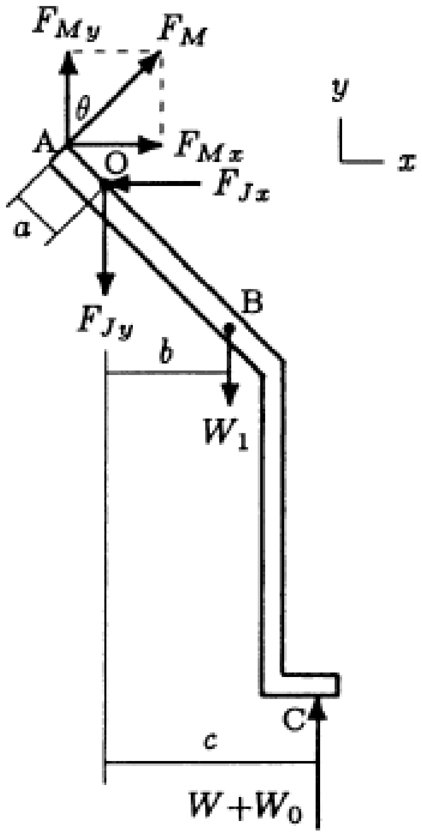


Selected muscles of the neck and spine: (1) splenius, (2) sternocleidomastoid, (3) hyoid, (4) levator scapula, (5) erector spinae, (6) obliques, (7) rectus abdominis, (8) transversus abdominis

