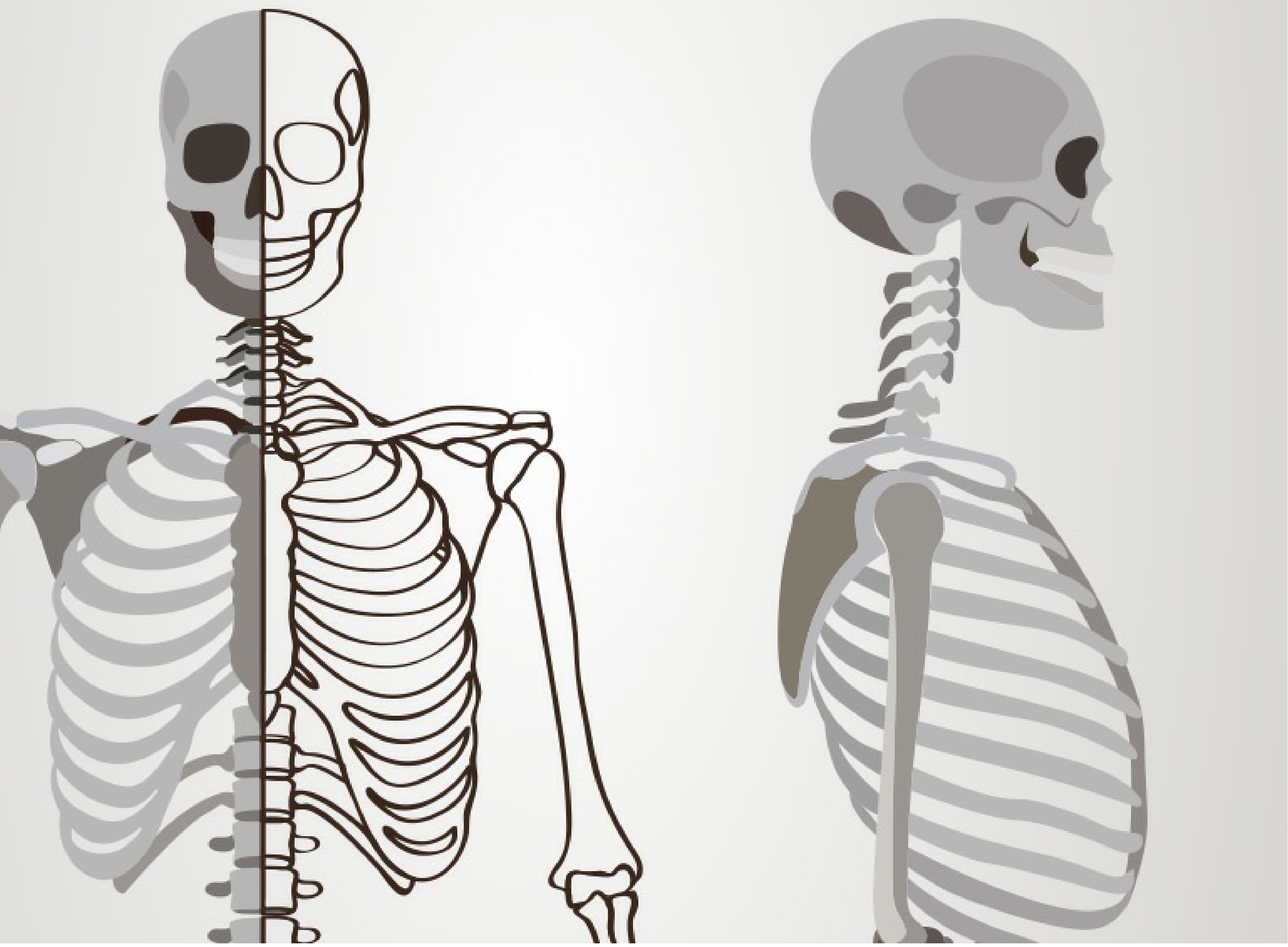
Upper and Lower Extremity Biomechanics

Biomechanics for health sciences – A study guide part 1

Gerard Gorniak



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GERARD GORNIAK

UPPER AND LOWER EXTREMITY BIOMECHANICS

BIOMECHANICS FOR HEALTH SCIENCES – A STUDY GUIDE PART 1

Upper and Lower Extremity Biomechanics
Biomechanics for health sciences – A study guide part 1
1st edition

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ABOUT THE AUTHOR

Professor Gerard C. Gorniak PhD. PT retired in 2015 from the University of St. Augustine for Health Sciences. He has been married for 45 years, has 2 children and 3 grandchildren. He is active in his church, prayer community, neighborhood, and enjoys gardening, writing and working with his hands.

After receiving a BSPT in Physical Therapy from the State University of New York at Buffalo in 1971, he remained at the University to earn a Ph.D. in Anatomical Sciences from the College of Medicine in 1976. He then went to The University of Michigan for 5 years as a NIH post-doctoral scholar with Professor Carl Gans working in muscle transplantation, biomechanics, and functional anatomy. In 1981, Dr. Gorniak accepted an Assistant Professor position in the Department of Biological Science and Program in Medical Sciences at Florida State University and became an Assistant Director of Clinical Affairs, Program in Medical Sciences in 1986. In 1988, he joined the Physical Therapy Program at Florida A&M University as an Assistant Professor. From 1994–2015 Dr. Gorniak was at the University of St Augustine for Health Sciences, starting as an Associate professor and promoted in 1999 to full Professor. From 2000–2008, he was the Director of Physical Therapy Program at the University and the Director of the Institute of Physical Therapy from 2006–2008. From 1986–1997 he also practiced Physical Therapy part-time. Currently Dr. Gorniak is an Adjunct online Professor and Consultant at the University of St Augustine.

Dr. Gorniak began his teaching experience as an undergraduate physical therapy student, teaching physical therapy, nursing and physical education anatomy labs. In his over 40 years of teaching, he has taught mainly gross anatomy and biomechanics, but has also taught embryology, histology, neuroanatomy, pharmacology, pathology, physical therapy differential diagnosis, research, psychosocial and ethical aspects of physical therapy, and physical therapy skills and procedures. He has developed online courses in Anatomy, Biomechanics, pre-anatomy Basic Human Musculoskeletal Anatomy, and Pharmacology.

Over the years Dr. Gorniak has developed note packs for the students in Anatomy (826 pages), Biomechanics (407 pages), Pharmacology (93 pages), Differential Diagnosis (144 pages), Histology (199 pages), as well as a Lab Manual for Applied Human Anatomy (146 pages) and high definition, cadaver Video Dissector of the Human Body series (8 anatomical regions). He has published over 30 peer reviewed journal articles, most in the areas of anatomy and biomechanics, delivered many invited presentations and workshops on the extremities and pelvis, and has been a reviewer for several journals and an associate editor for the Journal of Morphology. He was an Item Writer and Reviewer for the Federation of State Boards of Physical Therapy, on the Medical Advisory Board for Medical Personnel Pool, and was active in the Florida Physical Therapy Association as a member of the Ethics Committee, Board of Directors, Practice Panel Coordinator, Research committee chair and a delegate to the National Assembly.

Dr. Gorniak is listed in American Men and Women in Science, Who's Who in the Midwest, and Who's Who in the South. He received the Richard Winzon Teaching Award four times from Programs in Medical Sciences, and outstanding instructor awards from Florida A&M University and the University of St Augustine. Dr. Gorniak received recognition from the Florida Physical Therapy Association for Ethic Committee and Research Committee Service and the Rick Shutes Committee Service Award. He has served on numerous University committees, councils, task forces, and has been involved in 4 national accreditations.

Dr. Gorniak has also been active in the community. He coached little league baseball and girls softball and grade school basketball. He was the Chairperson of BOD of St. Augustine House of Prayer and Evangelization Center, Inc.; a member of the Curisillo Secretariat, Dioceses of Pensacola-Tallahassee; made 8 missions trips to Slovakia and Czech Republic with Renewal Ministries; planned and participated in nearly 20 Dioceses of St. Augustine Catholic Charismatic Renewal Conferences, and is currently the Vice president of the Home Owner Association where he lives.

PREFACE

These study notes started in 1990 when I was teaching Physical Therapy Biomechanics and Occupational Therapy Functional Anatomy at Florida A&M University. Since that time, these have been revised 6 times. Major revisions were made in 1995 when the notes were adapted for the Biomechanics course at the Institute of Physical Therapy (now the University of St Augustine). Another major revision occurred in 2003 when study questions were added and references updated. In 2006 and 2011, the text, study questions, references and illustrations were reviewed and updated. In the current 2016, the title was modified, learning activities were added, extensive revisions made to the illustrations and text.

This study guide for Biomechanics was developed as the primary source of information for courses for Physical and Occupational Therapy students at the University of St Augustine for Health Sciences. Embedded is the guide are study questions and simple activities associated with joint movement. There are two parts to this study guide. Part 1 of the guide begins with a section on basic mechanics. Next, the mechanics of upper extremity movements are described for the shoulder complex, elbow complex, wrist complex and hand. This section is followed by the mechanics of the lower extremity, including the hip, knee, ankle complex, foot and the mechanics of gait. Part 2 describes the mechanics of the spine, the mechanics of a good posture and the movements of the temporomandibular joint. The final sections of part 2 describe the mechanics associated with connective tissues, cartilage, bone, muscle and nerve and the effects of aging on these tissues.

I am most grateful Drs. Hilmir Augustsson, Kunal Bhanot, Steve Laslovich, Stanley Paris, Catherine Patla, Alec Stenhouse, and Jim Viti for their useful comments, help and support with this study guide and for the feedback from the many students who have studied from these materials over the years. I am also very grateful for the University of St. Augustine for Health Sciences their support and assistance.

I wish to dedicate this work to Dr Frank Kallen and Dr Carl Gans for their valuable mentorship and wisdom early in my academic career and to all those authors and researchers who have advanced our understanding in the biomechanics of the Human body.

Gerard Gorniak
Retired Professor
The University of St Augustine for Health Sciences

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1 BASIC MECHANICS

MOTION

Movements at joints are the result of forces that produce movement at the joint competing against forces resisting that movement. Muscle shortening contraction will produce joint motion while the weight of a structure or tightness of a structure will resist movement. To better understand this relationship between force and motion, a review of Newton's Laws of Motion is useful.

NEWTONS LAWS

1. An object stays in a state of rest or moves in a uniform motion in a straight line unless it is acted upon by forces that change that motion.
   - Force is needed to start motion.
   - Force is needed to change the direction of motion.
     - applied force = resistance = no movement
     - applied force < resistance = no movement
     - applied force > resistance = movement
     - applied force 1 > applied force 2 = movement by force 1
     - applied force 1 < applied force 2 = movement by force 2

   - an example of elbow flexion
     - biceps and brachialis muscles apply an upward force on the radius and ulna
     - weight of forearm and hand resist the upward forces of these flexor muscles
     - if the flexor forces > weight of the forearm and hand, elbow flexion occurs
     - if the flexor forces = the weight of the forearm and hand, no movement at the elbow occurs
     - if weights are added to the forearm and hand so that the flexor forces are < weight of the forearm, hand and added weights, elbow extension occurs

2. Acceleration of a body is proportional to the magnitude of the resultant forces acting on it and inversely proportional to the mass of the object.

   - $\text{Acceleration} \propto \frac{\text{Force}}{\text{Mass}}$
   - Force is needed to slow down or speed up a moving object.
   - A large mass requires more force than a small mass to attain the same acceleration.

3. For every action, there is an equal and opposite reaction between contacting objects
    - In walking, the force of the foot on the ground equals the force of the ground on the foot. Movement of the foot occurs because the mass of the foot (body) is much less than the mass of the earth (ground), and thus the foot can accelerate and move.
    - In a space launch, the force of the rocket equals the force of the launch pad. Movement of the rocket occurs because the mass of the rocket is less than mass of the earth (launch pad) and the rocket accelerates and moves.

FORCES

- **FORCE** = a quantity that accelerates or decelerates a mass
    - F = mass X acceleration (F = MA)
    - **FORCE** as defined by acceleration
        - actions that accelerate an object
            + For example, when forces applied by the biceps and brachialis muscles flex the elbow.
        - actions that resist the acceleration of an object
            + For example, when the weight of the forearm, hand and a barbell type weight resist elbow flexion.

- **COMMON TYPES OF FORCES**
    - loads
    - stress
    - weight
    - centrifugal
    - magnetic
    - hydrostatic
    - friction
    - pressure
    - chemical bonds

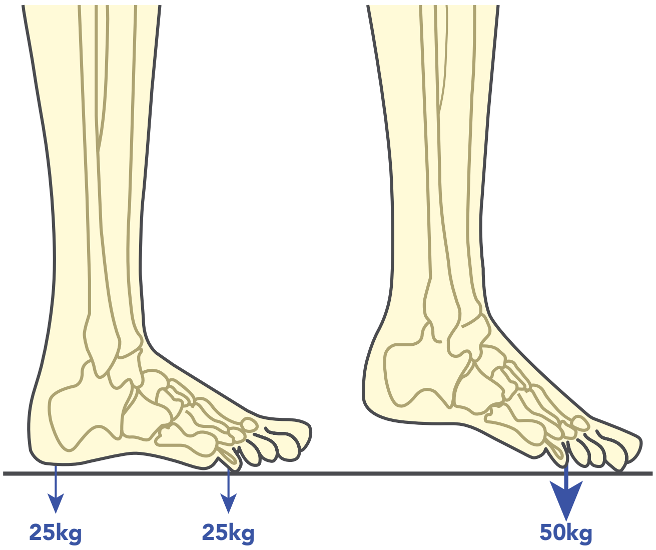
- **UNITS OF FORCE**
    - **c.g.s. system** (cm., gram, second)
        - force unit = DYNE
        - 1 dyne = the force which in 1 second accelerates 1 gram mass to a speed of 1 cm/sec

- **m.k.s system** (meter, kilogram, second)
  - force unit = NEWTON
  - 1 newton = the force which in 1 second accelerates a mass of 1 kilogram to a speed of 1 meter/sec.

- **ft.,lb.,sec system** (foot, pound, second)
  - force unit = POUNDAL
  - 1 poundal = the force which in 1 second accelerates a 1 pound mass to a speed of 1 foot/sec.

- **WEIGHT** (grams, kilograms, ounces, pounds, tons, etc.)
  - WEIGHT = FORCE = MASS × ACCELERATION (gravity)
  - gravity = 9.8 m/sec 2
  - The units of weight are also commonly used to describe the amount of force at a joint or produced by muscle or in contact with the body.

- **TOTAL VS. UNIT FORCE**
  - total force = the total amount of force being applied
  - unit force = the amount of force being applied per unit area
  - if the total force applied to an area is 50 kilograms and the area is 100 mm^2 then the unit force is 50 kg ÷ 100 mm^2 = 0.5 kg/mm^2
  - Unit forces are used to discribe force distributions on joint surfaces, changes in force distribution during movements, and when forces are distributed unevenly.



(LEFT) At the heel, the force is 25 kg and at the ball of foot it is 25 kg for a total force of 50 kg on the foot. The unit force at the heel is 25 kg/area of the heel and at the ball of the foot it is 25kg/area at the ball of the foot. (RIGHT) Force at the heel is now 0 kg but force at the ball of the foot is 50 kg. The total force on the foot is still 50 kg but the unit force at the ball of the foot is 50 kg/area on the ball of the foot. Comparing the left vs right drawings, the unit force on the ball of the foot in the right drawing is 2X that of the left because the force is doubled on the right but the areas are the same in both drawings.

LOADS and STRESSES

- **LOADS**
  - Loads are any force or combination of forces that are applied to the outside of an object.
  - These are external forces as opposed to forces within an object or material.
  - Example, when your fingers apply a load on a book to hold it; a tendon applies a load to a bone to move it; your feet apply a load to the floor when standing or walking.

- **TYPES OF LOADS**
  - TENSION is a force that pulls and tenses, producing a stretching, separating or elongating deformation of a structure.
    - For example, pulling on a rope; a muscle pulling on a tendon; the pulling or tightening of a ligament or joint capsule during a movement

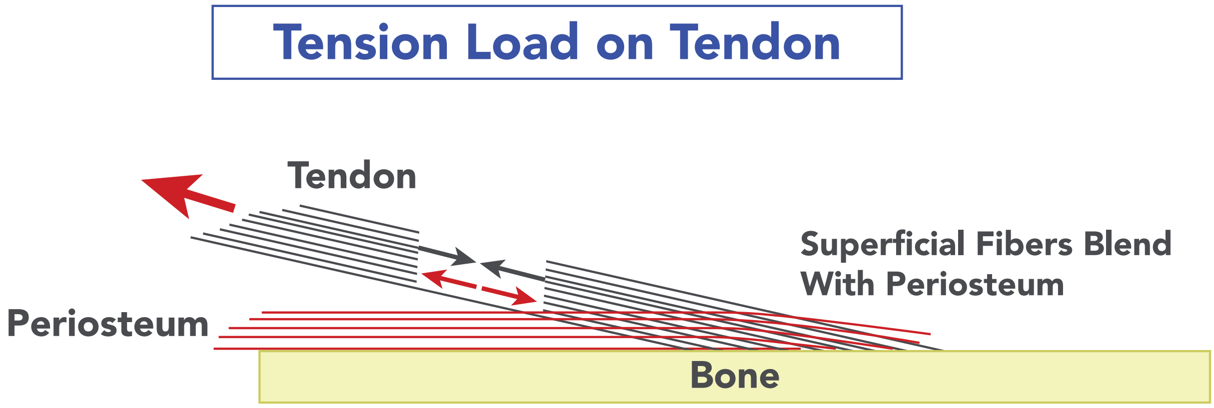
- COMPRESSION is a force that pushes structures together producing a squeezing or compressing deformation of a structure.
    - For example, squeezing a ball or balloon; compression of a intervertebral disc between adjacent vertebrae; compression of a blood vessel during an injury
- SHEAR involves (1) parallel but opposite translatory forces producing a slicing or scissor-like action on a structure, and (2) parallel but opposite rotational forces (torques) producing a twisting motion.
    - For example, tearing or cutting a piece of paper; biting food with your incisors; rotation between 2 vertebrae; rotation of the lower extremity joints during walking

- **STRESSES**
    - Stresses are forces that develop or are transmitted within a structure or material.
    - Loading forces are transmitted into a structure producing stresses within a structure.
    - Within the structure, stresses are also develop to resist loading
    - TYPES OF STRESS
        - TENSION
        - COMPRESSION
        - SHEAR

When any load is applied to an object, tension, compression and shear stresses all occur within the object.

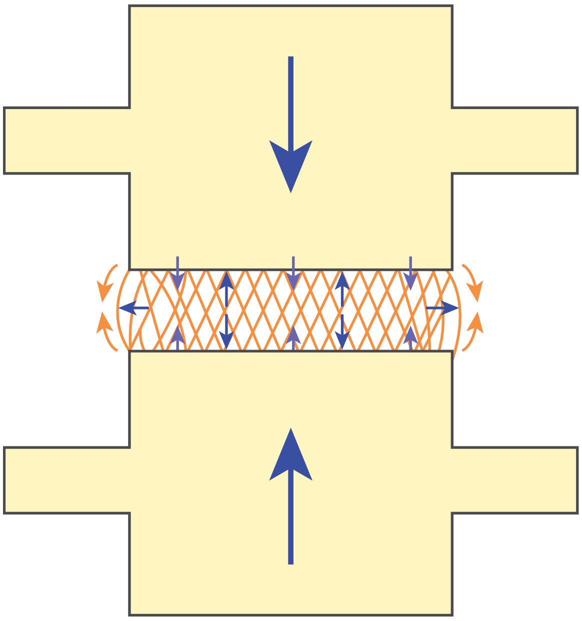
- **EXAMPLES OF LOADS AND STRESS**

1. TENDONS
    - When a muscle applies a tension load to tendon, the tension load forces are transmitted through the tendon as tension stresses.
    - The tendon resists these tension stresses with compression stresses.
    - Tension and compression stresses act in parallel and in opposite directions producing shear stresses.



In this figure, a tension load (large red arrow) pulls on the tendon that is attached to the bone. Within this tendon, tension stresses are transmitted (small red arrows) through the collagen fibers of the tendon. The collagen fibers also resist the tension like the fibers of a rope being pulled. The resisting forces opposing the tension stresses act as compression stresses (small black arrows). Because the tension stresses and the compression stresses are acting parallel and opposite to each other, shear stresses are produced in the tendon.

2. INTERVERTEBRAL DISC
   - A compression load to the intervertebral disc transmits compression stresses in disc.
   - This transmitted compression stresses in disc are resisted by tension stresses in disc.
   - Tension and compression stresses are forces acting in parallel and in opposite directions producing shear stresses.



Two adjacent vertebrae are applying a compression load (large blue arrows) to the intervertebral disc. The disc transmits the compression forces producing compression stresses (small faded blue arrows) in the disc. The material of the disc is resisting the compression force by acting in the opposite direction as tension stresses (small blue arrows) somewhat like pillars act between the roof and the ground. The opposing parallel compression and tension stresses produce shear stresses in the disc.

LOAD → STRESS → STRAIN

External Forces → Internal Forces → Deformation

- **STRAIN** (deformation)
  - Strain = ∊ (epsilon) is the physical or molecular deformation of a structure as a result of stresses within that structure.
  - TYPES OF STRAIN
    - TENSION = elongation, stretching, separation

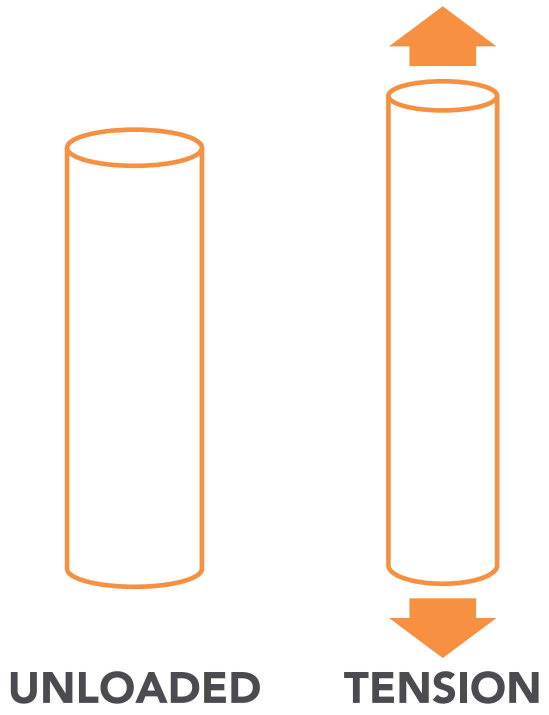


Diagram of tension strain; materials elongate, stretch, lengthen in response to a tension load and stress.

- COMPRESSION = squeezing, constriction, compressing

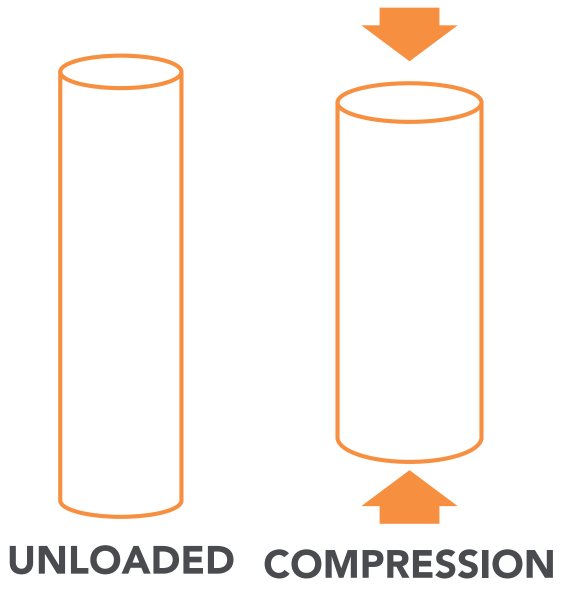


Diagram of compression strain; materials compress, constrict, compact, squeeze in response to compression load and stress.

- SHEAR = cutting, tearing, ripping, splitting

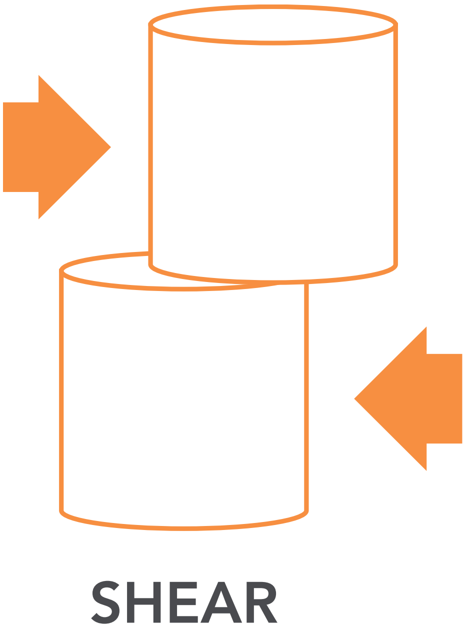
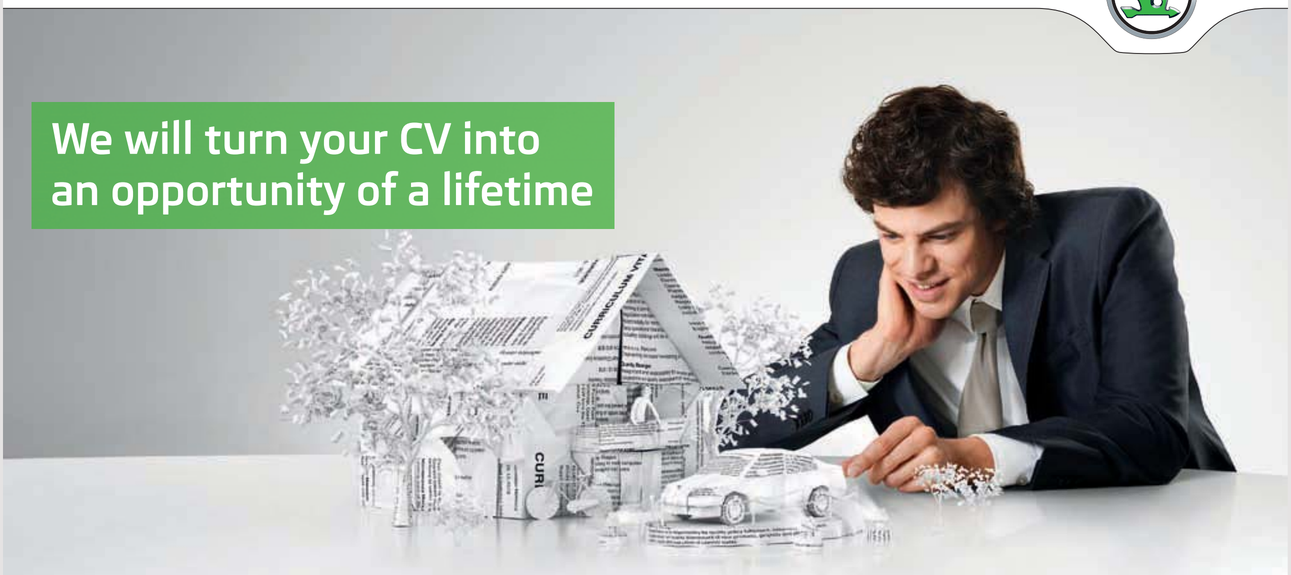


Diagram of shear strain; materials tear, rip, cut in response to a shear load and stress.



- BENDING = curving, bowing, angling

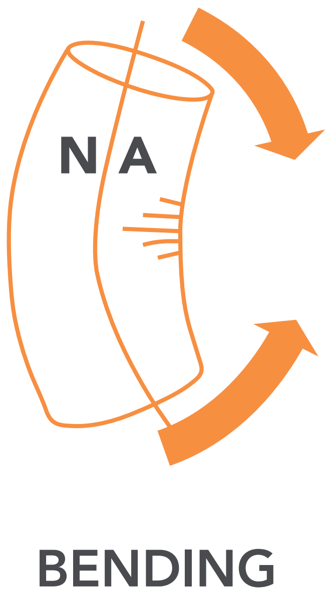


Diagram of bending strain. When a material bends, compression stress lies on the concave side of the bend and tension stress on the convex side. A neutral axis (NA) passes through the center of the structure where compression and tension stresses are at equilibrium. The compression and tension stresses are highest at the periphery and lowest near the neutral axis.

- TORSION = twisting, turning, rotational shearing

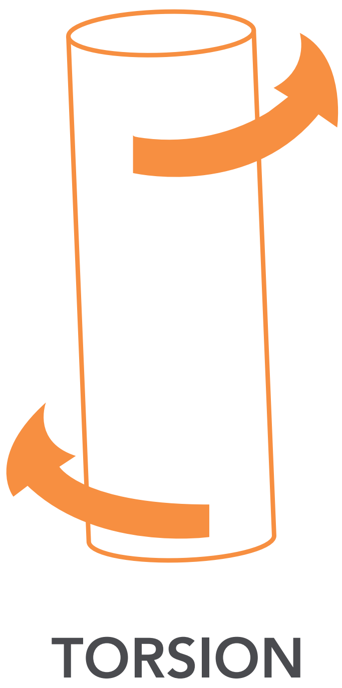
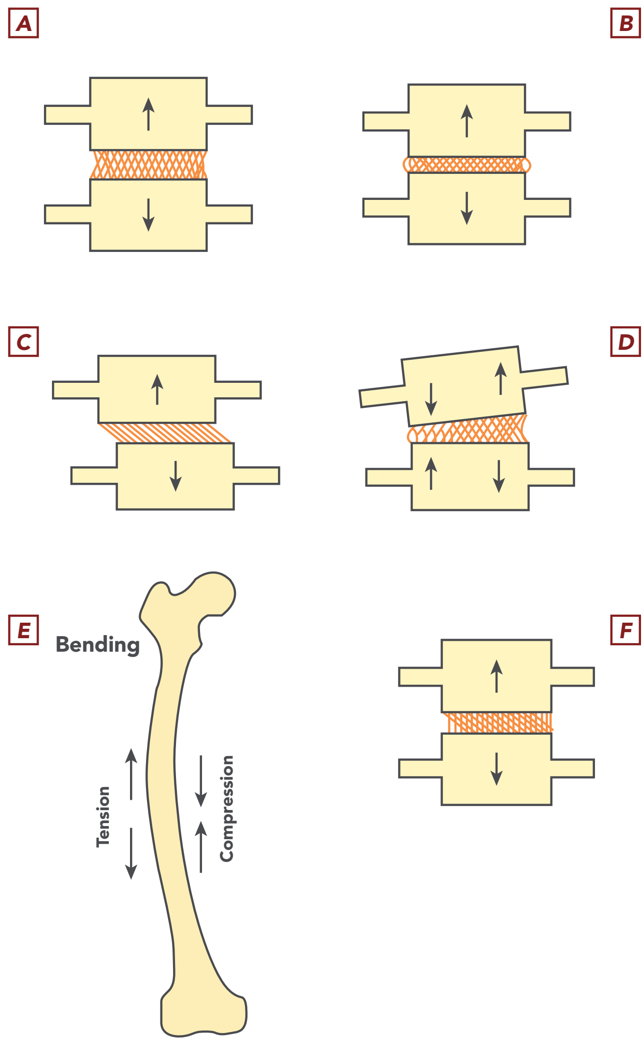


Diagram of torsional strain. When rotational forces (torques) act in parallel but in opposite directions, these rotational shear stresses twist the material. When a rotational force (torque) acts on a stationary structure, the rotational stress turns, twists, curls the material.



Diagrams showing strains on vertebrae and bending on the femur (E). (A) Tension Strain on a vertebral disc: Tension loads separating adjacent vertebrae and lengthening or elongating the disc. (B) Compression Strain on a vertebral disc: Compression loads pushing adjacent vertebrae together and squeezing or compressing the disc. (C) Shear Strain on a vertebral disc: Parallel vertebral loads acting in opposite directions and tearing or ripping the disc. (D) Combined Tension and Compression Strains on a vertebral disc: On one side of adjacent vertebrae, compression loads are squeezing the disc and on the opposite side, tension loads are elongating the disc. (E) Bending Strain on the femur: Compression stress is on the concave side of the bent femur and tension stress on the convex side. (F) Torsional Strain on the vertebral disc: A rotational force (torque) of one vertebral relative to an adjacent vertebrae produces a twisting or turning strain on the disc.

- **MECHANICAL WORK**
  - WORK (W) = FORCE (F) X DISTANCE (L)

  - Mechanical work is force acting over a distance.
  - Mechanical work is not a function of time.
  - With isometric exercise, there is no movement and no mechanical work.

- **POWER**
  - POWER (P) = FORCE (F) X DISTANCE (L) / TIME

    $$P = F \times \frac{L}{\text{TIME}}$$
  - Power is work done per unit time.
  - The longer it takes to move an object of "X" weight (force) over a "Y" distance, the lower the power.

- Power is inversely proportional to time.
  - increase time → decrease power (force & distance constant)
  - decrease time → increase power (force & distance constant)

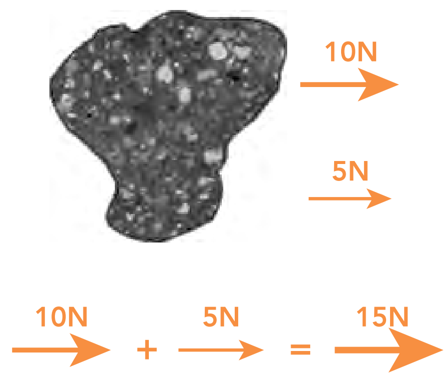
Study Questions (Newton's Laws and Forces)

1. Apply Newton's First Law to the movements of the glenohumeral joint.
2. Apply Newton's Second Law to an exercise for increasing elbow flexion strength.
3. Apply Newton's Third Law to gripping and holding an object in your hand.
4. What is the difference between total and unit force?
5. What is the difference between loads and stresses?
6. What are the stresses occurring in a tendon when a tensile load is applied by the contraction of a muscle?
7. What are the stresses occurring in a vertebral disc when a compression load is applied by the vertebral bodies?
8. What is the difference between stress and strain?
9. What strains occur at a tendon when a tensile load is applied?
10. What strains occur when a long bone is bending?
11. What is the difference between work and power?

FORCES as VECTORS

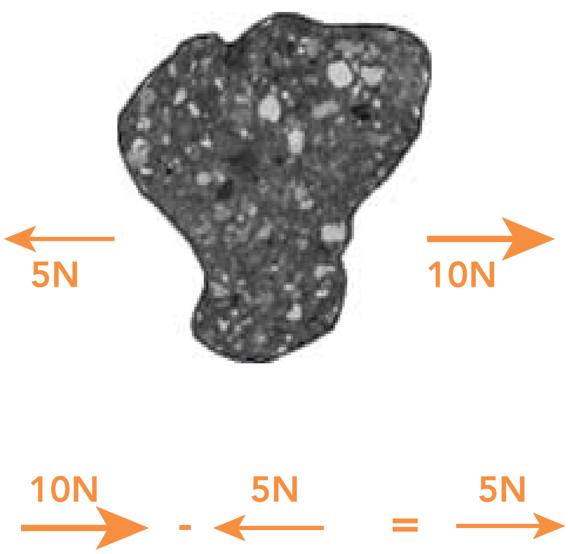
- A force has a magnitude and direction.
- A vector can be use to show the direction and magnitude of a force.

  - FORCES ACTING IN SAME DIRECTION
    - These types of forces are added together.
    - For example



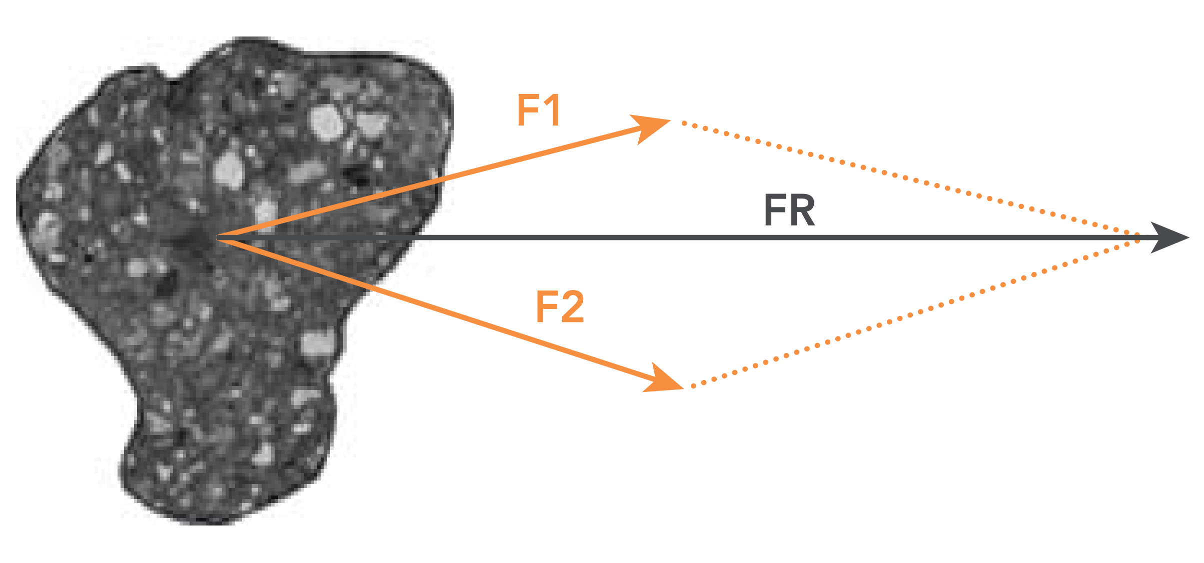
The rock above has a 5 Newton (N) force and a 10 N force acting in the same direction producing a 15 N force.

  - FORCES ACTING IN OPPOSITE DIRECTIONS
    - These types of forces are subtracted
    - For example



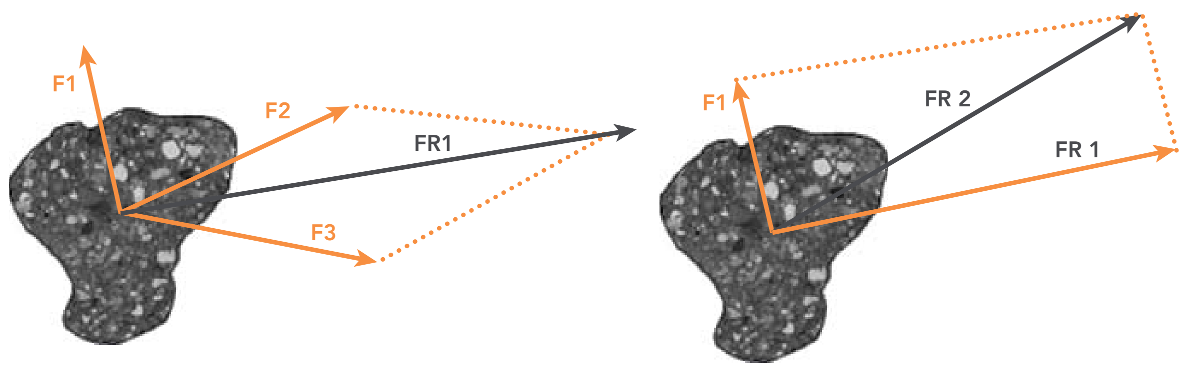
The rock above has a 5 Newton (N) force pulling left and a 10 N force pulling right. The result is a 5N force pulling the rock to the right.

- TWO FORCES ACTING AT AN ANGLE TO EACH OTHER
  - A parallelogram can be easily used to determine the resultant force (FR) from two forces (F1, F2) acting at angles to the structure.
  - For example



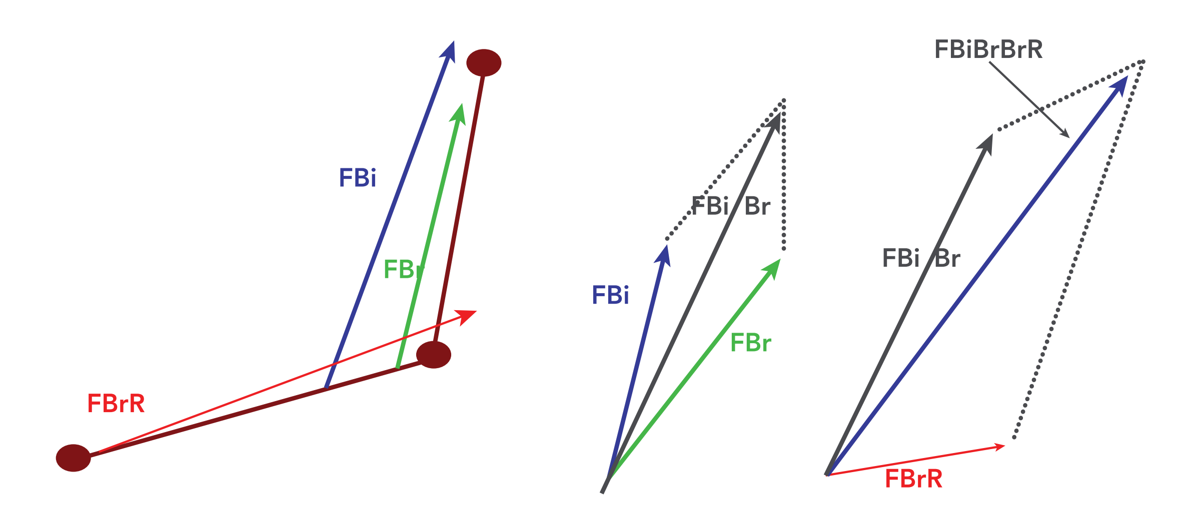
The rock above has a F1 force pulling right at an upward angle and a F2 force pulling right at a downward angle. The resulting FR force is pulling the rock to the right and at a greater force than either F1 or F2.

- MULTIPLE FORCES ACTING AT ANGLES TO EACH OTHER
  - Parallelograms can also be used in these cases to determine the total resultant force by first finding the resultant force (FR1) for two force vectors (F2, F3).
  - Using that resultant force from the F2 and F3 vectors (FR1) with a third force vector (F1), draw a parallelogram to determine second resultant force vector (FR2).
  - If there is a fourth force vector (F4), use the second resultant force (FR2) and the F4 vector to form a parallelogram and determine the next resultant force vector (FR3).
  - Once all the vector forces (F#) are used one time, the final resultant force is the total resultant force (FRt) for all the vector forces.
  - For example



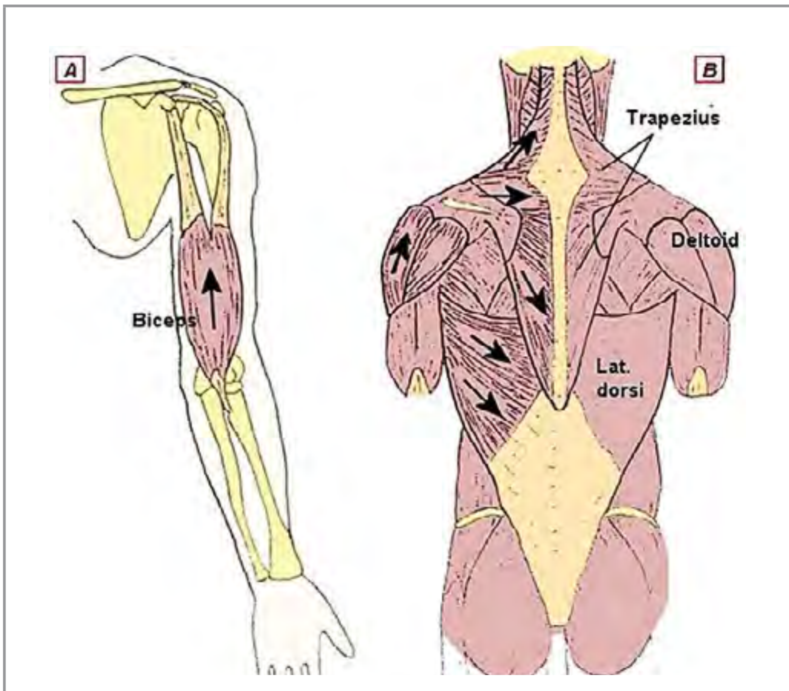
(LEFT) This left rock shows 3 forces (F1, F2, F3) acting on it at different angles. The result of F2 and F3 is FR1 which lies between the direction of F2 and F3 and is greater than either F2 or F3. (RIGHT) This right rock shows FR1 which is the resultant force from F2 and F3 acting on the left rock. When F1 is added, the resulting force of F1 and FR1 produces the resultant force FR2. Because FR1 was the result of F2 and F3, and FR2 the result of FR1 and F1, the vector FR2 shows the relative direction and magnitude of F1, F2, and F3 acting on the rock.

- EXAMPLE OF BICEPS (FBi), BRACHIALIS (FBr), AND BRACHIORADIALIS (FBrB) FORCE VECTORS ON ELBOW FLEXION



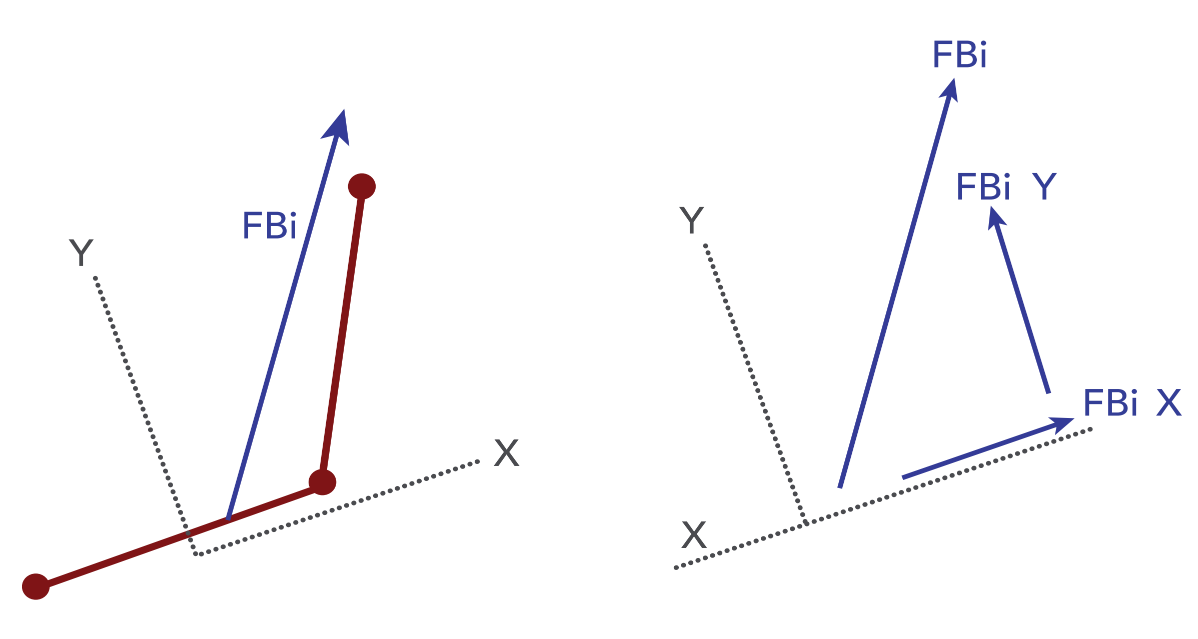
(LEFT) The left diagram shows the line of action of the biceps (FBi), brachialis (FBr) and brachioradialis (FBrR). (MIDDLE) This diagram shows the resultant vector FBiBr for the biceps (FBi) and the brachialis (FBr). (RIGHT) This diagram shows that by adding the brachioradialis (FBrR) to the resultant of the biceps and brachialis (FBiBr), the resultant direction and magnitude of motion is FBiBrBrR when all three muscles are active.

- COMPONENT FORCES OF THE LINE OF MUSCLE ACTION
  - The line of action(s) of a muscle can be estimated by aligning the direction of the muscle fibers with the attachment sites of those fibers.



Drawings showing the line of action (arrow) of the (A) biceps muscle and the (B) trapezius, deltoid and latissimus dorsi muscles. Notice that the line of action of these muscles differs regionally.

- A lines of muscle action can be represented as a vector.
- The vector can then be subdivided into its X and Y components by forming a right triangle.
  - + The X component is always aligned with the bone that is moving.
  - + The Y component is perpendicular to the X component.
- An example showing the biceps line of action (FBi) and the X (FBiX) and Y (FBiY) components with the elbow in flexion.



(LEFT) Diagram of the line of action of the biceps (FBi) with superimposed X – Y axes. The top red dot is the glenohumeral joint, the middle dot is the elbow and the left dot is the wrist. The X axis is aligned with the ulna of the forearm. (RIGHT) Diagram showing the line of action of the biceps (FBi) and its X component (FBiX) and Y component (FBiY).