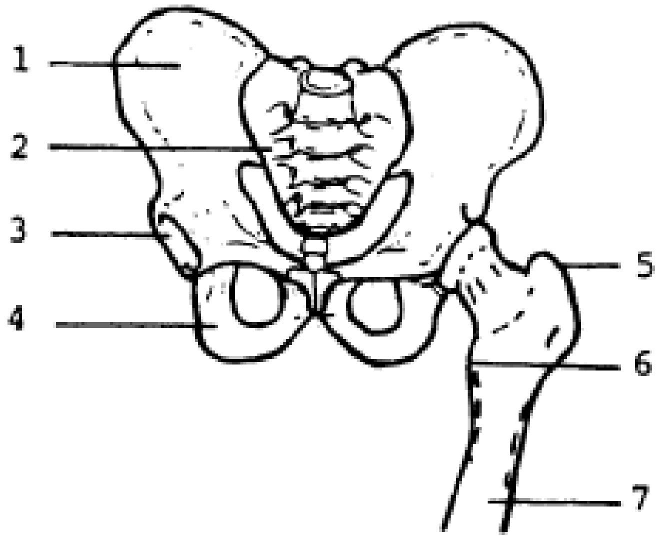
Example





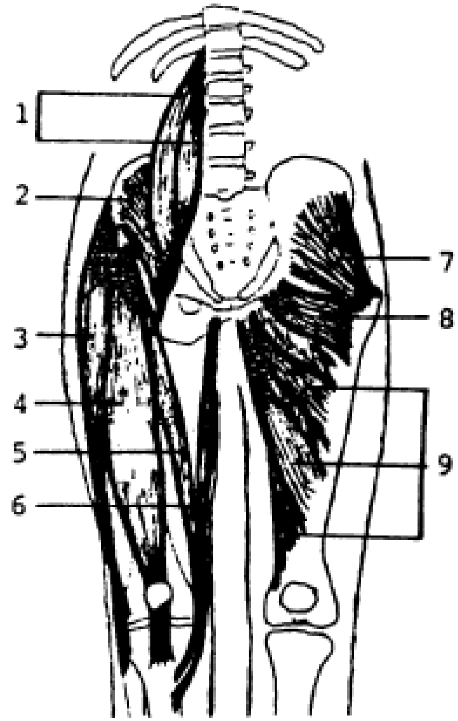


Mechanics of Hip

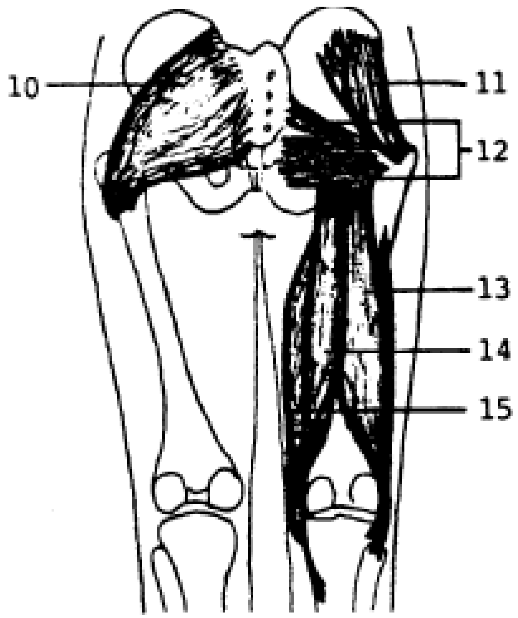


Pelvis and the hip: (1) ilium, (2) sacrum, (3) acetabulum, (4) ischium, (5) greater trochanter, (6) lesser trochanter, (7) femur

Mechanics of Hip



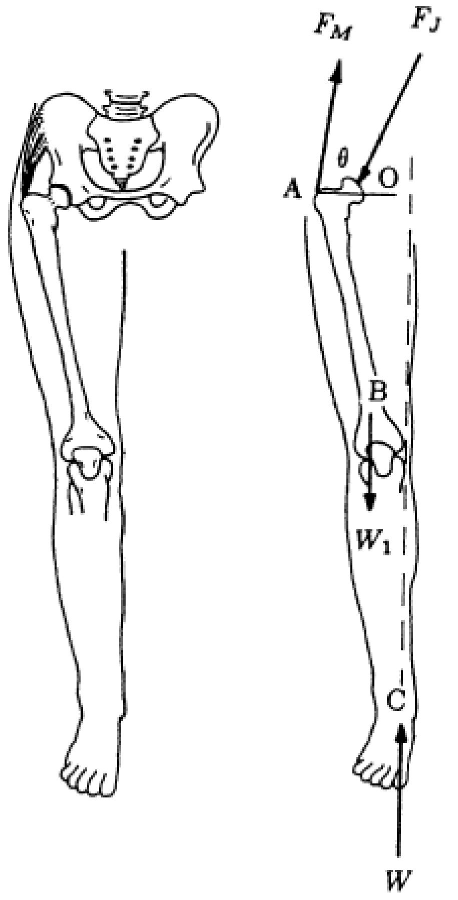
a



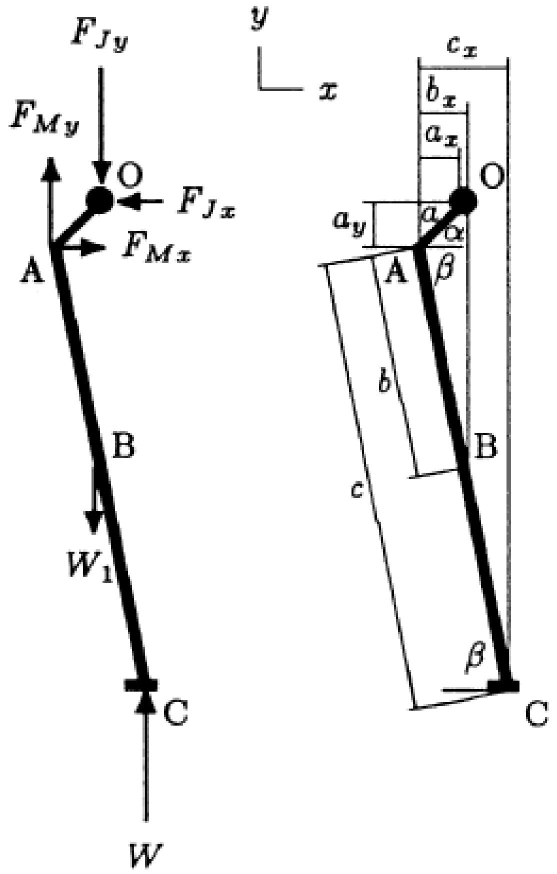
b

*Muscles of the hip (**a**) anterior and (**b**) posterior views: (1) psoas, (2) iliacus, (3) tensor fascia latae, (4) rectus femoris, (5) sartorius, (6) gracilis, (7) gluteus minimus, (8) pectineus, (9) adductors, (10, 11) gluteus maximus and medius, (12) lateral rotators, (13) biceps femoris, (14) semitendinosus, (15) semimembranosus*

Example

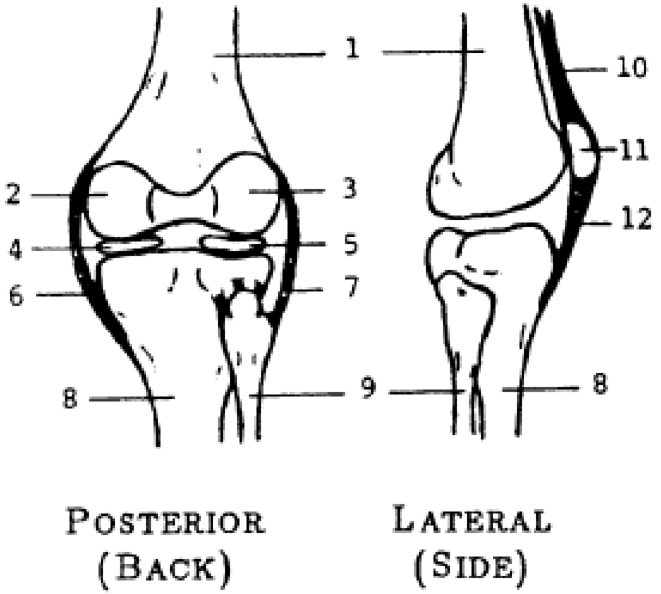


F_M
F_J
θ
A
O
B
W_1
C
W



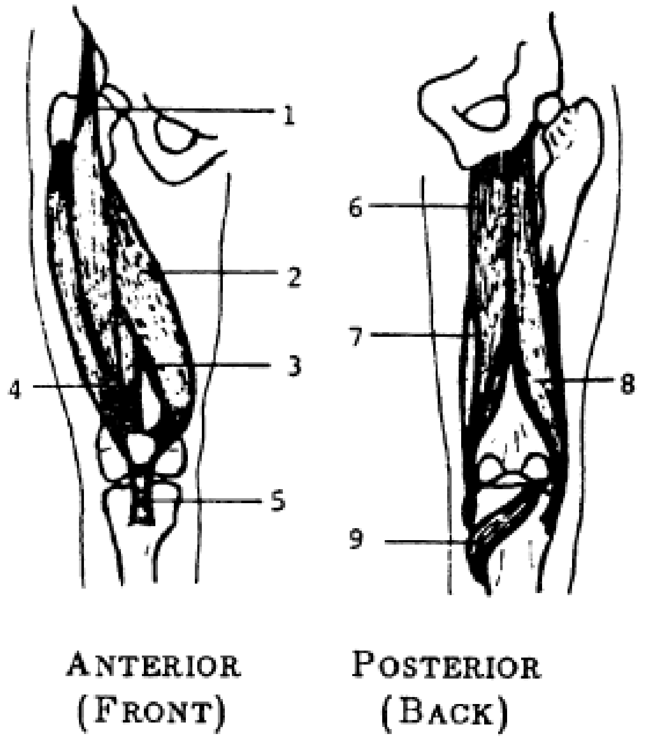
F_{Jy}
F_{My}
O
F_{Jx}
F_{Mx}
A
B
W_1
C
W
y
x
c_x
b_x
a_x
O
a_y
a
α
A
β
b
B
c
β
C