  - + The FBiY component indicates an upward force that would rotate the bone (ulna, X axis) upward.
  - + The FBx component indicates a posterior force that would compress the humeroradial joint.
- As the line of action of a muscle changes during motion so do the X and Y components.
- These changes in the X and Y components reflect changes in the amount of available force used to produce movement and the amount acting at the joint.

- The magnitude of the line of action, and the X and Y components, can be calculated using the Pythagorean theorem or trigonometry

Pythagorean theorem

$$a^2 = b^2 + c^2 \text{ or } Fr^2 = Fx^2 + Fy^2$$

trigonometric functions

$$\sin o = \frac{Fy}{Fr} = \frac{\text{opposite side}}{\text{hypotenuse}}$$

$$\cos o = \frac{Fx}{Fr} = \frac{\text{adjacent side}}{\text{hypotenuse}}$$

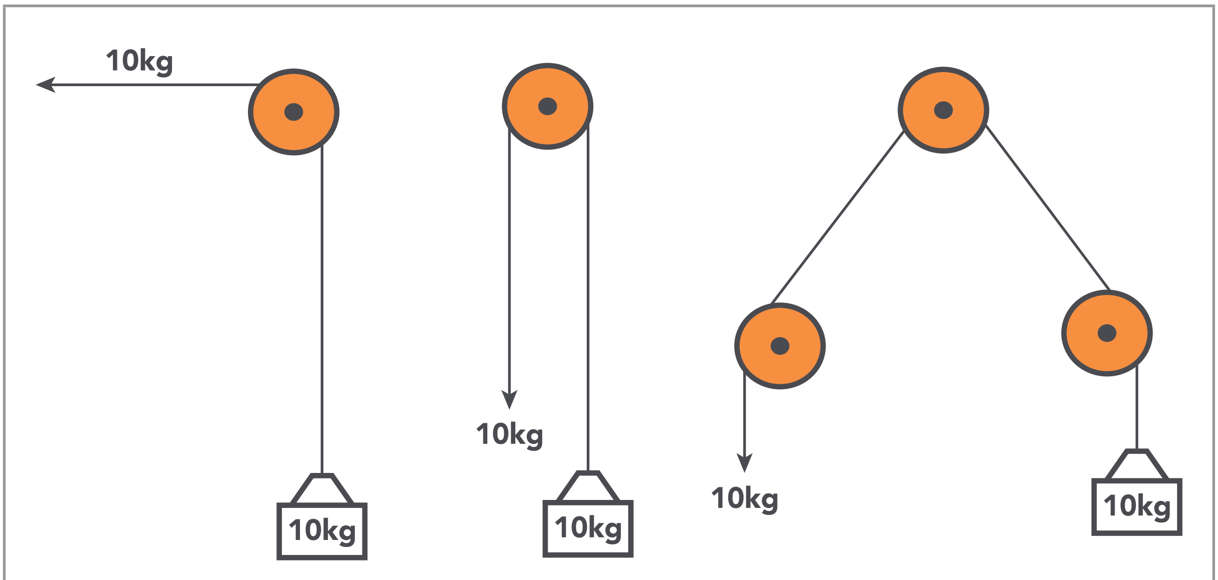
$$\tan o = \frac{Fy}{Fx} = \frac{\text{opposite side}}{\text{adjacent side}}$$

MECHANICAL ADVANTAGE

- Mechanical advantage refers to the mechanical gain from the transmission of an output force relative to an input force or resistance as when using movable pulleys or levers.

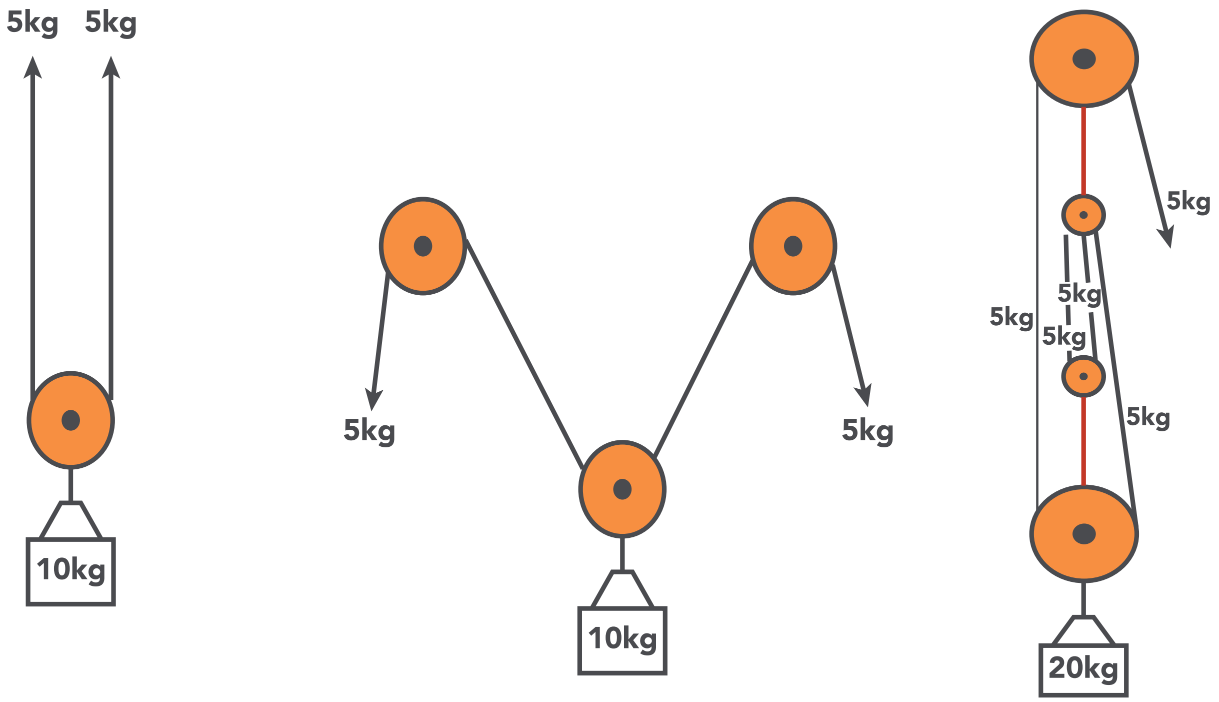
- **FIXED PULLEYS**

  - Fixed pulleys are used to change direction of force but not magnitude and therefore does not provide a mechanical advantage.
  - Force is equal in each strand of the fixed pulley.
  - Force in each strand is equal to the force of resistance.
  - There are many fixed pulleys in the body associated with tendons moving around bony prominences or through osteofibrous tunnels or surgically made pulleys.
  - Examples of fixed pulleys



Three Fixed Pulleys: (LEFT) Pulley diverts the force at a right angle to the weight. (MIDDLE) Pulley diverts the force around toward the weight. (RIGHT) Series of 3 fixed pulleys moving the line of output force up to the left and down to the left. In each of these diagrams the magnitude of the output force is the same as the resisting input force.

- **MOVABLE PULLEYS**
  - Movable pulleys change the direction and magnitude of the force.
  - Forces on the supporting strands of the system are less than the resistive force.
  - Movable pulleys can be used in combination with fixed pulleys.
  - In the body, the patella is a movable pulley.
  - Examples of movable pulleys



Three Movable Pulleys: (LEFT) A simple movable pulley with each strand needing 5kg to move the 10kg weight. (MIDDLE) A movable pulley with each strand going around a fixed pulley to change the direction of pull. Even with the fixed pulleys, the strands of the movable pulley need only 5kg to move the 10kg weight. (RIGHT) This block and tackle has a fixed pulley at the top connected (red line) to a movable pulley just below and another fixed pulley at the bottom connected (red line) to a movable pulley just above. With this combination of pulleys, only 5kg is needed to move a 20kg weight.

- **LEVERS**
  - There are three classes of levers.
  - Each lever has the following 5 parts: a Fulcrum (Δ), Weight/Resistance (W), Force (F), Weight arm, Force arm.

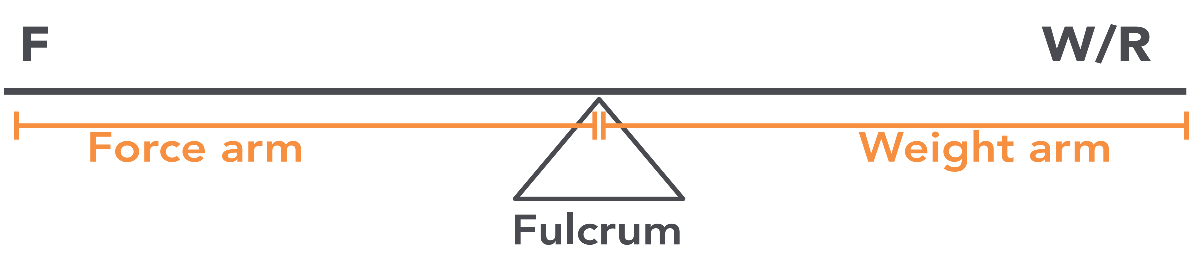
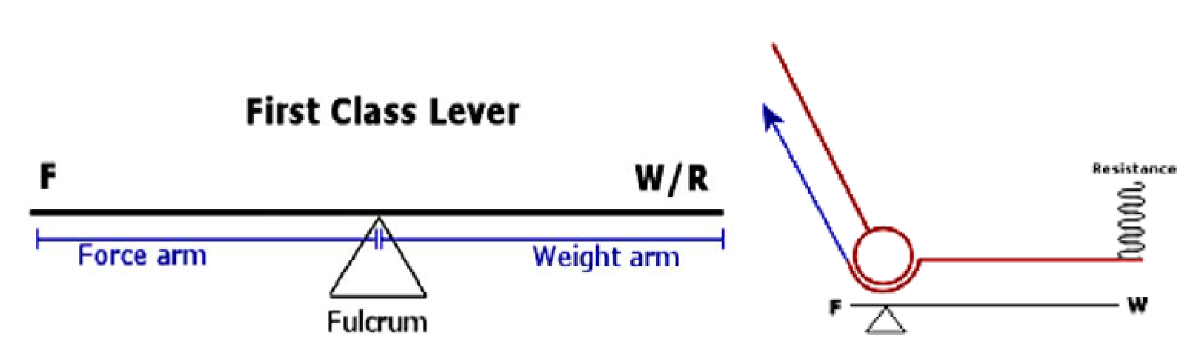
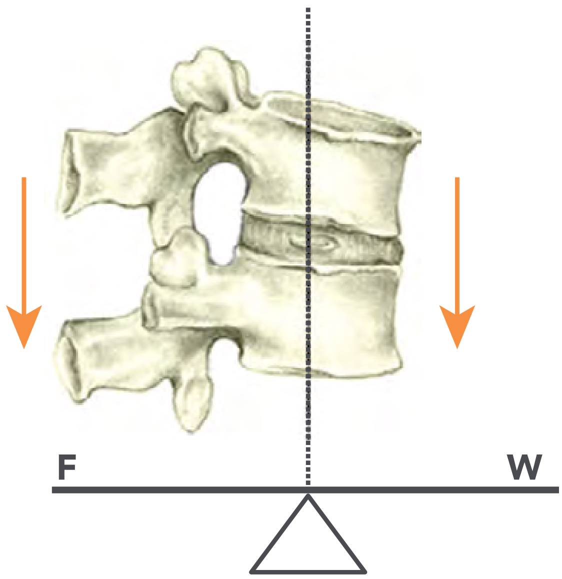


Diagram showing the basic component of a lever.

- CLASS I LEVER (see saw)
  - The force (F) and the weight (W/R) are on each side of the fulcrum.
  - Examples are the triceps acting on elbow; soleus acting on ankle; erector spinae acting on spine and abdominal weight.

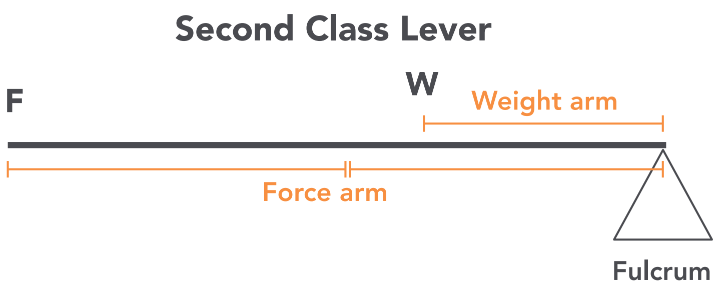


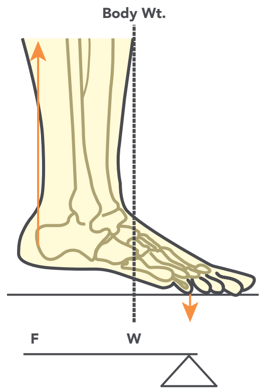
(LEFT) Diagram showing the configuration of a First Class Lever. (RIGHT) Example of the triceps acting as a First Class Lever at the elbow joint. The fulcrum is the axis of the elbow joint, the Force (F) is where the triceps attaches to the olecranon process and the Weight (W) is the weight of forearm and hand. In this example the Force Arm is very short and the Weight Arm long.



Example of the lumbar spine as a First Class Lever. The fulcrum is through the vertebral bodies, the Force (F) consists of the paraspinal muscles and ligaments, and the Weight is the weight of the abdominal contents.

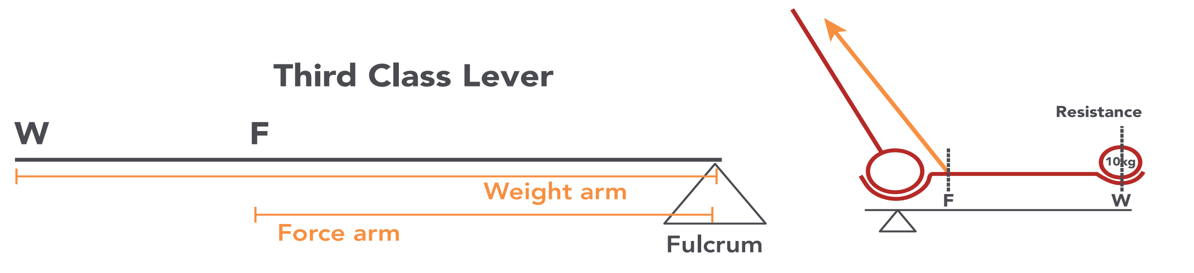
- CLASS II LEVER (wheelbarrow)
  - The Fulcrum is at one end and the Force (F) at the opposite end and in between is the Weight (W). In this lever, the Force Arm is longer than the Weight Arm.
  - An example are toe raises with axis at metatarsophalangeal joints.





(LEFT) Diagram showing the configuration of a Second Class lever. (RIGHT) With toe raises, the fulcrum is across the metatarsophalangeal joints, the Force is the attachment of the Achilles Tendon to the calcaneus and the Weight is the center of gravity weight of the body which passes through the midfoot.

- CLASS III LEVER
  - The Fulcrum is at one end and the Weight (W) at the opposite end and in between is the Force (F). In this lever, the Weight Arm is longer than the Force Arm.
  - Examples are the biceps acting at elbow; quadraceps acting at knee.



(LEFT) Diagram showing the configuration of a Third Class lever. (RIGHT) Example of the biceps acting as a Third Class Lever at the elbow joint. The fulcrum is the axis of the elbow joint, the Force (F) is where the biceps attaches to the radius and the Weight (W) is the weight of forearm and hand. In this example the Force Arm is very short and the Weight Arm long.

- **LEVERS AND TORQUE** (moment)
  - At the fulcrum of a lever, the forces produced by the Force (F) and Weight (W) result in rotational forces acting about an axis.
  - The rotational force is called a TORQUE or moment.
  - The formula for calculating torque is

TORQUE (T) = FORCE (F) × PERPENDICULAR DISTANCE FROM THE CENTER OF ROTATION ($\perp$d)

  - With a lever, there are two torques being applied to the fulcrum (axis)
    - Torque (Tf) is from the force (Ff) and force arm (df).
    - Torque (Tw) is from the weight (Fw) and weight arm (dw).

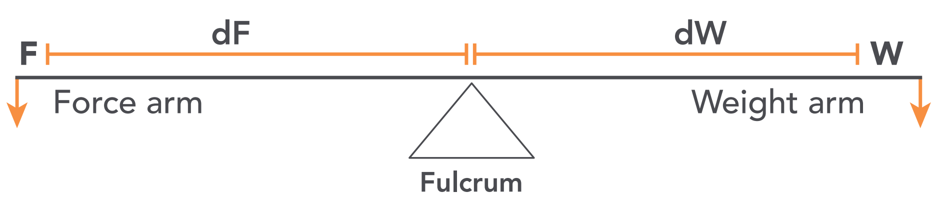


Diagram showing the configuration of a First Class lever and the components of torque.

- At equilibrium, the torque of the force (Tf) = the torque of the weight (Tw)

$$Tf = Ff \times df \qquad Tw = Fw \times dw$$
$$Tf = Tw = \text{equilibrium}$$

- Using this equilibrium relationship, the relative effects of changes in Force, Weight, Force Arm and Weight Arm can be derived for the different levers.
- Examples are shown below for each class of lever when some of these components are changed.

- CLASS I LEVER TORQUE
  - With an increase in weight arm, the force needed to hold weight at equilibrium is greater than weight.
  - For example with pregnancy or a weight gain.

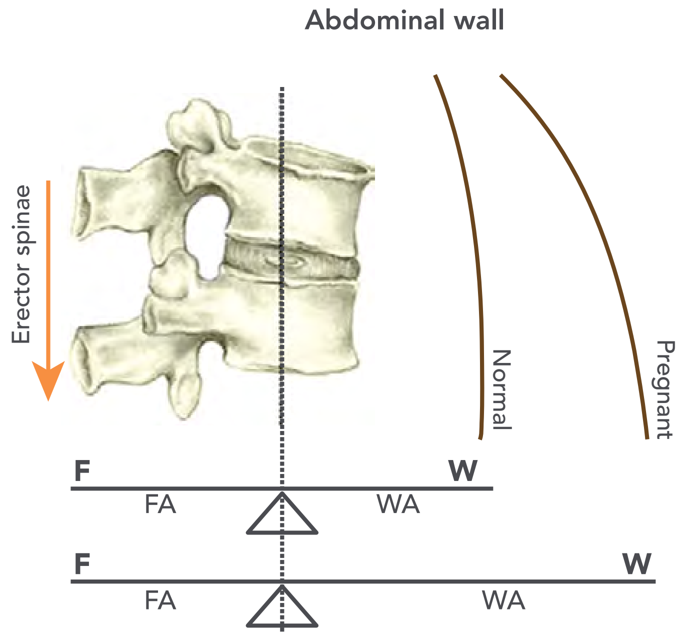


Diagram of a First Class lever acting on the lumbar spine with a normal weight arm and one in which the weight arm may be increased with pregnancy.
F = Force, FA = Force Arm,
W = Weight, WA = Weight Arm

- If the weight arm has been increased from 15 cm to 25 cm but the force arm is 5 cm for both, what happens to the force?

<u>starting position</u>

Tf = Tw
F X df = W X dw
F X 5 cm = W X 15 cm
5F = 15W
F = 3W
If W=50 kg, than F=150 kg

<u>increased weight arm</u>

Tf = Tw
F X df = W X dw
F X 5 cm = W X 25 cm
5F = 25W
F = 5W
If W=50 kg, than F=250 kg

- When the weight arm increases as in pregnancy or weight gain, the forces needed by the paraspinal muscles to hold weight at equilibrium increase which can produce low back muscle pain.
- The increase load on the paraspinal muscles is why it is important for individuals with large abdominal weight and low back pain to lose weight and decrease the weight arm.
- With low back pack during pregnancy, forces needed by the parapinal muscles can be reduced with a pregnancy support belt, producing deceased low back pain.
- The next example below shows the results of increasing the force arm from 5 cm to 30 cm but maintaining the weight are at 15 cm. What happens to the force?

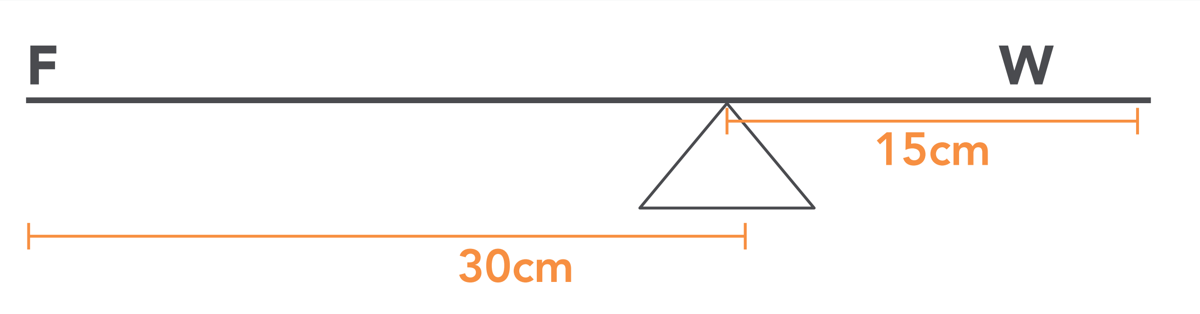


Diagram of a First Class lever with a 30 cm force arm.

starting position

$$Tf = Tw$$
$$F \times df = W \times dw$$
$$F \times 5\ cm = W \times 15\ cm$$
$$5F = 15W$$
$$F = 3W$$

If W=50 kg, than F=150 kg

increased force arm

$$Tf = Tw$$
$$F \times df = W \times dw$$
$$F \times 30\ cm = W \times 15\ cm$$
$$30F = 15W$$
$$F = 1/2W$$

If W=150 kg, than F=75 kg*

- CLASS II LEVER TORQUE
  - At equilibrium, the force needed to hold weight is always less than weight whether the weight arm or the force arm are lengthened or shortened.
  - If the weight arm is increased, the force needed also increases but the force is still less than the weight.

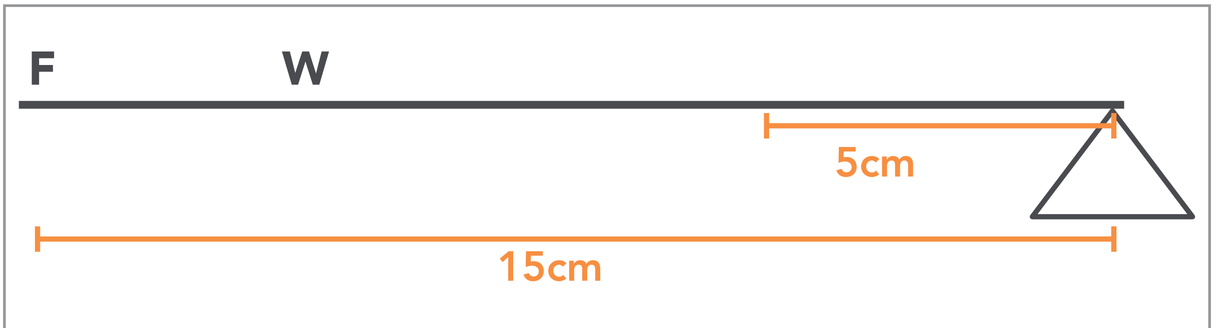


Diagram of a Second Class lever with a 15 cm force arm and 5 cm weight arm.

  - when the weight arm is increased from 5 cm to 10 cm but the force arm remains at 15 cm, but the weight is not changed. What happens to the force?

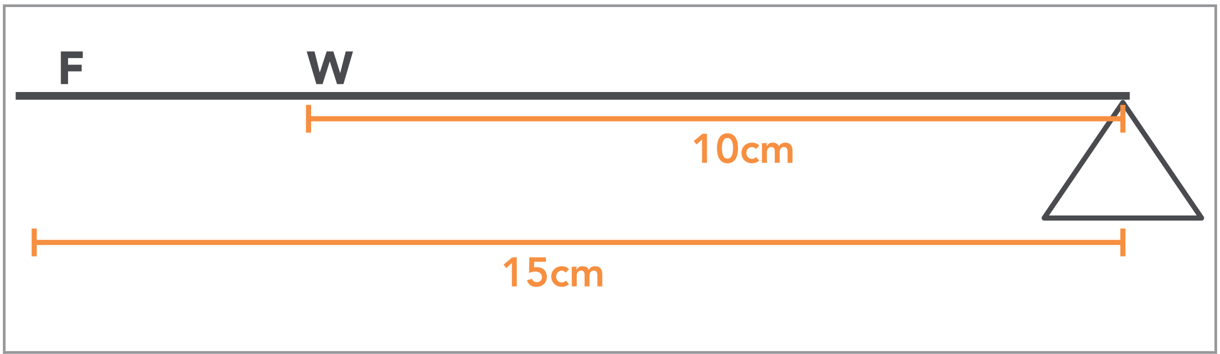


Diagram of a Second Class lever with a 15 cm force arm and 10 cm weight arm.

<u>starting position</u>

Tf = Tw
F X df = W X dw
F X 15 cm = W X 5 cm
15F = 5W
F = 1/3W
If W =150 kg, than F=50 kg

<u>increase weight arm</u>

Tf = Tw
F X df = W X dw
F X 15 cm = W X 10 cm
15F = 10W
F = 2/3W
If W =150 kg, than F=100 kg

- When the force arm is increased, the force needed decreases but the force is still less than the weight.
- If the force arm is increased from 15 cm to 25 cm but the weight arm is 5 cm. What happens to the force?

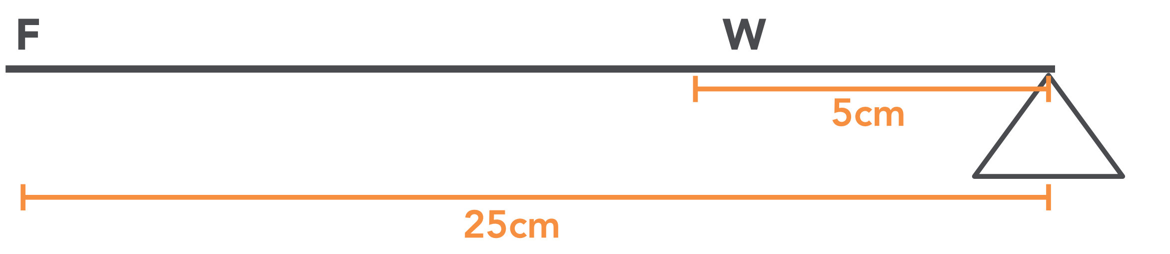


Diagram of a Second Class lever with a 25 cm force arm and 5 cm weight arm.

<u>starting position</u>

Tf = Tw
F X df = W X dw
F X 15 cm = W X 5 cm
15F = 5W
F = 1/3W
If W=150 kg, than F=50 kg

<u>increase force arm</u>

Tf = Tw
F X df = W X dw
F X 25 cm = W X 5 cm
25F = 5W
F = 1/5W
If W=150 kg, than F=30 kg

- CLASS III LEVER TORQUE
  - The force needed to hold a weight is always greater than weight whether the force arm or weight arm are lengthened or shortened.
  - If the force arm is increased, the force needed decreases but the force is still greater than the weight.

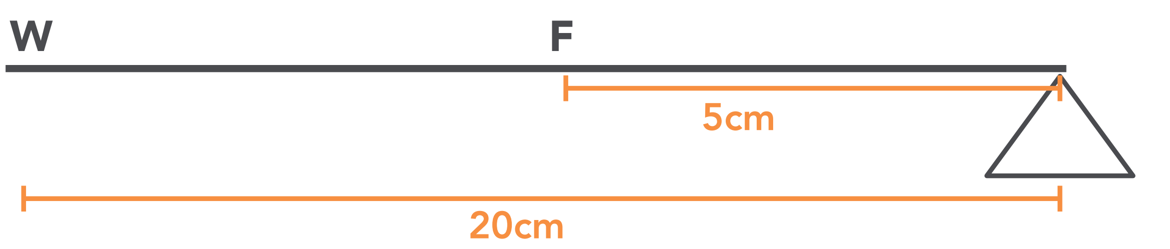


Diagram of a Third Class Lever with a 5 cm force arm and a 20 cm weight arm

- If the force arm is increased from 5 cm to 10 cm but the weight arm remains at is 20 cm. What happened to the force?

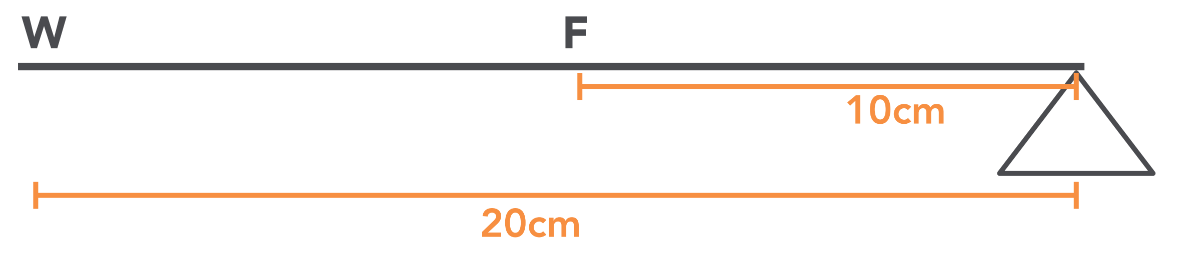


Diagram of a Third Class Lever with a 10 cm force arm and a 20 cm weight arm

starting position	increase weight arm
Tf = Tw	Tf = Tw
F X df = W X dw	F X df = W X dw
F X 5 cm = W X 20cm	F X 5 cm = W X 50cm
5F = 20W	5F = 50W
F = 4W	F = 10W
If W=150 kg, than F=600 kg	If W=150 kg, than F=1500 kg

- If the weight arm increases from 20 cm to 50 cm but the force arm is 5 cm. What happens to the force?

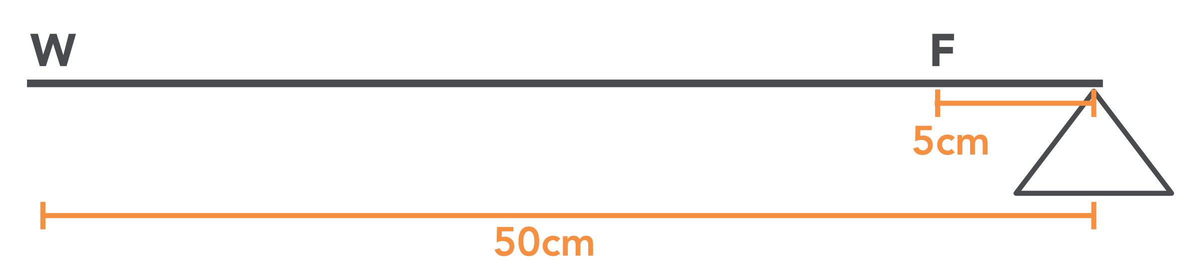


Diagram of a Third Class Lever with a 5 cm force arm and a 50 cm weight arm

starting position	increase weight arm
Tf = Tw	Tf = Tw
F X df = W X dw	F X df = W X dw
F X 5 cm = W X 20cm	F X 5 cm = W X 50cm
5F = 20W	5F = 50W
F = 4W	F = 10W
If W=150 kg, than F=600 kg	If W=150 kg, than F=1500 kg

- **DISTANCE AND SPEED**
  - changing the length of the force arm (fa) and the weight arm (wa) will change the distance and velocity each arm moves in space
  - because both arms are moving at the same time, the arm that moves the farthest also moves the fastest
  - CLASS I LEVER

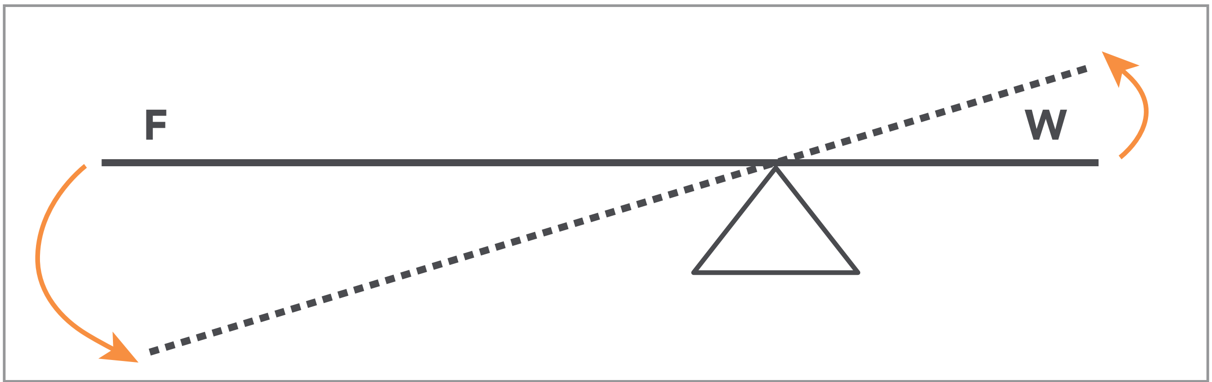


Diagram of Class I lever with a long force arm and short weight arm

- Distance and speed of movement of the force arm is greater than weight arm.
- Because of the long force arm, a small force is needed to move the weight and the muscle would need to shorten a long distance to move the weight a short distance.
- Considering the Length vs Tension Curve described below, the shortening of the muscle a long distance reduces the muscles ability to generate force.

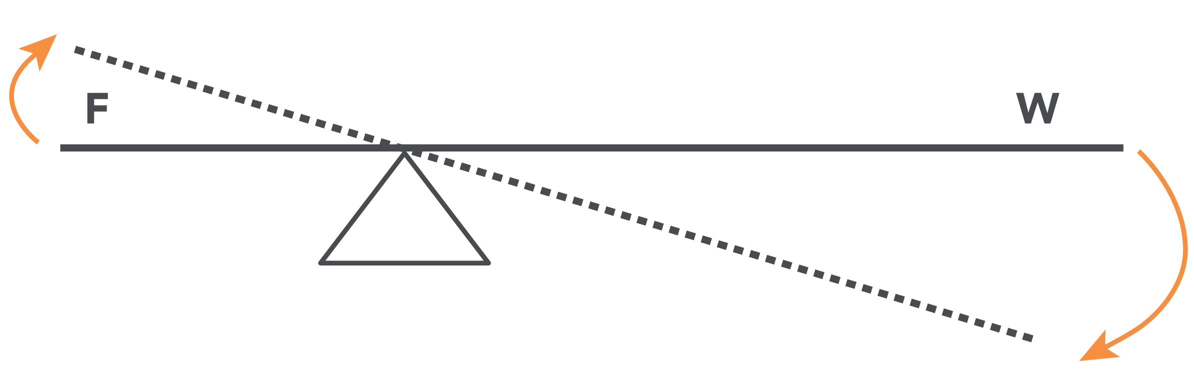


Diagram of Class I lever with a short force arm and long weight arm

- Distance and speed of movement of the force arm is less than weight arm.
- Because of the short force arm, a large force is needed to move the weight and the muscle would need to shorten a short distance to move the weight a long distance.
- Considering the Length vs Tension Curve again, the shortening of the muscle a short distance enhances the muscles ability to generate force and move heavy weights.

- CLASS II LEVER

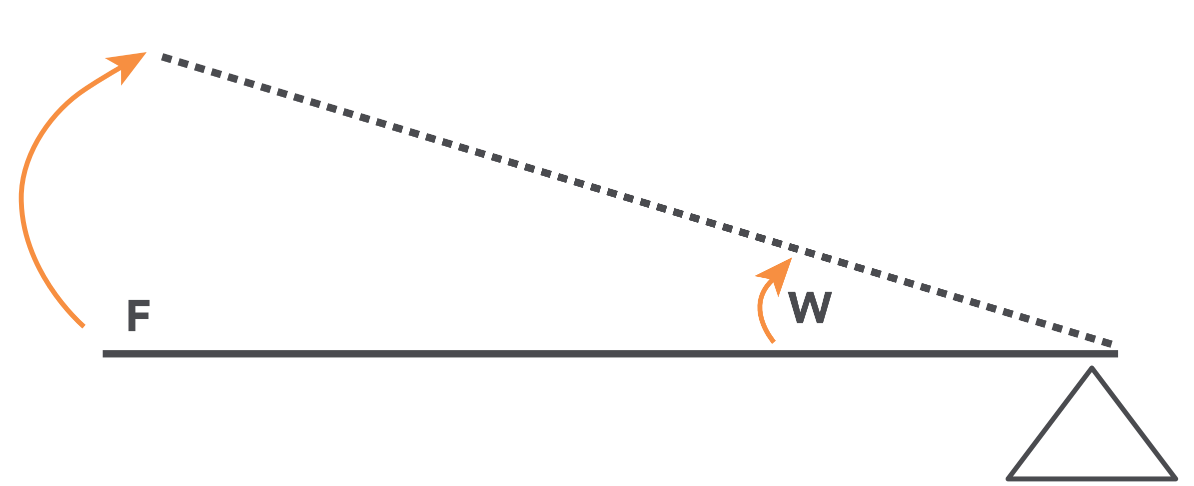


Diagram of Class II lever with a long force arm and short weight arm

- Distance and speed of movement of the force arm is greater than weight arm.
- Because of the long force arm, a small force is needed to move weight and the muscle would need to shorten a long distance to move the weight a short distance.
- Because of the Length vs Tension Curve, the shortening the muscle a long distance reduces the muscle ability to generate force.

• CLASS III LEVER

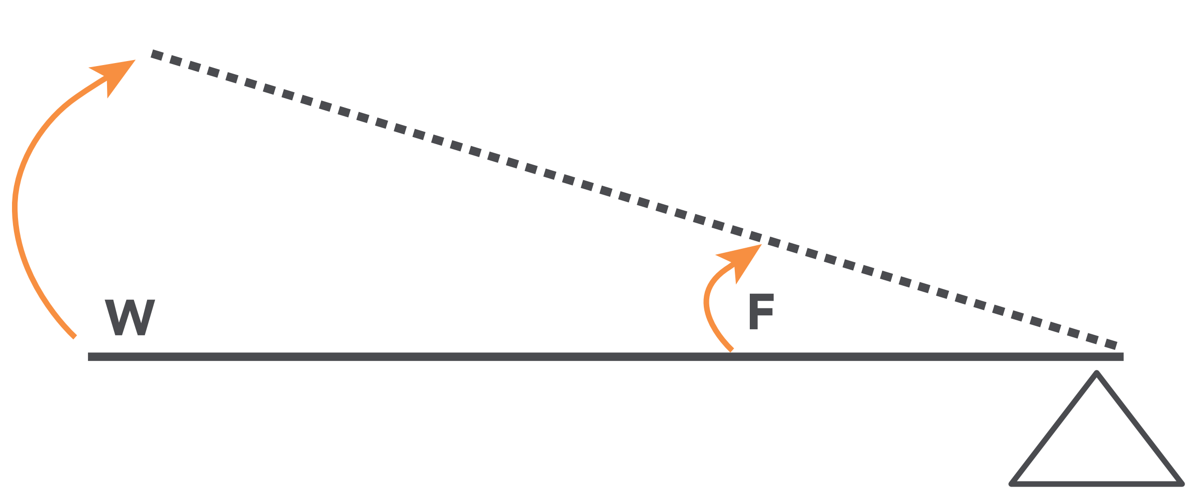


Diagram of Class III lever with a short force arm and long weight arm

- Distance and speed of movement of the force arm is less than weight arm.
- Because of the short force arm, a large force is needed to move weight and the muscle would need to shorten a short distance to move the weight a long distance.
- Because of the Length vs Tension Curve, shortening the muscle a short distance will increase its ability to generate force.

• In Class I and Class III levers, the length of the force arm is shorter than the length of the weight.

• The advantage of this arrangement is that
  - A little shortening of the muscle produces a small movement of the force arm which results in a large movement of the weight.
  - For example, when muscles moving the glenohumeral or hip joints contract a short distance, the small movement produced at these joints results in large movements of the hand and foot.
  - Further, because these muscles are shortening only a short distance from the resting position of the muscle, the Length vs Tension Curve shows that these muscles can produce high tension forces at this position.

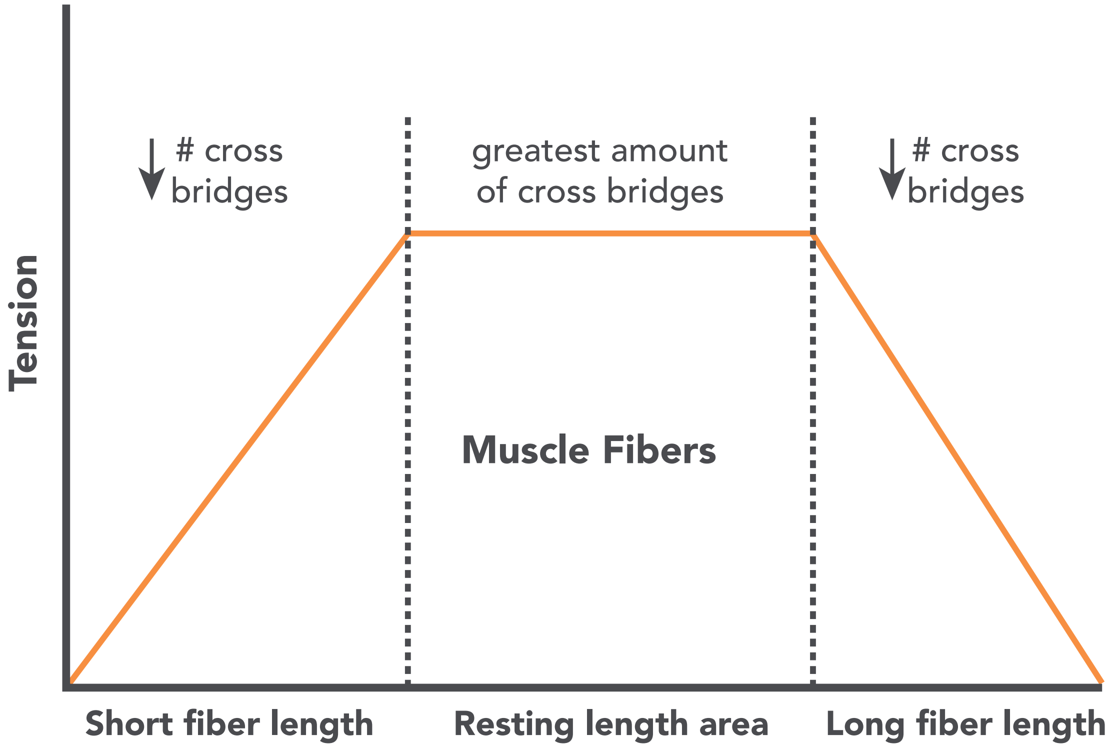
- The disadvantage of this arrangement is that muscle force must be high to move the weight, because of its short force arm relative to the weight arm.

ACTIVITIES: 1) Take a ruler (or pencil/pen) and balance it on you index finger. This is a first class lever at equilibrium with the index finger as your fulcrum. Now move one end of the ruler down and notice the distance it moved. How much did the other end move? The ends should have moved the same distance. Because the distance moved at both ends was the same and the time of movement was the same, than the velocity of motion will be the same. 2) Move your index finger (fulcrum) 3 inches toward one end of the ruler and move the end closest to the fulcrum up and down. Did the end farthest away from the fulcrum move more than the end closest to the fulcrum? As the time of movement is the same, velocity of the end farthest away was greater than the end closest to the fulcrum because it moved a great distance. 3) Move the fulcrum to one the end of the ruler and make a third class lever. Near the fulcrum rotate the ruler up and again note the distances of movement of the ruler. Did the end farthest from the fulcrum move more than where you lift the ruler? Would the velocity of movement be more at the end farthest from the fulcrum or end near the fulcrum? As for the distance and velocity of motion, can you see the benefit of a short force arm and a long weight arm in moving the hand and foot?

MUSCLE LENGTH vs TENSION RELATIONSHIP

- The non-contracted length of a muscle is referred to as its RESTING LENGTH.
- The distance the muscle lengthens or shortens relative to that resting length effects the amount of force that muscle produces.
- The LENGTH VS TENSION CURVE below shows this relationship.

- **LENGTH VS TENSION CURVE**



- As a muscle shortens, sarcomeres shorten, the number of cross bridges decreases and tensile force development decreases.
- This decrease in muscle tensile force development may offset any mechanical advantage obtained by increasing the length of the force arm (⊥ fa).
- A decrease in force will also occur when the muscle is elongated beyond its resting length.
- For example, during elbow flexion, the force produces by the biceps changes relative to its force arm.

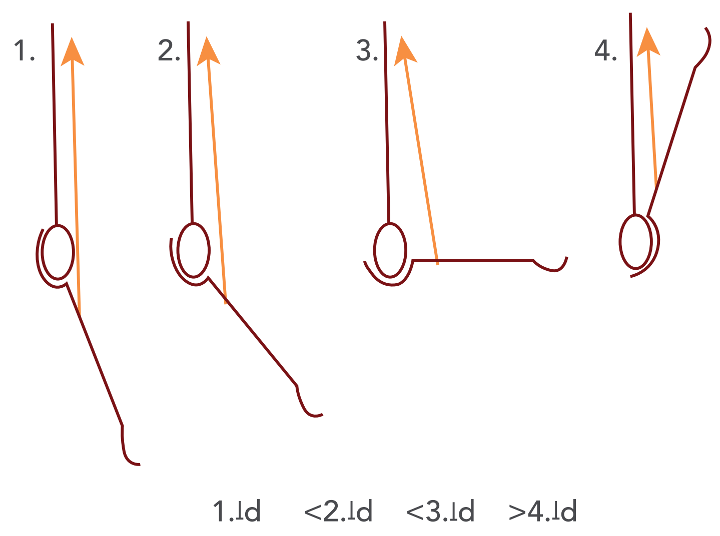


Diagram showing the lines of action of the biceps relative to the elbow joint. The box at the bottom gives the relative length of the force arm ⊥ d of the biceps at 4 positions of elbow flexion. Position 1 = resting position and 4 = full flexion. At position 3 the biceps has its greatest mechanical advantage during elbow flexion.

- Position #1
  - This is the resting length of the biceps.
  - The force arm is very short so the mechanical advantage is poor.
  - The resting position of the muscle places it high on length/tension curve so high muscle tensile force can development.

- Position #2
  - The elbow is at about 45 degrees of flexion.
  - The force arm is longer than #1 so the mechanical advantage is greater than #1.
  - The biceps length has shortened so the muscle is lower than #1 on length/tension curve and muscle force development is less than #1.
  - The gain in mechanical advantage is reduced by the lowering of muscle force.

- Position #3
  - The elbow is at about 90 degrees of flexion.
    The force arm is longer than #2 so the mechanical advantage is greater than #2.
  - At this position, the mechanical advantage of the biceps on the elbow is greatest during flexion.
  - Because the biceps has shortened more, the biceps is lower than #2 on length/tension curve and so muscle force development is less in #3 than #2.
  - Again the gain in mechanical advantage is reduced by the decrease in muscle force.

- Position #4
  - The elbow is at about 120 degrees of flexion.
  - The force arm is less than in #2 and #3 so the mechanical advantage is very poor.
  - Because of muscle shortening beyond that of #3, the biceps is lower than #2 and #3 on length/tension curve and muscle tensile force development is also lower than #2 and #3.
  - In this position, the mechanical advantage and biceps force development are lowest during flexion.

- Force production of a muscle at a joint varies with joint postion and this is an important factor in the mechanics of joint movement. Other factors include the length of the force and weight arms, the magnitude of the muscle component forces, the type and mobility of the joint, and the axis of motion.

- Force production of a muscle at a joint is also a factor of the position of the muscle on the length vs tension curve, the slackness of the muscle at the time of contraction, the type of contraction (concentric or eccentric), the velocity of contraction, the type of muscle (parallel or pinnate fibered), and the fiber type distribution of the muscle. (These muscle factors will be discussed in more detail in the section on muscle mechanics.)

Study Questions (vectors and torque)

1. How would you determine the final resultant force and movement of a bone when three different muscles are applying forces (F1, F2, F3) at three different angles to the bone?
2. How can the component forces be determined from the line of action of a muscle?
3. What is the difference between fixed and movable pulleys?
4. What is the difference between type I and type III levels?
5. What is toque and how is it calculated?
6. With a type I lever, what would the Force be if dW=6 cm and dF=2 cm?
   What if the dW=3 cm and dF=9 cm?
7. With a type III lever, what would the Force be if dW=10 cm and dF=2 cm?
   What if the dW=20 cm and dF=2 cm?
8. How can the distance that the weight arm moves be increased relative to the distance that the force arm moves in a Class I lever? How about in a Class III lever?
9. How does movement of the force arm only a short distance affect muscle contraction force?

2 JOINT MOVEMENT

- **DESCRIPTIONS OF MOVEMENT**

  - OSTEOKINEMATIC MOVEMENTS
    - These are visible movements of a bone as it moves about
    - the joint axis of the X, Y and Z planes.
    - Movements of a bone as described with muscle actions and ranges of motion.
    - Examples of osteokinematic movements are flexion, extension, abduction, adduction, supination, and pronation.

  - ARTHROKINEMATIC MOVEMENTS
    - These movements occur at the articular surface of a bone as it moves about the joint axis of the X, Y and Z planes.
    - Depending on the structure of the joint, arthrokinematic movements may occur in the same or opposite direction of osteokinematic movement.
    - Examples of arthrokinematic movements are translation (glide, slide), rotation, and rotation coupled with translation (curvilinear movement).

- **DEGREES OF FREEDOM OF JOINT MOTION**

  - The degree of freedom of movement at a joint is the number of planes (X, Y, Z) in which the joint allows movement to occur.

  - 1 DEGREE OF FREEDOM
    - movement in one plane only
    - Examples are sagittal plane flexion and extension at the elbow or interphalangeal joints of fingers.

  - 2 DEGREES OF FREEDOM
    - movements in two planes
    - Examples are sagittal plane flexion/extension and frontal plane adduction/abduction at the metacarpophalangeal joint, or the radiocarpal joint.

  - 3 DEGREES OF FREEDOM
    - movements in three planes
    - Examples are sagittal plane flexion/extension, frontal plane adduction/abduction, and transverse plane internal/external rotation at the glenohumeral joint or the hip joint.

- CIRCUMDUCTION
  - Circumduction requires at least 2 degrees of freedom.
  - Examples are a circular movement of the metacarpophalangeal joint of index finger, or the glenohumeral joint.
  - Circumduction movements above are a combination of extension, abduction, flexion, and adduction.

- DIAGONAL MOVEMENTS
  - These movements combine movements in two planes at the same time.
  - Examples are flexion (sagittal plane) combined with abduction (frontal plane) at glenohumeral joint; extension (sagittal plane) combined with abduction (frontal plane) at hip joint.

- **AXIS OF MOVEMENT**

  - The line about which joint movement occurs.
  - AXIS FOR FLEXION AND EXTENSION movements
    - Movement is in the sagittal plane.
    - The axis of movement is in the frontal plane through a medial to lateral axis.

- AXIS FOR ADDUCTION AND ABDUCTION movements
  - Movement is in the frontal plane.
  - The axis of movement is in the sagittal plane through an anterior to posterior axis.

- AXIS OF ROTATION
  - Movement is in the transverse plan.
  - The axis of movement is along the long axis of the bone.

- **TYPES OF ARTHROKINEMATIC MOVEMENT**

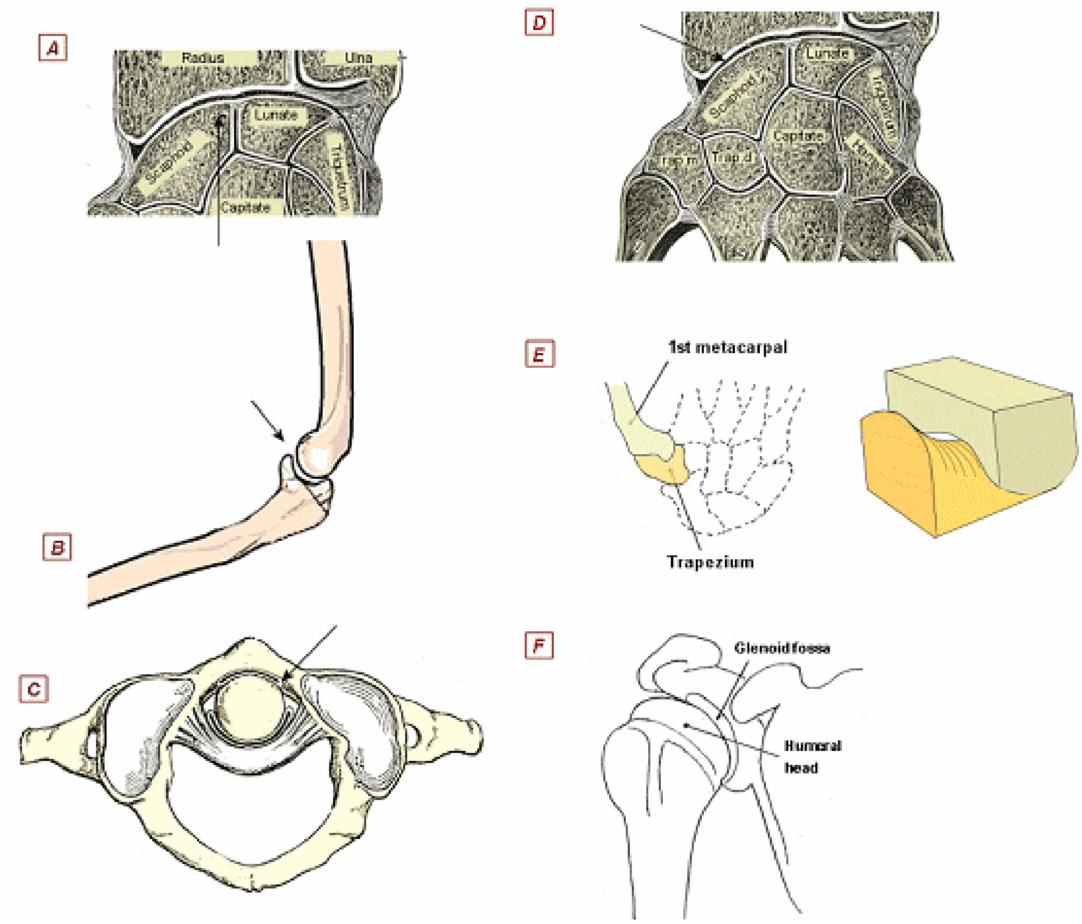
  - ROTATION
    - Circular, angular, rotational movement about an axis.
    - Examples are a spin or pivot type motion; a spinning top; the earth rotating on its axis

  - TRANSLATION
    - Movement of an object in a straight line
    - A gliding or sliding movements
    - Examples are sliding a box along the floor; walking straight forward.

  - CURVILINEAR MOTION
    - Curving movement
    - A rotation coupled with translation
    - Examples are a rolling tire; rolling over in bed; movement of a rolling pins.

In this Study Guide, the arthrokinematic movements of the joints of upper and lower limbs and the spine will be described. These descriptions will used only the terms "Rotation" and "Translation or "Glide". If the motion is a curvilinear movement, than both rotation and translation will be coupled together to describe the arthrokinematics. For example, the arthokinematic movement during flexion of the metacarpophalangeal joint of the index finger is a curvilinear motion involving rotation coupled with translation toward the palm.

2.1 TYPES OF SYNOVIAL JOINTS AND THEIR MOVEMENTS



Drawing showing the different types of synovial joints. A) *Plane*, e.g. intercarpal joints of the wrist; B) Hinge, e.g. humeroulnar joint at the elbow; C) *Pivot*, e.g. median atlantoaxial joint; D) *Condyloid*, e.g. radiocarpal joint of the wrist; E) *Saddle*, e.g. carpometacarpal joint of the thumb; and F) *Ball and Socket*, e.g. glenohumeral joint. (Parts modified from Gray 1918) See the descriptions below for each joint type.

- **PLANE JOINTS**
  - These joints have planar/flat articular surfaces.
  - These show little displacement and mainly translation.
  - The joints may show 1–3 degrees of freedom.
  - Examples are the intercarpal joints of hand; intertarsal joints of foot.

- **HINGE JOINTS**
  - These joints have a convex surface articulating with a concave surface.
  - These joints show angular movement, and usually have 1 degree of freedom.
  - Movements are mainly rotational.
  - Examples are the humeroulnar joint of elbow; interphalangeal
  - joints of hand and foot; knee joint.

- **PIVOT JOINTS**
  - These joints have a convex surface articulating with a concave surface.
  - These joints show angular movement, and usually have 1 degree of freedom.
  - Movements are mainly a spin type of rotation.
  - Examples are proximal radioulnar joint of elbow; median atlantoaxial joint of spine.

- **CONDYLOID JOINTS**
  - These joints have a biplanar concave surface articulating with biplanar convex surface.
  - These joints show curvilinear movement, and usually have 2 degrees of freedom.
  - Rotation and translation occur producing a curvilinear motion, but spin blocked by curvature of articular surfaces.
  - Examples are radiocarpal joint of wrist; metacarpophalangeal joints of hand.

- **SADDLE JOINTS**
  - Each articular surface is concave in one plane but convex in a perpendicular plane; the concave surface of one bone articulates with the convex surface of the adjoining bone.
  - These joints show curvilinear movement, with 2 or 3 degrees of freedom depending on the presence or absence of an articular disc.
  - Rotation and translation occur producing a curvilinear motion.
  - Examples are the carpometacarpal joint of thumb; sternoclavicular joint.

- **BALL AND SOCKET JOINTS**
  - These joints have a rounded convex surface articulating with cup-like concave surface.
  - These joints show curvilinear motion and have 3 degrees of freedom.
  - Rotation and translation occur producing the curvilinear motion.
  - Examples are the glenohumeral and hip joints.

2.2 DETERMINING ARTHROKINEMATIC MOTION

- **METHOD OF REULEAUX**
  - This is an early radiographic method for describing joint surface movements.
  - It compares radiographs before and after slight movements of a joint.

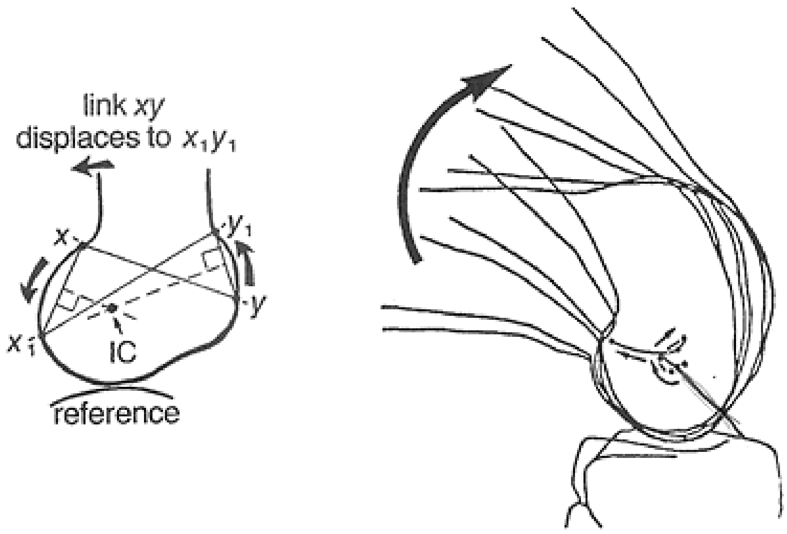


Diagram showing the Method of Reuleaux. (LEFT) The curved bone is moved relative to the reference bone below. Points (X and Y) are mark at the start of movement and then at the end of movement (X1 and Y1). As described in the text below, the change in movement of the points is bisected and from this the instantaneous center of rotation is determined. (RIGHT) The condyle of the femur is shown moving relative to the tibia. By tracking the instantaneous centers of motion, the movements of the articular surface of the femoral condyle can be described during this motion.

  - A distinct point on each side of the image is located (X and Y).
  - The changes in the position of each distinct point between the before and after images are marked (X1 and Y1).
  - One line is drawn connecting X and X1 and a second line connecting Y and Y1.
  - The X-X1 line and the Y-Y1 line are each bisected by a perpendicular line.
  - The intersection of these two perpendicular lines marks the center of rotation for that specific motion or the instantaneous center of rotation.
  - The joint is then moved further using the X1 and Y1 points as the starting points and marking the positional changes in these points as X2 and Y2 and then computing the instantaneous center of rotation for that specific movement.
  - The process continues until the entire joint movement is completed and a series of markings are present showing the sequential path of the instantaneous centers of rotation.
  - This path can then be used to describe the arthrokinematic movements of the joint.

- **VIDEO FLUOROSCOPY**
  - This imaging technique is used to record and study movements at joints as these actually occur.
  - From these videos, movements of the articular surface of a moving bone can be digitized, graphed and described.

- **ULTRASOUND**
  - This imaging technique in which high frequency sound ways are passed through structures of varying density and composition producing an echo which is computer interpreted into an image.
  - Real time scans are able to show moving structures and are used as a musculoskeletal diagnostic procedure.

2.3 CONCAVE/CONVEX RULE

- This rule only applies to translational/gliding arthrokinematic movement and not the direction of rotation**.** (Kaltenborn, 1980).
- When the CONVEX surface at a joint moves on a fixed CONCAVE surface, arthrokinematic joint translation/glide is opposite the direction of the osteokinematic movement.

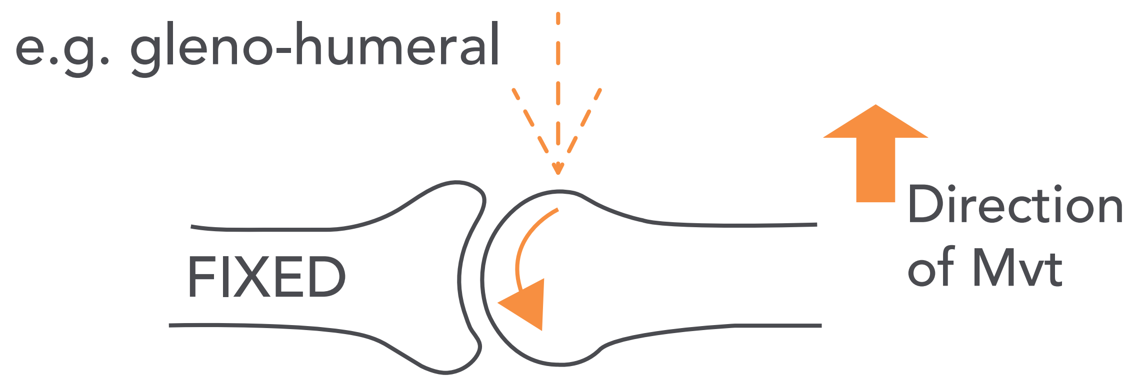


Diagram of the glenohumeral joint with the convex head of the humerus moving upward (large arrow) on the concave glenoid fossa. The translation/glide occurring is opposite the direction (dashed arrow) of osteokinematic movement.

- When a CONCAVE surface at a joint moves on fixed CONVEX surface, arthrokinematic joint translation/glide is in the same direction as osteokinematic movement.

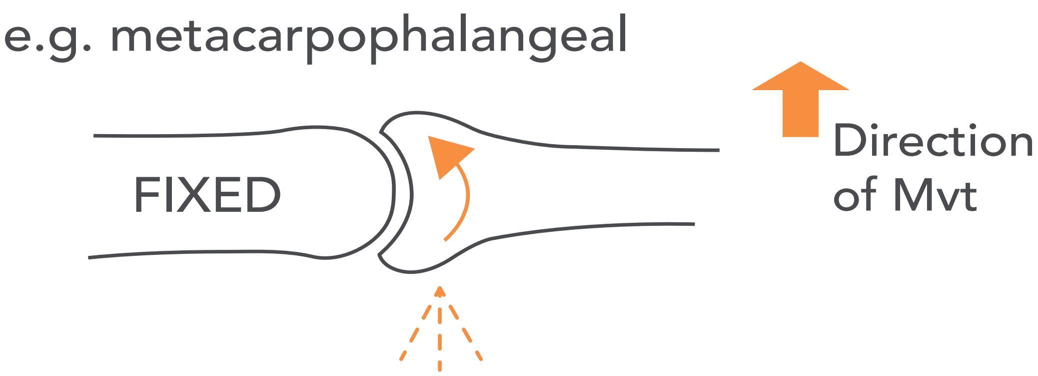
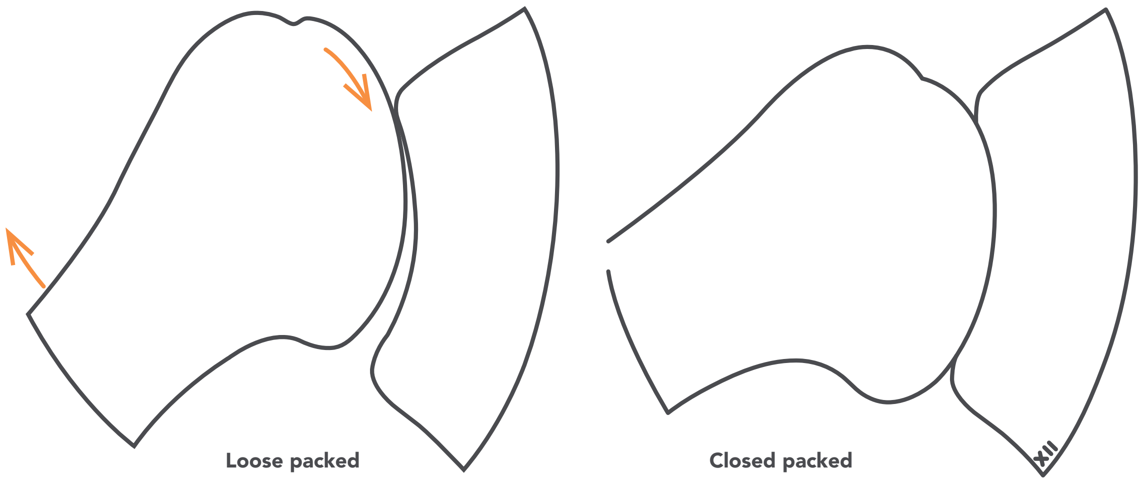


Diagram of the metacarpophalangeal joint with the concave head of the phalanx moving upward (large arrow) on the convex metacarpal head. The translation/glide occurring is in the same direction (dashed arrow) as the osteokinematic movement.

2.4 JOINT ARTICULAR POSITIONS

- The relative position of two articulating joint surfaces changes during movement and during different activities.
- When joint stability is needed, the articulating surfaces lie very close together in a CLOSE PACKED POSITION.
- When joint flexibility is needed, the articulating surfaces are less close together and in a LOOSE PACKED POSITION.
- CLOSE PACKED POSITION CHARACTERISTICS
  - maximum congruency
  - maximum ligament and capsule tightness
  - minimal joint space
  - good position for static load bearing
  - joint injury with dynamic unexpected movement
  - poor position for joint mobilization

- LOOSE PACKED POSITION CHARACTERISTICS
  - minimum congruency
  - ligaments and capsule slack
  - maximum joint space, minimal joint surface loading
  - poor position for static load bearing
  - joint injury least with dynamic unexpected movement
  - best position of joint mobilization



(LEFT) Drawing of the glenohumeral joint is the Loose packed position. (RIGHT) Drawing of the glenohumeral joint in the Close packed position.

Study Questions (movement)

1. What is the difference between osteokinematic and arthrokinematic movements?
2. Give an example of the following types of synovial joints and there degrees of freedom.
   a. plane
   b. hinge
   c. condyloid
   d. saddle
3. What is the concave/convex rule?
4. What is the difference between a loose pack and close pack position of a joint?

3 UPPER EXTREMITY

3.1 SHOULDER COMPLEX

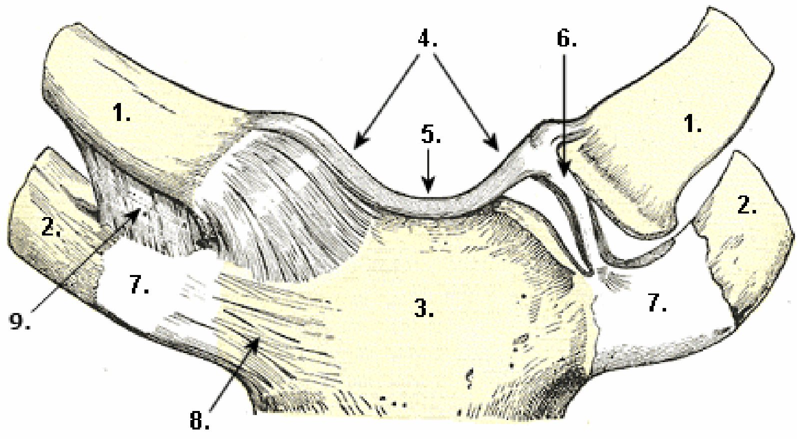
COMPONENTS OF THE SHOULDER COMPLEX

1) STERNOCLAVICULAR JOINT
2) ACROMIOCLAVICULAR JOINT
3) SCAPULOTHORACIC ARTICULATION
4) GLENOHUMERAL JOINT

- Normal and pain free movements of the arm at the glenohumeral joint require the integration of movements and muscle action among all four components.
- Any restriction of joint movements and/or the reduction of muscle actions in any of the components will alter arm motion.
- Arm movements are produced by a complex chain of interactions involving bony, muscular and soft tissue elements.

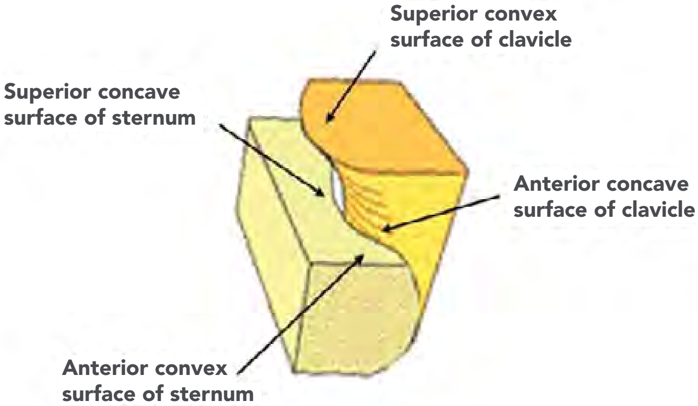
3.1.1 STERNOCLAVICULAR JOINT

- **ANATOMY OF THE STRENOCLAVICULAR JOINT**



Drawing of the stenoclavicular joint. 1. Clavicle, 2. 1st rib, 3. sternum, 4. interclavicular ligament, 5. sternal notch, 6. articular disc, 7. costal cartilage, 8. sternocostal ligament, and 9. costoclavicular ligament. (Modified from Gray 1918)

- SADDLE TYPE JOINT
  - Anterior/posterior surfaces of the clavicle are concave moving on fixed convex sternal surfaces (concave on convex).
  - **Anterior osteokinematic** movement of the clavicle at the sternoclavicular joint produces **anterior arthrokinematic** movement at the joint.
  - **Posterior osteokinematic** movement of the clavicle at the sternoclavicular joint produces **posterior arthrokinematic** movement at the joint.



Drawing showing the articulations between the clavicle and sternum. During anterior osterokinematic movement of the clavicle, the concave clavicle glides anteriorly on the fixed convex sternum. During osterokinematic elevation of the clavicle, the convex clavicle glides inferiorly on the fixed concave sternum.

- Superior/inferior surfaces of clavicle are convex moving on fixed concave sternal surfaces (convex on concave).
- **Osteokinematic elevation** of the clavicle (lateral end of the clavicle moves upward) produces **arthrokinematic depression** of the clavicle at the sternoclavicular joint.
- **Osteokinematic depression** of the clavicle (lateral end of clavicle moves down) produces **arthrokinematic elevation** of the clavicle at the joint the sternoclavicular joint.

- **MOVEMENTS**
  - ANTERIOR/POSTERIOR GLIDE
    - The clavicle protracts (anterior glide) and retracts (posterior glide) relative to sternum.
    - There is about 15 degrees of movement in each direction.

  - ELEVATION/DEPRESSION
    - Clavicular elevation: The medial end of the clavicle depresses at the sternoclavicular joint while the lateral end of clavicle elevates.
    - Clavicular depression: The medial end of the clavicle elevates at the sternoclavicular while lateral end of clavicle depresses.
    - There is about 35–45 degrees of clavicular elevation from rest.
    - There is about 15 degrees of clavicular depression from rest.
    - About 4 degrees of clavicular elevation occurs for every 10 degrees of glenohumeral flexion/abduction during the initial 90 degrees of glenohumeral flexion/abduction; essential 0 degrees of clavicular elevation occurs beyond 90 degrees of glenohumeral flexion/abduction.

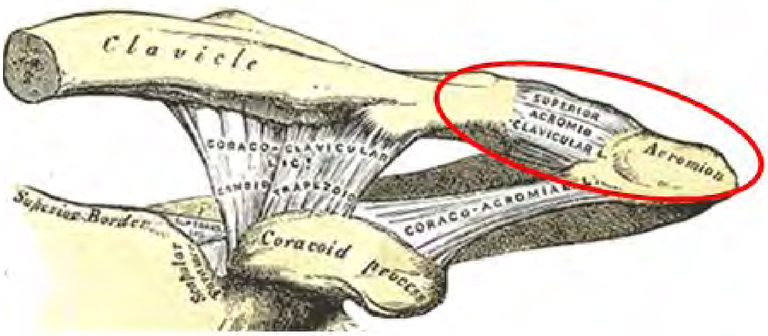
  - CLAVICULAR ROTATION
    - Rotation is possible at this saddle type joint because of the articular disc.
    - The disc separates the joint surfaces enough to allow for rotation of the clavicle on the sternum.
    - Rotation occurs posteriorly from neutral and than anteriorly back to neutral.
    - The clavicle does not rotate anteriorly beyond neutral.
    - Anterior and posterior clavicular rotations to and from neutral occur along long axis of clavicle.
    - Rotation occurs in the same direction at both ends of the clavicle.
    - There is about 30–45 degrees of clavicular rotation in each direction.

ACTIVITIES: Place your left hand on the superior surface of the right clavicle. 1) Move your right shoulder up and then down several times. Can you feel the lateral end of the clavicle elevating and the medial end depressing? What is the direction of the arthrkinematic glide of the clavicle at the sternoclavicular joint? What about during depression? 2) Place you left hand on the anterior surface of the right clavicle. Move your right shoulder forward and back several times. Can you feel the entire clavicle moving forward when the shoulder moves forward and back when the shoulder moves back? Both the medial and lateral ends of the clavicle are moving in the same direction. 3) Place you hand on the superior surface of the clavicle. Flex your glenhumeral joint to about 120 degrees several time. Can you feel the clavicle rotating anteriorly when the glenohumeral joint is flexed above 90 degrees and posteriorly when the glenohumeral joint is extended from 120 degree past 90 degrees.

- CLOSE PACKED POSITION at the sternoclvicular joint occurs with full glenohumeral abduction in frontal plane and full external humeral rotation.
- LOOSE PACKED POSITION at the sternoclavicular joint occurs at 20 degrees of scapulohumeral (horizontal) abduction (same as glenohumeral joint)

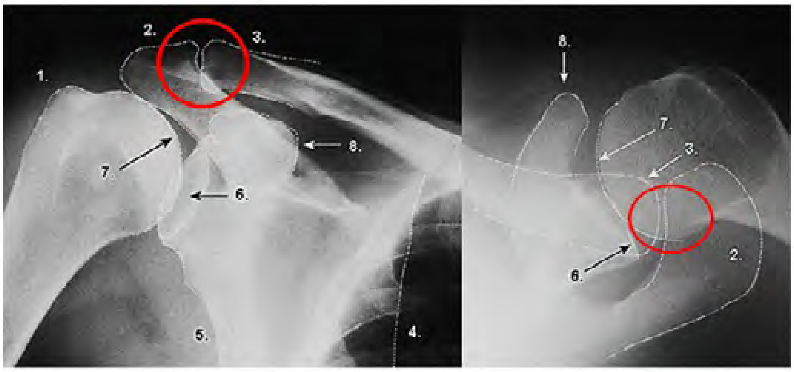
3.1.2 ACROMIOCLAVICULAR JOINT

- **ANATOMY OF THE ACROMIOCLAVICULAR JOINT**



Drawing showing the lateral clavicle articulating with the acromion process of the scapula to form the acromioclavicular joint (red oval) (Modified from Gray 1918)

- PLANE TYPE JOINT
  - The articular surface of the lateral end of the clavicle and the matching articular surface of the acromion are flat.
  - There is an articular disc which allows the clavicle to move relative to the acromion and the acromion (scapula) to move relative to the clavicle.
  - Because of the joint capsule and joint ligaments, movements of both the lateral clavicle and acromion can occur concurrently.



Radiographs of the glenohumeral and acromioclavicular (AC) joints: (LEFT)) Frontal view and (RIGHT) Axillary view. RED circles mark the AC joint. Notice the flat articular surfaces of this plane type joint. 1. greater tubercle, 2. acromion, 3. clavicle, 4. medial border of scapula, 5. lateral border of scapula, 6. glenoid fossa, 7. humeral head, and 8. coracoid process.

- **MOVEMENTS**

  - ANTERIOR/POSTERIOR (AP) GLIDE
    - The lateral end of the clavicle translates anteriorly and posteriorly relative to disc.
    - The lateral and medial ends of the clavicle move in the same direction.
    - AP glide is about 30 degrees of total motion.
    - AP movement of lateral clavicle is limited by conoid ligament.

  - ELEVATION/DEPRESSION
    - Movement of the lateral end of the clavicle occurs relative to the articular disc.
    - Movement of the acromion also occurs relative to the disc.
    - Clavicular elevation at the AC joint can be produced by either elevation of the lateral end of the clavicle or elevation of the acromion process of the scapula or concurrent elevation of both.
    - Clavicular depression at the AC joint can be produced by either depression of the lateral end of the clavicle or depression of the acromion process of the scapula or concurrent depression of both.
    - About 30–40 degrees of clavicular elevation is possible.
    - Elevation of the lateral end of the clavicle at the AC joint is accompanied by depression of the medial end of the clavicle at the sternoclavicular joint and vise versa for depression of the lateral clavicle.
    - The trapezoid and conoid ligaments of the coracoclavicular ligament limit elevation.

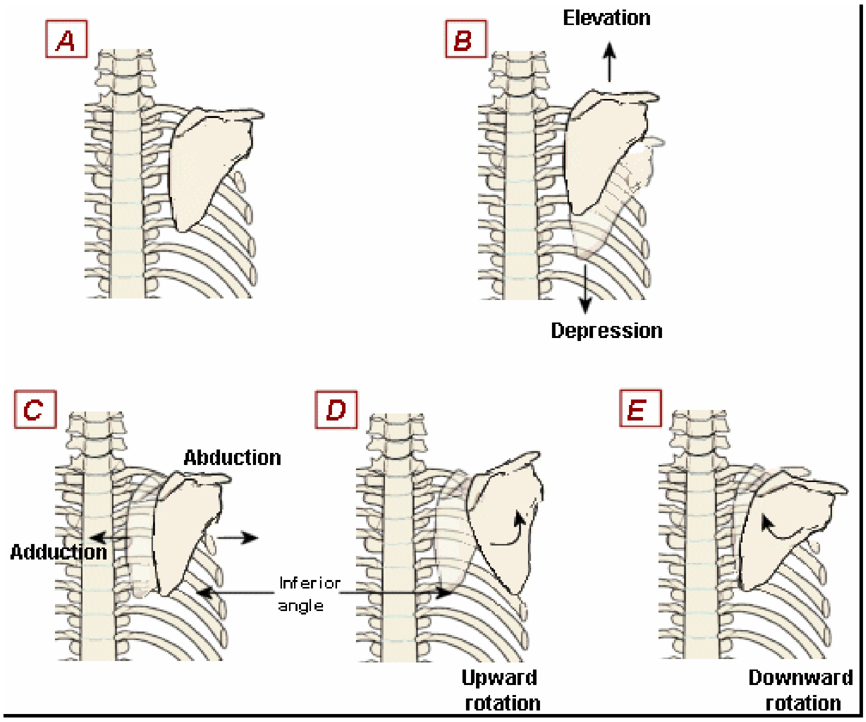
  - ROTATION OF CLAVICLE
    - Rotation of lateral end of clavicle relative to the disc or rotation of the acromion during scapular rotation produces rotation of the clavicle.
    - The clavicle rotates posteriorly from neutral and then anteriorly back to neutral along its long axis.
    - Rotation of clavicle at AC joint and sternoclavicular joint occur in same direction.
    - The trapezoid ligament acts as hinge for rotation of the clavicle.
      + The trapezoid ligament is twisted.
      + Its anterior fibers become taut at the limit of posterior clavicular rotation.
      + Its posterior fibers become taut at the limit of anterior rotation which is at neutral.
    - About 30–40 degrees of rotation occur in each direction.

- CLOSE PACKED POSITION: 90 degrees of abduction in the frontal plane
- **LOOSE PACKED POSITION**: 20 degrees of scapulohumeral (horizontal) abduction (same as glenohumeral joint)

3.1.3 SCAPULOTHORACIC ARTICULATION

- **COMPONENTS OF THIS ARTICULATION**
  - posterior rib cage between ribs 2 – 8
  - serratus anterior muscle between costal surface of scapula and ribs
  - subscapularis muscle on the costal surface of scapula
  - associated structures
    - trapezius
    - rhomboid major and minor
    - levator scapulae

- **SCAPULAR MOVEMENTS**
  - The scapula is very mobile because its only bony attachment to the trunk is by the clavicle and because the scapula is essentially surrounded by muscle.
  - This mobility of the scapula is critical for glenohumeral range of motion.



Drawing showing the movements of the scapula. A) resting position, B) elevation and depression, C) abduction and adduction, D) upward rotation. E) downward rotation.

- ELEVATION AND DEPRESSION
  - These motions result from superior and inferior translation of the scapula relative to the posterior thoracic wall.
- ADDUCTION OR RETRACTION
  - This movement is from medial (horizontal) translation of the scapular toward the spine.
- ABDUCTION OR PROTRACTION
  - This movement is from lateral (horizontal) translation of the scapula away from the spine.
- UPWARD ROTATION
  - This movement occurs when the glenoid fossa arcs upward and the inferior angle of the scapula arcs laterally and upward.
  - This movement increases the degrees of glenohumeral flexion and abduction and helps to maintain subacromial space.
  - This rotation also allows the deltoid, rotator cuff muscles and coracobrachialis to function nearer the top of the length vs tension curve for a longer period of time than without upward scapular rotation.

- DOWNWARD ROTATION
  - This movement occurs when the glenoid fossa arcs downward and the inferior angle of the scapula arcs medially and downward.
  - This movement increases glenohumeral backward extension (hyperextension).

- **SCAPULAR RHYTHM**
  - Scapular rhythm is the degree of movement of the scapula relative to movement at the glenohumeral joint.
  - The average rhythm is 2 degrees of glenohumeral motion to 1 degree of scapular motion (2:1).
  - For example, 90 degrees of osteokinematic flexion/abduction at the glenohumeral joint is the result of 30 degrees of scapular movement plus 60 degrees of glenohumeral movement.
  - For example, 120 degrees of osteokinematic glenohumeral flexion/abduction results from 40 degrees of scapular movement plus 80 degrees of glenohumeral movement.
  - From 0 to 60 degrees of osteokinematic glenohumeral flexion/abduction movement, scapular movement is irregular; the 2:1 ratio may not be accurate in this range, but for overall scapular movement the 2:1 ratio provides a good general guideline for scapular rhythm.

- **THE TWO PHASES OF SCAPULAR MOVEMENT DURING GLENOHUMERAL ABDUCTION AND FLEXION**

  - **PHASE I OF SCAPULAR MOVEMENT**
    - Phase I is from 0–90 degrees of osteokinematic glenohumeral abduction and flexion.
    - From 0–90 degrees, the scapula elevates with slight upward scapular rotation beginning at about 60 degrees.
    - During this scapular elevation, the lateral clavicle and AC joint elevate while the medial clavicle depresses at the sternoclavicular joint.

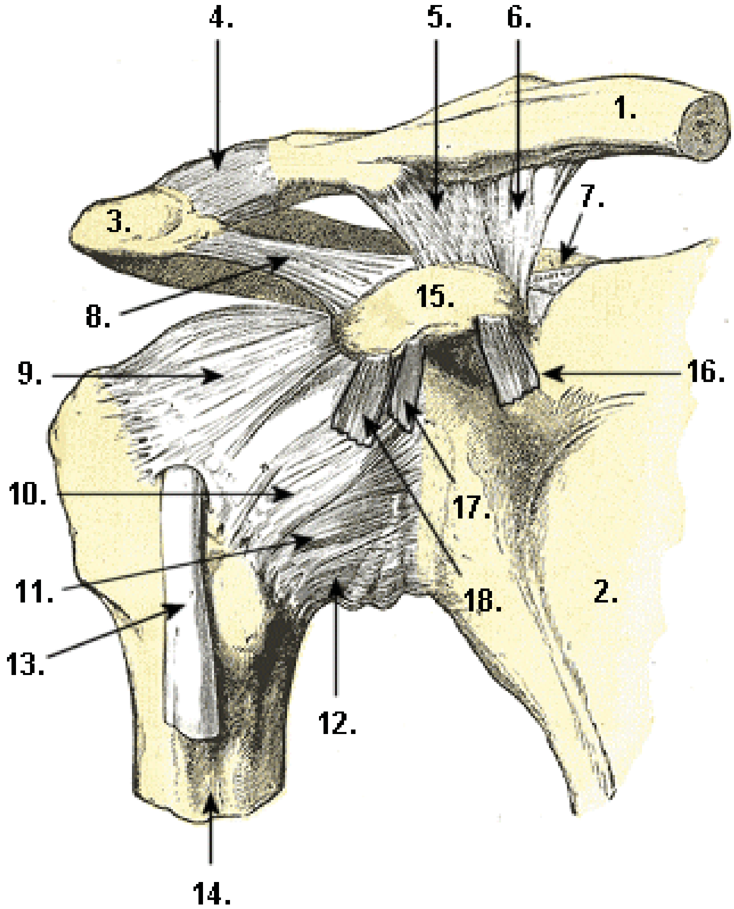
  - **PHASE II OF SCAPULAR MOVEMENT**
    - Phase II is above 90 degrees of osteokinematic glenohumeral abduction and flexion.
    - During this phase, clavicular and scapular elevation stop at about 90 degrees of osteokinematic glenohumeral abduction/flexion.
    - The upward rotation of the scapula that began at 60 degrees, continues to full abduction/flexion of the glenohumeral joint.

- After 90 degrees, the clavicle rotates posteriorly from neutral as the acromion and glenoid fossa rotate upward with the scapula.
- Clavicular rotation is needed to attain osteokinematic glenohumeral abduction/flexion beyond 120 degrees.
- Beyond 90 degrees of osteokinematic glenohumeral abduction/flexion, compression increases between the lateral clavicle, disc and acromion at AC joint.

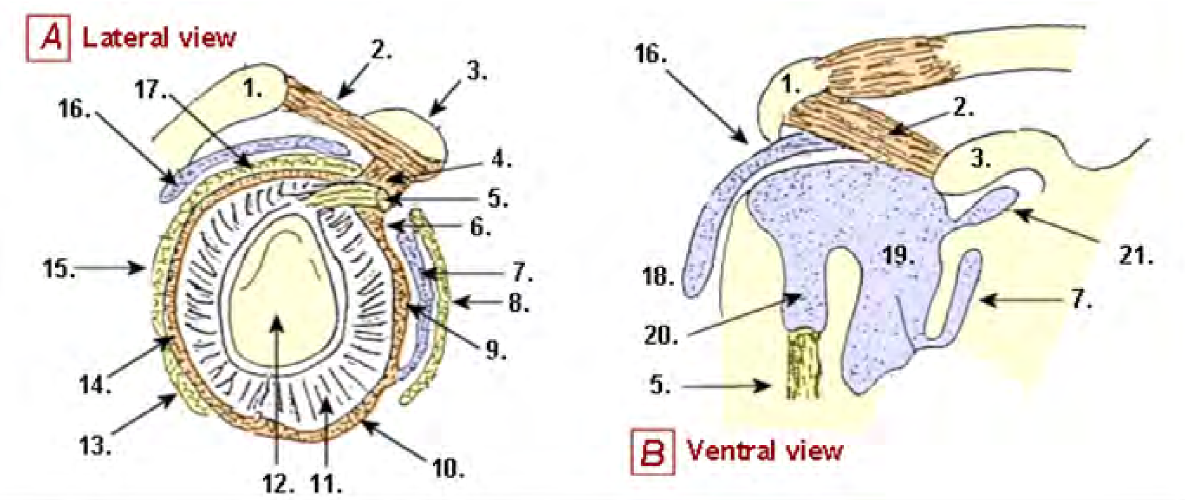
ACTIVITIES: 1) Elevate, depress, adduct, abduct, upwardly rotate and downwardly rotate your scapula. Can you see the difference between abduction/adduction and upward/downward rotation? 2) What are the movements of the clavicle during these movements of the scapula? How do movements of the medial and lateral ends of the clavicle differ? During what movements of the scapula does the entire clavicle move in the same direction? 3) Move your left hand across the axilla and place it on the lateral aspect of the scapula. Now abduct the arm more than 120 degrees and return then return it to your side. Do this several time. Can you feel the scapula rotate? Can you differentiate between Phase I and Phase II of scapular movement? What is your scapular rhythm?

3.1.4 GLENOHUMERAL JOINT

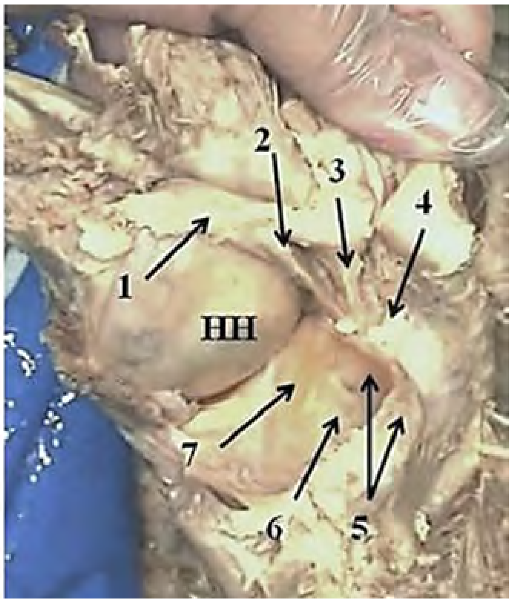
- **ANATOMY OF THE GLENOHUMERAL JOINT**



Drawing of the glenohumeral joint: 1. Clavicle, 2. scapula, 3. acromion, 4. capsule of acromioclavicular joint, 5. trapezoid ligament, 6. conoid ligament, 7. transverse scapular ligament, 8. coracoacromial ligament, and 9. coracohumeral ligament, 10. superior glenohumeral (GH) ligaments, 11. middle GH ligament, 12. inferior GH ligament. 13. long head of biceps, 14. intertubercular groove, and 15. coracoid process. *Origin of*: 16. pectoralis minor, 17. coracobrachialis, and short head of biceps. (Modified from Gray 1918)



Drawing of the Lateral A) and Ventral B) views of the glenohumeral joint. 1. Acromion, 2. coracoacromial ligament, 3. coracoid process, coracohumeral ligament, 5. tendon of long head of biceps, 6. superior glenohumeral (GH) ligaments, 7. subscapular bursa, 8. tendon of subscapularis, 9. middle GH ligament, 10. inferior GH ligament, 11. labrum, 12. glenoid fossa, 13. tendon of teres minor, 14. capsule, 15. tendon of infraspinatus, 16. subacromial bursa, 17. tendon of supraspinatus, 18. subdeltoid bursa, 19. synovial ling of GH joint, 20. biceps bursa, and 21. subcoracoid bursa.



Dissection of a disarticulated glenohumeral joint showing an intracapsular view of the ligaments. 1. Inferior glenohumeral lig., 2. Middle glenohumeral lig., 3. Superior glenohumeral lig. 4. Coracohumeral lig., 5. Glenoid labrum, 6. Glenoid fossa, 7. Long head of biceps, HH = Humeral head.

- **MOVEMENTS OF THE GLENOHUMERAL JOINT**
  - The glenohumeral joint is a Ball and Socket type joint consisting of the humeral head and glenoid fossa of the scapula.
  - The glenoid fossa is much smaller than the humeral head.
  - This difference allows for increased movement but decreased stability.

- **JOINT STABILTY**
  - The glenoid labrum deepens the fossa slightly and acts as suction cup on humeral head to improve stability.
  - Tendons, ligaments and the joint capsule provide joint stability during movements.
  - Dislocations and subluxations of this joint are common.
    - + The glenohumeral joint is most vulnerable to anterior dislocation when the shoulder is vertically abducted near 90 degrees and fully externally rotated.
    - + In this abducted/rotated position, the anterior ligaments and the subscapularis tendon are rotated upward, leaving only a thin inferior-anterior capsule to prevent anterior dislocation of the humeral head.
  - Superior displacement of the humeral head is blocked by the coracoacromial arch which consists of the acromion and the coracoacromial ligament.
    - + Between this arch and the humeral head is the subacromial space containing the subacromial bursa, tendon of the supraspinatus, and tendon of the longhead of the biceps.
    - + The subacromial bursa is a closed sac lined with synovial membrane that allows the greater tubercle of the humerus to slide under the coracoacromial arch.

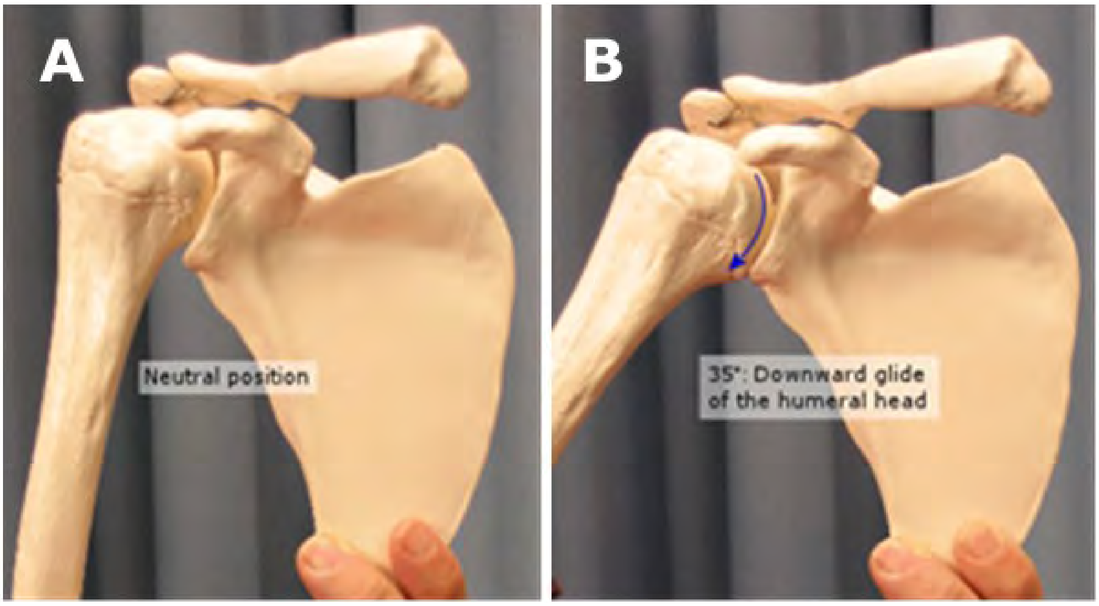
+ Narrowing or filling of the space between the coracoacromial arch and the greater tubercle of the humerus will limit osteokinematic glenohumeral movement causing an impingement.
+ This narrowing or filling of this subacromial space may result from thickening of the subacromial bursa because of inflammation, calcium deposits in the bursa, thickening of the coracoacromial ligament, inflammation of the tendons of the rotator cuff or long head of the biceps, and thickening or hooking of the lateral part of the acromion process.

- **OSTEOKINEMATIC MOVEMENTS AT THE GLENOHUMERAL JOINT**

  - Osteokinematic ranges of motion vary depending on the reference (Norkin, White, Malone 2009; Reese and Bandy 2013).
  - The ranges shown below are commonly used ranges.
  - flexion/extension (0–180 degrees)
  - hyperextension (0–45/60 degrees)
  - vertical adduction/abduction (0–180 degrees)
  - horizontal adduction/abduction
  - internal rotation (0–55/70 degrees)
  - external rotation (0–80/90 degrees)
  - circumduction

- **ARTHROKINEMATIC MOVEMENTS AT THE GLENOHUMERAL JOINT**

  o FLEXION
    - From 0–60 degrees of flexion, there is an inferior glide and posterior rotation of the humeral head in the sagittal plane.
    - The head is seated in glenoid fossa at the end of inferior glide.
    - From 60–180 degrees of flexion, there is a posterior rotation of the humeral head in the sagittal plane.



Posterior view of the glenohumeral joint. A) joint in the neutral rest position and B) joint flexed 35 digress. Notice the inferior (downward) glide coupled with the posterior rotation of the humeral head.