Mechanics of Knee



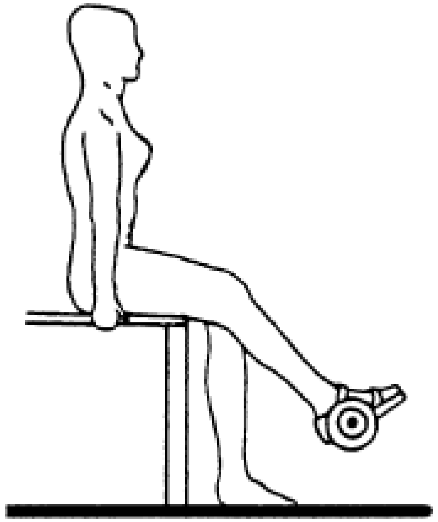
The knee: (1) femur, (2) medial condyle, (3) lateral condyle, (4) medial meniscus, (5) lateral meniscus, (6) tibial collateral ligament, (7) fibular collateral ligament, (8) tibia, (9) fibula, (10) quadriceps tendon, (11) patella, (12) patellar ligament

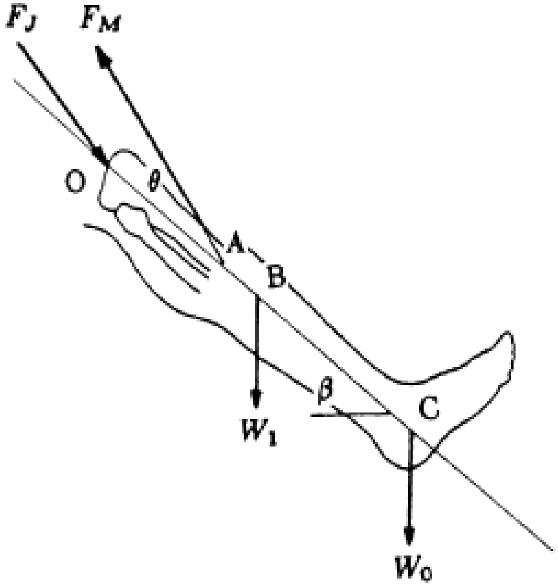
Mechanics of Knee



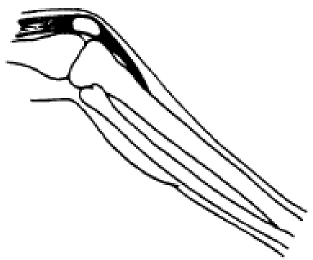
Muscles of the knee: (1) rectus femoris, (2) vastus medialis, (3) vastus intermedius, (4) vastus lateralis, (5) patellar ligament, (6) semitendinosus, (7) semimembranosus, (8) biceps femoris, (9) gastrocnemius