- ABDUCTION
  - From abduction 0–60 degrees of abduction, there is an inferior glide and medial rotation of the humeral head in the frontal plane.
  - The head is seated in glenoid fossa at the end of inferior glide.
  - From 60–180 degrees of abduction, there is a medial rotation of the humeral head in the frontal plane.

- EXTENSION TO NEUTRAL (0 DEGREES)
  - From 180 –60 degrees of extension, there is an anterior rotation of the humeral head in the sagittal plane.
  - From 60–0 degrees of extension, there is an anterior rotation of the humeral head in the sagittal plane and a superior glide to its resting position.

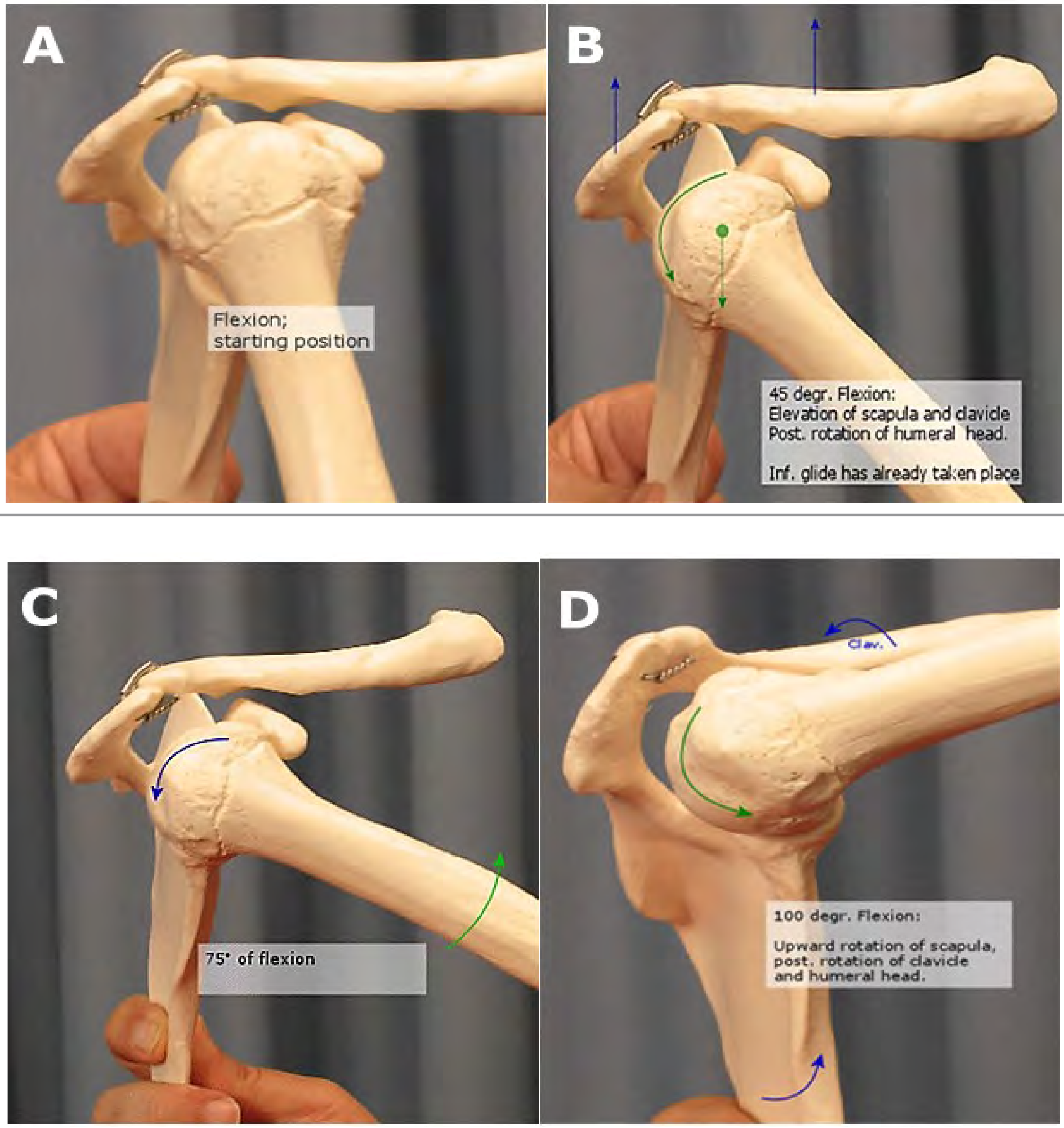
- ADDUCTION TO NEUTRAL (0 DEGREES)
  - From 180–60 degrees of adduction, there is a lateral rotation of the humeral head in the frontal plane.
  - From 60–0 degrees of adduction, there is a lateral rotation of the humeral head in the frontal plane and a superior glide to its resting position.

- HYPEREXTENSION (BACKWARD EXTENSION)
  - Early movements are an inferior glide and anterior rotation of the humeral head in the sagittal plane followed by only anterior rotation of the humeral head.
  - Most of the range of movement is due to scapular retraction and downward rotation.

- EXTERNAL ROTATION
  - Early movements are an anterior glide and external (lateral) rotation of the humeral head about the long axis of the humerus followed by external rotation only of the humeral head.

- INTERNAL ROTATION
  - Early movements are a posterior glide and internal (medial) rotation of the humeral head about the long axis of the humerus followed by internal rotation only of the humeral head.

- **COMBINED GLENOHUMERAL, CLAVICULAR AND SCAPULAR MOVEMENTS**
  - FLEXION FROM NEUTRAL_(0 degrees)_
    - flexion 0–60 degrees
      - scapular elevation
      - clavicular elevation
      - inferior glide coupled with posterior rotation of the humeral head
      - at the end of the inferior glide, the humeral head is seated in the glenoid fossa
    - flexion 60–90 degrees
      - scapular elevation and the start of upward scapular rotation
      - clavicular elevation
      - continued posterior rotation of the humeral head with the humeral head seated in the glenoid fossa
    - flexion 90–180 degrees
      - scapula and clavicle elevation stops
      - upward scapular rotation continues
      - posterior clavicular rotation
      - posterior rotation of the humeral head with the head seated in the glenoid fossa

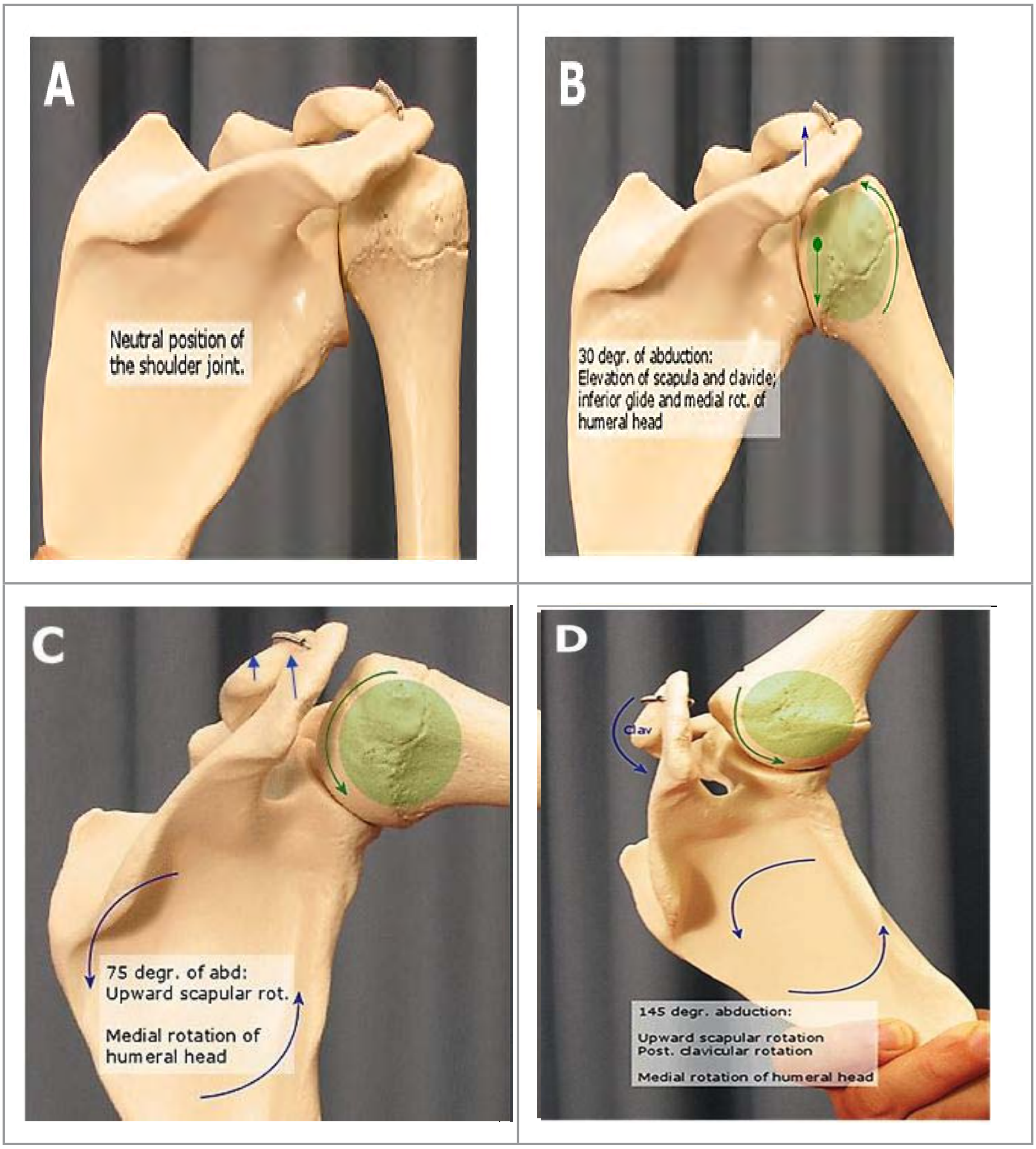


Arthrokinematic flexion of the glenohumeral joint with coinciding movements of the clavicle and scapula as seen in lateral view. A) Starting position (neutral) of glenohumeral joint. B) At 45 degrees of flexion, the humeral head glides inferiorly and rotates posteriorly (green arrows). At the same time, the clavicle and scapula elevate (blue arrows). C) At about 75 degrees of flexion, the humeral head is seated in the glenoid fossa and continues to rotate posterior (blue arrow). The clavicle and scapula continue to elevate but the scapular begins to upwardly rotate. D) At about 100 degrees of flexion, the humeral head continues to rotate posteriorly (green arrow). Elevation of the clavicle and scapula stop, upward rotation of the scapula continues (blue arrow) and the clavicle rotate posteriorly (blue arrow).

- EXTENSION FROM FULL FLEXION TO NEUTRAL (0 degrees)
  - extension 180-90 degrees
    - + downward scapular rotation
    - + anterior clavicular rotation
    - + anterior rotation of the humeral head with the head seated in the glenoid fossa
  - extension 90–60 degrees
    - + scapular depression and the end of downward scapular rotation
    - + clavicular depression and the end of anterior clavicular rotation
    - + anterior rotation of the humeral head with the head seated in the glenoid fossa
  - extension 60–0 degrees
    - + scapular depression
    - + clavicular depression
    - + anterior rotation of the humeral head with a superior glide of the head as it moves from its seated position in the glenoid fossa to its resting position

- HYPEREXTENSION FROM NEUTRAL (backward extension)
  - scapular retraction with slight depression and maybe some downward scapular rotation
  - clavicular posterior translation and slight depression
  - early inferior glide coupled with anterior rotation of the humeral head
  - continue anterior rotation of the humeral head

- VERTICAL ABDUCTION FROM NEUTRAL (0 degrees)
  - generally same as for flexion but in frontal plane
  - abduction 0–60 degrees
    + scapular elevation
    + clavicular elevation
    + inferior glide of the humeral head coupled with medial rotation
    + the inferior glide of the humeral head seats the head in the glenoid fossa
  - abduction 60–90 degrees
    + scapular elevation and the start of upward scapular rotation
    + clavicular elevation
    + medial rotation of the humeral head with the head seated in the glenoid fossa
  - abduction 90–180 degrees
    + scapula and clavicle elevation stops
    + upward scapular rotation
    + posterior clavicular rotation
    + medial rotation of the humeral head with head seated in the glenoid fossa
- VERTICAL ADDUCTION FROM FULL ABDUCTION TO NEUTRAL (0 degrees)
  - opposite vertical abduction and generally the same as extension to neutral
  - adduction 180–90 degrees
    + downward scapular rotation
    + anterior clavicular rotation
    + lateral rotation of the humeral head with the head seated in the glenoid fossa
  - adduction 90–60 degrees
    + scapular depression and the end of downward scapular rotation
    + clavicular depression and the end of anterior clavicular rotation
    + lateral rotation of the humeral head with the head seated in the glenoid fossa
  - adduction 60–0 degrees
    + scapular depression
    + clavicular depression
    + lateral rotation of the humeral head with a superior glide of the head as it moves from its seated position in the glenoid fossa to its resting position



Arthrokinematic abduction of the glenohumeral joint with coinciding movements of the clavicle and scapula as seen in posterior view. A) Starting position (neutral) of the glenohumeral joint. B) At about 30 degrees of abduction, the humeral head glides inferiorly and rotates medially (green arrows). At the same time, the clavicle and scapula elevate (blue arrow). C) At about 75 degrees of abduction the humeral head is seated in the glenoid fossa and continues to rotate medially (green arrow). The clavicle and scapula continue to elevate (blue arrows) but the scapular begins to upwardly rotate (blue arrows). D) At about 140 degrees of abduction, the humeral head continues to rotate medially (green arrow). Elevation of the clavicle and scapula stop, upward rotation of the scapula continues (blue arrow) and the clavicle rotates posteriorly (blue arrow).

- EXTERNAL ROTATION WITH GLENOHUMERAL JOINT AT NEUTRAL (0 degrees)
  - arm is at the side and the elbow is flexed 90 degrees in the sagittal plane (forearm pointing anteriorly)
  - scapular retraction
  - posterior clavicular translation
  - external (lateral) rotation of the humeral head about the long axis of the humerus coupled with anterior glide of the humeral head

- INTERNAL ROTATION WITH GLENOHUMERAL JOINT AT NEUTRAL (0 degrees)
  - opposite that of external rotation
  - arm is at the side and the elbow is flexed 90 degrees in the sagittal plane (forearm pointing anteriorly)
  - scapular protraction
  - anterior clavicular translation
  - internal (medial) rotation of the humeral head about the long axis of the humerus coupled with posterior glide of the humeral head

ACTIVITES: For the following activities you will need to cup your left hand and point your left index finger forward and make a fist with your right hand. The cup represents the glenoid fossa, the left forearm is the scapula and the index finger is the clavicle. The right fist is the humeral head and the forearm is the shaft of the humerus. 1) Place your fist into the cup so that both forearms are pointing downward. This represents the neutral position of the glenohumeral joint. Now move your arms to mimic the movements of the humeral head, scapula and clavicle during flexion (a combined forward and upward movement of the right forearm) as described above for *COMBINED MOVEMENTS*. Try to mimic flexion to 120 degrees. Do the same for vertical abduction (a combined upward and lateral movement of the right forearm). How are the movements for flexion different from abduction? 2) Place your arms in the position reached at the end of the flexion activity above. Starting from this position, mimic extension to neutral as described in the *COMBINED MOVEMENTS*. Next place your arms in the position reached at the end of the abduction activity above and mimic adduction to neutral. How are the movements of extension to neutral different from adduction to neutral?

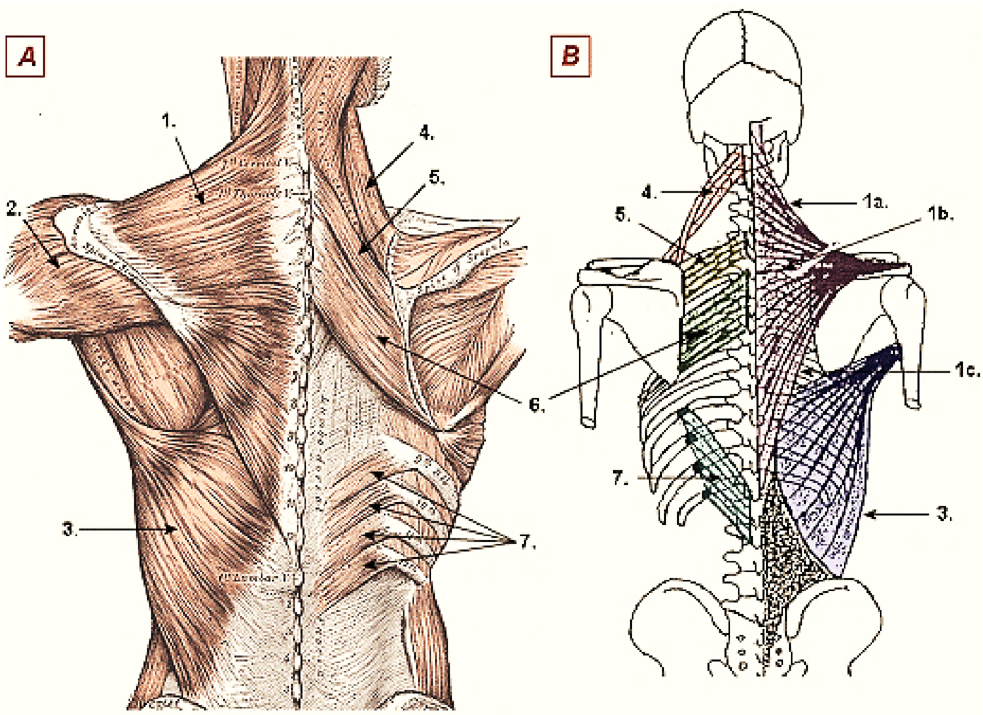
Study Questions (shoulder complex movements)

1. What movements of the clavicle occur at the sternoclavicular and acromioclavicular joints during the following movements:
   a. clavicular elevation
   b. clavicular posterior rotation
   c. clavicular protraction
2. What are the benefits of upward scapular rotation during arm flexion and abduction?
3. What is scapular rhythm?
4. When is phase II of scapular movement and what movements occur during this phase?
5. What can decrease the size of the subacromial space?
6. What are the movements of the shoulder complex structures during flexion?
7. What are the movements of the shoulder complex structures during extension?
8. What are the movements of the shoulder complex structures during external rotation?

3.1.5 MUSCLES OF SHOULDER COMPLEX

- The movements described for the components of the shoulder complex are generated by muscles acting separately and in groups.
- Muscles producing individual movements are described first and then combinations of muscles acting together to generate the coordinated movements of the shoulder complex are listed and presented in TABLES.

- **MUSCLES MOVING THE CLAVICLE AND SCAPULA**
  - CLAVICULAR ELEVATION
    - upper trapezius
    - sternocleidomastoid
  - SCAPULAR ELEVATION
    - upper trapezius
    - levator scapulae
    - rhomboids major and minor
  - CLAVICULAR DEPRESSION
    - subclavius
    - pectoralis major
  - SCAPULAR DEPRESSION
    - lower trapezius
    - pectoralis minor
    - latissimus dorsi



Drawing of the A) the superficial back muscles and a diagram B) showing the attachment sites of these muscles. 1. trapezius, 1a. upper trapizius, 1b. middle trapezius, 1c. lower trapezius, 2. deltoid, 3. latissimus dorsi, 4. levator scapulae, 5. rhoimboid minor, 6. rhomboid major, 7. post. Inf. serratus (Partly modified from Gray 1918)

- ANTERIOR CLAVICULAR ROTATION AND TRANSLATION
  - pectoralis major

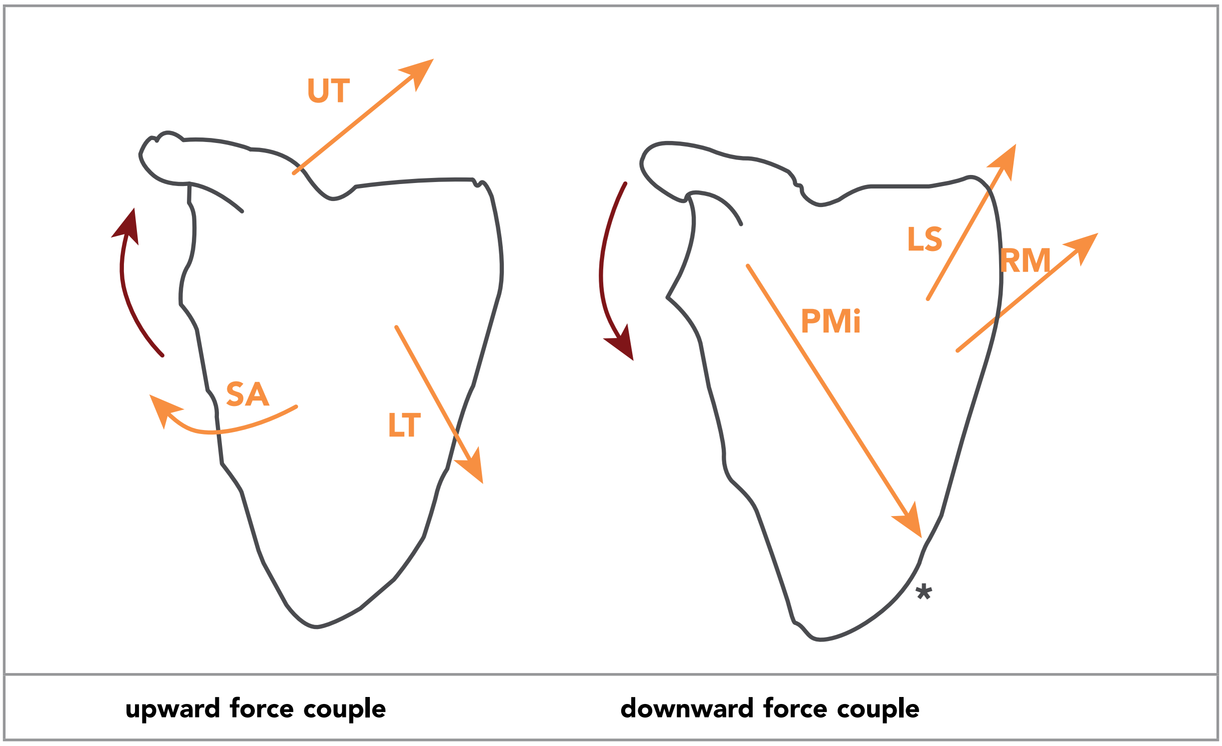
- POSTERIOR CLAVICULAR ROTATION AND TRANSLATION
  - upper trapezius
  - sternocleidomastoid

- SCAPULAR ABDUCTION (protraction)
  - serratus anterior

- SCAPULAR ADDUCTION (retraction)
  - middle trapezius
  - rhomboids major and minor

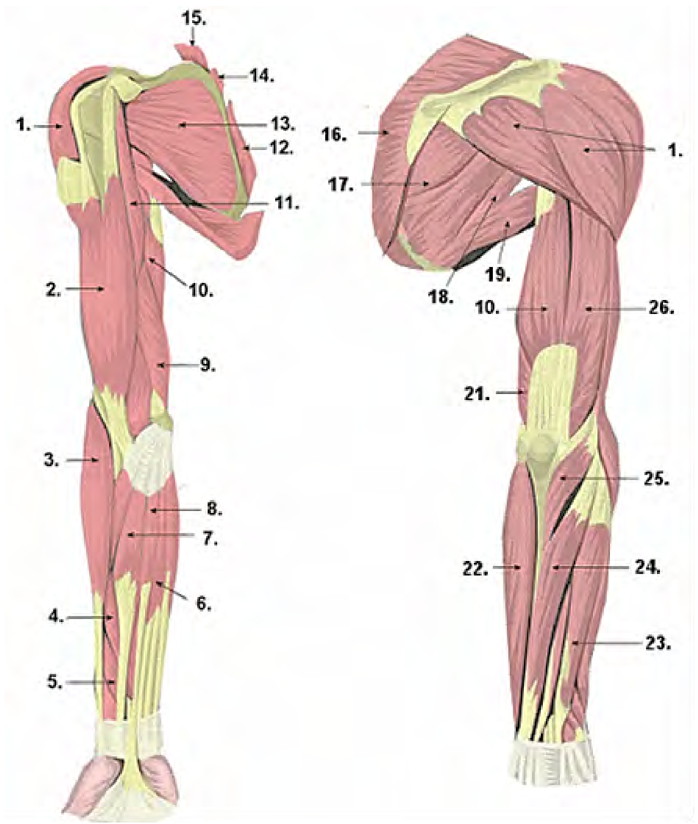
- UPWARD SCAPULAR ROTATION (all three act together to form a force couple to produce this movement)
  - upper trapezius
  - lower trapezius
  - serratus anterior

- o DOWNWARD SCAPULAR ROTATION (all three act together to form a force couple to produce this movement)
  - levator scapulae
  - rhomboids major and minor
  - pectoralis minor



(LEFT) Muscles acting together as a force couple to produce upward scapular rotation. (RIGHT) Muscles acting together as a force couple to produce downward scapular rotation. UT = upper trapezius, LT = lower trapezius, SA = serratus anterior, LS = levator scapulae, RM = rhomboid major and minor, PMi = pectoralis minor

- Muscles moving the humerus at the glenohumeral joint need to have a stable proximal (medial) attachment site. If both the proximal (medial) and distal (lateral) attachments are mobile then one gets an accordion effect. Many of the glenohumeral muscles have a proximal attachment site on the movable scapula. Thus, these muscles that move the scapula must also act to stabilize it so that the attaching glenohumeral muscles can move the humerus. Stability here does not mean that the proximal attachment is ridged and immobile. It means that the proximal site is less mobile than the distal site. The trapezius and rhomboids, in particular, function to stabilize as well as move the scapula.



Drawing of the muscles of the shouler complex. 1. Deltoid, 2. biceps, 3. brachiradialis, 4. flexor digitorum profundus, 5. flexor pollicis longus, 6. flexor digitorum superficialis, 7. flexor carpi radialis, 8. palmaris longus, 9. medial head of triceps, 10 long head of triceps. 11. coracobrachialis, 12. rhomboid major and 14. minor, 15. levator scapulae, 16. trapezius, 17. infraspinatus, 18. teres minor, 19. teres major, 21. medial head of triceps, 22. flexor carpi ulnaris, 23. extensor digitorum, 24. extensor carpi ulnaris, 25. anconeus, and 26. lateral head of triceps.

- **MUSCLE MOVING THE GLENOHUMERAL JOINT**
  - FLEXION
    - coracobrachialis
    - anterior deltoid
    - long and short heads of the biceps
    - pectoralis major when arm hyperextended
    - latissimus dorsi with are hyperextended
  - EXTENSION
    - posterior deltoid
    - pectoralis major with arm flexed
    - latissimus dorsi with are flexed
    - teres major
    - long head of triceps
  - HYPEREXTENSION
    - posterior deltoid
    - long head of triceps

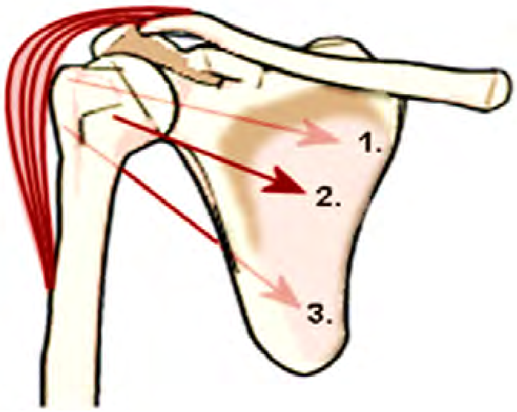
- VERTICAL ABDUCTION
  - anterior, middle, posterior deltoid
  - supraspinatus
  - long head of biceps with arm externally rotated

- VERTICAL ADDUCTION
  - pectoralis major
  - latissimus dorsi
  - teres major
  - subscapularis
  - infraspinatus
  - long head of triceps with arm internally rotated

- INTERNAL (MEDIAL) ROTATION
  - pectoralis major
  - latissimus dorsi
  - teres major
  - subscapularis
  - anterior deltoid
  - supraspinatus

- EXTERNAL (LATERAL) ROTATION
  - infraspinatus
  - teres minor
  - posterior deltoid
  - supraspinatus

- inferior humeral glide force couple
  - infraspinatus (1)
  - subscapularis (2)
  - teres minor (3)



Drawing showing the lines of action of the muscles that generate a force couple producing inferior glide of the humeral head during flexion and abduction.

- **SUPRASCAPULAR AND AXILLARY NERVE BLOCK** (Colachis and Strohm 1971)

  - SUPRASCAPULAR NERVE BLOCK
    - This block results in the loss of supraspinatus muscle function but not the deltoid muscle which is the other major abductor of the glenohumeral joint.
    - This loss results in a 60% decrease in abduction force from 0–60 degrees of osteokinematic abduction but only a 30% decrease in abduction force above 60 degrees.

  - AXILLARY NERVE BLOCK
    - This block results in the loss of deltoid muscle function but not supraspinatus muscle function.
    - This loss results in a 35% decrease in abduction force from 0–60 degrees of osteokinematic abduction and a 60–80% decrease in abduction force above 90 degrees.

- These nerve block data indicate that the supraspinatus is the main abductor of the glenohumeral joint from 0–60 degrees but that the deltoid is the main abductor above 90 degrees.

- Based on these data, the best range of motion for strengthening the supraspinatus would be from 0–60 degrees of abduction and the best range of motion for strengthening the deltoid would be above 90 degrees of abduction.

- **COMBINED MUSCLE ACTION DURING GLENOHUMERAL MOVEMENTS**

  - COMMON ACTIVITY PATTERNS

    - upward scapular rotation force couple:
      + upper and lower trapezius
      + serratus anterior

    - downward scapular rotation force couple:
      + rhomboid major and minor
      + levator scapulae
      + pectoralis minor

    - inferior glide and hold of humeral head:
      + subscapularis
      + infraspinatus
      + teres minor

    - elevation of scapula/clavicle and posterior clavicular rotation:
      + upper trapezius

    - stability and controlled upward scapular rotation:
      + rhomboids

- **SPECIFIC MUSCLE ACTIVITIES**

  - FLEXION FROM NEUTRAL (0 degrees)

    - flexion 0–60 degrees
      + upper trapezius: scapular and clavicular elevation
      + subscapularis, infraspinatus, teres minor: glenohumeral inferior glide
      + coracobrachialis (initiates): glenohumeral posterior rotation
      + anterior deltoid and biceps: glenohumeral posterior rotation

- flexion 60–90 degrees
  - + upper trapezius: scapular and clavicular elevation
  - + upper and lower trapezius, serratus anterior: start of upward scapular rotation
  - + rhomboids: stabilize scapula and control upward scapular rotation
  - + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
  - + supraspinatus: assists in holding humeral head in glenoid fossa
  - + coracobrachialis, anterior deltoid, biceps: glenohumeral posterior rotation

- flexion 90–180 degrees
  - + scapula and clavicle stop elevation
  - + upper and lower trapezius, serratus anterior: upward scapular rotation
  - + rhomboids: stabilize scapula and control upward scapular rotation
  - + upper trapezius: posterior clavicular rotation
  - + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
  - + supraspinatus: assists in holding humeral head in glenoid fossa
  - + coracobrachialis, anterior deltoid, biceps: glenohumeral posterior rotation

- EXTENSION FROM FULL FLEXION TO NEUTRAL (0 degrees)

  - extension 180–90 degrees
    + rhomboids major and minor, levator scapulae, pectoralis minor: downward scapular rotation
    + pectoralis major: anterior clavicular rotation
    + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
    + supraspinatus: assist in holding humeral head in glenoid fossa
    + latissimus dorsi, pectoralis major, teres major: glenohumeral anterior rotation
    + infraspinatus, teres minor: counterbalance internal rotation component of latissimus dorsi, pectoralis major, teres major

  - extension 90–60 degrees
    + rhomboids major and minor, levator scapule, pectoralis minor: downward scapular rotation
    + pectoralis minor, latissimus dorsi, lower trapezius: scapular depression
    + pectoralis major, subclavius: clavicular depression
    + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
    + latissimus dorsi, pectoralis major, teres major, posterior deltoid, long head of triceps: glenohumeral anterior rotation
    + infraspinatus, teres minor: counterbalance internal rotation component of latissimus dorsi, pectoralis major, teres major

  - extension 60–0 degrees
    + pectoralis minor, latissimus dorsi, lower trapezius: scapular depression
    + pectoralis major, subclavius: clavicular depression
    + subscapularis, infraspinatus and teres minor: activity decreases and stops and humeral head glides superiorly
    + latissimus dorsi, pectoralis major, teres major, posterior deltoid, long head of triceps: glenohumeral anterior rotation
    + infraspinatus, teres minor: counterbalance internal rotation component of latissimus dorsi, pectoralis major, teres major

- HYPEREXTENSION (backward extension) FROM NEUTRAL (0 degrees)

  - rhomboid major and minor, middle trapezius: scapular retraction with mechanical pulling of clavicle posteriorly producing posterior clavicular translation
  - pectoralis minor, lower trapezius: slight scapular depression with mechanical pulling of clavicle downward producing slight clavicular depression
  - pectoralis minor, rhomboid major and minor,levator scapulae: some downward rotation
  - subscapularis, infraspinatus, teres minor: glenohumeral inferior glide
  - posterior deltoid, long head of triceps: anterior rotation

- VERTICAL ABDUCTION FROM NEUTRAL (0 degrees)

  - similar to flexion from neutral
  - abduction 0–60 degrees
    + upper trapezius: scapular and clavicular elevation
    + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
    + supraspinatus, all three parts of deltoid: glenohumeral medial rotation
  - abduction 60–90 degrees
    + upper trapezius: scapular and clavicular elevation
    + upper and lower trapezius, serratus anterior: start of upward scapular rotation
    + rhomboids: stabilize scapula and control upward scapular rotation
    + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
    + supraspinatus, all three parts of deltoid: glenohumeral medial rotation

  - abduction 90–180 degrees
    + scapula and clavicle stop elevation
    + upper and lower trapezius, serratus anterior: upward scapular rotation
    + rhomboids: stabilize scapula and control upward scapular rotation
    + upper trapezius: posterior clavicular rotation
    + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
    + supraspinatus, all three parts of deltoid: glenohumeral medial rotation

- VERTICAL ADDUCTION TO NEUTRAL (0 degrees)
  - generally similar to extension to neutral
  - adduction 180–90 degrees
    - + rhomboids major and minor, levator scapulae, pectoralis minor: downward scapular rotation
    - + pectoralis major: anterior clavicular rotation
    - + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
    - + latissimus dorsi, pectoralis major, teres major: glenohumeral lateral rotation
    - + infraspinatus, teres minor: counterbalance internal rotation component of latissimus dorsi, pectoralis major, teres major

- adduction 90–60 degrees
  + rhomboids major and minor, levator scapulae, pectoralis minor: downward scapular rotation
  + pectoralis minor, latissimis dorsi, lower trapezius: scapular depression
  + pectoralis major, subclavius: clavicular depression
  + subscapularis, infraspinatus and teres minor: hold seated humeral head in glenoid fossa
  + latissimus dorsi, pectoralis major, teres major: glenohumeral lateral rotation
  + infraspinatus, teres minor: counterbalance internal rotation component of latissimus dorsi, pectoralis major, teres major

- adduction 60–0 degrees
  + pectoralis minor, latissimus dorsi, lower trapezius: scapular depression
  + pectoralis major, subclavius: clavicular depression
  + subscapularis, infraspinatus and teres minor: activity decreases and stops and humeral head glides superiorly
  + latissimus dorsi, pectoralis major, teres major: glenohumeral lateral rotation
  + infraspinatus, teres minor: counterbalance internal rotation component of latissimus dorsi, pectoralis major, teres major

o EXTERNAL ROTATION WITH GLENOHUMERAL JOINT AT NEUTRAL (0 degrees)

- rhomboid major and minor, middle trapezius: scapular retraction with mechanical pulling of clavicle posteriorly producing posterior clavicular translation
- infraspinatus, teres minor, posterior deltoid: glenohumeral external (lateral) rotation and anterior glide
- supraspinatus: assists in later stage of external rotation as greater tubercle moves posteriorly

o INTERNAL ROTATION WITH GLENOHUMERAL JOINT AT NEUTRAL (0 degrees)

- serratus anterior: scapular protraction with mechanical pushing of the clavicle anteriorly producing anterior clavicular translation
- pectoralis anterior: may assist in anterior clavicular translation
- subscapularis, latissimus dorsi, pectoralis major, teres major,anterior deltoid: glenohumeral internal (medial) rotation and posterior glide
- supraspinatus: assists in later stage of internal rotation as greater tubercle moves anteriorly

- CONTROLLED (ECCENTRIC, PASSIVE) GLENOHUMERAL EXTENSION

  - starting at 90 degrees of glenohumeral flexion and slowly lowering the arm in extension to neutral (0 degrees)
  - eccentric contraction of the glenohumeral flexors: coracobrachialis, anterior deltoid, and biceps (with elbow stabilized and glenohumeral joint at neutral rotation)

- CONTROLLED (ECCENTRIC, PASSIVE) GLENOHUMERAL ADDUCTION

  - starting at 90 degrees of glenohumeral abduction and slowly lowering the arm in adduction to neutral (0 degrees)
  - eccentric contraction of the glenohumeral abductors: deltoid, supraspinatus and long head of the biceps (with the elbow stabilized and glenohumeral joint externally rotated)

TABLES SHOWING THE MOTIONS AND THEN THE MUSCLE ACTIVITIES OCCURRING AT DIFFERENT DEGREES IN GLENOHUMERAL MOTION. (FC = force couple, active = muscles are actively generating the inferior glide, hold= muscles are contracting to hold the humeral head in its seated position)

Glenohumeral Flexion

Movement	0–60°	60°–90°	90°+
Humeral Head Posterior Rotation	X	X	X
Scapular Elevation	X	X	
Scapula Upper Rotation		X	X
Clavicle Elevation	X	X	
Clavicle Posterior Rotation			X
Inferior Glide FC (active)	X		
Inferior Glide FC (hold)		X	X

Movement	0–60°	60°–90°	90°+
Humeral Head Posterior Rotation	Coracobrachialis (initiator) Anterior Deltoid	Coracobrachialis Anterior Deltoid	Coracobrachialis Anterior Deltoid
Scapular Elevation	Upper Trapezius	Upper Trapezius	
Scapula Upper Rotation		Upper Trapezius Lower Trapezius Serratus Anterior (Controlled by Rhomboids)	Upper Trapezius Lower Trapezius Serratus Anterior (Controlled by Rhomboids)
Clavicle Elevation	Upper Trapezius	Upper Trapezius	
Clavicle Posterior Rotation			Upper Trapezius
Inferior Glide FC (active)	Subascapularis Infraspinatus Teres Minor		
Inferior Glide FC (hold)		Subscapularis Infraspinatus Teres Minor (supraspinatus)	Subscapularis Infraspinatus Teres Minor (supraspinatus)

Glenohumeral Extension

Movement	90+°	90°–60°	60–0°
Humeral Head Anterior Rotation	X	X	X
Scapular Depression		X	X
Scapula Down Rotation	X	X	
Clavicle Depression		X	X
Clavicle Anterior Rotation	X		
Superior Glide FC			X
Inferior Glide FC (hold)	X	X	

Movement	90°+	90°–60°	60°–0°
Humeral Head Anterior Rotation	Latissimus Dorsi Pectoralis Major Teres Major (Long Hd Triceps if elbow stable) Post Deltoid	Latissimus Dorsi Pectoralis Major Teres Major (Long Hd Triceps if elbow stable) Post Deltoid	Latissimus Dorsi Pectoralis Major Teres Major (Long Hd Triceps if elbow stable) Post Deltoid
Clavicle Anterior Rotate	Pectoralis Major		
Clavicle Depress		Pectoralis Major Subclavius	Pectoralis Major Subclavius
Scapula Downward Rotate	Levator Scapulae Rhomboids M & M Pectoralis Minor (Controlled by Ant. Serratus	Levator Scapulae Rhomboids M & M Pectoralis Minor (Controlled by Ant. Serratus	
Scapula Depress		Pectoralis Minor	Pectoralis Minor
Inferior Glide (Hold)	Subscapularis Infraspinatus Teres Minor (supraspinatus)	Subscapularis Infraspinatus Teres Minor (supraspinatus)	

Glenohumeral Abduction

Movement	0–60°	60°–90°	90°+
Humeral Head Medial Rotation	X	X	X
Scapular Elevation	X	X	
Scapula Upper Rotation		X	X
Clavicle Elevation	X	X	
Clavicle Posterior Rotate			X
Inferior Glide FC (active)	X		
Inferior Glide FC (hold)		X	X

Movement	0–60°	60–90°	90°+
Humeral Head Medial Rotation	Supraspinatus (initiator) Ant., Mid, Post Deltoid (long head Biceps)	Supraspinatus (initiator) Ant., Mid, Post Deltoid (long head Biceps)	Supraspinatus (initiator) Ant., Mid, Post Deltoid (long head Biceps)
Scapular Elevation	Upper Trapezius	Upper Trapezius	
Scapular Upper Rotation		Upper Trapezius Lower Trapezius Serratus Anterior (Controlled by Rhomboids)	Upper Trapezius Lower Trapezius Serratus Anterior (Controlled by Rhomboids)
Clavicle Elevation	Upper Trapezius	Upper Trapezius	
Clavicle Posterior Rotation			Upper Trapezius
Inferior Glide FC (active)	Subscapularis Infraspinatus Teres Minor		
Inferior Glide FC (hold)		Subscapularis Infraspinatus Teres Minor Supraspinatus	Subscapularis Infraspinatus Teres Minor Supraspinatus

Glenohumeral Adduction

Movement	90+°	90°–60°	60–0°
Humeral Head Lateral Rotation	X	X	X
Scapular Depression		X	X
Scapula Down Rotation	X	X	
Clavicle Depression		X	X
Clavicle Anterior Rotation	X		
Superior Glide FC			X
Inferior Glide FC (hold)	X	X	

Movement	90°+	90°–60°	60°–0°
Humeral Head Lateral Rotation	Latissimus dorsi Pectoralis Major Teres Major Long hd Triceps if elbow stable	Latissimus dorsi Pectoralis Major Teres Major Long hd Triceps if elbow stable	Latissimus dorsi Pectoralis Major Teres Major Long hd Triceps if elbow stable
External Rotate (to counter balance interior rotation)	Infraspinatus Teres Minor	Infraspinatus Teres Minor	Infraspinatus Teres Minor
Clavicle Anterior Rotate	Pectoralis Major		
Clavicle Depress		Subclavius Pectoralis Major	Subclavius Pectoralis Major
Scapula Downward Rotate	Levator Scapulae Rhomboids M & M Pectoralis Minor (Controlled by Ant. Serratus	Levator Scapulae Rhomboids M & M Pectoralis Minor (Controlled by Ant. Serratus	
Scapula Depress		Pectoralis Mnor	Pectoralis Mnor
Inferior Glide (Hold)	Subscapularis Infraspinatus Teres Minor Supraspinatus	Subscapularis Infraspinatus Teres Minor Supraspinatus	

Glenohumeral Internal Rotation

Movement	Muscle Action
Humerus Internal Rotation and Posterior Glide	Pectoralis Major Subscapularis Latissimus Dorsi Teres Major Anterior Deltoid
Scapula Abduct	Serratus Anterior (Controlled by Rhomboids)
Scapula Stabilize, control	Trapezius Rhomboids M & M
Clavicular Anterior Glide	Pectoralis Major (end of IR)/passive motion

Glenohumeral External Rotation

Movement	Muscle Action
Humerus External Rotation And Anterior Glide	Infraspinatus Teres Minor Posterior Deltoid Supraspinatus (later)
Scapula Retract	Middle Trapezius Rhomboids (Controlled by Serratus Anterior)
Clavicle Posterior Glide	Upper Trapezius (End of ER)/passive motion
Scapula Stabilize, control	Serratus Anterior Pectoralis Minor

Glenohumeral HyperExtension

Movement	Muscle Action
Humerus Anterior Rotation	Posterior Deltoid Long Head Triceps
Depress Humeral Head	Subscapularis Infraspinatus/Teres Minor
Retract Scapula	Middle Trapezius Rhomboids Major and Minor (Controlled by Serratus Anterior maybe)

- **GLENOHUMERAL MUSCLE STRENGTH**
    - relative muscle group strength from strong to weak
        - adductors ≥ internal rotators > extensors > flexors > abductors > external rotators
        - Adductors and internal rotators are the strongest and the external rotators are the weakest.
        - These differences in muscle strength are an important factor when assessing muscle strength.

- isometric strength decreases with age
  - comparison between males and females 25–36 Y.O. with males and females 55–66 Y.O.
  - 55–66 Y.O. group had 66 to 93% less strength than the younger group.
  - This difference seems very high, probably a lot of variables including subjects activity level, occupation, muscles tested.

- At 90 degrees of abduction, the deltoid generates 8× the weight of the upper extremity and the reaction force at the glenohumeral joint is 10× the weight of the extremity.

- At 60 degrees of abduction, the rotator cuff generates a glenohumeral reaction force of 9.6× the weight of the upper extremity.

- For the deltoid and rotator cuff muscles, flexion of the elbow decreases the weight arm as the center of gravity moves from the mid-forearm to mid-upper arm and thus the forces generated by the muscle and at the glenohumeral joint are reduced.

- For the deltoid and rotator cuff muscles, adding a weight to the hand increases the weight of that side of the lever (arm weight bar bell) so the that forces generated by the muscles and at the glenohumeral joint increase as a factor of the added weight.

- Shoulder muscles, especially the trapezius, supraspinatus and deltoid, fatigue significantly more rapidly with work above 90 degrees then when the arms are at 45 degrees so then activities to increase shoulder muscle endurance should include activities above 90 degrees.

ACTIVITIES: Muscles can generate movements but also limit movements when the muscles are weak, damaged or tight. For the following activities, you need to picture or locate certain mucles on yourself, visualize the actions of these mucles and figure out how the condition of these muscles affects gleonhumeral movements. The TABLES may help. 1) Tightness of the rhomboids will restrict scapular rotation and protraction. What glenohumeral movements may be limited and why? 2) Shortening of the pectoralis major due to poor posture will limit posterior rotation and translation of the clavicle. What glenohumeral movements may be limited and why? 3) A rotator cuff tear involving the supraspinatus and the infraspinatus may limit what glenohumeral movements that are normally generated by these muscles? 4) Weakness of the upper trapezius will reduce scapular and clavicular movements. What glenohumeral movements may be limited and why?

Study Questions (shoulder complex movements and muscle actions)

1. What scapular and clavicular movements are produced by the upper trapezius?
2. What muscles produce downward rotation of the scapula?
3. What muscles produce upward rotation of the scapula?
4. What are the actions of the deltoid?
5. What muscles produce glenohumeral adduction and internal rotation?
6. What muscles produce an inferior glide of the humeral head?
7. What muscle is the main glenohumeral abductor from 0–60 degrees? What about abduction over 90 degrees?
8. What are the muscles producing glenohumeral flexion from 0–60 degrees and from 90–180 degrees?
9. What movements and muscles actions producing glenohumeral flexion are common to those during glenohumeral abduction? What are different?
10. What movements and muscle actions are common during glenohumeral extension (180–0 degrees) and adduction (180–0 degrees)? What are different?
11. What are the two strongest groups of shoulder muscles? What are the two weakest groups? How does this relate to muscle testing?
12. Why is the amount of force generated by the deltoid to hold the arm at 90 degrees of abduction so much greater than the weight of the arm? How about the rotator cuff holding the arm in abduction at 60 degrees?

3.2 ELBOW COMPLEX

3.2.1 COMPONENTS OF THE ELBOW COMPLEX

- The elbow complex consists of 3 joints and the articulations of 3 bones.
- Flexion, extension, supination and pronation of the forearm occur at the elbow.
- Supination and pronation movements may occur separately or in combination with flexion and extension.
- It is estimated that during ADLs, joint forces at the elbow are > 2 × body weight.

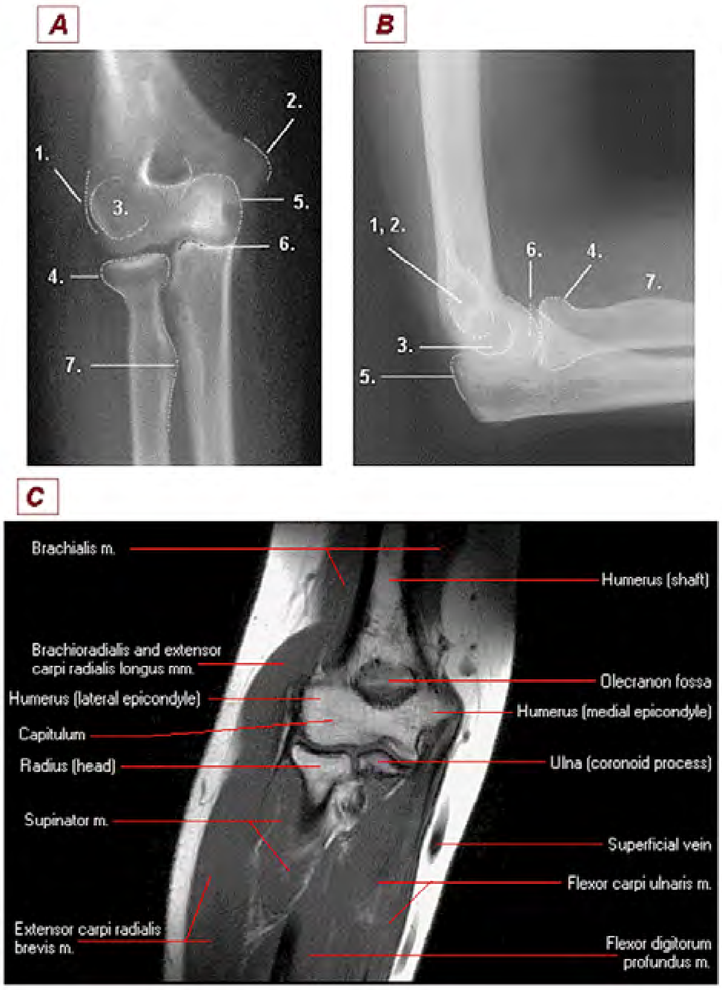
- **HUMEROULNAR JOINT**
  - articulation between trochea of the humerus and trochear notch of ulna
  - hinge type synovial joint
  - main motions are flexion and extension

- **HUMERORADIAL JOINT**
  - articulation between the capitellum of the humerus and the head of the radius
  - hinge type synovial joint
  - main motions are flexion and extension

- **PROXIMAL RADIOULNAR JOINT**
  - articulation between the head of the radius and the radial notch of the ulna
  - pivot type synovial joint
  - main motions are supination and pronation

- **ELBOW JOINT STABILITY**

  - BONY LIMITATIONS TO MOVEMENT
    - The trochlear notch of olecranon of ulna contacting the trochlea of humerus limits extension, anterior translation and superior translation of the ulna.
    - The coronoid process of ulna contacting the trochlea of humerus limits superior translation of the ulna.
    - The radial head contacting the capitellum of the humerus limits superior translation of the radius.
    - The radial head contacting the radial notch of the ulna limits lateral translation of the radial head.
    - The least bony stability:
      + posteriorly directed force on the forearm or an anteriorly directed force on the humerus when elbow fully extended
      + downward force on the forearm when elbow is flexed 90 degrees



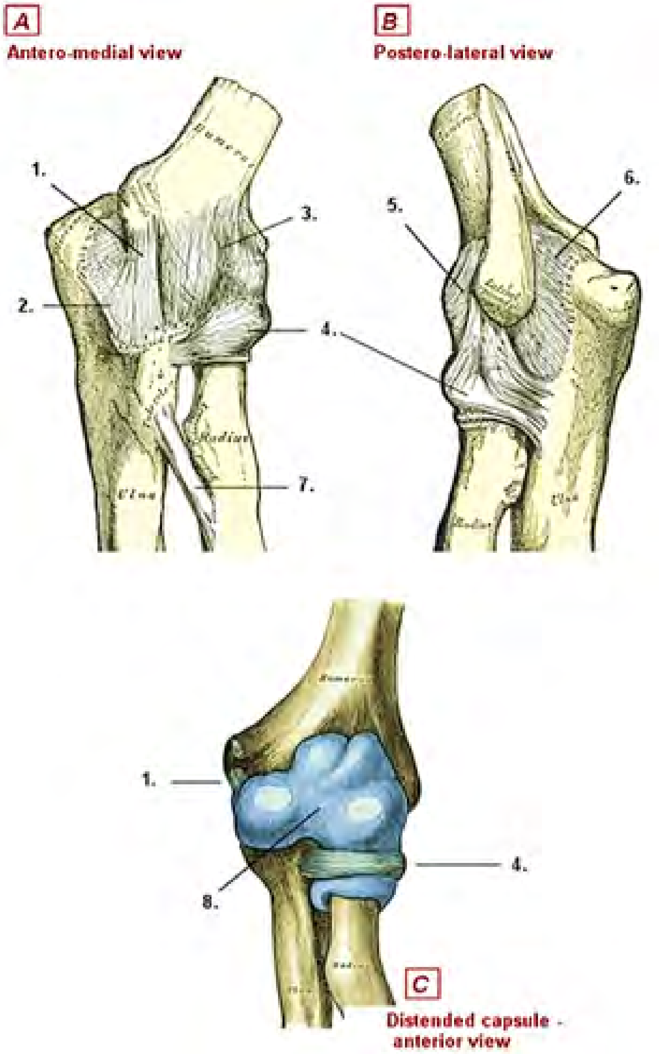
Elbow Joint Radiographs and MRI: A) AP radiograph, B) lateral radiograph, and C) coronal plane T1 MRI. The numbers in the radiographs indicate: 1. lateral epicondyle, 2. medial epicondyle, 3. capitulum, 4. head of radius, 5. olecranon, 6. coronoid process of ulna, and 7. radial tuberosity

- o LIGAMENTOUS SUPPORT OF THE ELBOW COMPLEX

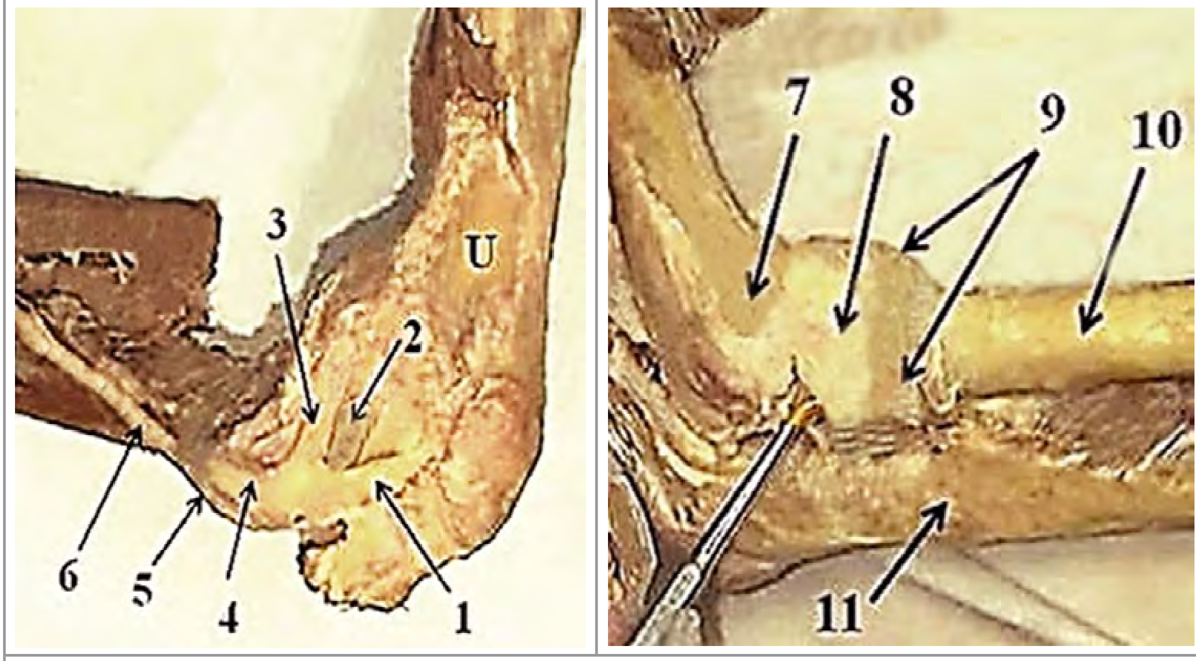
  - ▪ medial collateral ligament (MCL)
    - + This is a strong ligament with anterior, posterior and transverse bands.
    - + Superior fibers of the anterior band are slack in flexion but taut in extension.
    - + Inferior fibers of the anterior band are taut in flexion and slack in extension.
    - + Fibers of the posterior band become taut after 90 degrees of flexion.
    - + Most ADLs increase valgus strain at the elbow because of the outward movement of forearm relative to the humerus.
    - + MCL resists valgus strain at the forearm.
    - + Valgus strain at the elbow tenses the MCL and medial tissues of the elbow, placing traction on the humeroulnar joint, compression on the humeroradial joint, and slackening of the lateral tissues of the elbow.
    - + The valgus strain stimulates fibrocytes to increase collagen production which thickens the MCL.

- lateral collateral ligament (LCL)
  - This is a weak ligament that attaches to the annular ligament.
  - It provides slight resistance to tension strain and varus strain.
  - Varus strain on the elbow occurs infrequently when the forearm is moved medially relative to the humerus.
  - Varus strain tenses the (LCL) and lateral tissues of the elbow, distracts the humeroradial joint, compresses the humeroulnar joint, and slackens the MCL and medial tissues of the elbow.
  - The anconeus muscle, bone and joint capsule provide resistance to varus strain at the elbow.

- annular ligament
  - This is a strong, circular ligament that wraps around the head of the radius at the proximal radioulnar joint.
  - It holds the radial head against the radial notch of the ulna to allow smooth rotation of the head during supination and pronation.
  - The annular ligament also prevents dislocation of radial head from the radial notch of the ulna.
  - The interosseous membrane also helps to maintain the position of the radial head in the radial notch and resist dislocation of the radial head.



Drawings of the elbow complex. A) medial, B) lateral, and C) anterior views of the elbow: 1. Medial collateral ligament anterior band, 2. posterior band, 3. anterior joint capsule, 4. annular ligament of radius, 5. lateral collateral ligament, 6. capsule, 7. oblique cord, and 8. synovial membrane. (Modified from Gray 1918)



Dissection of the Medial elbow (Left) and Lateral elbow (Right) ligaments. 1. Anterior band of medial collateral lig., 2. Ulnar nerve, 3. Posterior band of medial collateral lig., 4. Transverse band of medial collateral lig., 5. Cubital tunnel, 6. Ulnar nerve, 7. Lateral epicondyle, 8. Lateal collateral lig., 9. Annular lig., 10. Radius, 11. Ulna.

- BONY AND LIGAMENTOUS RESISTANCE TO STRAIN

TABLE SHOWING THE PERCENTAGE OF RESISTANCE PROVIDED BY THE MEDIAL AND LATERAL COLLATERAL LIGAMENTS, JOINT CAPSULE AND BONE when valgus, varus and distraction strains are applied when the elbow is positioned a 0 and 90 degrees (Nordin and Frankel, 2001, 20012).

	VALGUS		VARUS		DISTRACTION	
	0 deg.	90 deg.	0 deg.	90 deg.	0 deg.	90 deg
MEDIAL COLLATERAL RESISTANCE	31%	54%	none	none	6%	78%
LATERAL COLLATERAL RESISTANCE	none	none	14%	9%	5%	10%
JOINT CAPSULE RESISTANCE	38%	10%	31%	13%	85%	8%
BONE RESISTANCE	31%	33%	55%	75%	none	none

- valgus strain with the elbow at 0 degrees
  - Resistance is nearly equally provided by the medial collateral ligament, joint capsule and bone equally resist.
  - There is no resistance from lateral collateral ligament.

- valgus strain with elbow at 90 degrees
  - About half of the resistance is provided by the medial collateral ligament and about one third by bone.
  - There is no resistance from the lateral collateral ligament and about ten percent from the joint capsule.

- varus strain with the elbow at 0 degrees
  - About half of the resistance is provided by bone and about one third by the joint capsule.
  - There is no resistance from the medial collateral ligament and about ten percent from the lateral collateral ligament.

- varus strain with the elbow at 90 degrees
  + Three fourths of the resistance is provided by bone and about ten percent from the joint capsule and another ten percent from the lateral collateral ligament.
  + There is no resistance from the medial collateral Ligament.

- distraction strain with the elbow at 0 degrees
  + More than 80 percent of the resistance is provided by the joint capsule and about 5 percent each from the medial and lateral collateral ligaments.
  + There is no bony resistance.

- distraction strain with the elbow at 90 degrees
  + About 80 percent of the resistance is provided by the medial collateral ligament and about ten percent each from the lateral collateral ligament and joint capsule.
  + There is no resistance from bone.

- testing MCL, joint capsule, bony articulation
  + Based on the information above, the application of a particular strain with the elbow at 0 or 90 degrees can be used to stress a particular structure more than others and determine the status of that particular structure based on the subjects response.
  + The application of a distraction strain to the elbow when it is at 90 degrees would primarily test the medial collateral ligament.
  + The application of a distraction strain at the elbow with it at 0 degrees would best test the joint capsule.
  + A varus strain at the elbow with it at 90 degrees would best stress the bony component of the humeroulnar joint.
  + A valgus strain with the elbow at 90 degrees would stress the medial collateral ligament.
    i. Because bone is also resisting this strain, the stress on the medial collateral would be less than if distraction is applied with the elbow at 90 degrees.
    ii. A valgus strain would appear to be less sensitive for the MCL than a distraction strain.
  + A valgus strain with the elbow at 0 degrees would appear to be of little use as it would not help to differentiate among the MCL, joint capsule or bone.

3.2.2 MOVEMENTS AT THE ELBOW COMPLEX

- **OSTEOKINEMATIC JOINT MOVEMENT**
  - Osteokinematic range of motion values will vary depending on the source (Norkin, White, Malone 2009; Reese and Bandy 2013).
  - The degrees listed for each movment are commonly used.
  - flexion/extension = 0–140/150 degrees
  - pronation = 0–80/90 degrees
  - supination = 0–80/90 degrees
  - ranges needed to perform most activities of daily living (ADLs)
    - flexion/extension = 20–130 degrees
    - pronation = 50 degrees
    - supination = 50 degrees

- CARRYING ANGLE
  - This angle is lateral position of the forearm relative to the humerus when the elbow is at 0 degrees.
  - 5 degrees in males
  - 10–15 degrees in females
  - The carrying angle is the result of the medial end of trochlea being distal to capitellum which positions the ulna and radius at an angle lateral to the humerus.

- CLOSE PACKED POSITION
  - humeroulnar = full extension
  - humeroradial = semiflexion with semipronation
  - radioulnar = full pronation or full supination

- LOOSE PACKED POSITION
  - humeroulnar = 70–90 degrees of flexion
  - humeroradial = 70 degrees of flexion and 35 degrees of supination
  - radioulnar = 70 degrees of flexion with 35 degrees of supination

- **ARTHROKINEMATIC JOINT MOVEMENTS AT THE ELBOW**
  - HUMEROULNAR FLEXION
    - The ulna rotates anteriorly and glides slightly anteriorly.
    - The ulna adducts because the trochlear ridge of the ulna follows the tilted trochlear groove of the humerus.

  - HUMERORADIAL FLEXION
    - The radius rotates and glides anteriorly with the ulna.
    - The radius glides anteriorly on the capitellum.
    - The radius moves cranially on the ulna.

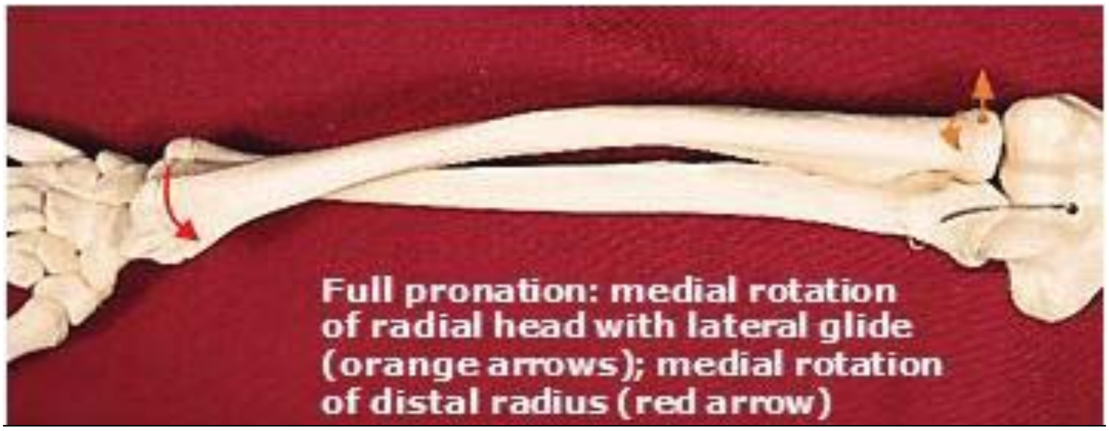
(TOP) Starting position for elbow flexion. (BOTTOM) 90 degrees of elbow flexion showing the anterior rotation and glide (orange arrows) of the ulna at the humeroulnar joint and the radial head at the humeroradial joint. 1 = radial head, 2 = olecranon process, 3 = trochlea of humerus

- HUMEROULNAR EXTENSION
  - The ulna rotates posteriorly and glides slightly posteriorly.
  - The ulna abducts because the trochlear ridge of the ulna follows the titled trochlear groove of the humerus.

- HUMERORADIAL EXTENSION
  - The radius rotated and glides posteriorly with the ulna.
  - The radius glides posteriorly on capitellum.
  - The radius moves caudally on the ulna (at full extension there is no contact between radial head and capitellum).

- SUPINATION
  - The radius rotates laterally.
  - The radial head glides medially.

- PRONATION
  - The radius rotates medially.
  - The radial head glides laterally.



(TOP) Forearm in full supination. (BOTTOM) Forearm in Full pronation. To move from a full supinated position to full pronation, the radial head rotates medially and translates laterally (orange arrows) while the distal radius rotates medially across the head of the ulna (red arrow). 1 = radial head; 2 = capitellum of humerus; 3 = junction of the trochlea of the humerus and trochlear notch of the ulna.

ACTIVITIES: For the following activities you need have your forearm near full supination. Now place your left thumb on the medial aspect of the olecranon process and your left index finger on the head to the radius. (Alternating pronation and supination movements will help you locate the radial head.) 1) With the forearm extended and supinated, flex the right elbow and then extend it. Flex and extend the right elbow several times. Can you feel or see the proximal ulna and radial head rotate and glide anteriorly during flexion and posteriorly during extension? 2) Keeping your left index finger on the radial head and the forearm extended and supinated, pronate and supinate your right forearm several times. Can you feel the medial rotation and lateral glide of the radial head during pronation and the lateral rotation and medial glide of the radial head during supination?

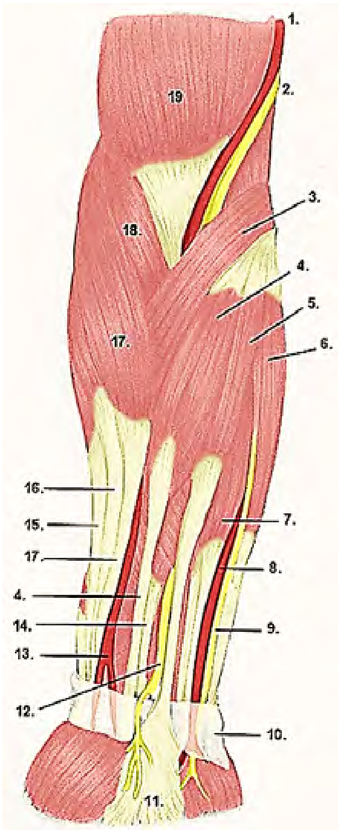
3.2.3 MUSCLES OF THE ELBOW COMPLEX

- **ELBOW FLEXORS**

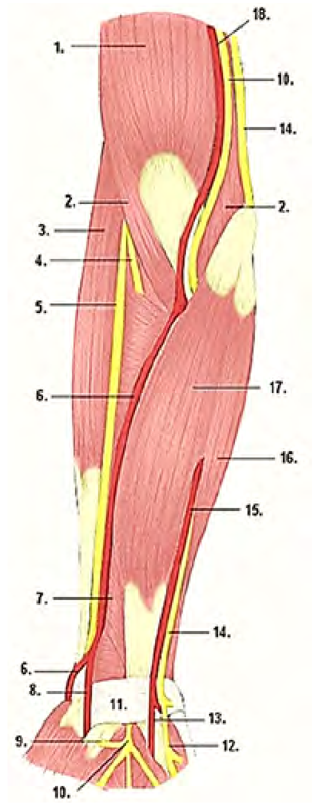
  - BRACHIALIS
    - highest elbow flexor in strength and work capacity
    - mechanical advantage greatest at 100 degrees of flexion
    - active in all positions and speeds of movement
    - active with non resistive and resistive movements
    - not affected by shoulder position

  - BICEPS
    - mechanical advantage greatest at 80 -90 degrees of flexion
    - least effective at full flexion with shoulder flexion
    - active with resisted elbow flexion
    - active with resisted supination
    - when flexion is beyond 100 degrees, biceps produces an anterior pull (anterior glide)on the radial head

- BRACHIORADIALIS
    - produces large compression forces on the elbow joint
    - not active during slow, non resisted flexion
    - not active eccentrically during controlled elbow extension when the motion is slow and the hand supinated
    - active when there is an increased resistance to flexion
    - best position is mid supination/pronation when flexion is resisted and movement is at a moderate to high speed



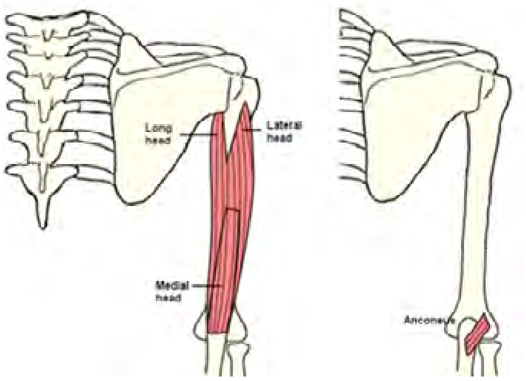
Drawing of the ventral forearm showing the superficial muscles: 1. Brachial artery, 2. median N., 3. pronator teres, 4. flexor carpi radialis, 5. palmaris longus, 6. flexor carpi ulnaris, 7. flexor digit. superficialis, 8. ulnar artery, 9. ulnar N, 10. flexor retinaculum, 11. palmar aponeurosis, 12. median N., 13. radial artery, 14. flexor pollicis longus, 15. extensor carpi radialis brevis and 16. longus, 17. brachioradialis, 18. brachialis, and 19. biceps



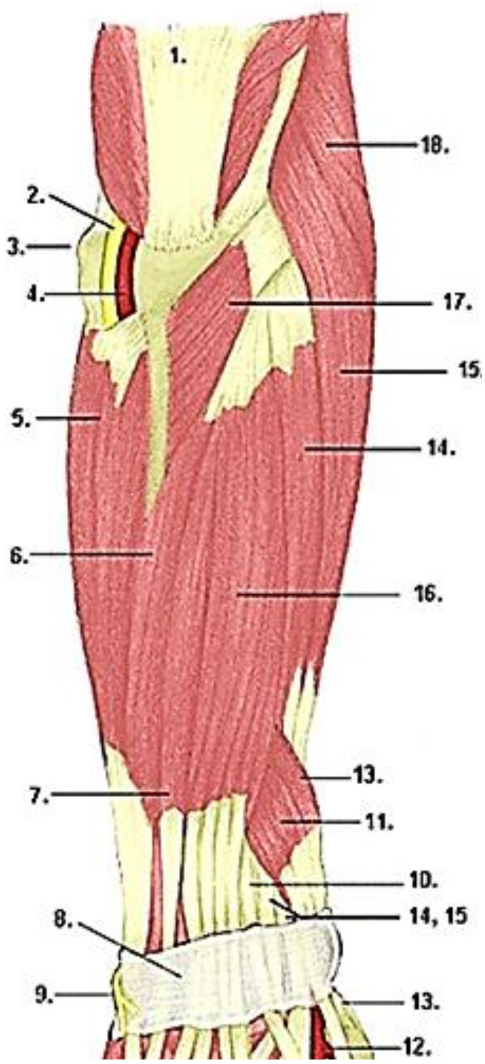
Drawing of the ventral forearm with the superficial muscles removed: 1. Biceps, 2. brachialis, 3. brachioradialis, 4. deep radial N., 5. superficial radial N., 6. radial artery, 7. flexor pollicis longus, 8. radial artery, superficial palmar branch of radial, 9. recurrent branch of median N., 10. median N., 11. flexor retinaclum, 12. superficial ulnar N., 13. superficial ulnar artery, 14. ulnar N., 15. ulnar artery, 16. flexor carpi ulnaris, 17. flexor digitorum superficialis, and 18. brachial artery.

- OTHER ELBOW FLEXORS
  - Because the lines of action of these muscles cross anterior to the axes of the humeroulnar and humeroradial joints, these muscles can assist in elbow flexion.
  - extensor carpi radialis longus
  - pronator teres
  - flexor carpi ulnaris
  - flexor carpi radialis
  - flexor digitorum superficialis

- **ELBOW EXTENSORS**
  - LONG HEAD OF TRICEPS
    - affected by shoulder position
    - least effective at full elbow extension with glenohumeral in backward extension (hyperextension)
    - greatest activity with heavy resistance or quick extension
  - MEDIAL AND LATERAL HEADS OF TRICEPS
    - not affected by shoulder position
    - medial head active with non resisted and resisted extension
    - lateral head active with resisted extension
    - triceps produce maximum torque at 90 degrees of flexion
  - OTHER EXTENSORS
    - anconeus
    - extensor carpi ulnaris



Drawing showing (LEFT) the three heads of the triceps and (RIGHT) the anconeus. The lines of action of these extensor muscles cross posterior to the axis of the humeroulnar joint.



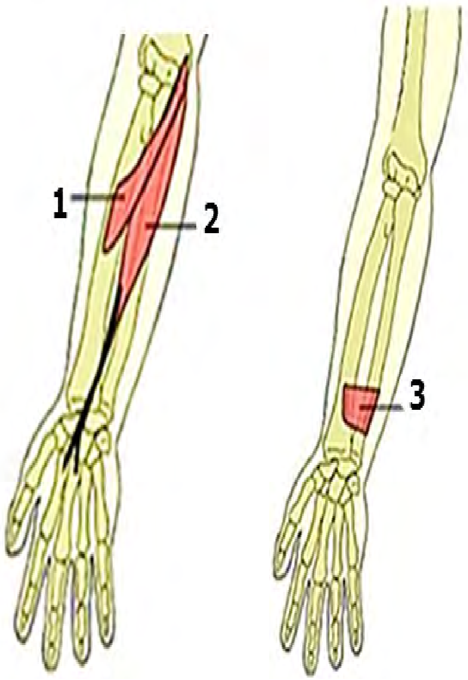
Drawing of the posterior forearm showing muscles of the superficial lateral and superficial posterior muscle groups: 1. tendon of triceps, 2. ulnar N., 3. medial epicondyle, 4. ulnar collateral A., 5. flexor and 6. extensor carpi ulnaris 7. extensor digiti minimi, 8. extensor retinaclum with tunnels, 9. branch of the superficial ulnar N., 10. tendon of extensor pollicis longus and 11. brevis, 12. radial A., 13. tendon of abductor pollicis longus, 14. and 15. tendons of extensor carpi radialis longus and brevis, 16. extensor digitorum, 17. anconeus, and 18. brachioradialis.

- PRONATORS

  - PRONATOR TERES
    - active with rapid pronation and with resisted movement
    - maintains position of radial head relative to capitellum

  - PRONATOR QUADRATUS
    - active during non resisted and resisted pronation
    - active during slow and rapid pronation
    - maintains compression of the distal radioulnar joint

  - OTHER PRONATORS
    - flexor carpi radialis
    - palmaris longus



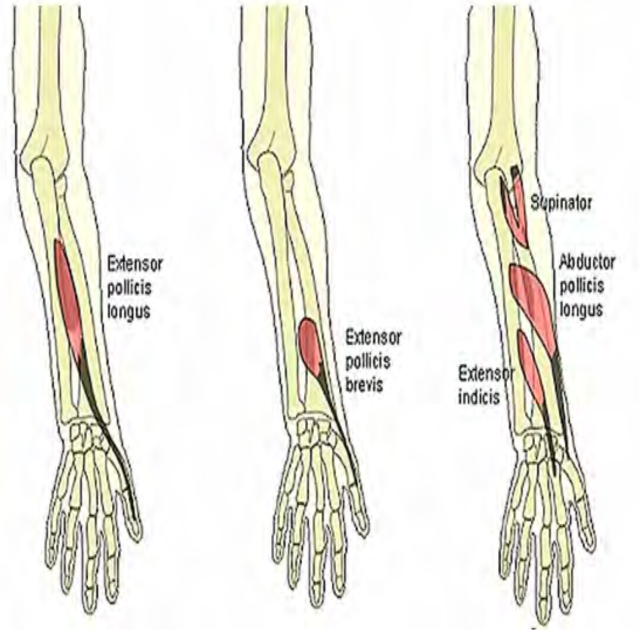
Drawing showing pronators of the forearm. 1 = pronator teres; 2 = palmaris longus; 3 = pronator quadratus

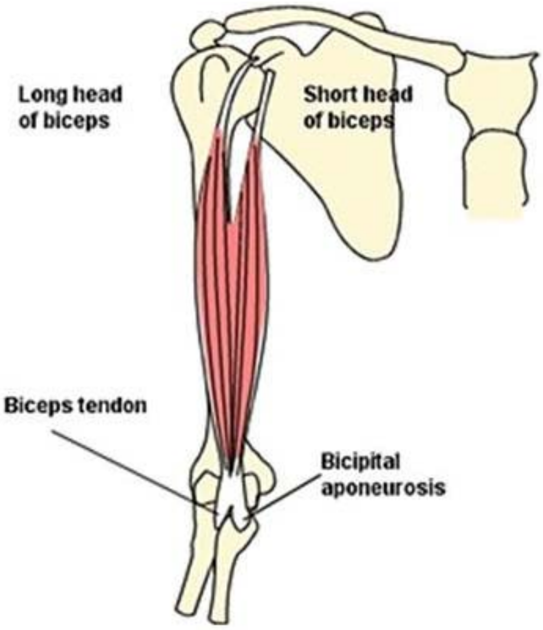
- **SUPINATORS**

  - SUPINATOR
    - active with non resisted and resisted supination
    - active during slow and rapid supination
    - maintains position of radial head relative to capitellum

- BICEPS
  - active during resisted supination
  - active during rapid supination

- OTHER SUPINATORS
  - abductor pollicis longus
  - extensor pollicis brevis
  - extensor indicis





Drawing of muscles that supinate the forearm. Notice that the lines of action of the abductor pollicis longus, extensor pollicis brevis and extensor indicis run from medial to lateral. When the forearm is pronated, this medial to lateral angulation rotates the radius laterally producing supination. When the forearm is pronated, the line of action of the biceps has a lateral pull on the radial tuberosity producing lateral rotation of the radius and supination

ACTIVITIES: 1) With your right arm supported by a desk top/table/ plinth, extend the right elbow and fully supinate the right forearm. With your left hand, palpate the biceps. Now flex and extend the elbow several times. Can you feel the biceps contract during elbow flexion? Does the biceps relax during extension? 2) Now, palpate the triceps with your left hand and flex/extend the elbow as before. Can you feel the triceps contract during elbow extension? What does the triceps do during elbow flexion? 3) Keep the right arm supported and the elbow extended and now fully pronate the forearm. With your left arm palpate the biceps, and supinate and pronate the right forearm several times. Can you feel the biceps contract during supination of the forearm? What about during pronation? 4) Keep the supported right elbow extended, and palpate the triceps. Does the triceps contract when you supinate and pronate the forearm? 5) Based on these 4 activates, what do you think are the actions of the biceps and triceps?

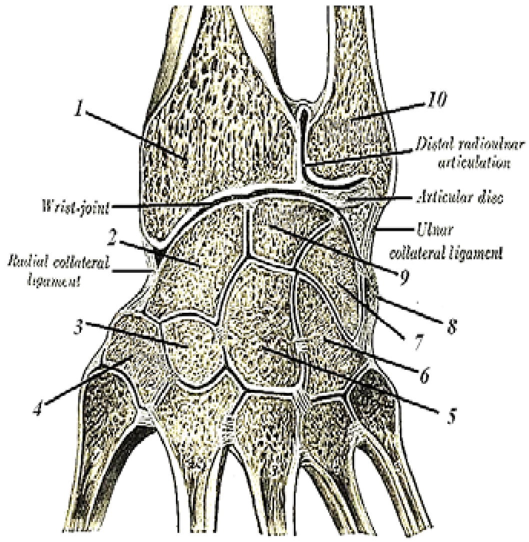
Study Questions (elbow)

1. Why is the medial collateral ligament of the elbow more developed than lateral collateral ligament and what movements do the medial collateral ligament resist.
2. What is the best way to test the medial collateral ligament and the joint capsule of the elbow joint?
3. What elbow movements are needed for most ADLs?
4. What arthrokinematic movements are common at the humeroulnar and humeroradial joints during flexion? What movements are not common?
5. What arthrokinematics movements occur at the proximal radioulnar joint during pronation of the forearm?
6. If the musculocutaneous nerve is damaged, what muscles could still flex the elbow?
7. What is the main flexor of the elbow and why?
8. What are the differences in the actions of the three heads of the triceps?
9. What is the main pronator of the forearm and why?

3.3 THE WRIST COMPLEX

3.3.1 COMPONENTS OF THE WRIST COMPLEX

- The wrist complex consists of 8 carpal bones aligned into a distal and proximal rows, distal radius and ulna, 4 joints and extrinsic and intrinsic ligaments.
- The distal row contains the trapezium, trapezoid, capitate and hamate
- The proximal rows contains the scaphoid, lunate, triquetrum, and pisiform.



Bones forming the joints of the wrist. 1. Radius, 2. Scaphoid, 3. Trapezoid, 4. Trapezium, 5. Capitate, 6. Hamate, 7. Triquetrum, 8. Pisiform, 9. Lunate, 10. Ulna. (modified from Gray 1918)

3.3.2 JOINTS OF THE WRIST COMPLEX

- **DISTAL RADIOULNAR**
  - Articulations are between the head of the ulna and the ulnar notch of the radius.
  - Movements are supination and pronation.

- **RADIOCARPAL JOINT**
  - Articulations are between the distal radius and the scaphoid and lunate bone
  - Main movements are flexion and extension (dorsiflexion).

- **ULNOCARPAL JOINT**
  - Articulations are between the head of the ulna and an interarticular disc and between the disc and the triquetrum.
  - Main movements are flexion and extension (dorsiflexion).

- **MIDCARPAL JOINT**
  - Articulation are between the proximal carpal row and the distal carpal row.
  - Movements are flexion and extension (dorsiflexion) and radial and ulnar deviation.

3.3.3 LIGAMENTS OF THE WRIST

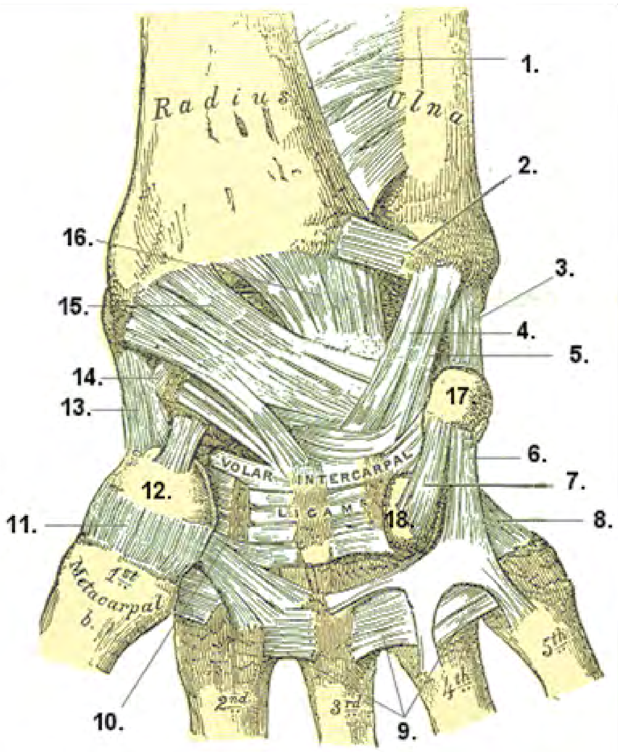
- The radiocarpal and ulnocarpal joints are enclosed by a single joint capsule containing a PALMAR and a DORSAL RADIOCARPAL LIGAMENT, a PALMAR ULNOCARPAL LIGAMENT, a RADIAL COLLATERAL LIGAMENT, and an ULNAR COLLATERAL LIGAMENT. A dorsal ulnocarpal ligament is occasional present connecting the ulna to the triquetrum.

- Stabilizing this array of carpal bones are intrinsic and extrinsic ligaments.
  - Extrinsic ligaments connect the radius or ulna to the carpal bones.
  - Intrinsic ligaments begin and end on carpal bones.

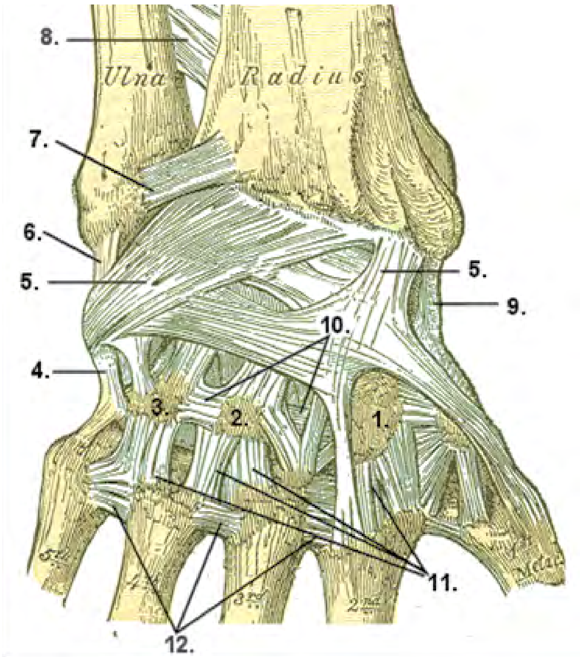
- Movements at the wrist involve patterns of extrinsic and intrinsic ligaments tightening and loosening.
  - Tightening of these ligaments can produce carpal movements as well as restrict them.
  - Loosening of these ligaments allow movements to occur in the area.

- **EXTRINSIC LIGAMENTS**
    - Palmar extrinsic ligaments are thicker and stronger than dorsal extrinsic ligaments.
    - The extrinsic ligaments resist wrist extension more than they resist flexion because the palmar extrinsic ligaments are stronger.
    - The PALMAR RADIOCARPAL LIGAMENT extends from the palmar surface of the distal radius and the styloid process of the radius to the palmar surface of the scaphoid, lunate, and capitate.
    - The DORSAL RADIOCARPAL LIGAMENT is narrower, thinner, and weaker than the palmar radiocarpal ligament. It extends from the dorsal surface of the distal medial half of the radius to the dorsal surface of the scaphoid, lunate and triquetrum.
    - The PALMAR ULNOCARPAL LIGAMENT extends from the palmar surface of the lateral head of the ulna and the lateral interarticular disc to the palmar surface of the proximal triquetrum.
    - The RADIAL COLLATERAL LIGAMENT extends from the distal aspect of the styloid of the radius to the radial (lateral) surface of the scaphoid, trapezium, and flexor retinaculum.
    - The ULNAR COLLATERAL LIGAMENT extends from the styloid process of the ulna to the ulnar (medial) surface of the triquetrum, pisiform and flexor retinaculum.
    - The PALMAR AND DORSAL RADIOULNAR LIGAMENTS cross the distal ulnocarpal joint.

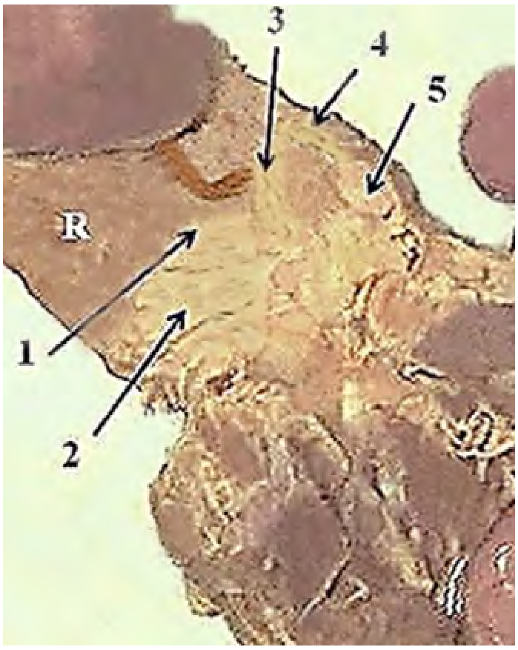
- **INTRINSIC LIGAMENTS**
    - Dorsal and palmar intrinsic ligaments are named by the carpal bones to which they attach.
    - Interosseous ligaments are between adjacent carpal bones.
    - Examples are the dorsal and palmar intercarpals, pisohamatelig., ulnolunate lig., ulnotriquetrial lig.



The picture shows the palmar ligaments of the wrist and distal radioulnar joints: 1. Interosseous membrane, 2. palmar radioulnar lig., 3. ulnar collateral lig., 4. ulnolunate lig. of ulnocarpal lig. 5. ulnotriquetrial lig. of ulnocarpal lig. 6. pisometacarpal lig. 7. pisohamate lig. 8. carpometacarpal lig. 9. palmar metacarpal ligs., 10. trapezoid, 11. capsule of 1st carpometacarpal joint., 12. trapezium, 13. radial collateral lig., 14. tubercle of scaphoid, 15. and 16. palmar radiocarpal lig. (Modified from Gray 1918)



The picture shows the dorsal ligaments of the wrist and distal radioulnar joints: 1. Trapezoid, 2. capitate, 3. hamate., 4. pisohamate lig, 5. dorsal radiocarpal lig., 6. ulnar collateral lig., 7. dorsal radioulnar lig., 8. interosseous membrane, 9. radial collateral lig., 10. dorsal intercarpal ligs., 11. carpometacarpal ligs., and 12. dorsal metacarpal ligs. (Modified from Gray 1918)



Dissection of the palmar radiocarpal ligaments (Left) and the Dorsal radiocarpal ligaments (Bottom). 1. Radiocapitate lig. of radiocarpal lig. , 2. Radiolunate lig. of radiocarpal lig., 3. Ulnocarpal lig., 4. Ulnar collateral lig. 5. Pisiform, 6. Radius, 7. Ulna, 8. Dorsal radiocarpal lig. 9. Metacarpophalengeal joints, DI = Dorsal inteosseus, R = Radius.

3.3.4 MOVEMENTS

- **OSTEOKINEMATIC MOVEMENT AT WRIST**

  - Osteokinematic range of motion values will vary depending on the source (Norkin, White, Malone 2009; Reese and Bardy, 2013).
  - The degrees listed for each movement are commonly used.
    - palmar flexion (flexion) = 0–85/90 degrees
    - dorsiflexion (extension) = 0–75/80 degrees
    - radial deviation = 0–15/20 degrees
    - ulnar deviation = 0–35/37 degrees
    - pronation = 0–80/90 degrees
    - supination = 0–80/90 degrees
  - Most ADLs can be done with 10 degrees of palmar flexion and 35 degrees of dorsiflexion.
  - Wrist immobilization
    - 10–20 degrees of dorsiflexion (extension) is best for ADL function.
    - Greater than 20 degrees of palmar flexion results in a marked decrease in hand function.

- **ARTHROKINEMATIC MOVEMENT AT THE WRIST**

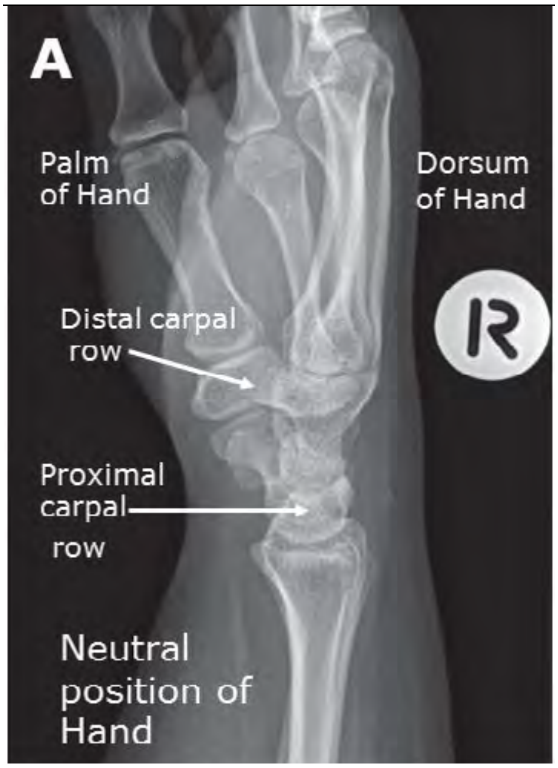
  - PALMAR FLEXION
    - 60% of the movement occurs at the midcarpal joint
    - 40% of the movement occurs at the radiocarpal joint

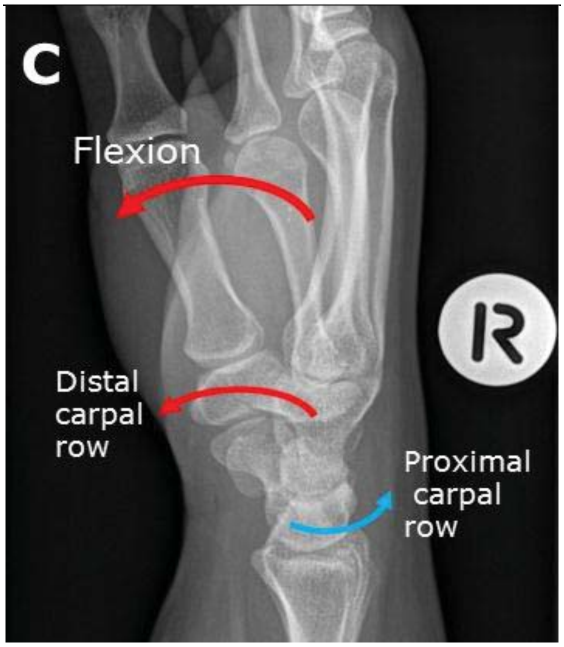
- DORSIFLEXION (EXTENSION)
  - 60–70% of the movement occurs at the radiocarpal joint
  - 30–40% of the movement occurs at the midcarpal joint

- Dysfunction at the wrist in palmar flexion and dorsiflexion (extension) secondary to a wrist fracture depends on the location of the fracture and which carpal bones and joints are involved.
  - fractures involving the radiocarpal joint
    - + Palmar flexion may be good because 60% of this movement occurs at midcarpal and only 40% at the radiocarpal joint.
    - + Dorsiflexion (extension) may be poor because 60–70% of this movement occurs at the radiocarpal joint and only 30–40% at the midcarpal joint.
  - fractures involving the midcarpal joint
    - + Palmar flexion may be poor because 60% of this movement occurs at midcarpal and only 40% at the radiocarpal joint.
    - + Dorsiflexion (extension) may be good because 60–70% of this movement occurs at the radiocarpal joint and only 30–40% at the midcarpal joint.

- SEQUENTIAL MOVEMENTS DURING WRIST EXTENSION FROM NEUTRAL
  - The distal carpal row moves dorsally and the proximal row moves palmarly until about 60 degrees of extension.
  - At about 60 degrees of extension, the hamate, capitate, trapezoid and scaphoid lie in a close pack position and form a rigid mass; the position of these four carpal bones also produces radial deviation which occurs with the wrist in this extended position.
  - This ridge mass moves dorsally as a unit on the triquetrum and lunate.
  - The triquetrum and lunate move palmarly on the radius at the radiocarpal joint as the ridge mass moves dorsally until full extension is reached.
  - At full extension, the wrist is in a close packed position with the exception of the pisiform and trapezium.
  - During extension, the pisiform moves distally (inferiorly) and the radius moves proximally (superiorly) on the ulna.

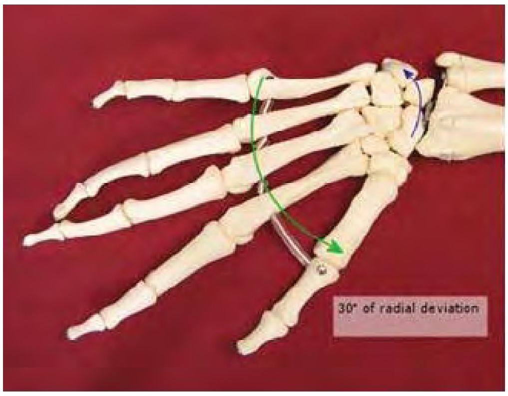
- SEQUENTIAL MOVEMENTS DURING WRIST FLEXION FROM NEUTRAL
  - The distal carpal row moves palmarly and the proximal row moves dorsally.
  - The scaphoid does not come to a close packed position with the distal row during flexion but both rows move until about 60 degrees of flexion.
  - During about the last 30 degrees of wrist flexion, movement occurs mainly at the midcarpal joint with the distal row moving palmarly.
  - During wrist flexion, there is a considerable distal shift of the radius on the ulna.