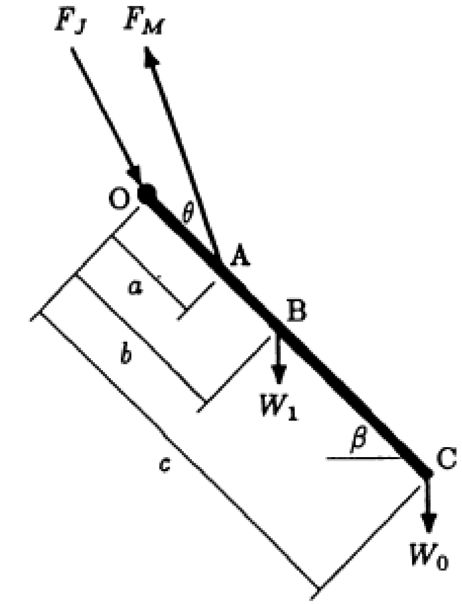
Example



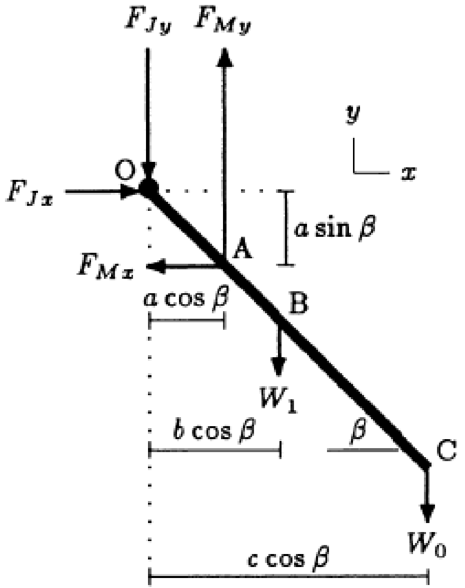


F_J
F_M
O
θ
A
B
β
C
W_1
W_0



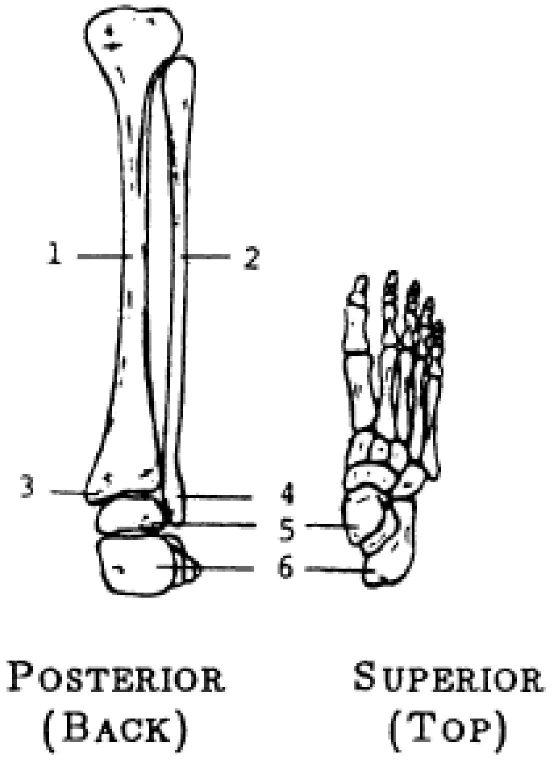


F_J
F_M
O
θ
A
a
B
b
W_1
β
C
c
W_0



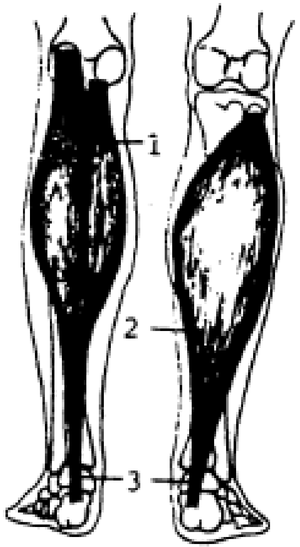
F_{Jy}
F_{My}
y
x
O
F_{Jx}
$a \sin\beta$
A
F_{Mx}
$a \cos\beta$
B
W_1
$b \cos\beta$
β
C
W_0
$c \cos\beta$

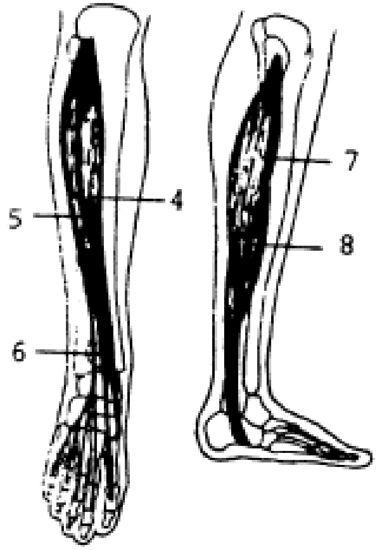
Biomechanics of Ankle



The ankle and the foot:
(1) tibia, (2) fibula, (3) medial malleolus, (4) lateral malleolus, (5) talus, (6) calcaneus

Biomechanics of Ankle

a 

b 

c

Ankle muscles (a) posterior, (b) anterior, and (c) lateral views: (1) gastrocnemius, (2) soleus, (3) Achilles tendon, (4) tibialis anterior, (5) extensor digitorum longus, (6) extensor hallucis longus, (7) peroneus longus, (8) peroneus brevis

Degrees of Freedom

- Many joints of the body vary in their degrees of freedom. Therefore, a wide range of muscles and muscle attachments is needed to move the segments of our skeletal system through all of the available degrees of freedom.
- Degrees of freedom (DOF) is the number of independent ways in which a system can move or the number of values required to completely describe system motion relative to the established coordinate reference frame.
- In some cases, increasing the available DOF at a segmental link is accomplished by having many muscles of both a uniarticular and multiarticular nature (e.g., the shoulder area has many muscles). Having one multiarticular muscle perform more than one function can also provide added DOF.