Lateral radiographs of the wrist and hand showing the distal and proximal carpal rows. (A) Neutral position of the hand and wrist. B) Extension of the wrist and hand. As the hand moves dorsally in extension, the distal carpal row moves dorsally in the same direction of the metacarpals (red arrows) but the proximal carpal row moves palmarly (blue arrow). C) As the hand moves palmarly in flexion, the distal carpal row moves palmarly in the same direction of the metacarpals (red arrows) but the proximal carpal row moves dorsally (blue arrow).

- SEQUENTIAL MOVEMENTS DURING RADIAL DEVIATION
  - Movements are mainly at mid-carpal joint with little movement at radiocarpal joint.
  - The distal carpal row moves radially.
  - Most references agree that the proximal row moves ulnarly but some say there is no or very little ulnar movement of the proximal row during radial deviation.
  - Scaphoid and lunate move palmarly (as in flexion) to make room for the trapezium which moves between radial styloid process and scaphoid.
  - Radial deviation is limited when the wrist is fully flexed.
    - Wrist flexion moves the scaphoid and lunate dorsally which blocks palmar movement of these carpals.
    - This blockage prevents a space from opening between the styloid process of the radius and scaphoid, blocking the movement of the trapezium and limiting radial deviation.
  - Radial deviation is limited when the wrist is fully extended.
    - Close pack position of the carpals at full wrist extension decreases intercarpal movement at the midcarpal joint.
    - Decreased midcarpal movement blocks radial movement of the distal carpal row which decreases deviation.

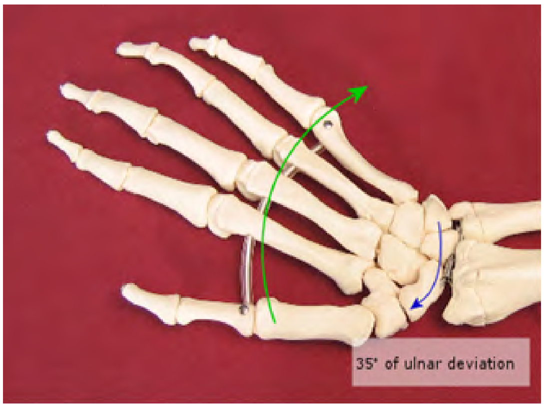


(LEFT) Skelton of the hand showing the distal and proximal carpal rows in neutral position. (RIGHT) The hand is positioned in 30 degrees of radial deviation (green arrow). The distal row of carpal bones moves radially with the metacarpals but the proximal row moves ulnarly (blue arrow).

- SEQUENTIAL MOVEMENTS DURING ULNAR DEVIATION
  - Distal carpal row moves ulnarly and the hamate is pulled proximally
  - Most references agree that the proximal row moves radially but some say there is no or very little radial movement of the proximal row during ulnar deviation.
  - Scaphoid and lunate move dorsally (extend).
  - Ulnar deviation is extensive when the wrist is fully flexed.
    - + During wrist flexion the scaphoid and lunate move dorsally so they are already in a dorsal position for ulnar deviation.
    - + During wrist flexion, the midcarpal joint is not blocked as during wrist extension and so the distal row can move ulnarly to produce ulnar deviation.
  - Ulnar deviation is limited when the wrist is fully extended.
    - + the close pack position of the carpals at full wrist extension blocks intercarpal movement at the midcarpal joint.
    - + the blockage of midcarpal movement, blocks the distal carpal row from moving ulnarly for ulnar deviation.

- FULL PRONATION TO FULL SUPINATION
  - The distal radius rotates laterally over the head of the ulna.
  - Ulnar head glides palmarly as it moves from a dorsal position at full pronation to a palmar position at full supination.

- FULL SUPINATION TO FULL PRONATION
  - The distal radius rotates medially over the head of the ulna.
  - Ulnar head glides dorsally as it moves from a palmar position at full supination to a dorsal position at full pronation.



(LEFT) Skelton of the hand showing the distal and proximal carpal rows in neutral position. (RIGHT) The hand is positioned in 35 degrees of ulnar deviation (green arrow). The distal row of carpal bones moves ulnarly with the metacarpals but the proximal row moves radially (blue arrow).

- **LOADING OF WRIST**
  - The wrist is designed to withstand compression forces.
  - Compression is transmitted mainly through the lunate and scaphoid to the radius and less so through fibrocartilage disc to ulna.
    - About 80% of the compression forces at the wrist are transmitted to the large distal radius.
    - About 20% of the compression forces by disc to the ulna.

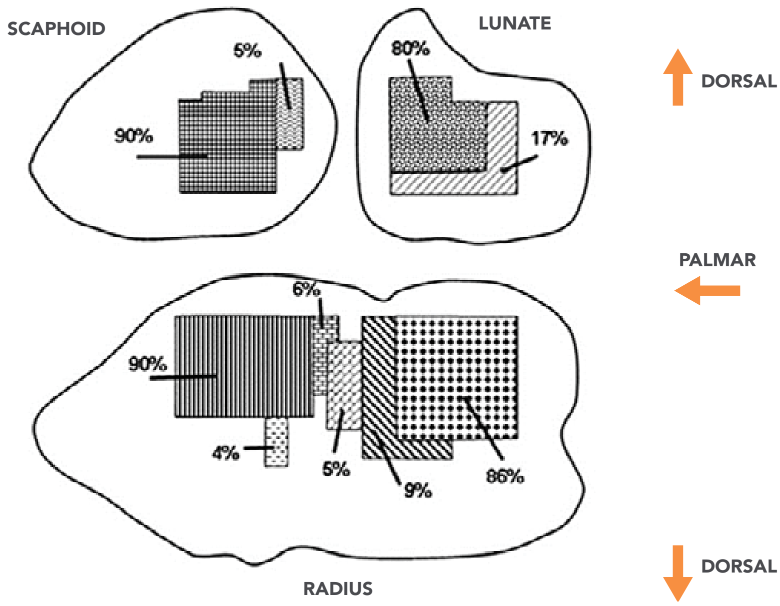


Diagram summarizing the locations of wear on the radius by the scaphoid and lunate, as well as the scaphoid, and lunate. The percentages indicate the percentage of times wear occurred at these locations on the articular surfaces. (Gorniak et al, 2012)

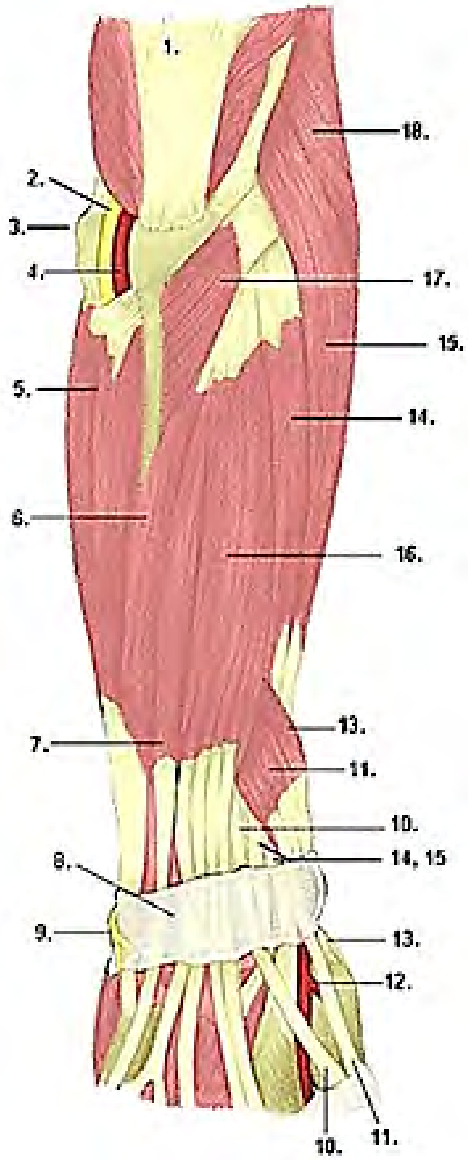
- In a fall where a person breaks the fall by extending their arm, wrist and hand, force is transmitted as follows:
  - The ground force is transmitted via third metacarpalto capitate.
  - From the capitate, force is transmited to the lunateand scaphoid.
  - From the lunate and scaphoid force is transmitted to the radius.
  - If the forces are high, the distal radius or scaphoid may fracture or the lunate dislocate.

ACTIVITIES: With your right palm down find your ulnar styloid process with your left index finger. Slide your index finger slightly distal to the styloid process and move your wrist several times in extension and flexion. Feel for the movement at the ulnocarpal joint. Now locate the radial styloid process on the dorsum of the wrist and place your left index finger flat on the wrist so that the index finger runs between the ulna and radial styloid processes. Move your wrist several times in flexion and extension. Can you feel the line of bones moving under your index finger? You have located the proximal carpal row. Now put your left middle finger flat on the wrist and distal and right up against your index finger. Your two fingers should be flat on the wrist and lie side-by-side. Again move the wrist in extension and flexion several times. Can you feel the bones moving under your middle finger? Your middle is on the distal carpal rows. 1) Move your wrist in flexion and extension. What are the movements of the distal carpal row during extension and during flexion? How does the movement of the distal carpal row compare with movement of the metacarpal bones of the hand? 2) What are the movements of the proximal carpal row during wrist flexion and extension? How do these compare with movements of the distal carpal row? 3) Keeping your left middle and index in the same position and your wrist and hand in a neutral flexion/extension position, radially and ulnarly deviate the hand several times. Which direction does the distal carpal row move with radial deviation and then with ulnar deviation? What directions are the metacarpals moving compared to the distal carpal row? 4) With your left index and middle fingers still in place, radially and ulnarly deviate the wrist and hand. What are the movements of the proximal carpal row during radial and ulnar deviation? How do the movements of the proximal row compare with those of the distal carpal row?

3.3.5 MUSCLES OF THE WRIST

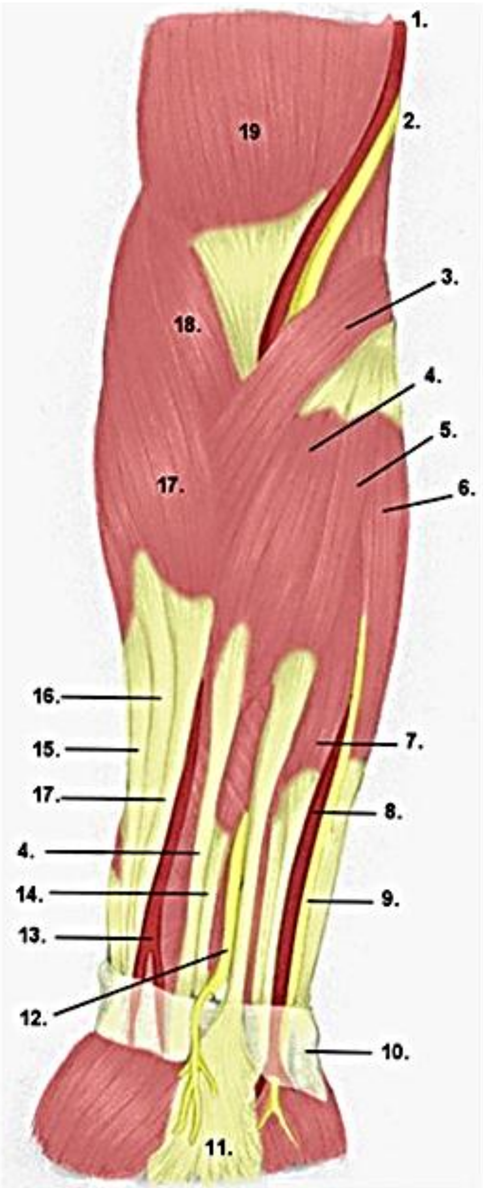
- **MUSCLES MOVING WRIST**
  - Muscles crossing the wrist joint generate movements of the hand at the wrist and provide DYNAMIC STABILITY of the wrist joint during ADLs.

  - EXTENSORS (ext.) OF THE WRIST
    - ext. carpi radialis longus
    - ext. carpi radialis brevis
    - ext. carpi ulnaris
    - other muscles that may assist in wrist extension
      - + ext. digitorum
      - + ext. indicis
      - + ext. digiti minimi
    - Extensor carpi ulnaris, extensor carpi longus and brevis lie at periphery of wrist and away from the axis of motion so that they have a longer force arm and thus a mechanical advantage over the other muscles that can assist in wrist extension.



WRIST EXTENSORS: Drawing of the dorsal forearm showing muscles of the superficial lateral and superficial posterior muscle groups: 1. Tendon of triceps, 2. ulnar N., 3. medial epicondyle, 4. ulnar collateral A., 5. flexor and 6. extensor carpi ulnaris 7. extensor digiti minimi, 8. extensor retinaculum with tunnels, 9. branch of the superficial ulnar N., 10. tendon of extensor pollicis longus and 11. brevis, 12. radial A., 13. tendon of abductor pollicis longus, 14. and 15. tendons of extensor carpi radialis longest brevis, 16. extensor digitorum, 17. anconeus, and 18. brachioradialis

- FLEXORS OF THE WRIST
  - flexor carpi radialis
  - flexor carpi ulnaris
  - other muscles that may assist in wrist flexion
    - + Flexor digitorum superficialis (The flexor digitorum profundus is so close to axis of movement that its position is mechanically too poor to produce wrist flexion.)
    - + palmaris longus
  - Flexor carpi ulnaris and flexor carpi radialis lie at periphery of wrist and away from the axis of motion, so that they have a longer force arm and thus a mechanical advantage over those muscles that can assist in wrist flexion.



WRIST FLEXORS: Drawing of the ventral forearm showing the superficial muscles: 1. Brachial artery, 2. median N., 3. pronator teres, 4. flexor carpi radialis, 5. palmaris longus, 6. flexor carpi ulnaris, 7. flexor digit. superficialis, 8. ulnar artery, 9. ulnar N, 10. flexor retinaculum, 11. palmar aponeurosis, 12. median N., 13. radial artery, 14. flexor pollicis longus, 15. extensor carpi radialis brevis and 16. longus, 17. brachioradialis, 18. brachialis, and 19. biceps.

- ULNAR DEVIATION MUSCLES
  - extensor carpi ulnaris with the wrist in neutral and in extension
  - flexor carpi ulnaris with the wrist in neutral and in flexion

- RADIAL DEVIATION MUSCLES
  - extensor carpi radialis longus with the wrist in neutral and in extension
  - Extensor carpi radialis brevis produces only slight radial deviation with the wrist in neutral and in extension because its distal attachment is so centrally located that the muscle can move the wrist only slightly in a radial direction.
  - flexor carpi radialis with the wrist in neutral and in flexion

- other muscles that may assist in radial deviation
  - + abductor pollicis longus
  - + extensor pollicis brevis

- **DYNAMIC STABILITY OF THE WRIST**
  - o At times, various functions of the fingers and hand require that the radial and ulnar sides of the wrist be stable when the wrist is in a neutral position, extended or flexed.
  - o When the wrist is in neutral, the radial and ulnar wrist extensors and flexors provide the stability.
  - o When the wrist extends, the tendons of the radial and ulnar wrist flexors shift position relative to the wrist axis of motion and stabilize the wrist.
  - o When the wrist flexes, the tendons of the radial and ulnar wrist extensors shift position relative to the wrist axis of motion and stabilize the wrist.
    - Extensor carpi ulnaris will stabilize the ulnar side of the wrist with the wrist in neutral or in flexion.
    - Flexor carpi ulnaris will stabilize the ulnar side of thewrist with the wrist in neutral or in extension.
    - Extensor carpi radialis longus will stabilize the radialside of the wrist with the wrist in neutral and flexion.
    - Flexor carpi radialis will stabilize the radial side of the wrist with the wrist in neutral or in extension.
    - Abductor pollicis longus will stabilize the radial side ofthe wrist with the wrist inflexion.
    - Extensor pollicis brevis will stabilize the radial side of the wrist with the wrist in flexion.

- **WRIST POSITION AND HAND FUNCTION**
  - o WRIST EXTENSION
    - This position stretches the finger flexors to take up the elastic component of the muscles and increases force production.
    - Wrist extension slackens the finger extensors which decreases extension force.
    - Extension tightens the finger flexors and loosens the finger extensors making it difficult to fully extend the fingers.

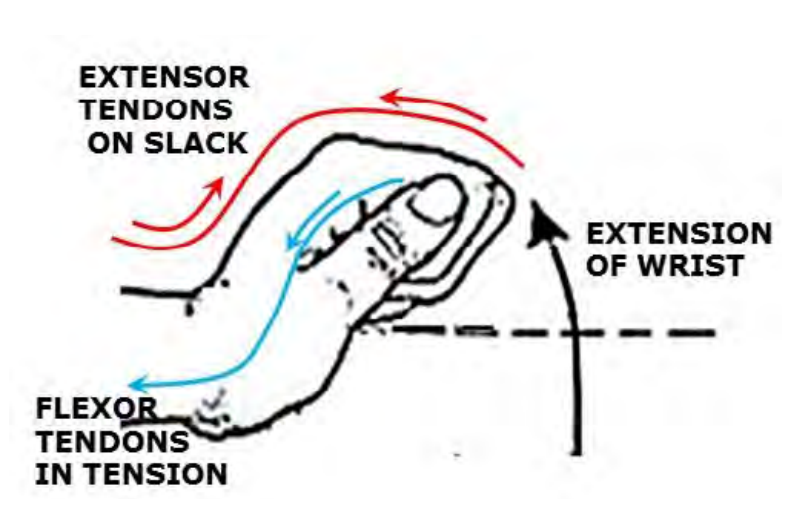


Diagram showing the wrist in extension placing the fingers extensor tendons on slack (red arrows) and the flexor finger tendons on stretch (blue arrows). This combination of extensor tendon slack and flexor tendon tension makes full finger extension difficult.

- WRIST FLEXION
  - Wrist flexion stretches the finger extensors to take up the elastic component of the muscle increasing force production.
  - Flexion slackens the finger flexors decreasing flexion force.
  - Wrist flexion tightens the finger extensors and loosens the finger flexors making it difficult to fully flex the fingers.

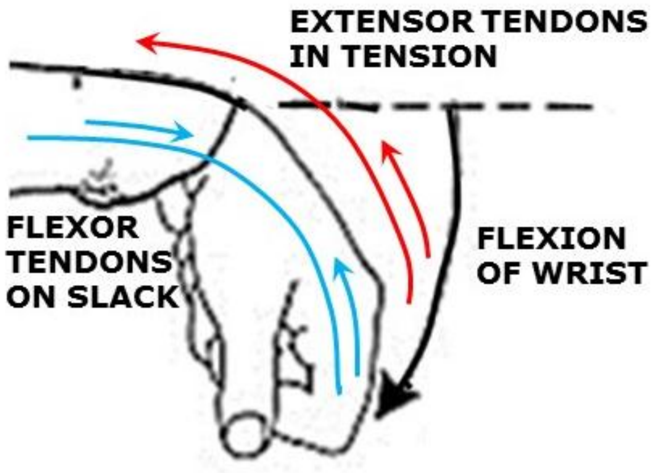


Diagram showing the wrist in flexion placing the fingers extensor tendons on stretch (red arrows) and the flexor finger tendons on slack (blue arrows). This combination of extensor tendon tension and flexor tendon slack makes full finger flexion difficult.

- GRIP STRENGTH
  - greatest with wrist in about 20 degrees of extension
  - When grip strength is the greatest, the wrist is extended and in ulnar deviation to position radiocarpal joint so that the contact area between the scaphoid and lunate and the radius is greatest.
  - least with wrist about 40 degrees of flexion

Photograph of a power fist. Notice the slight extension of the wrist.

- THUMB POSITION RELATIVE TO WRIST POSITION
  - With the wrist flexed and hand relaxed, the tip of the thumb reaches the level of the DIP of index finger which makes it easier to pick up objects between the tip of the thumb and the tip of the index finger.
  - With the wrist extended and hand relaxed, the tip of the thumb lies short of the PIP joint of the index finger which make it difficult to pick up objects between the tip of the thumb and tip of the index finger.

ACTIVITIES: Place you right forearm in full supination with your elbow flexed about 45 degrees. 1) Place your left hand over the medial and proximal aspect of your right forearm. Move your wrist in flexion and extension. Can you feel the muscles contract during flexion and relax with extension? Now move your hand in radial and ulnar deviation. Can you feel the contraction? This is the flexor carpi ulnaris producing wrist flexion and ulnar deviation. Now move your left hand to the middle of the proximal forearm and flex and extend the wrist. The muscles you feel flexing the wrist are the flexor digitorum superficialis and profundus. Because these muscles cross the wrist, these muscles flex the wrist and the fingers. 2) Place your left hand on the proximal lateral forearm and flex and extend the wrist. Can you feel the wrist extensors contract during extension? Now move your wrist in radial and ulnar deviation. Do these wrist extensors also contract during radial deviation? What about ulnar deviation? 3) Fully flex your wrist and try to make a tight fist. Was it difficult or easy? With the wrist still in full flexion, extend the fingers. Was it easy to full extend the fingers? With the wrist fully flexed, the finger flexors are on slack and it is difficult to form a closed fist. This slack of the finger flexors decreases any resistance to the finger extension produced by the stretch finger extensors. 4) Fully extend your wrist and try to make a tight fist. Was it difficult or easy? With the wrist still in full extended, extend the fingers. Was it easy or difficult to fully extend the fingers? With the wrist fully extended, the finger flexors are on stretch and it is easy to form a fully closed fist. This stretch of the finger flexors increases the resistance to finger extension making it difficult for the slack finger extensors to fully extend the fingers.

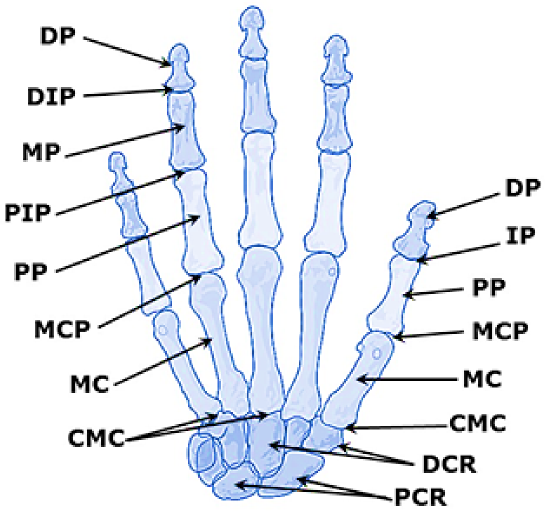
Study Questions (wrist)

1. What are the roles of the intrinsic and extrinsic ligaments of the wrist?
2. What wrist movements are needed for most ADLs?
3. What is the movement sequence during wrist extension (dorsiflexion) and where does most of the movement take place.
4. How does the movement sequence during wrist flexion (palmar flexion) differfrom that of dorsiflexion?
5. What is the movement sequence during wrist ulnar deviation?
6. How does radial deviation differ for ulnar deviation?
7. Why are radial and ulnar deviations limited when the wrist is in full extension?
8. How might fractures or dislocations at the wrist affect movement?
9. What muscles produce the following movements:
   a. wrist extension
   b. wrist flexion and ulnar deviation
   c. wrist flexion
   d. wrist extension and radial deviation
10. Which muscles stabilize the following:
   a. ulnar side of the wrist when the wrist is in a neutral position
   a. radial side of the wrist when the wrist is in a neutral position
   b. ulnar side of the wrist when the wrist is in extension

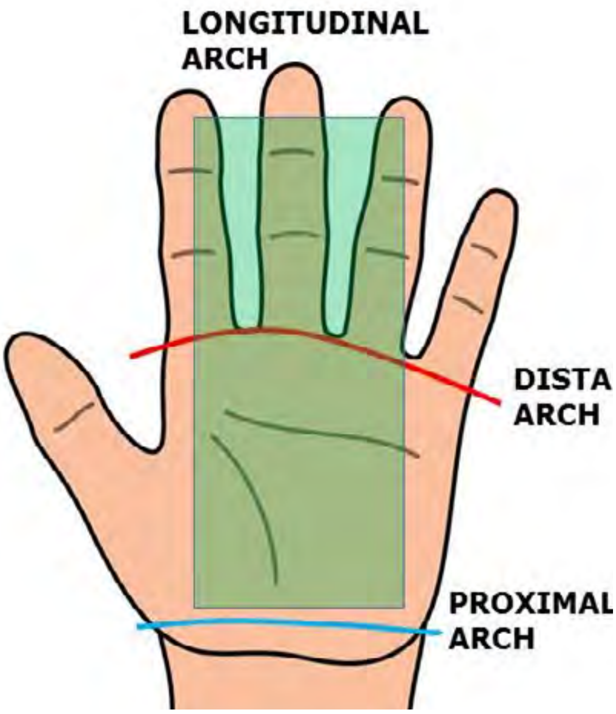
3.4 THE HAND

3.4.1 COMPONENTS OF THE HAND

- Each finger consists of a metacarpal, and proximal, middle and distal phalanges.
- The thumb differs in that it has a metacarpal, and only proximal and distal phalanges.
- Each metacarpal articulates with a distal carpal at the carpometacarpal joint and with the proximal phalanx at the metacarpophalangeal joint.
- Each finger has a proximal interphalangeal joint (PIP) between the proximal and middle phalanges and a distal interphalangeal joint (DIP) between the middle and the distal phalanges.
- The thumb only has an interphalangeal joint (IP) between the proximal and distal phalanges.
- Stabilizing the joints of the fingers are collateral ligaments and an extensor assembly (mechanism).

	**Drawing showing the bones and joints of the hand. CMC – Carpometacarpal joint, DCR – Distal carpal row, DIP – Distal interphalangeal joint, DP – Distal phalanx, IP – Interphalangeal joint, MC – metacarpal, MCP – metacarpophalangeal joint, MP – Middle phalanx, PCR – Proximal carpal row, PIP – Proximal interphalangeal joint, PP – Proximal phalanx.**

- **ARCHES OF THE HAND**
  - The proximal transverse arch is at level of the distal carpal row and carpometacarpal joints.
  - The distal transverse arch is through the heads of the metacarpals at the metacarpophalangeal joints.



Drawing of the palm of the hand showing the Proximal, Distal and Longitudinal arches.

- The longitudinal arch extends through the center of the hand from the proximal carpal row through the four fingers.
- Arches are maintained by the intrinsic muscles of the hand.
- A flat hand results from a collapse of these arches because of paralysis of the intrinsic hand muscles.

3.4.2 JOINTS OF THE HAND

- **CARPOMETACARPAL JOINT (CMC)**
  - The metacarpals of the little and ring fingers articulate with the hamate bone, the middle finger articulates with the capitate, the index finger with the trapezoid and the metacarpal of the thumb with the trapezium.

- **METACARPOPHALANGEAL JOINT (MCP)**
  - The head of the metacarpal bone articulates with the base of the proximal phalanx.

- **PROXIMAL INTERPHALANGEAL JOINT (PIP)**
  - The head of the proximal phalanx articulates with the baseof the middle phalanx.

- **DISTAL INTERPHALANGEAL JOINT (DIP)**
  - The head of the middle phalanx articulates with the baseof the distal phalanx.

- **INTERPHALANGEAL JOINT (IP)**
  - The head of the proximal phalanx of the thumb articulates with the base of the distal phalanx.

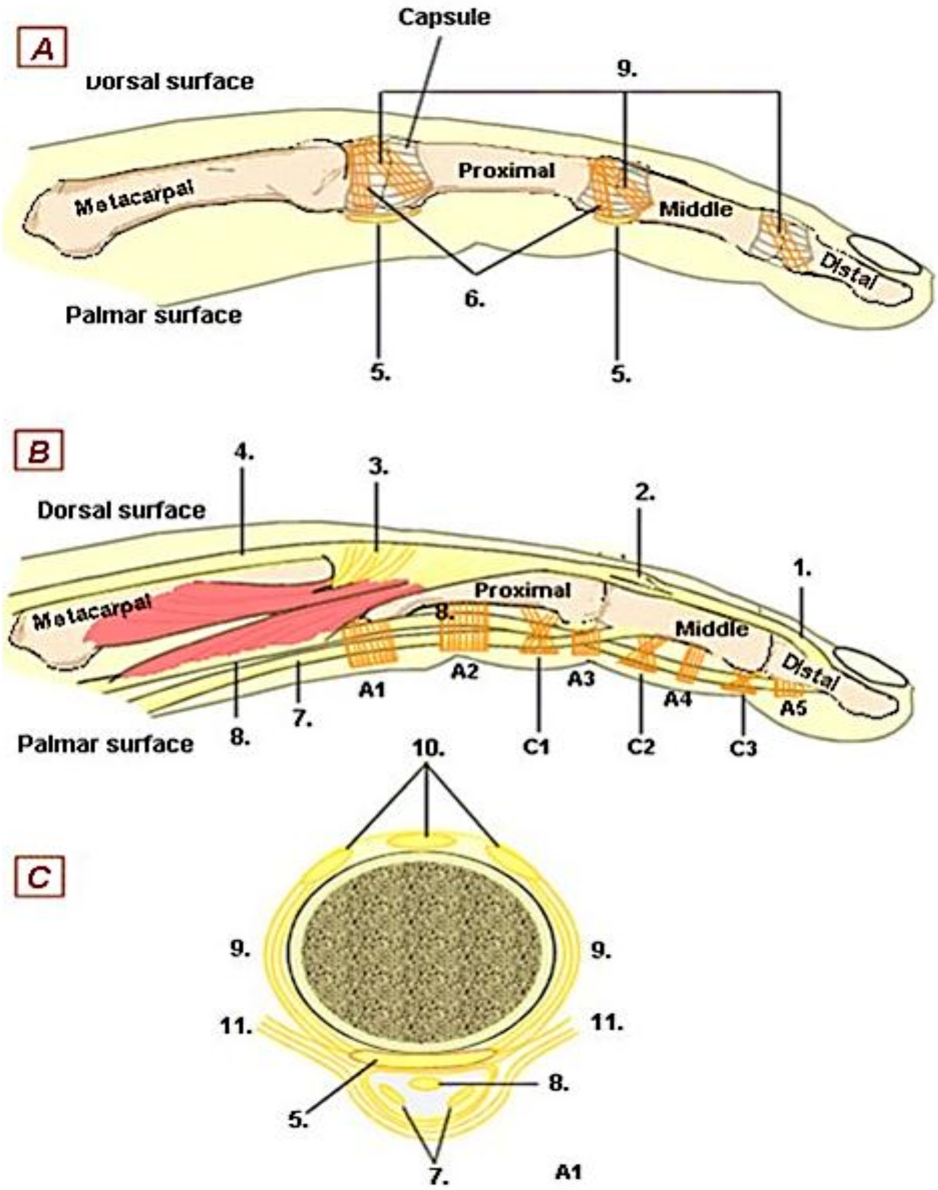
3.4.3 LIGAMENTS, FLEXOR TENDON SHEATH, EXTENSOR ASSEMBLY OF THE HAND

- COLLATERAL LIGAMENTS

  - MCP, PIP, DIP of fingers have a joint capsule and medial (ulnar) and lateral (radial) collateral ligaments.
    - dorsal part of the collateral ligaments resist flexion
    - palmar part of the collateral ligaments resist extension
    - Collateral ligaments also resist distal distraction, dorsal and palmar dislocation, adduction, abduction and rotation about the long axis of the phalanges.

- PALMAR PLATE

  - This fibrocartilage plate is on the palmar surface of the MCP, PIP and DIP.
  - It is suspended dorsally by the collateral ligaments.
  - At the MCP, the palmar plate is connected to the transverse intermetacarpal ligament which interconnects and stabilizes the metacarpal heads so that the proximal phalanx can move at the MCP joint on a secured base.
  - There are two proximal and two distal check reign ligaments that attach the sides of the palmar plate to bone which helps to hold the palmar plate in place.
  - The sides of palmar plate also attach to the flexor tendon sheath which lies palmarly.
  - The palmar plate (top) and flexor sheath (bottom and sides) form a tunnel for the flexor tendons of the fingers.

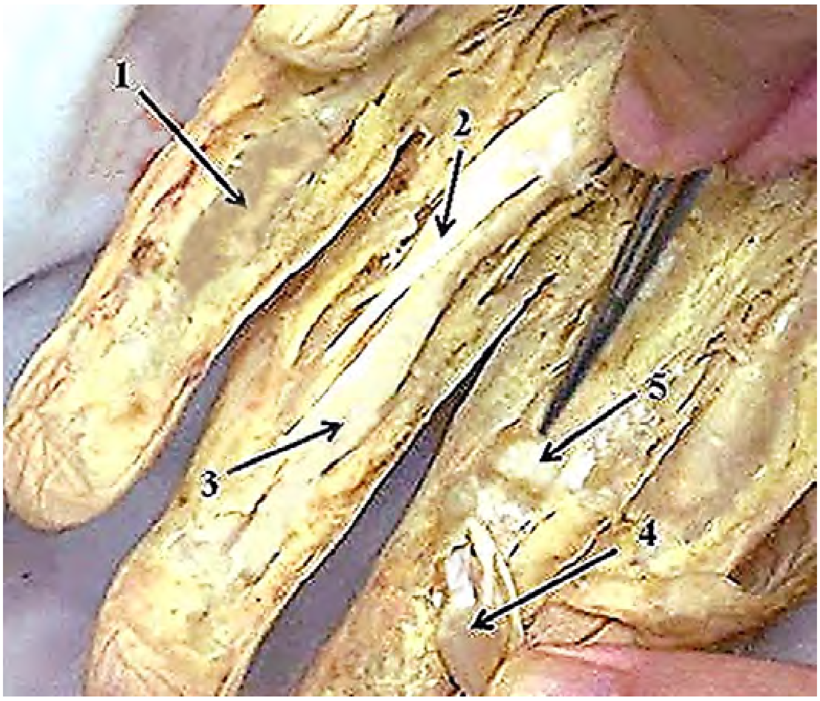


Ligaments of the Finger: 1. Terminal tendon of ext. digitorum, 2. central slip of tendon, 3. extensor hood, 4. tendon of ext. digitorum, 5. palmar plates, 6. accessory collateral ligaments, 7. tendon of flex. digitorum superficialis and 8. profundus, 9. collateral ligaments, 10 extensor assembly, and 11. transverse intermetacarpal ligaments.

- FLEXOR TENDON SHEATH

  - The flexor sheet has 5 annular (A) pulleys and 3 cruciform (X) pulleys.
    - When these pulleys are removed in a sequential pattern and the space between the finger tips and the palm measured during flexion, the A2 and A4 pulleys seem to be the most important for full flexion of the fingers.
    - The A2 is more important for finger flexion than the A4 (Nordin and Frankel 2001, 2012).

- The sheath forms a tunnel containing the tendons of the flexor digitorum superficialis and profundus and the synovial sheet covering them.
- The tunnel keeps tendons close to the axis of motion as they slide proximally during flexion and distally during extension.
- Maintaining the proper position of these flexor tendons relative to the axis of motion results in the smooth distal to proximal flexion pattern of the fingers during flexion.
- The flexor sheath prevents bow stringing of tendons always from the axis of motion which increases the mechanical advantage of the tendon and produces premature joint flexion and an irregular pattern of finger flexion.
- Maintaining the proper position of these flexor tendons relative to the axis of motion also minimizes the amount a tendon needs to slide to produce joint flexion.



Dissection of the palmar plate. 1. Flexor sheath, 2. Flexor digitorum superficialis tendon,
3. Flexor digitorum profundus tendon, 4. Flexor tendons reflected distally, 5. Palmar plate.

TABLE SHOWING THE AMOUNTS OF FLEXOR DIGITORUM PROFUNDUS (FDP) AND SUPERFICIALIS (FDS) TENDON MOVEMENT to flex the finger joint and amounts of extensor tendon (ET) movement to extend finger joints (Nordin and Frankel 2001, 2012)

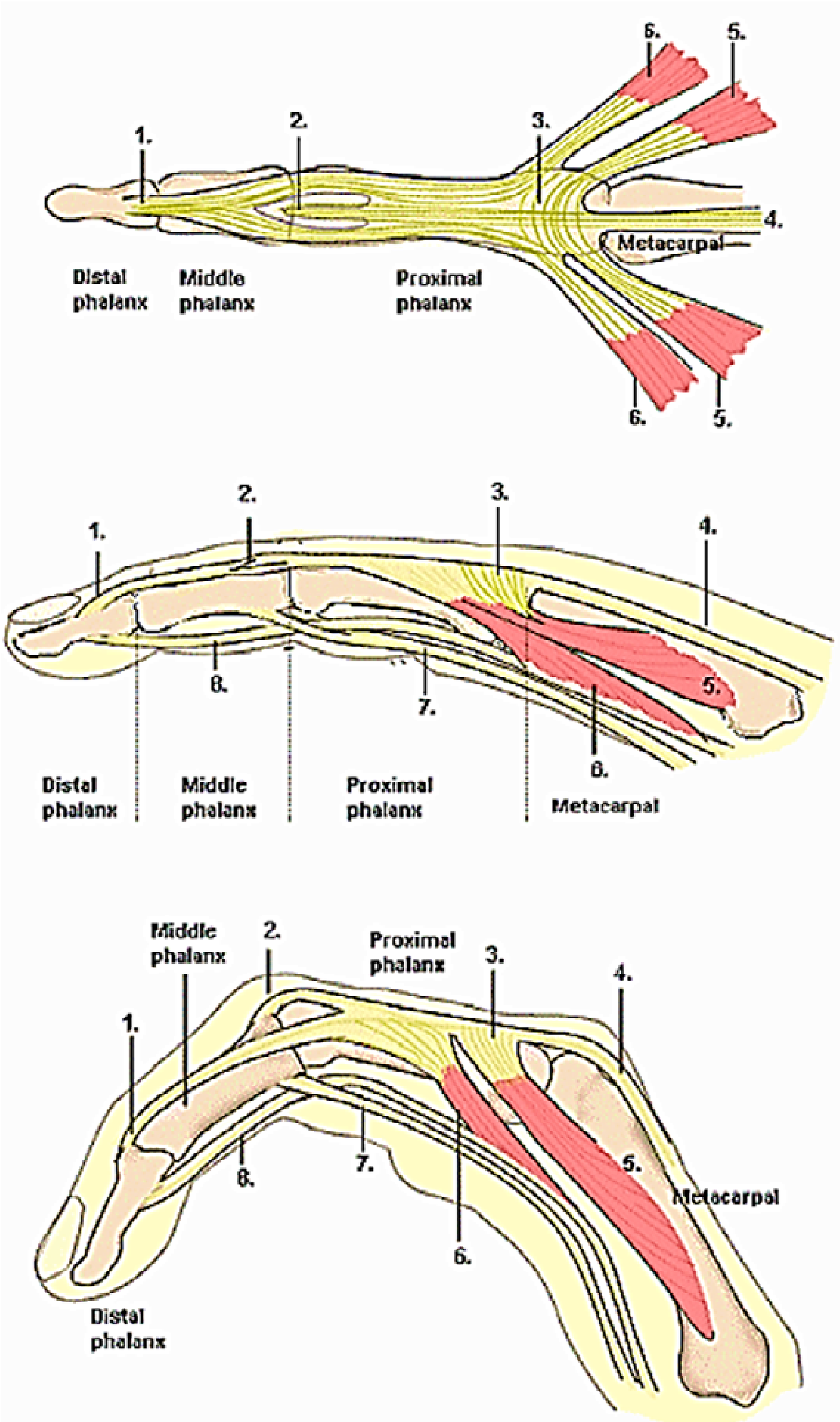
JOINT	FDP	FDS	ET
DIP	5mm		
PIP	17 mm	16 mm	3 mm
MCP	23 mm	26 mm	16 mm
CMP	38 mm	46 mm	44 mm

- Notice that the amounts of tendon movement are less at the more distal joints than at the more proximal joints.
- Because the amount a tendon moves is related directly to the amount the muscle shortens, when a weak muscle contract it may shorten only a short distance and this action will tend to produce movement at the more distal joints (DIP, PIP) rather than the more proximal joints (MCP, CMC).

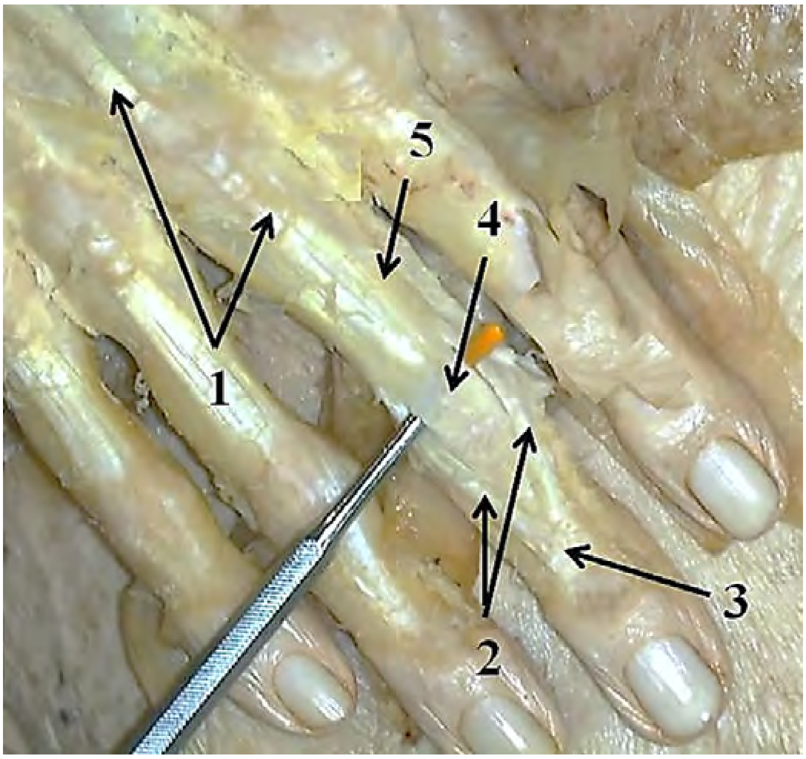
- Based on these amounts of tendon movement, the position of the wrist is important.
  - With the wrist in flexion, the finger flexor tendons are on slack and so a weak flexor muscle producing little tendon movement may take up some of the slack but produce no joint movement.
  - With the wrist in extension, the finger flexor tendons are stretched and so a weak flexor muscle producing little tendon movement may produce some joint movement.
- If surgery fails to repair the flexor sheath, finger flexion would likely require greater tendon excursion and greater muscle shortening to flex the fingers.

- EXTENSOR ASSEMBLY (MECHANISM)

  - This assembly is on the dorsal or extensor surface of the fingers, and is a tendinous continuation of the extensor digitorum muscle tendon.
  - The assembly consists of the extensor expansion or hood on which interossei and lumbrical muscles attach.
  - Distal to the expansion are a central slip, two lateral bands and a terminal tendon.
    - After the extensor digitorum tendon crosses the metacarpophalangeal joint, it expands to form the extensor expansion.
    - The extensor expansion divides into a central slip and 2 lateral slips which join distally to form the terminal tendon.
    - The central slip crosses the PIP to attach middle phalanx and acts to extend the PIP.
    - The 2 lateral bands also cross the PIP but the join as the terminal tendon which crosses the DIP and act to extend the DIP.



Dorsal view (top) and lateral views (middle, bottom) of the of the extensor assembly. Notice the change in position of the components of the extensor assembly and the flexor tendons when the finger is flexed (bottom). 1. terminal tendon, 2. central slip, 3. extensor expansion, 4. tendon of ext. digitorum, 5. interosseous muscle, 6. lumbrical, 7. tendon of flex. digitorum superficialis and 8. profundus.



Dissection of extensor assembly. 1. Extensor digitorum tendon, 2. Lateral bands, 3. Terminal tendon, 4. Central slip, 5. Extensor expansion or hood

- The extensor assembly extends the MCP, PIP and DIP by action of extensor digitorum, interossei and lumbricals.
- Extensor assembly must be tight for the interossei and lumbricals to extend the PIP and DIP joints.
- If the interossei and lumbricals are weak or paralyzed because of nerve injury, full extension of the PIP and DIP is problematic.
- Active extension of the PIP will normally be accompanied by extension of the DIP.
  - The central slip tightens to extend the PIP because of the movement of the extensor expansion proximally.
  - Tightening of the central slip and movement of the expansion also tightens the lateral bands which tighten the terminal tendon producing extension of the DIP.
- Active or passive full flexion of the PIP will prevent the DIP from extending or what is termed "the release of the distal phalanx".
  - With full PIP flexion, the central slip tightens and pulls extensor expansion distally.
  - This distal movement of the expansion causes the lateral bands and terminal tendon to become slack.
  - The slack terminal tendon prevents active extension of the DIP.
- Active and passive flexion of the DIP will normally be accompanied by flexion of the PIP.
  - Flexion of the DIP tightens the terminal tendon and lateral bands and pulls the extensor expansion distally.
  - Distal movement of the expansion relaxes (slacks) the central slip.
  - The relaxed central slip decreases the dorsal restraints on the PIP which allows the passive components of the flexor digitorum superficialis and profundus to flex the PIP.

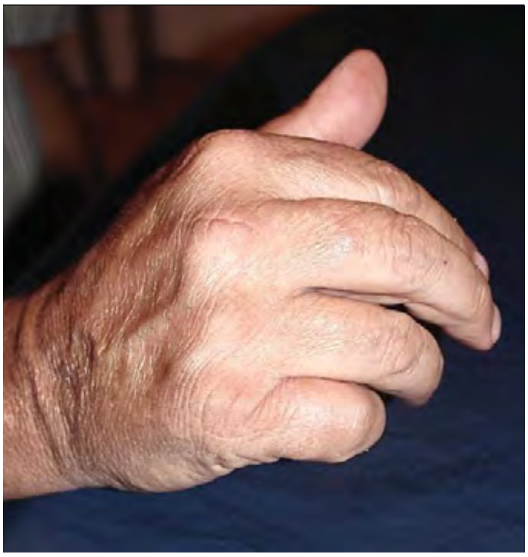
ACTIVITIES: 1) Looking at the side of your right index finger, begin to flex it. Notice that the DIP bends first, then the PIP and then the MCP. This sequence of finger flexion reflects the amount of tendon movements of the flexor digitorum profundus and superficialis shown in the table below flexor sheath. 2)Place your right wrist in full extension (dorsiflexion) and make a tight fist. Making a fist should have been easy because of the slack of the extensor tendons and the stretch of the flexor digitorum superficialis and profundus tendons. 3) Keep the wrist extended fully and now try to fully extend the PIP and DIP. This action should have been difficult because the finger flexor tendons are stretched and resisting extension of the PIP and DIP. In addition, the tendons of the extensor digitorum are slackened and unable to overcome the flexion resistance of the flexor tendons. 4) Place your right wrist in full flexed (palmar flexion) and make a tight fist. Making a fist should now have been difficult because of the resisting stretch of the extensor digitorum tendons and the slackness of the flexor digitorum superficialis and profundus tendons. 5) With the right wrist still in full flexion, extend the fingers. Full finger extension should have been easy because the finger flexor tendons are slack and not resisting finger extension produced by the stretched extensor digitorum muscle. 6) Position your right index finger so that it is pointing forward. Now, fully flex the right index PIP and actively hold the PIP in that position. Try to actively extend the right DIP. Can you do it? You may see some slight extension but only a small amount. Can you move the DIP passively in extension and flexion with the left thumb and index finger? You should be able to move the DIP with little to resistance. This is called the *Release of the DIP*.

- **DEFORMITIES**

  o ULNAR NERVE PALSY
  - This deformity results from damage to the ulnar nerve.
  - Damage at the elbow or at the wrist is most common.
  - Effected are the muscles in the hand innervated by the ulnar nerve and the sensation on the dorsal and palmar surfaces of the little and ring fingers.
  - Involvement of the hand muscles will affect
    1) flexion, abduction and opposition produced by the hypothenar muscles of the little finger;
    2) flexion, abduction and adduction of the metacarpophalangeal (MCP) joints of the little, ring, middle and index fingers produced by the dorsal and palmar interossei;
    3) extension of the PIP and DIP of the little, ring, middle and index fingers produced by the palmar and dorsal interossei acting on the extensor assembly;
    4) flexion of the MCP of the little and ring fingers produced by the lumbricals
    5) extension of the PIP and DIP of the little and ring fingers produced by the lumbricals acting on the extensor assembly;
    6) adduction of the thumb.

- PIP and DIP extension of the little and ring fingers will be less then PIP and DIP extension of the index and middle because the lumbricals and both the palmar and dorsal interossei of the little and ring are involved compare to only the interossei of the index and middle fingers.
- Extension movements of the MCP at these finger are near normal as the extensor digitorum is innervated by the radial nerve and not involved.
- The involvement of the interossei and lumbricals to the little and ring fingers but not the index and middle fingers and no involvement of the extensor digitorum. results in a deformation called the ULNAR CLAW HAND.
- In this deformity, when trying to actively extend the fingers
  + The PIP and DIP of the little and ring fingers are flexed more than the flexion occurring at the PIP and DIP of the index and middle fingers because of involvement of the interossei and lumbricals of the little and ring fingers.
  + The MCPs of all the fingers are extended because the extensor digitorum in intact.
  + The thumb is usually abducted because the adductor pollicis is involved.

- In this deformity , when actively trying to flex the fingers
  + Flexion movements of the ring and index fingers are less than flexion of the index and middle fingers because of involvement of the flexor digitorum profundus and lumbricals to the little and the ring fingers.
  + The thumb is usually abducted because the adductor pollicis is involved.

	
Ulnar nerve palsy during active finger extension. Notice the little and ring fingers extend less because of involvement of lumbricals and interossei than the index and middle fingers with lumbricals intact.	**Ulnar nerve palsy during active finger flexion. Notice the little and ring fingers flex less because of involvement of flexor digitorum profundus than the index and middle fingers with flexor digitorum superficialis and profundus intact.**

o MEDIAN NERVE PALSY (Benediction Hand)

- Results from damage to the median nerve usually at the wrist.
- Effected are the muscles in the hand innervated by the median nerve and the sensation on the dorsal and palmar surfaces of the thumb and index and middle fingers.
- Involvement of the hand muscles will affect
  1) flexion, abduction and opposition produced by the thenar muscles of the thumb
  2) flexion of the MCP of the index and middle fingers produced by the lumbricals
  3) extension of the PIP and DIP of the index and middle fingers produced by the lumbricals acting on the extensor assembly

- In this deformity, when actively trying to extend the fingers
  + Extension movements of the PIP and DIP of the index and middle fingers are less than the extension of the little and ring fingers because of loss of the lumbricals to the index and middle fingers but not the little and ring fingers.
  + Extension movements of the MCP joints are not involved as the extensors of the fingers are intact because these are radial nerve innervated.
  + The thumb may be slightly extended and adducted because of involvement of the flexor pollicis brevis and abductor pollicis brevis.
- in this deformity, when actively trying to flex the fingers
  + The index and middle fingers will flex less than the little and ring fingers because the flexor digitorum superficialis and profundus and the lumbricals of the index and middle fingers are involved but the flexor digitorum profundus and lumbricals of the little and ring fingers are intact.
  + Thumb flexion will be good because the flexor pollicis longus is intact.
  + If the median nerve is damaged at or above the elbow, the flexor pollicis longus and brevis muscles will be involved and thumb flexion will be very poor.

MEDIAN NERVE PALSY during active finger extension. Notice the index and middle fingers are less extended because of the involvement of the lumbricals than the little and ring fingers with lumbricals and interossei intact.

MEDIAN NERVE PALSY during active finger flexion. Notice the index and middle fingers are flexed less because of involvement of the flexor digitorum superficialis and profundus than the little and ring finger with the flexor digitorum intact.

- CLAW HAND
  - Intrinsic hand muscles are involved because of ulnar and median nerve damage.
  - Involvement of the hand muscles will affect
    1) Flexion, abduction and opposition produced by thethenar muscles of the thumb.
    2) Flexion, abduction and opposition produced by the hypothenar muscles of the thumb.
    3) Extension of the PIP and DIP of all the fingers produced by the palmar and dorsal interossei and the lumbricals acting on the extensor assembly.
    4) Flexion of the MCP of all the fingers produced by lumbricals.
    5) If the median nerve is damaged in the area of the elbow or above, flexion of the MCP, PIP, and DIP of all the fingers produced by the flexor digitorum superficialis and profundus will be involved.
  - the intact extensor digitorum
    + holds the MCP of the fingers in extension
    + It cannot alone fully counteract the passive elastic flexion forces produced by the flexor digitorum superficialis and profundus.
    + This results in flexion of the PIP and DIP and extension of the MCP all the fingers at rest.

- In this deformity, when actively trying to extend the fingers
  + Extension of the PIP and DIP of all the fingers will be greatly limited because of involvement of the palmar and dorsal interossei and the lumbricals.
  + Extension of the MCP of the fingers will occur.
  + Extension of the IP and MCP of the thumb should be normal because the extensor pollicis longus and brevis are intact.
- In this deformity, when actively trying to flex the fingers
  + Flexion of the MCP of the fingers will be reduced because of involvement of the lumbricals and the palmar and dorsal interossei.
  + Flexion of the MCP of the thumb will be reduced because of involvement of the flexor pollicis brevis.
  + If the median nerve is damaged near or above the elbow, flexion of the fingers and thumb will be greatly reduced because of involvement of the flexor digitorum superficialis and profundus and the flexor pollicis longus.

CLAW HAND from damage to the Median and Ulnar nerves.

- SWAN – NECK DEFORMITY

  - This deformity is the result of rheumatoid arthritis.
  - There is palmar synovitis and distension of the PIP palmar joint capsule.
  - The distension results palmar subluxation of the PIP with dorsal displacement of the lateral bands.
  - The dorsal shift of the lateral bands hold the PIP in hyperextension as the bands lie dorsal to the joint axis of the PIP.
  - The dorsal shift of the lateral bands decreases tension on the terminal tendon allowing flexion at the DIP joint by the passive flexor pull of the flexor digitorum profundus.
  - The characteristic joint position of this deformity is MCP flexion, PIP hyperextension, and DIP flexion.

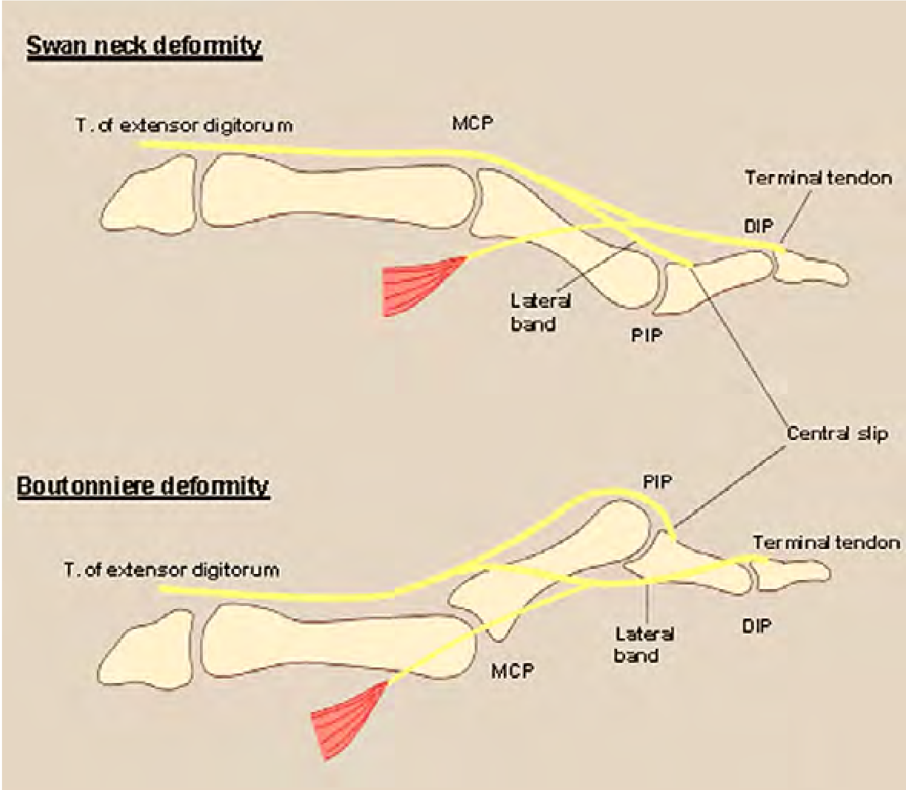


Diagram showing the position of the metacarpophalangeal joint (MCP), proximal interphalangeal joint (PIP), distal interphalangeal joint (DIP) and lateral bands of the extensor assembly with Swan-neck deformity and Boutonniere deformity.

- BOUTONNIERE DEFORMITY

  - This deformity is the result of rheumatoid arthritis.
  - There is dorsal synovitis and distension of the PIP dorsal capsule.
  - The distension results in the dorsal subluxation of the PIP joint with the lateral bands displaced palmarly.
  - Palmar shift of the lateral bands hold the PIP in flexion as the bands lie palmar to the joint axis of the PIP.
  - The terminal tendon remains dorsal to the axis of the DIP producing DIP hyperextension.
  - The characteristic joint position of this deformity is MCP hyperextension, PIP flexion, and DIP hyperextension.

3.4.4 MOVEMENTS OF THE HAND

- **OSTEOKINEMATIC MOVEMENTS OF THE HAND**
  - Osteokinematic range of motion values will vary Odepending on the source (Norkin, White, Malone 2009; Reese and Bardy, 2013).
  - The degrees listed in the TABLE For each movement are commonly used.

TABLE SHOWING JOINT MOVEMENTS OF THE HAND

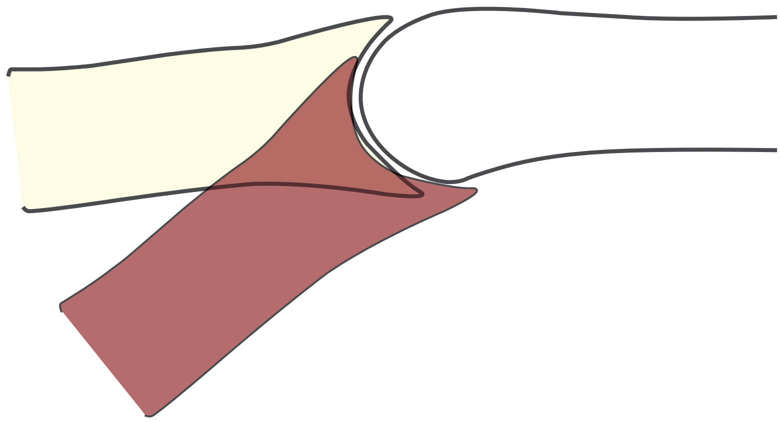
JOINT	TYPE OF MOVEMENT	DEGREES OF MOVEMENT
CMC OF THUMB	FLEXION / EXTENSION ABDUCTION / ADDUCTION	0–45 / 0–15 0–70 / 0–80
CMC INDEX, MIDDLE FINGERS	FLEXION / EXTENSION ABDUCTION / ADDUCTION	SLIGHT TO NONE SLIGHT TO NONE
CMC RING FINGER	FLEXION / EXTENSION	0–15
CMC LITTLE FINGER	FLEXION / EXTENSION ABDUCTION / ADDUCTION	0–30 0–10 / 0–20
MCP OF THUMB	FLEXION / EXTENSION ABDUCTION / ADDUCTION	0–50 SLIGHT
MCP INDEX, MIDDLE, RING, LITTLE FINGERS	FLEXTION / EXTENSION ABDUCTION / ADDUCTION	0–90 0–45 / 0–45
IP THUMB	FLEXION / EXTENSION	0–90
PIP INDEX, MIDDLE, RING, LITTLE FINGERS	FLEXION / EXTENSION	0–100
DIP INDEX, MIDDLE, RING, LITTLE FINGERS	FLEXION / EXTENSION	0–90 / 0–10

CMC = carpometacarpal; MCP = metacarpophangeal; IP = interphalangeal; PIP = proximal interphalangeal; DIP = distal interphalangeal

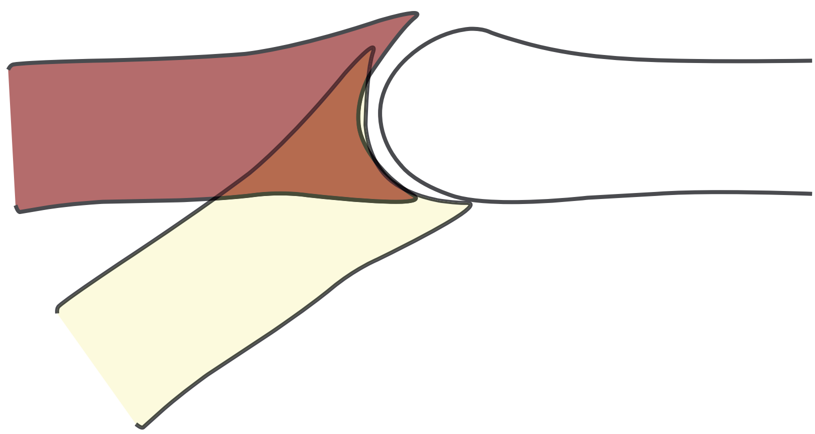
- Movements are very limited at the CMC of the index and middle fingers for the following reasons:
  - The flexor carpi radialis, extensor carpi radialis longus and brevis attach here and need a stable attachment site in order to move the wrist (attachment on the metacarpals give these muscles a long lever arm resulting in increased force production).
  - This stability at the CMC of the index and middle fingers provides a stable base against which the thumb can compress and hold objects.

- **ARTHROKINEMATIC MOVEMENTS OF THE HAND**
  - PIP, DIP of fingers and IP of the thumb
    - flexion: palmar rotation & palmar translation
    - extension: dorsal rotation & dorsal translation

Flexion



Extension



- MCP joints of the fingers
  - flexion: palmar rotation & palmar translation
  - extension: dorsal rotation & dorsal translation
  - because the middle finger is the midline of the hand, abduction and adduction occur in reference to the middle finger
  - abduction:
    - + index and middle fingers: radial rotation & radial translation
    - + middle, ring and little fingers: ulnar rotation & ulnar translation
  - adduction:
    - + index finger: ulnar rotation & ulnar translation
    - + ring and little fingers: radial rotation & radial translation

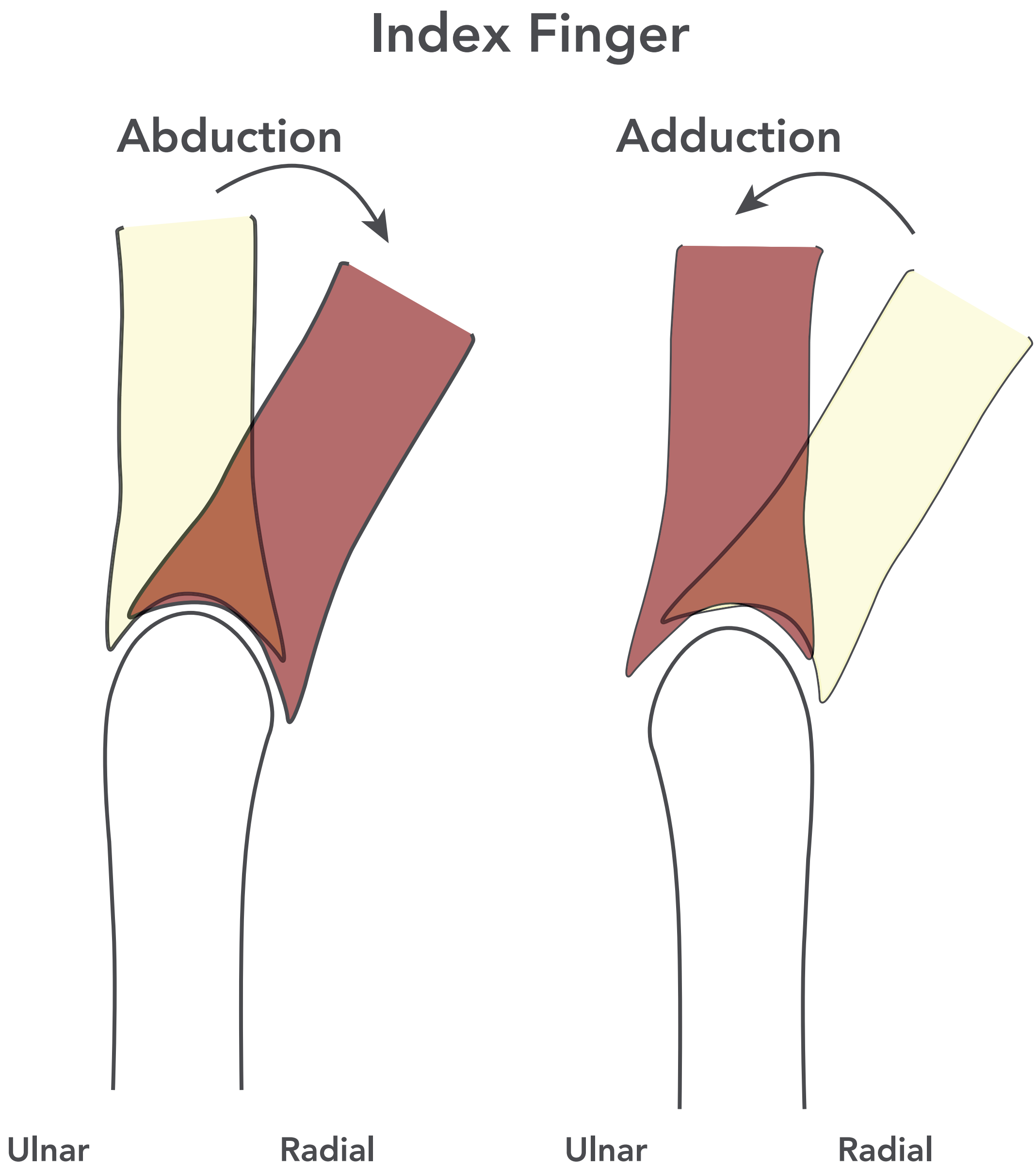
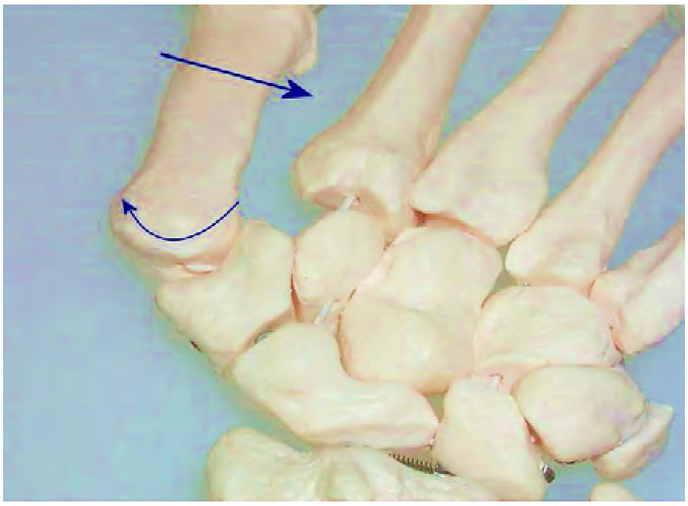


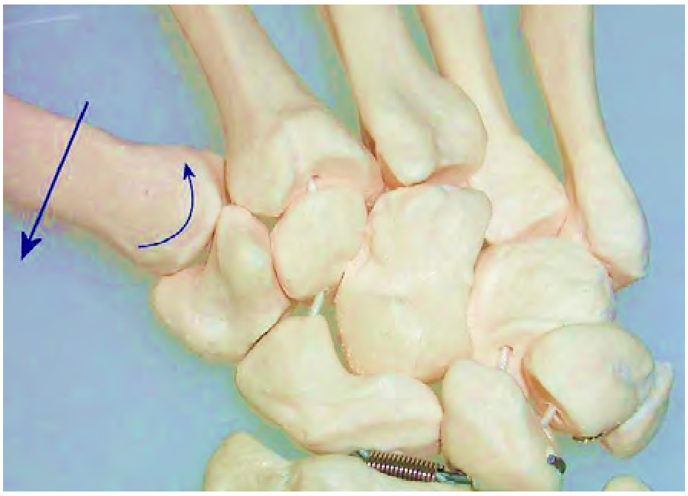
Diagram of the index showing the direction of arthrokinematic abduction and adduction. Remember that the middle finger represents the middle of the hand so that index finger adduction is toward the middle finger or the ulnar side of the hand. However, ring finger adduction is also toward the middle finger but toward the radial side of the hand.

- CMC joint of the thumb
  - flexion: palmar rotation & palmar translation
  - extension: dorsal rotation & dorsal translation
  - abduction (palmar abduction): ulnar rotation & ulnar translation
  - adduction (palmar adduction): radial rotation & radial translation

ADDUCTION



ABDUCTION



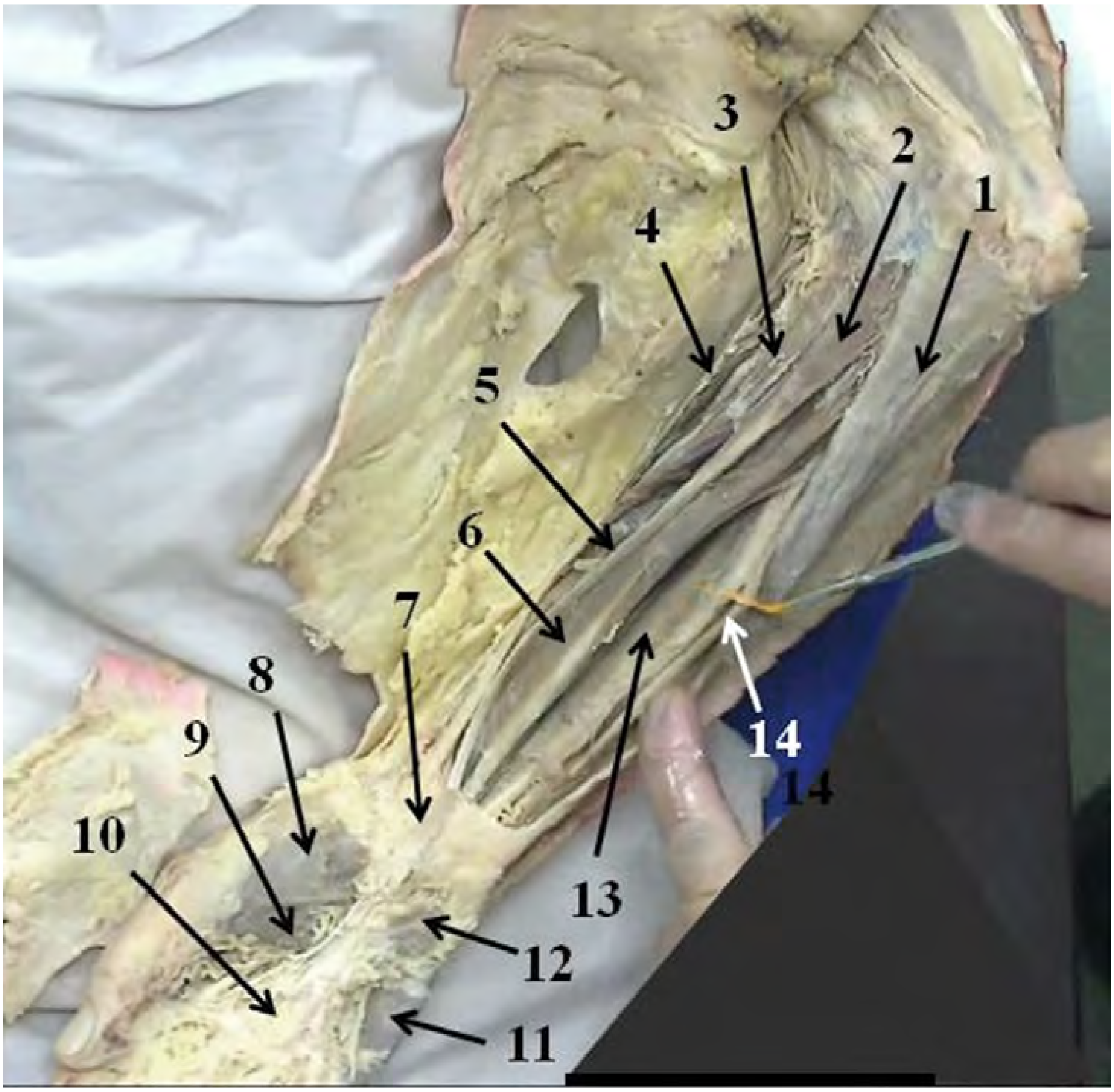
Picture showing the CMC joint of the thumb during arthrokinematic adduction and abduction. The straight arrows show the direction of thumb movement (metacarpal shaft) and the small curved arrows the direction of the base of the metacarpals relative to the trapezium. Note that during adduction and abduction, the base of the metacarpal moves in the opposite direction of the thumb and shaft.

3.4.5 MUSCLES OF THE HAND

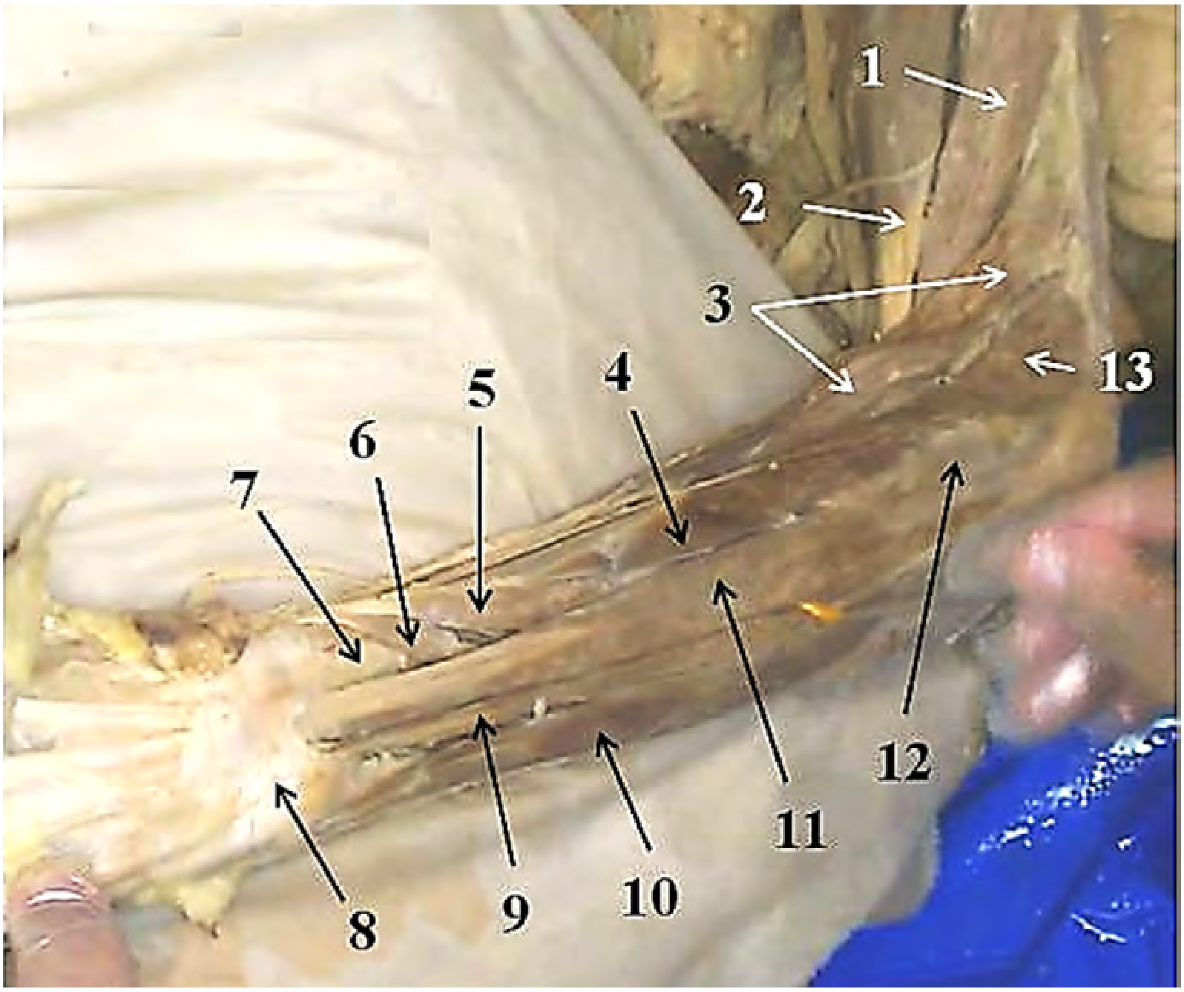
- **EXTRINSIC MUSCLES AND ACTIONS**

  - flexor digitorum superficialis
    - flexes CMC of ring and little fingers
    - flexes MCP and PIP of index, middle, ring and little fingers
  - flexor digitorum profundus
    - flexes CMC of ring and little fingers
    - flexes MCP, PIP, DIP of index, middle, ring and little fingers
  - flexor pollicis longus
    - flexes CMC, MCP, IP of thumb
  - extensor pollicis longus
  - extends CMC, MCP, IP of thumb
  - extensor pollicis brevis
    - extends CMC and MCP of thumb
  - extensor indicis
    - motion at CMC of index finger very limited
    - extends MCP of index finger
    - extends PIP and DIP of index finger via extensor assembly

- extensor digitorum
  - extends CMC of ring and little finger
  - extends MCP of index, middle, ring and little fingers
  - extends PIP and DIP of index, middle, ring, little fingers via extensor assembly
- extensor digiti minimi
  - extends CMC and MCP of little finger
  - extends PIP and DIP of little finger via extensor assembly
- abductor pollicis longus
  - abducts CMC of thumb



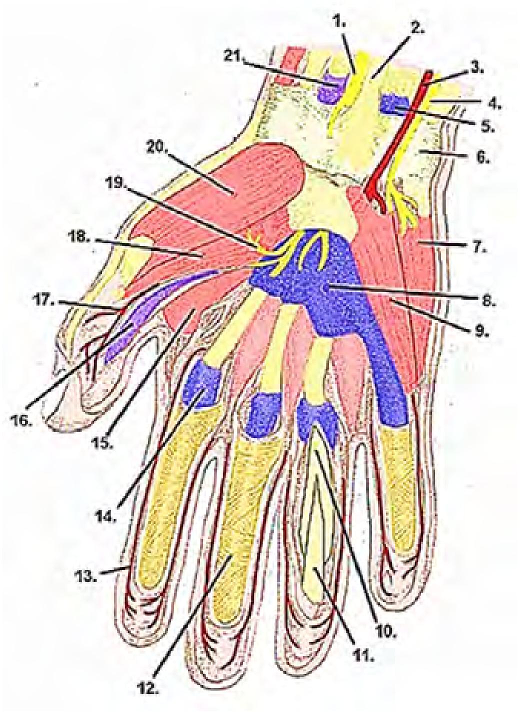
Extrinsic Hand Muscles. Dissection of the muscles of the anterior forearm. 1. Flexor carpi ulnaris, 2. Palmaris longus, 3. Pronator teres, 4. Flexor carpi radialis, 5. Palmaris longus tendon, 6. Flexor digitorum superficialis, 7. Flexor retinaculum, 8. Abductor pollicis brevis, 9. Flexor pollicis brevis, 10. palmar aponeurosis, 11. Abductor digiti minimi, 12. Palmaris brevis, 13. Flexor digitorum profundus, 14. Ulnar nerve.



Extrinsic Hand Muslces. Dissection of the extensor muscles of the forearm. 1. Brachialis, 2. Biceps, 3. Brachioradialis, 4. Extensor carpi radialis brevis, 5. Abductor pollicis longus, 6. Extensor pollicis brevis, 7. Extensor carpi radialis longus and brevis tendons, 8. Extensor retinaculum, 9. Extensor Digiti Minimi, 10. Extensor carpi ulnaris, 11. Extensor digitorum, 12. Common extensor tendon, 13. Extensor carpi radialis longus.

- **INTRINSIC MUSCLES AND ACTIONS**
  - abductor pollicis brevis
    - abducts CMC and MCP of thumb
  - flexor pollicis brevis
    - flexes CMC and MCP of thumb
  - opponens pollicis
    - rotates first metacarpal at CMC toward the little finger
  - adductor pollicis
    - adducts CMC of thumb
  - abductor digiti minimi
    - abducts CMC (slight) and MCP of little finger

- flexor digiti minimi
  - flexes CMC and MCP of little finger
- opponens digiti minimi
  - rotates fifth metacarpal at CMC toward the thumb
- lumbricals
  - flexes MCP of index, middle, ring and little fingers
  - extends PIP and DIP of the index, middle, ring and little fingers via the extensor assembly
- dorsal interossei
  - flexes the MCP of the index, middle and ring fingers
  - extends the PIP and DIP of the index, middle and ring fingers via the extensor assembly
  - abducts the MCP of the index, middle and ring fingers
- palmar interossei
  - flexes the MCP of the index, ring and little fingers
  - extends the PIP and DIP of the index, ring and little fingers via the extensor assembly
  - adducts the MCP of the index, ring and little fingers



Intrinsic Hand Muslces. Drawing of the palmar region of the hand showing components of the thenar, hypothenar and deep central spaces. 1. median N., 2. tendon of palmaris longus, 3. ulnar A., 4. ulnar N., 5. ulnar bursa, 6. flexor retinaculum, 7. abductor digiti minimi, 8. ulnar bursa, 9. flexor digiti minimi, 10. flexor digitorum superficialis, 11. flexor digitorum profundus, 12. flexor sheath, 13. proper digital A., 14. synovial sheath, 15. adductor pollicis, 16. flexor pollicis longus surrounded by radial bursa, 17. princeps pollicis A., 18. flexor pollicis brevis, 19. recurrent branch of median N., 20. abductor pollicis brevis, and 21. radial bursa.

- **RANKING OF EXTRINSIC MUSCLES BY FORCE PRODUCTION**

1. flexor digitorum superficialis (FDS)
2. flexor digitorum profundus (slightly less than flexor digitorum superficialis)
3. extensor digitorum (1/3 of FDS)
4. flexor pollicis longus (1/4 of FDS)
5. extensor indicis (1/10 of FDS)
6. abductor pollicis longus (1/10 of FDS)
7. extensor pollicis longus (1/50 of FDS)
8. extensor pollicis brevis (1/50 of FDS)

- Notice that the force output of the flexor digitorum superficialis and profundus is much greater then that of the extensor digitorum.
- The passive (elastic) components of these flexors are greater than the contraction component of the extensor digitorum.
- Alone the extensor digitorum cannot fully extend the fingers.
- Contraction of the interossei and lumbricales plus contraction of the extensor digitorum are needed to fully extend the fingers.

- With ulnar nerve damage, there will be a greater loss of full extension in the ring and little fingers because both interossi and lumbricales are involved than in the middle and index fingers where the interossi but not the lumbricales are involved.
- With median nerve damage, the middle and index fingers will have a loss of full extension but not the ring and little fingers which can be fully extended.
- When either the interossei or lumbricales are involved, the extensor digitorum itself cannot overcome the passive components of the strong finger flexors and thus the fingers are flexed and cannot fully extend.

3.4.6 HAND GRIPS AND FINGER PINCHES

- **GRIPS**

  - POWER GRIPS
    - the fingers are flexed at the MCP, PIP, DIP
    - the thumb is adducted, acting as a clamp
    - examples
      + cylindrical grip
      + hammer grip
      + fist
      + jar opening grip (big lid, palm on lid)

Pictures of two different Power grips. Note the adducted thumb.

- PRECISION GRIPS
  - the fingers are semi-flexed
  - the thumb is abducted and opposed; more of a holding than squeezing position
  - examples
    + spherical grip (holding baseball)
    + open jar lid with tips of fingers
    + screwing in a light bulb

Pictures of two different precision grips. Note the abducted position of the thumb.

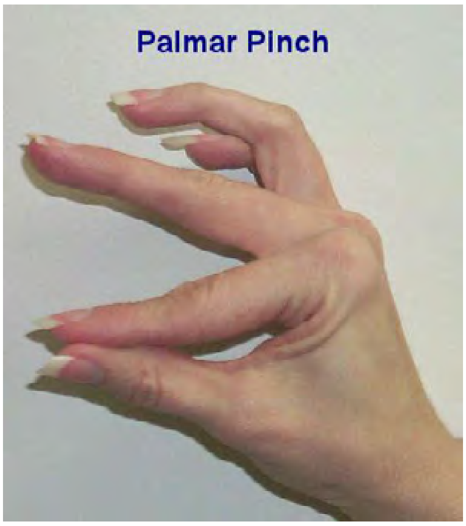
- **PINCHES**
    - DYNAMIC TRIPOD
        - the thumb, index and middle fingers hold the object and the ring and little fingers provide support and stability
        - writing position
        - cutting with a pair of scissors

Picture of a dynamic tripod pinch

-
    - TIP PINCH
        - the tip of thumb presses against tip of index or tip of another finger
        - picking up a button or coin from a table

Picture of a tip pinch

- PALMAR PINCH
  - the palmar surface of the thumb presses against the palmar surface of the index finger or another finger
  - holding a sheet of paper
  - holding a business card or credit card whilehanding to another person



Picture of a palmar pinch

- LATERAL (KEY) PINCH
  - the palmar surface of the thumb presses against the radial surface of the index finger
  - holding a key while inserting it into a lock

Picture of a lateral pinch

- **FORCES DURING GRIP AND PINCH**

    - COMPRESSION FORCES ON FINGER JOINTS
        - Forces are least at the DIP.
        - Forces at the PIP and MCP vary with function.

          Tip pinch forces are greater at the PIP than the MCP.

          + Lateral pinch forces are greater at the MCP than the PIP.
          + The forces when opening big jars are greater at the MCP than the PIP.
          + The forces when holding a glass are greater at the PIP than the MCP.

    - COMPRESSION FORCES AT THUMB
        - Forces at IP = 2–3 × the applied force.
        - Forces at MCP = 5–6 × the applied force.
        - Forces at CMC = 6–12 × the applied force.

    - During normal pinch and grip actions, the tensile forces on the tendons of the extrinsic muscles are 4–5 × the applied force.

    - During normal pinch and grip actions, the tensile forces on the tendons of the intrinsic muscles are 1.5–3 × the applied force.

ACTIVITIES: 1) Looking at the side of your right index finger, flex and extend the DIP, PIP, and MCP, and follow the arthrokinematic movements at each joint. Do you see the curvilinear movements (rotation coupled with translation) in the same direction as the osteokinematic movements of the finger? 2) Looking at the dorsum of your right hand, adduct and abduct the MCP. Follow the arthrokinematic movements of the base of the proximal phalanges relative to the metacarpals. Do you see the curvilinear movements in the same direction as the osteokinematic movements of the finger? Because the middle finger is the midline of the hand, how do the directions of adduction and abduction of the index and ring differ at the MCP? 3) Place the end of your left index finger on the dorsal surface of the CMC joint of the thumb. Flex and extend the CMC and note the directions of metacarpal base. Are directions of arthrokinematic and osteokinematic movements the same? 4) Now adduct and abduct the thumb. What are the directions of movements of the metacarpal base of the CMC during adduction and abduction? Are directions of arthrokinematic and osteokinematic movements the same or opposite? Because the CMC is a saddle joint, osteokinematic and arthrokinematic should be the same flexion and extension, but opposite for adduction and abduction. 5) The fleshy web between the thumb and index finger contains the adductor pollicis and first dorsal interosseous. What would happen to the thickness of this web with ulnar nerve palsy? Because both of these muscles are innervated by the ulnar nerve, the muscles would atrophy and the webbing become thin.

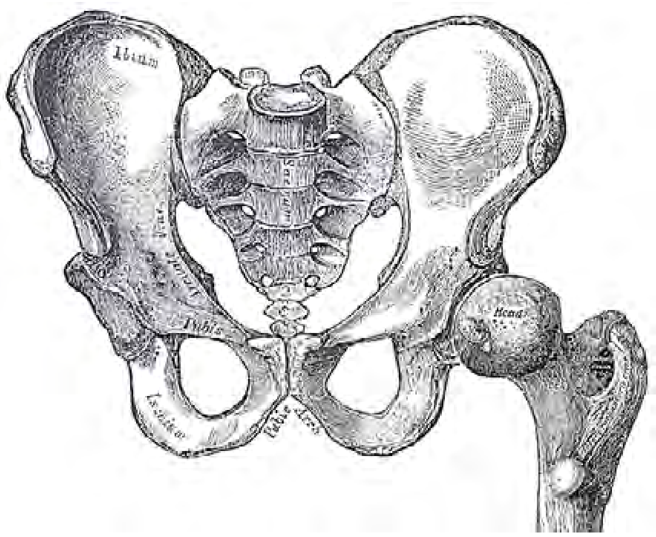
Study Questions (hand)

1. In what way does arthrokinematic abduction and adduction of the carpometacarpal joint of the thumb differ from arthrokinematic movements at the other joints of the fingers?
2. What joints are flexed by contraction of the flexor digitorum superficialis?
3. How would you differentiate between the following muscles:
    a. flexor digitorum superficialis and profundus
    b. flexor pollicis longus and brevis
    c. extensor pollicis longus and brevis
4. What muscles are needed to fully extend a finger and why are multiple muscles needed for this action?
5. What are the two main functions of the flexor tendon sheath?
6. How does the extensor assembly extend the PIP and DIP?
7. What are the differences between ulnar nerve palsy and median nerve palsy during active extension of the fingers and why?
8. What are the differences between ulnar nerve palsy and median nerve palsy during active flexion of the fingers and why?
9. What is the main difference between a power grip and a precision grip?
10. What is the main difference between a tip pinch and a lateral pinch?
11. If you are mobilizing a joint and are applying 5 pounds of compression to the thumb, how much compression force is occurring at each joint of the thumb?

4 LOWER EXTREMITY

4.1 EXTREMITY BIOMECHANICS OF THE HIP

ANATOMY OF THE HIP JOINT



- **FEMORAL NECK ANGLES**

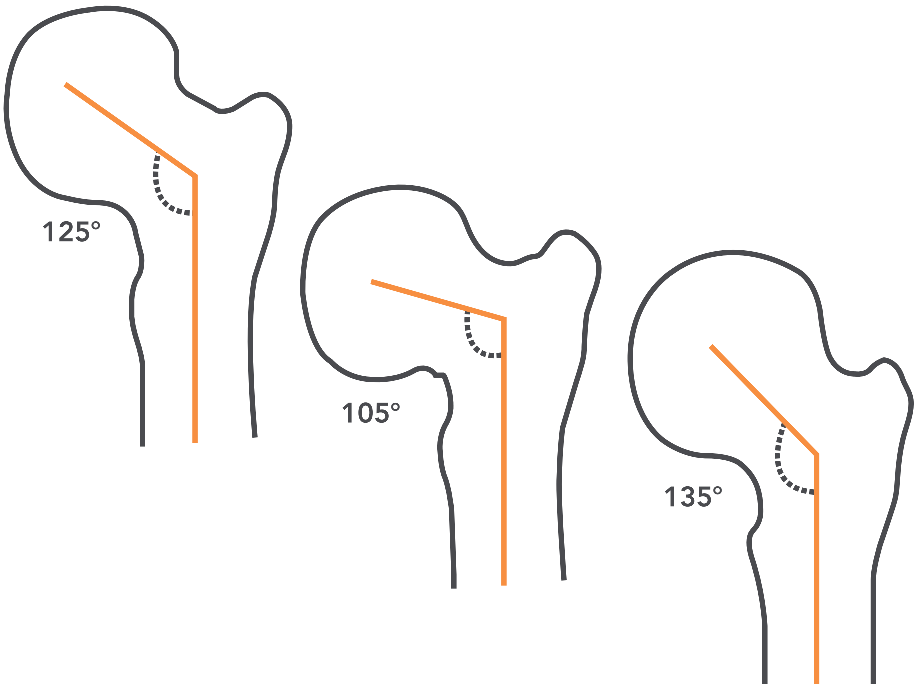
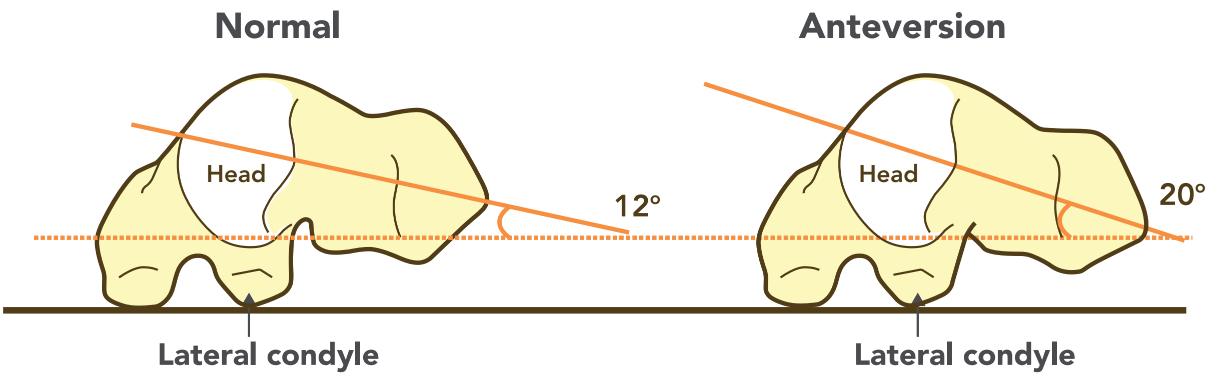


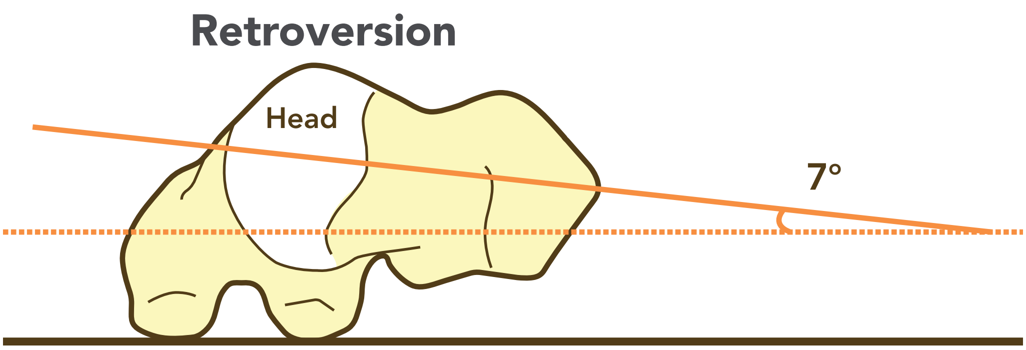
Diagram showing (LEFT) the normal angel to the of the femoral neck; (MIDDLE) a less the normal angle; (RIGHT) a greater than normal angle.

- ANGLES OF THE FEMORAL NECK to shaft angle in the frontal plane
    - **normal** angle = about 125 degrees
    - an angle < 125 degrees is **coxa vara**
    - an angle > 125 degrees is **coxa valga**



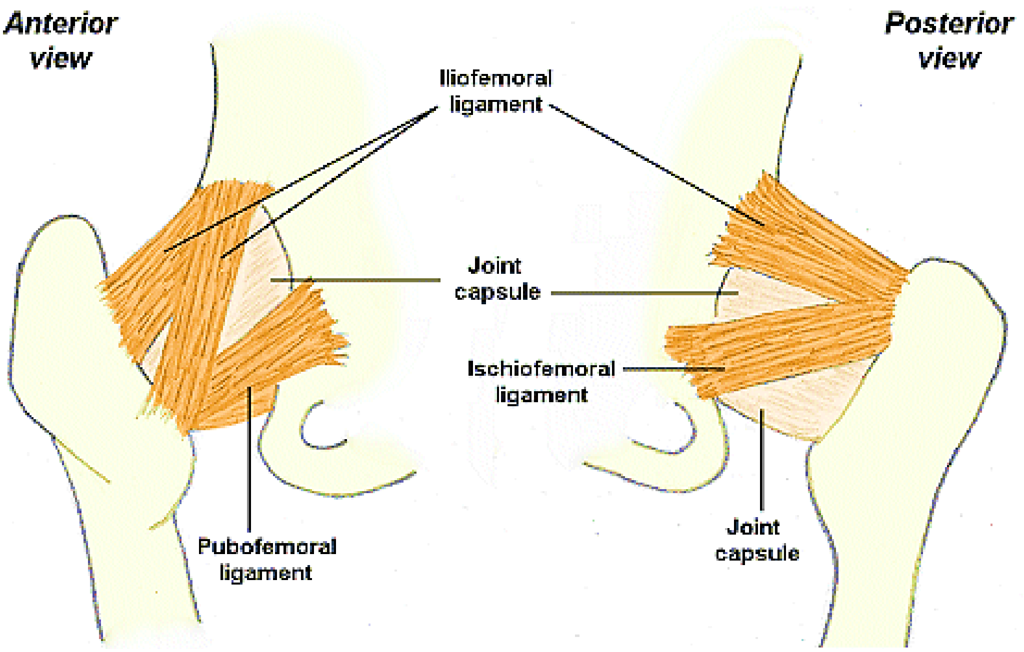
- o ANTERIOPOSTERIOR ANGLES of the femoral neck to the shaft in the transverse plan

  - ▪ This angle is formed by a line through the center of the long axis of the femoral head and neck and a line connecting the posterior end of the medial and lateral femoral condyles.
  - ▪ The **normal** femoral neck position is anterior at an angle = 12–15 degrees.
  - ▪ **Anteversion** is the position of the femoral head and neck when the anterior angle > 20 degrees.
    - + With the femoral head in an antevered position, the femur must be internally rotated for the head to fit properly in the acetabulum.
    - + Children with femoral head anteversion usually show the femur and the lower limb internally rotated (toes in).
      - Children may compensate for this internally rotated position by actively externally rotating the femur and thus the lower limb.
      - If the head of the femur is secure in the acetabulum, then external rotation would tend to move the weight bearing surface on the femoral head posteriorly.