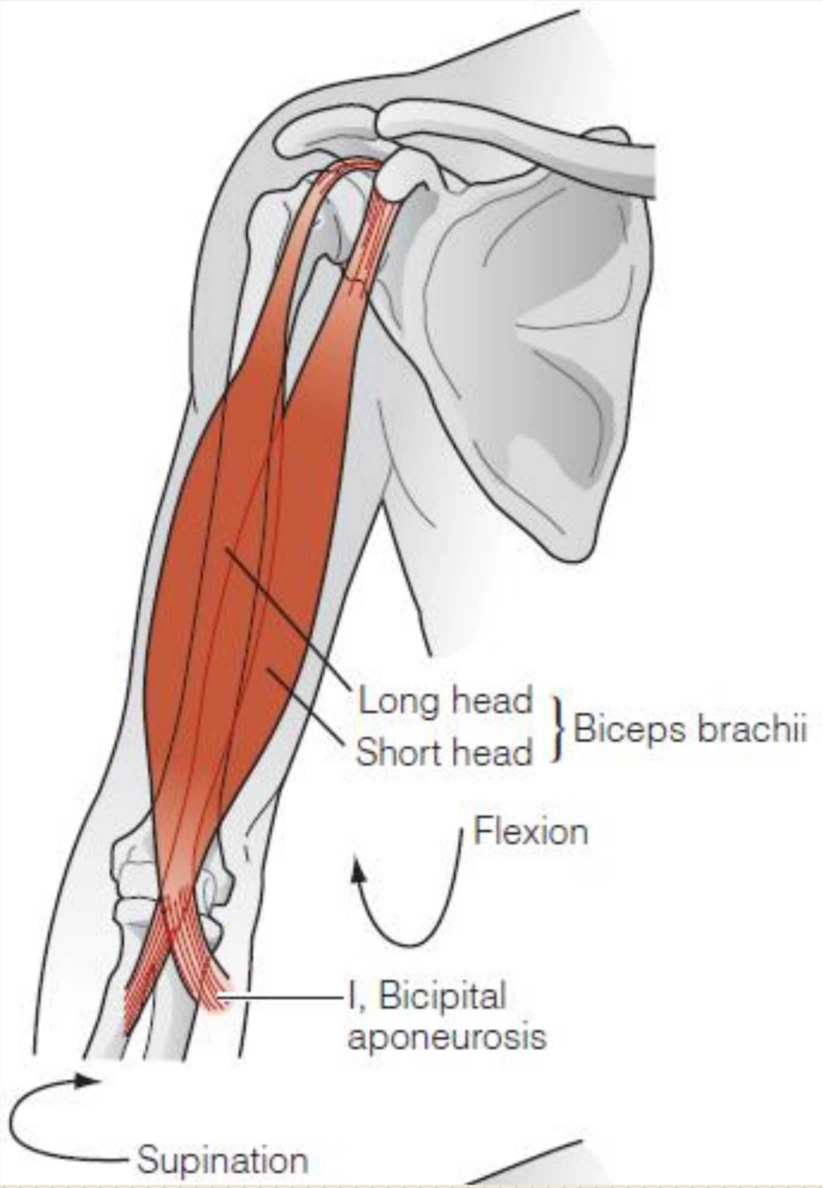
Degrees of Freedom

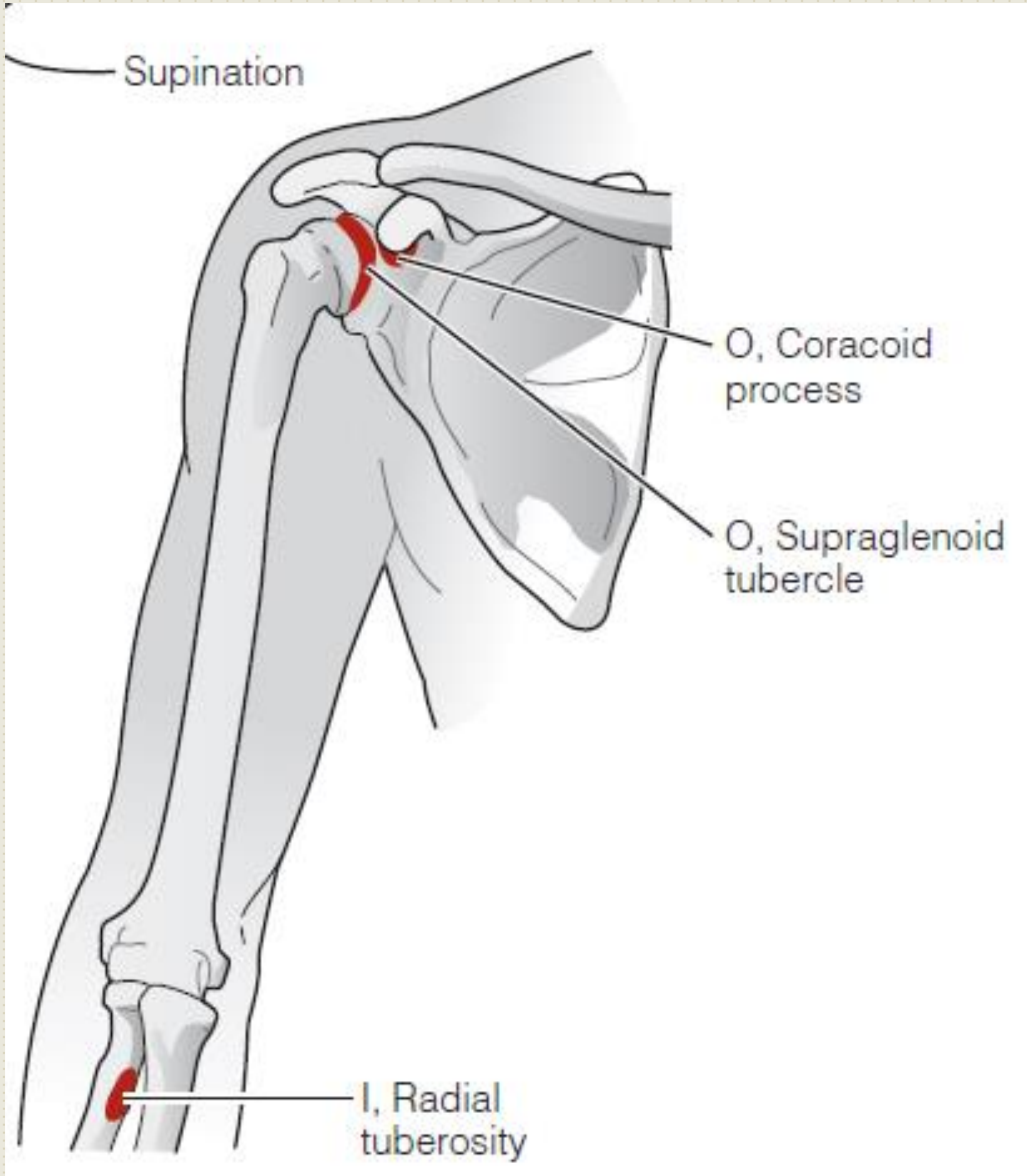
- A multiarticular muscle may have a specific insertion point that adds additional capabilities. For example, the biceps brachii can cause elbow flexion and shoulder flexion. But because its insertion is on the radius rather than on the ulna, it is also a powerful supinator of the forearm.

- When analyzing the full capabilities of a muscle, one must consider location and number of articulations in addition to specific origin and insertion.

Degrees of Freedom

- ss

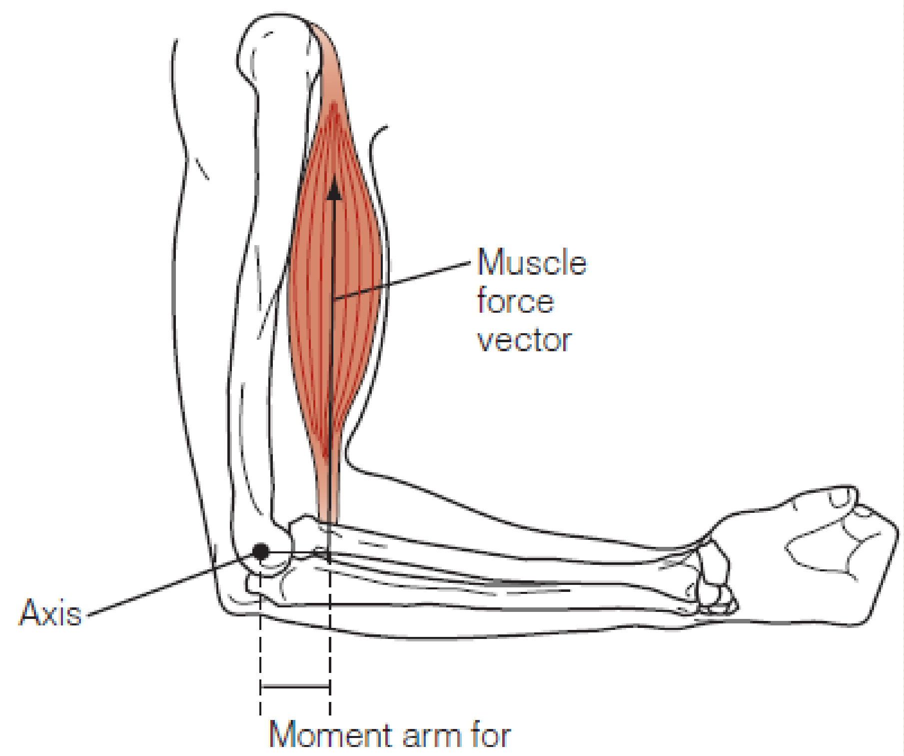




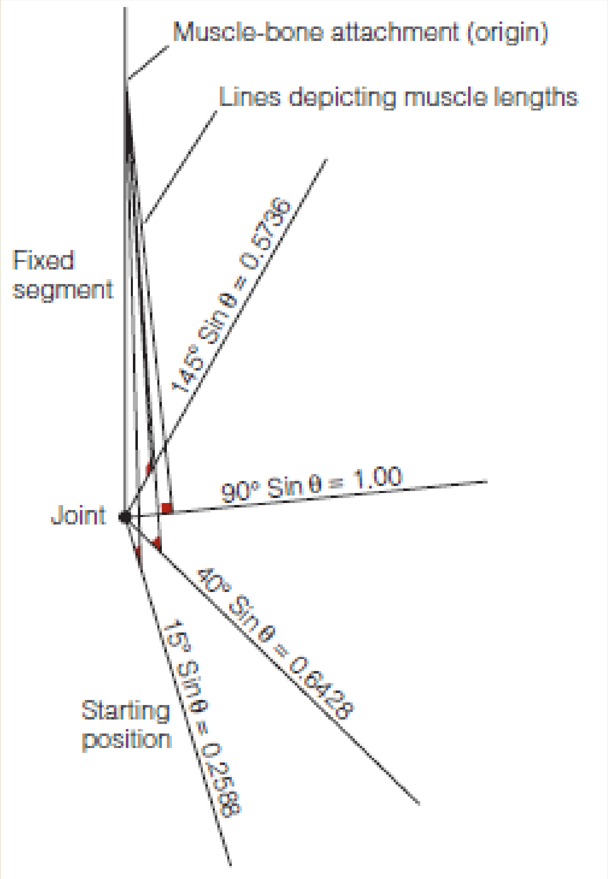
Moment Arm

- There are two moment arms are of interest:

(1) the moment arm for the muscle and (2) the moment arm for the resistance.



Muscle force vector, moment arm, and axis of rotation.



Change in muscle angle of pull and length of moment