  - ▪ **Retroversion** is the position of the femoral head and neck when the angle < 12 degrees.
    - + With the femoral head in retroversion, the femur and lower limb must be externally rotated to fit properly in the acetabulum.
    - + Children with femoral head retroversion usually show the femur and the lower limb externally rotated (toes out).
      - Children may compensate for this externally rotated position by actively internally rotating the femur andthus the lower limb.
      - If the head of the femur is secure in the acetabulum, then internal rotation would tend to move the weight bearing surface on the femoral head anteriorly.

- **HIP LIGAMENTS**



Drawing of the ligamants of the hip joints in (LEFT) anterior view and (RIGHT) posterior view.

- ILIOFEMORAL LIGAMENT
  - anterior capsule
  - all fibers twist to resist hyperextension
  - superior fibers resist adduction
  - inferior fibers resist abduction and external rotation

- PUBOFEMORAL LIGAMENT
  - anterior capsule
  - all fibers twist to resist hyperextension
  - all fibers resist abduction and external rotation

- ISCHIOFEMORAL LIGAMENT
  - posterior capsule
  - fibers spiral anteriorly and blend with iliofemoral ligament
  - all fibers twist to resist hyperextension
  - loose in flexion
  - resist adduction and internal rotation

4.1.1 MOVEMENTS

- **OSTEOKINEMATIC MOVEMENTS OF THE HIP JOINT**

    - Osteokinematic ranges of motion vary depending on the reference (Norkin, White, Malone 2009; Reese and Bandy 2013).

    - The ranges shown below are commonly used ranges.
        - flexion: 0–120/140 degrees
        - hyperextension: 0–15/30 degrees
        - abduction: 0–30/45 degrees
        - adduction: 0–25/30 degrees
        - internal rotation: 0–30/45 degrees
        - external rotation: 0–45/60 degrees

    - For activities such as tying a shoe, sitting down, stooping, squatting, ascending and descending stairs one needs at least the following movements.
        - 120 degrees of flexion
        - 20 degrees of external rotation
        - 20 degrees of abduction

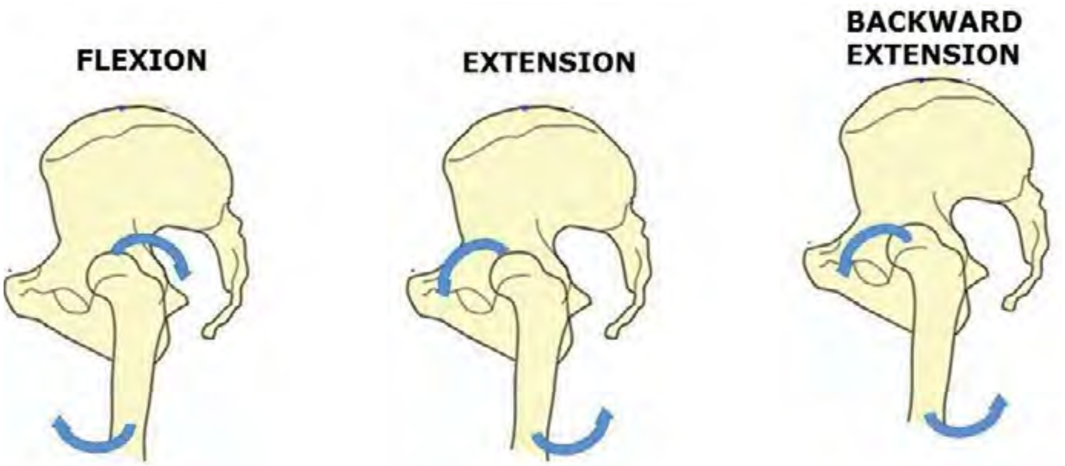
- When hip is flexed and adducted (and internally rotated), femoral head may be pushed out of acetabulum; precaution with total hip replacement.

- loose pack position:
  - 30 degrees of flexion
  - 30 degrees of abduction
  - slight external rotation

- close pack position:
  - full extension
  - full internal rotation
  - full abduction

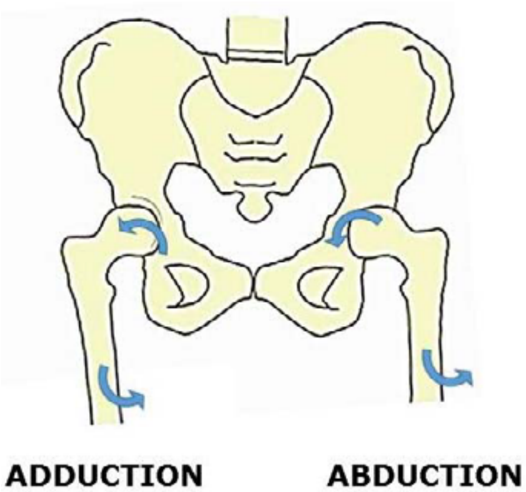
- **ARTHROKINEMATIC MOVEMENTS OF THE HIP JOINT**

  - Movements are mainly rotation; glide is negligible.
  - Movements of femoral head relative to fixed pelvis
    - FLEXION: posterior rotation in the sagittal plane
    - EXTENSION: anterior rotation in the sagittal plane
    - BACKWARD EXTENSION (hyperextension): anterior rotation in the sagittal plane



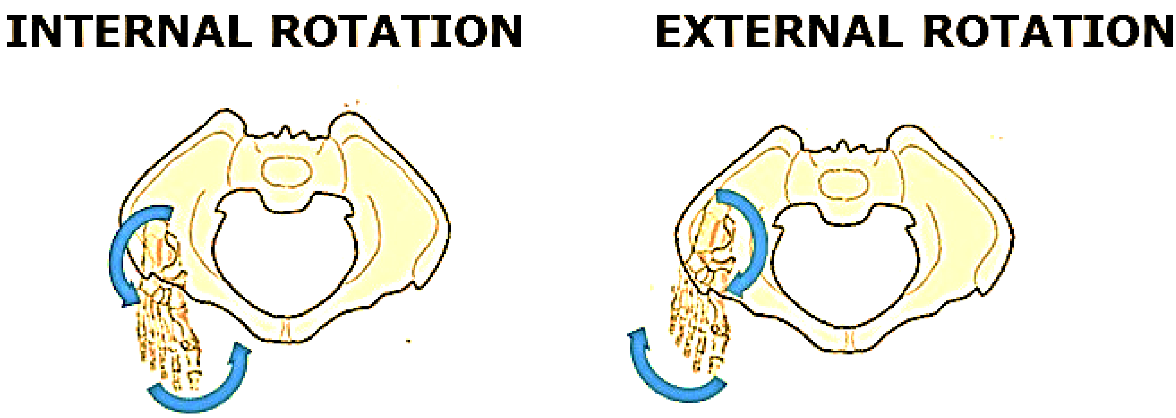
Drawings showing the arthrokinematic rotation of the femoral head during Flexion, Extension, and Backward extension.

    - ABDUCTION: medial rotation in the frontal plane
    - ADDUCTION: lateral rotation in the frontal plane



Drawing showing the arthrokinematic rotation of the femoral head during Adduction and Abduction.

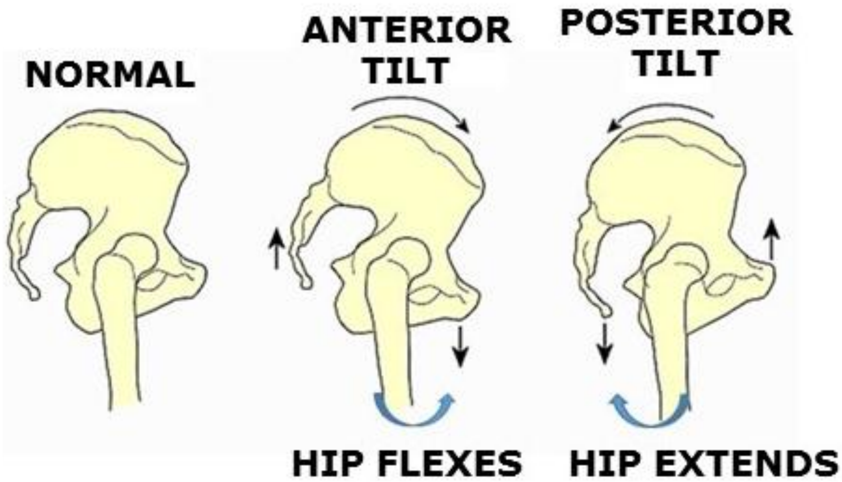
- INTERNAL ROTATION: medial rotation in the transverse plane about the long axis of the femur
- EXTERNAL ROTATION: lateral rotation in the transverse plane about the long axis of the femur



Drawings showing the arthrokinematic rotation of the femoral head during Internal and External rotation.

- **MOVEMENTS OF PELVIS ON FIXED FEMORAL HEAD**
  - ANTERIOR PELVIC TILT
    - ASIS moves downward and anteriorly
    - the sacrum moves up
    - the result is flexion at hip joint

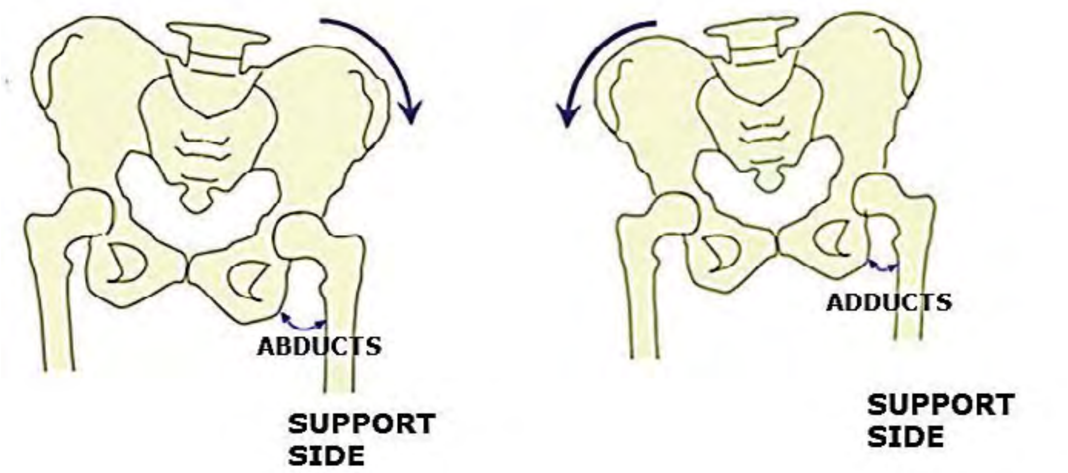
- POSTERIOR PELVIC TILT
  - ASIS moves upward and posteriorly
  - sacrum moves down
  - the result is extension at hip joint



Drawings showing anterior tilt producing hip flexion and posterior tilt producing hip extension.

- LATERAL PELVIC TILT WITH SUPPORT SIDE DROPPED
  - The support side pelvis is lower than the non-support side.
  - The position places the support side hip in abduction and tilts the pelvis to the support side.

- LATERAL PELVIC TILT WITH THE NON-SUPPORT SIDE DROPPED OR DEPRESSED
  - The support side pelvis is higher than the non-support side.
  - The position places the support side hip in adduction and tilts the pelvis to the non-support side.

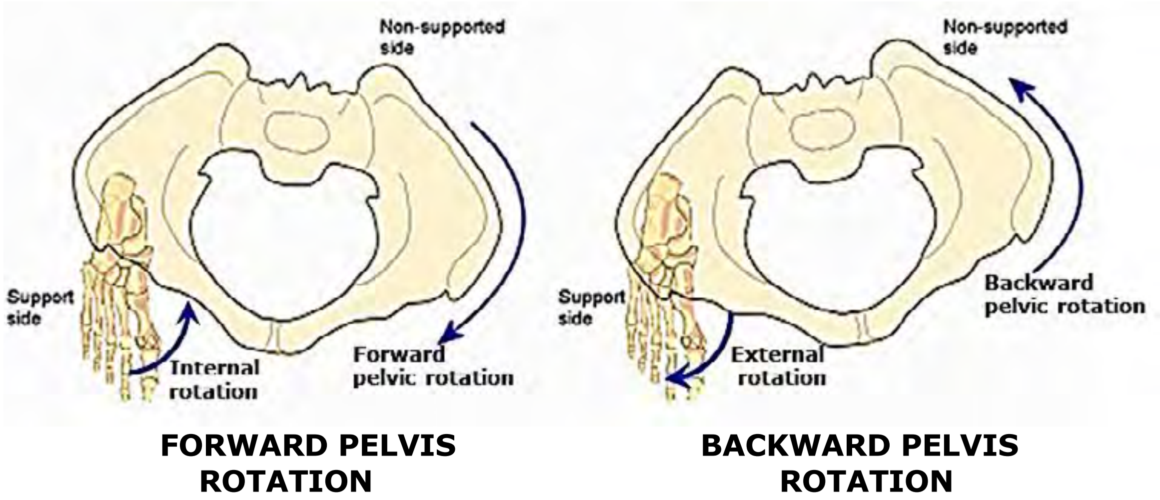


SUPPORT SIDE DROP **NON-SUPPORT SIDE DROP**

Drawings showing effects on hip with lateral drop of the pelvis.

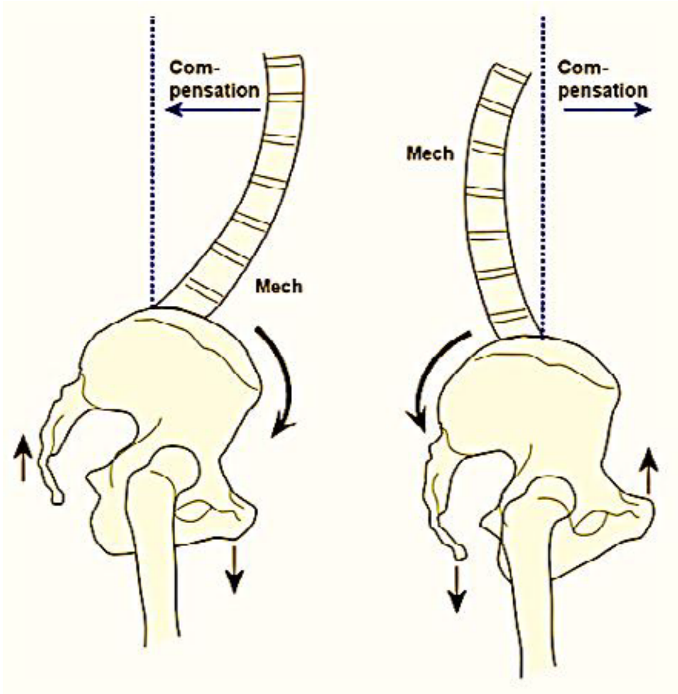
- FORWARD PELVIC ROTATION FROM NEUTRAL
  - The non-support side pelvis moves forward.
  - This position moves the non-support side hip joint medially and in adduction.
  - The support or pivot side femur rotates medially at the hip joint.

- BACKWARD PELVIC ROTATION FROM NEUTRAL
  - The non-support side pelvis moves backward.
  - This position moves the non-support hip joint laterally and in abduction.
  - The support or pivot side femur rotates laterally at the hip joint.



Drawings showing the effects of forward and backward pelvic rotation on the hip.

- **MOVEMENT OF LUMBAR SPINE WITH PELVIC MOVEMENT**
  - ANTERIOR PELVIC TILT
    - This movement would mechanically (Mech.) move head and trunk forward.
    - To maintain the position of the eyes so that sight is forward and parallel to the horizon, the lumbar spine would extend to move the head and trunk towards a straight vertical position compensating for the mechanical forward head and trunk movement.
  - POSTERIOR PELVIC TILT
    - This movement would mechanically (Mech.) move the head and trunk backward.
    - To maintain the position of the eyes so that sight is forward and parallel to the horizon, the lumbar spine would flex to move the head and trunk towards a straight vertical position compensating for the mechanical backward head and trunk movement.

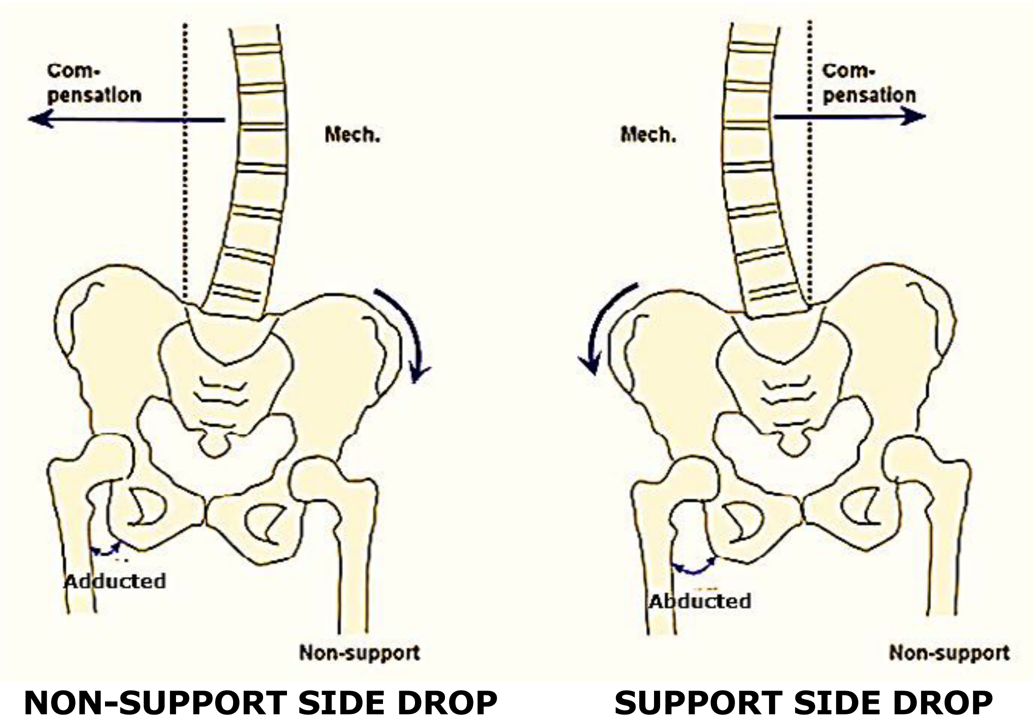


ANTERIOR PELVIC TILT **POSTERIOR PELVIC TILT**

Drawings showing the effects of anterior and posterior pelvic tilt on the spine.

- LATERAL PELVIC TILT WITH NON-SUPPORT SIDE PELVIC DROPPED (depressed)
  - This movement would mechanically (Mech.) move the trunk laterally towards the non-support or dropped side and shift head away from vertical.
  - To maintain the position of the eyes so that sight is forward and parallel to the horizon, the lumbar spine would laterally flex to the support side to move the head and trunk towards a straight vertical position compensating for the mechanical lateral head and trunk movement.

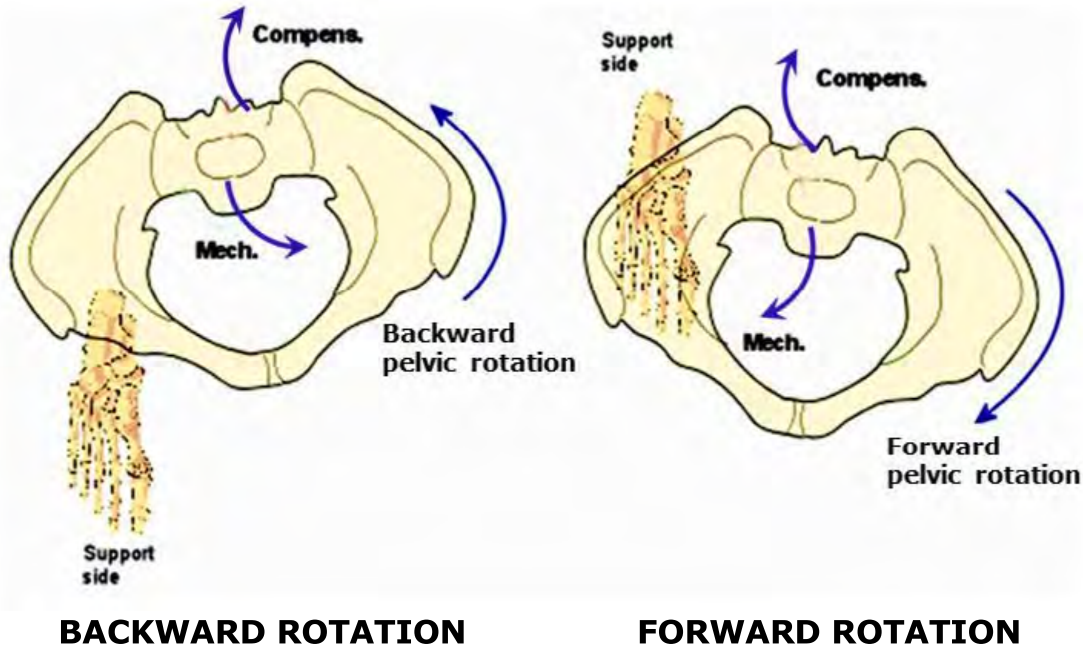
- LATERAL PELVIC TILT WITH THE SUPPORT SIDE DROPPED
  - This movement would mechanically (Mech.) move the trunk laterally towards the dropped support side.
  - To maintain the position of the eyes so that sight is forward and parallel to the horizon, the lumbar spine would laterally flex to the non-support side to move the head and trunk towards a straight vertical position compensating for the mechanical lateral head and trunk movement.



Drawings showing the effects of hip drop on the spine.

- BACKWARD PELVIC ROTATION OF NON-SUPPORT SIDE FROM NEUTRAL
  - This movement would mechanically (Mech) rotate the lumbar spine and trunk toward the non-support side.
  - To maintain the position of the eyes so that sight is forward and parallel to the horizon, the lumbar spine would rotate toward the support side to move the head and trunk towards a straight vertical position compensating for the mechanical rotation of the lumbar spine.

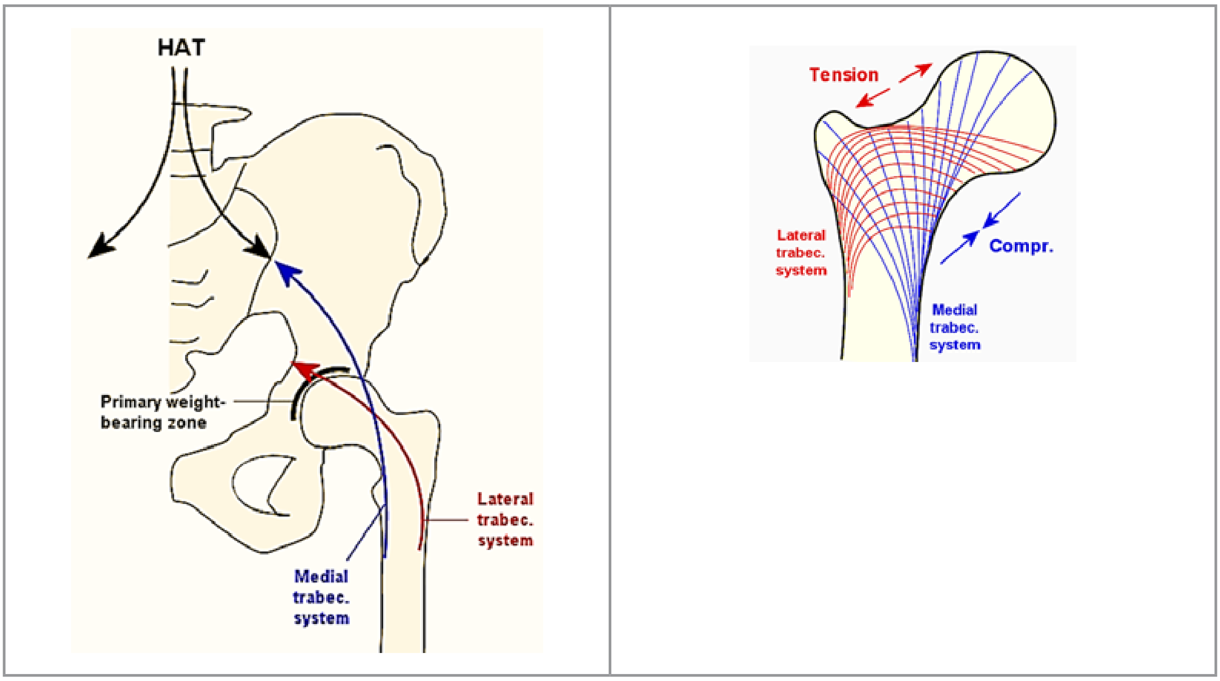
- FORWARD PELVIC ROTATION OF NON-SUPPORT SIDE FROM NEUTRAL
  - This movement would mechanically (Mech.) rotate the lumbar spine and trunk toward the support side.
  - To maintain the position of the eyes so that sight is forward and parallel to the horizon, the lumbar spine would rotate toward the non-support side to move the head and trunk towards a straight vertical position compensating for the mechanical rotation of the lumbar spine.



Drawings showing the effects of forward and backward rotation of the pelvis on the spine.

- **WEIGHT BEARING STRUCTURE OF THE HIP**

  - MEDIAL AND LATERAL TRABECULAR SYSTEMS
    - Trabecular bone aligns to resist strain and transmit stress.
    - In the femur, the trabecular bone is arranged to form medial and lateral systems.

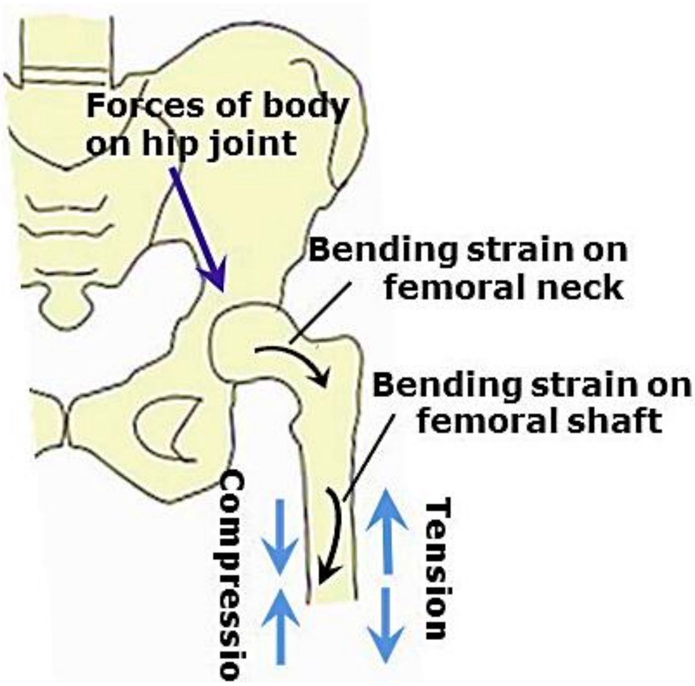


Drawings showing the medial and latera trabecular (trabec.) systems. (LEFT) Pathway of the medial and lateral trabecular systems responding to the forces of the HAT (head, arm, and trunk) imposed at the hip joint and the location of the primary load bearing zone. (RIGHT) Alignment of medial and lateral trabecular system forces at the femoral neck and head producing tension at the superior aspect of the neck and compression (compr.) at the inferior aspect of the neck.

- These systems transmit stresses along the shaft and into the neck of the femur.
- In the neck the systems converge and then diverge in such a way that forces from the femoral head are transmitted to the superior aspect of the acetabulum.
- A zone of weakness lies superior to where the systems converge.
- This zone is located where the distal neck and the greater trochanter merge.

o BENDING STRAINS ON FEMORAL SHAFT AND NECK WITH WEIGHT BEARING

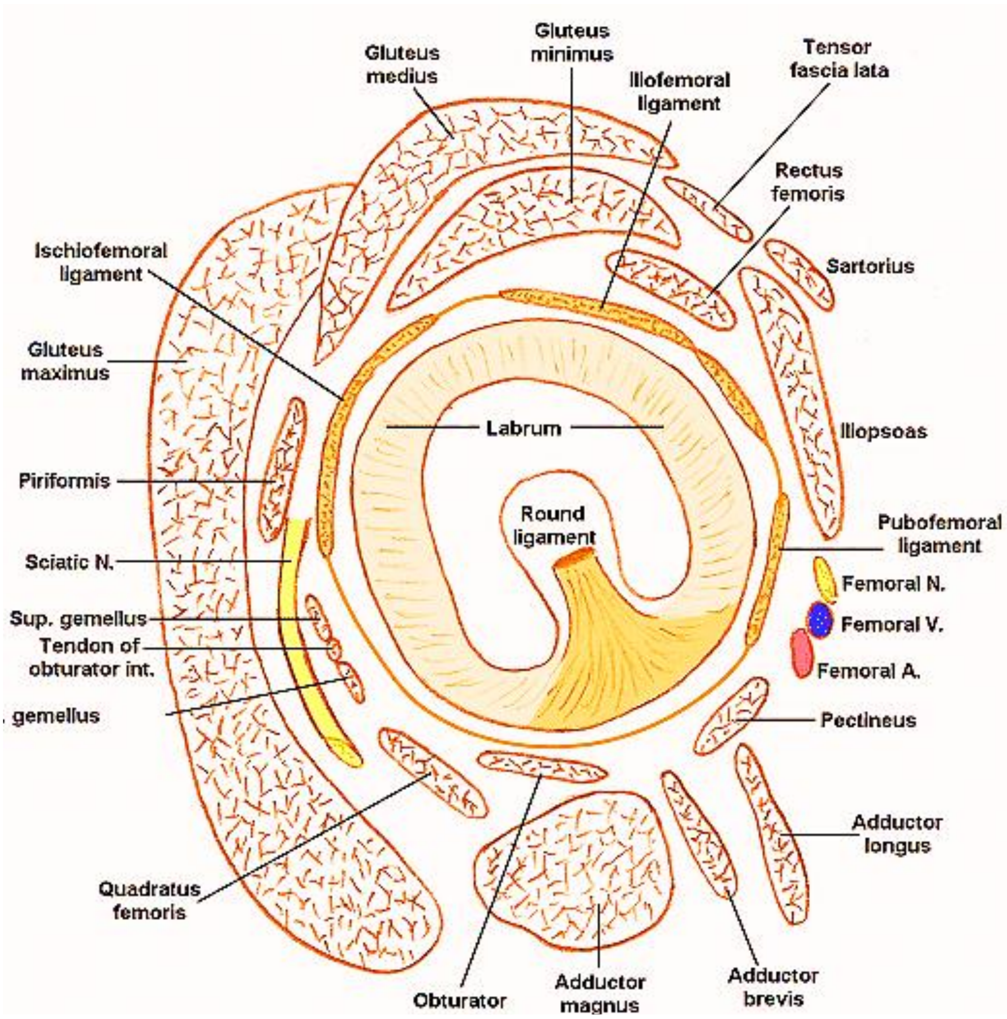
- Tensile strains occur along the lateral shaft and the superior aspect of the femoral neck.
- Compression strains occur along the medial shaft and the inferior aspect of the neck.
- As bone is stronger in compression than tension, those aspects of the shaft and neck deforming with tension would tend to be more vulnerable to fracture.
- Muscle contraction can reduce tensile strain.
  + Contraction of the large vastus lateralis produces compression force on the lateral side of the femoral shaft when it shortens, decreasing the tensile strain on the lateral shaft during weight bearing activities.
  + Contraction of the gluteus medius produces compression strain along the superior neck of the femur when it shortens to maintain a level pelvis during ambulationand while ascending and descending stairs and ramps.



Drawing of the bending strains on the femoral neck and shaft body forces.

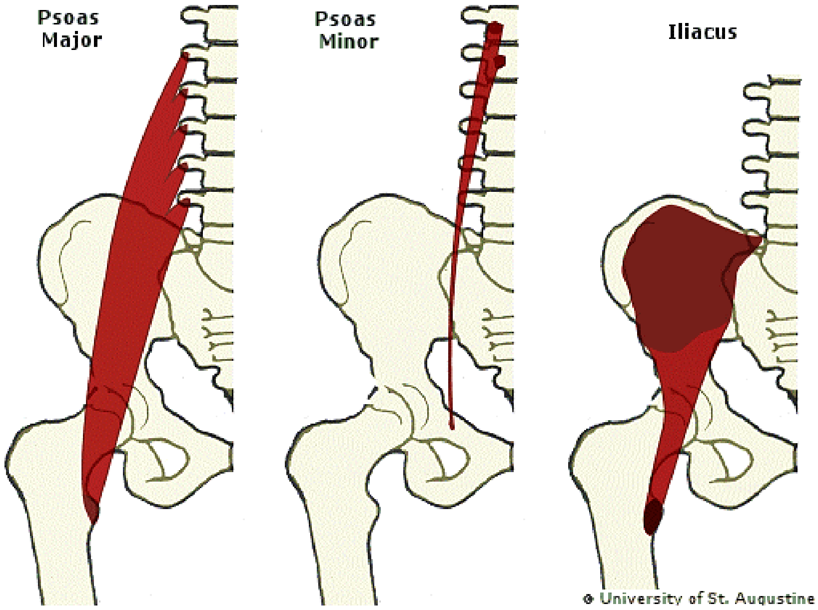
Activities: 1) While standing erect with you feet directly across from each other (the starting position), move your right pelvis forward and note the positions of the right and left legs and your spine. How would you compensate for these movements so that your right foot and head are facing straight forward? 2) Return to the starting position and now move you right pelvis backward. What are the positions of your right and left legs and your spine? Are these the same or different from the first activity? How would you compensate for these positions? 3) Now return again to the starting position and drop your right pelvis while supporting your body on your left leg. Note the positions of left leg and spine. Now move your spine lateral to the left. How does this compensating movement of the spine affect the right pelvis and the left hip? 4) Again return to the starting position, but this time elevate your right pelvis while supporting your body on your left leg. As if the right leg is longer than the left. What is the position of the left and right legs and the spine? How would you compensate for these positions so that the pelvis in level, the spine and legs are straight?

4.1.2 MUSCLES OF THE HIP



Drawing of the hip joint with the femoral head removed showing the muscles of the hip region.

- **HIP FLEXORS** – standing



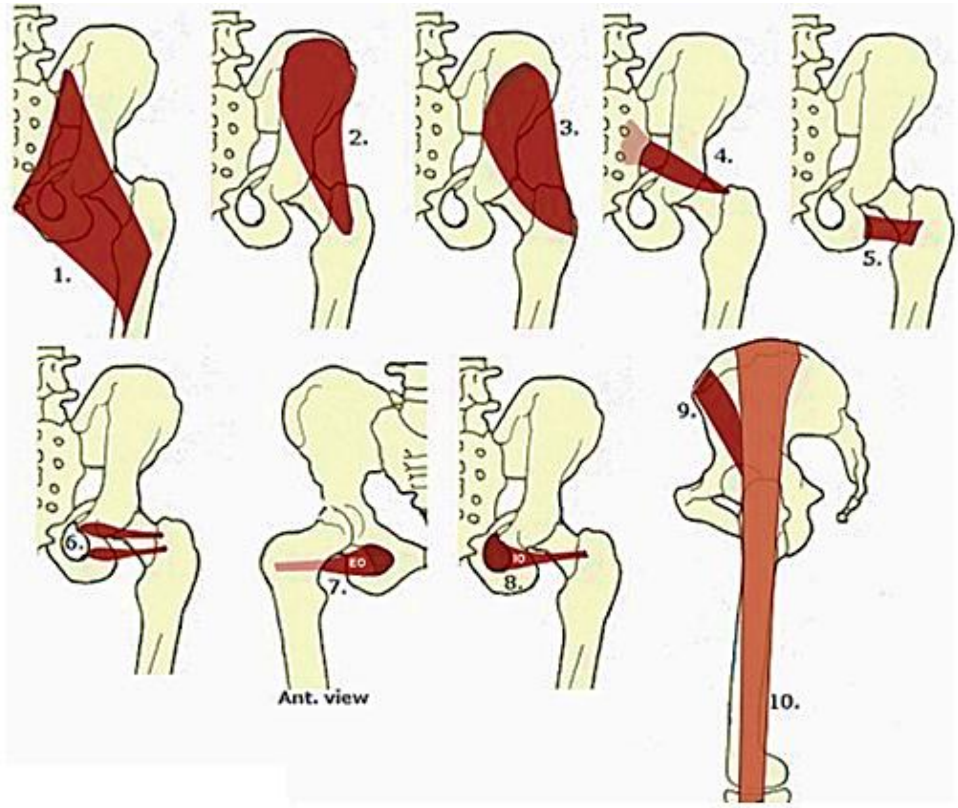
- iliopsoas
- rectus femoris
- pectineus (0–40 degrees of flexion)
- sartorius
  - external rotation component during hip flexion is counterbalanced by tensor fascia lata
- tensor fascia lata
  - internal rotation component during hip flexion is counterbalanced sartorius
- Adductor longus, brevis and magnus when hip is extended

- **HIP FLEXORS** – sitting

  - iliopsoas
    - main hip flexor above 90 degrees of hip flexion
    - Iliopsoas also acts on the lumbar spine by applying an anterior pull on the lumbar vertebral bodies which can help stabilize the lumbar spine or affect the lumbar lordosis.
      + Psoas tightness increases the anterior pull on the lumbar spine which increases the lordosis and can produce an anterior pelvic tilt.
      + Weakness in the psoas decreases trunk stability and canresult in a tendency to fall backward while sitting.
      + Psoas active in sitting up from a supine position and with straight leg raises (SLR).
      + Action of the psoas during SLR produces a large torque on the lumbar spine which may initiate or increase low back pain.

  - rectus femoris
    - It is slack with normal sitting making it a poor hip is sitting.
    - The slackness can be decreased by fully flexing the knee which increases the contribution of the rectus femoris in flexion above 90 degrees.

- **HIP EXTENSORS**
  - gluteus maximus
    - primary extensor of the hip
    - major muscle for lifting when using the legs
      + It produces posterior pelvic rotation at the hip during trunk extension.
      + It controls forward pelvic rotation at the hip during forward trunk bending.
  - hamstrings
    - biceps femoris
    - semimembranous
    - semitendinous
      + Knee flexion decreases extension by the hamstrings at the hip because the muscles are slack.
      + Hamstring tightness results in a posterior pelvictilt which decreases the lumbar lordosis.
    - These muscles are important in lifting.
      + These muscles produce posterior pelvic rotation at the hip during trunk extension.
      + These muscles control forward pelvic rotation at the hip during forward trunk bending.
    - Hamstrings can assist in hip adductors when the hip is flexed.
    - Hamstrings assist in extension SLR from a prone position.
      + This activity produces very high torque on the lumbar spine when extension SLR are done bilaterally.
      + This activity produces only moderate lumbar torque when extension SLR are unilateral.
  - The adductor magnus, longus, brevis and gracilis can assist in hip extension when the hip is flexed.



Diagrams (posterior view, with exception of obturator externus) of: 1. gluteus maximus, 2. gluteus medius, 3. gluteus minimus, 4. piriformis, 5. quadratus femoris, 6. superior and inferior gemellus, 7. obturator externus, 8. obturator internus, 9. tensor fasciae lata, and 10. iliotibial band.

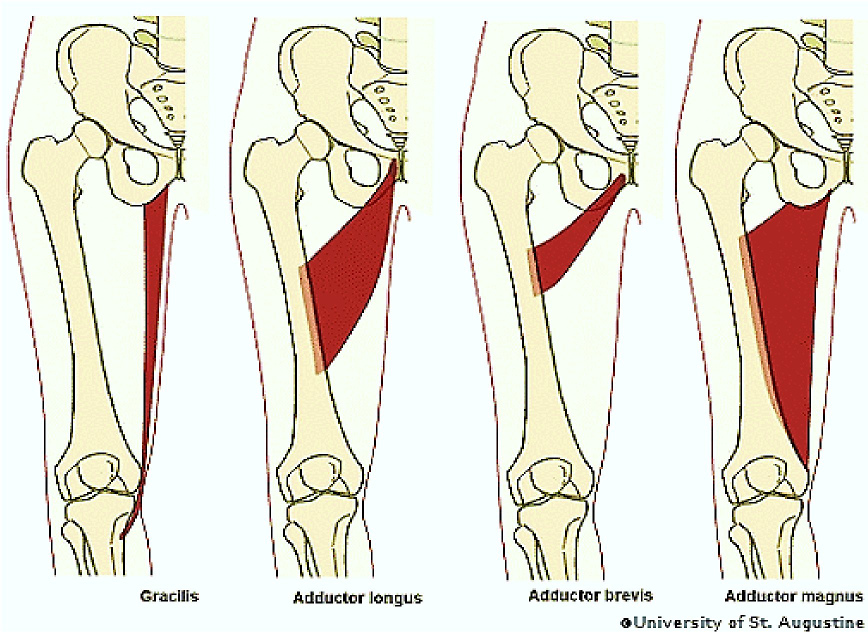
- **HIP ABDUCTORS**
  - gluteus medius (ant. & post.)
  - gluteus minimis (ant. & post.)
  - tensor fascia lata
  - piriformis
  - sartorius
  - abductor weakness = Trendelenburg sign
    - This sign occurs when standing on only one leg (support side).
    - This sign is positive if the pelvis on the non-support side drops.
    - This drop of the pelvis to the non-support side will typically be accompanied by a lateral bending of the trunk to the non-support side followed by a compensatory lateral bending of the trunk to the support side.
    - A positive sign means that there is weakness of support side gluteus medius.
    - As the support side gluteus medius acts to keep the pelvis level by pulling the illium toward the femur, weakness of this muscle results in the opposite side of the pelvis dropping.

- If a cane is used for patient stability, it should be used on the side of the strong gluteus medius.
    - + This position enables the patient to push on the cane to produce an upward force on the side that would drop when the opposite weak side is supporting the body during the stance phase of gait.
    - + This position also provides a long upward force arm which requires less force to counterbalance the downward torque produced by the lateral shift in the center of gravity when the trunk bends to the non-support side.

- **HIP ADDUCTORS**

  - o adductor magnus
  - o adductor longus
  - o adductor brevis
  - o gracilis
    - These adductors can assist in extension of the hip when the hip is in flexion.
    - These adductors can also assist in flexion of the hip when the hip is in extension.

- other muscles that can assist in adduction
  - pectineus
  - obturator externus
  - quadratus femoris
  - lower gluteus maximus

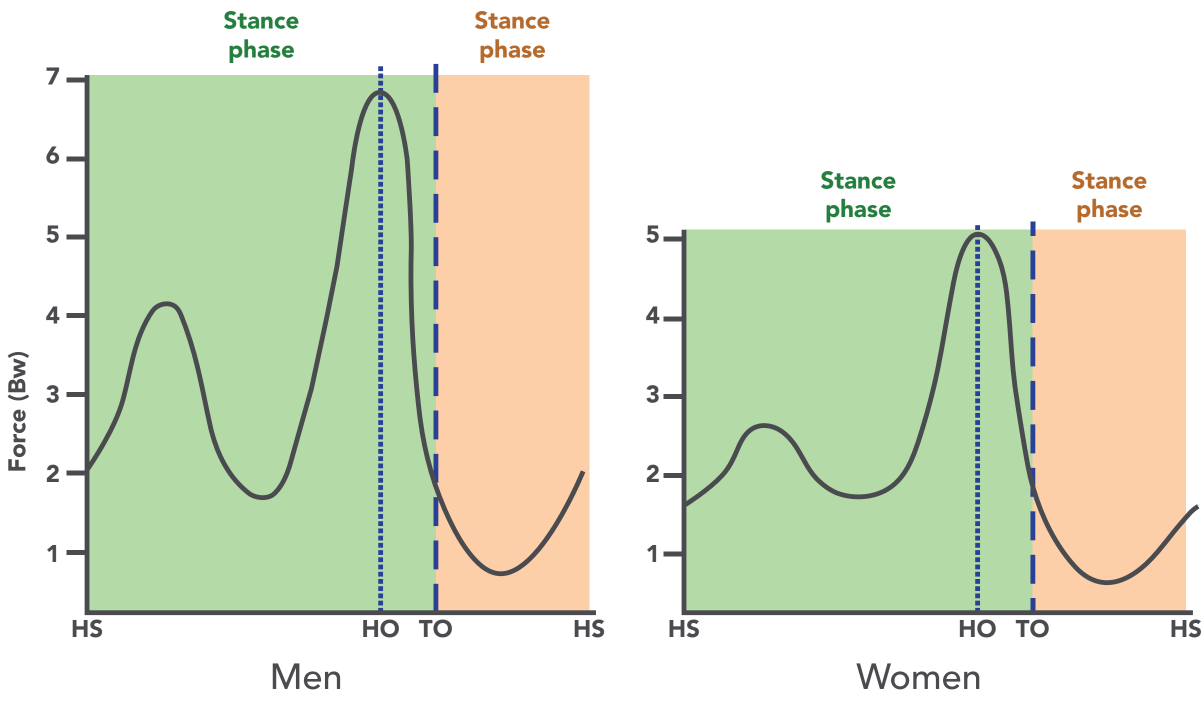


- HIP EXTERNAL (lateral) ROTATORS
  - gluteus maximus
  - gluteus medius (post.)
  - sartorius
  - obturator internus
  - obturator externus
  - quadratus femoris
  - gemellus superior
  - gemellus inferior
  - piriformis
    - When hip is in extension, the greater trochanter moves anteriorly.
    - This anterior position changes the line of action of the piriformis so that it has a posterior component of motion which enables it to externally rotate the femoral head.

- **HIP INTERNAL (medial) ROTATORS**
  - gluteus medius (ant.)
  - gluteus minimis
  - tensor fascia lata
  - piriformis
    - When hip is in flexion, the greater trochanter moves posteriorly.
    - This posterior position changes the line of action of the piriformis so that it has an anterior component of motion to internally rotate the femoral head.

4.1.3 FORCES AT HIP JOINT

- **FORCES DURING WALKING**



Graph of forces at the hip joint during walking for men and women (Norkin and Frankel, 2001). HS = heal strike; HO = heel off: TO = toe off.

  - Forces at the hip increase after heel strike but then decrease at midstance.
  - Peak force occurs at heel off but then decline sharply by toe off.
  - Forces at the hip are least during the swing phase.

- OTHER FORCES

  - Forces of 4 × BW occur at the hips when a patient lying supine uses their elbows to elevates their pelvis to use a bed pan.
  - When a patient uses a trapeze to pull themselves up to use a bed pan, forces at the hip decrease by a factor of 4 compared to forces when the patient uses their elbows to use a bed pan.

ACTIVITIES: 1) While in a sitting position and your trunk straight and upright, flex your right hip. Now flex your right knee as far as you can and flex the hip. Do the same thing with you knee full extended. Is hip flexion easier or more difficult with the knee flexed or extended? What does knee flexion do to the rectus femoris that would make this muscle more efficient in flexing the hip? 2) Remain sitting and have your knees bent at 90 degrees. Now lean you trunk forward to about 45 degrees of flexion and flex you right hip. Next straighten your trunk and flex your right hip. Is there a difference in hip flexion with your trunk forward vs upright? How would this change in trunk position affect the iliopsoas and how would this affect hip flexion? 3) Lay on your left side with your left hip and knee flexed but your right lower limb straight and aligned with your trunk. Holding your right leg straight, extend your hip. Return your right leg so that it is again aligned with your trunk and now flex your right knee to 90 degrees. Now extend your right hip. Is there a difference in hip extension with the knee straight vs the knee flexed? How might knee flexion affect hip extension?

Study Questions (hip)

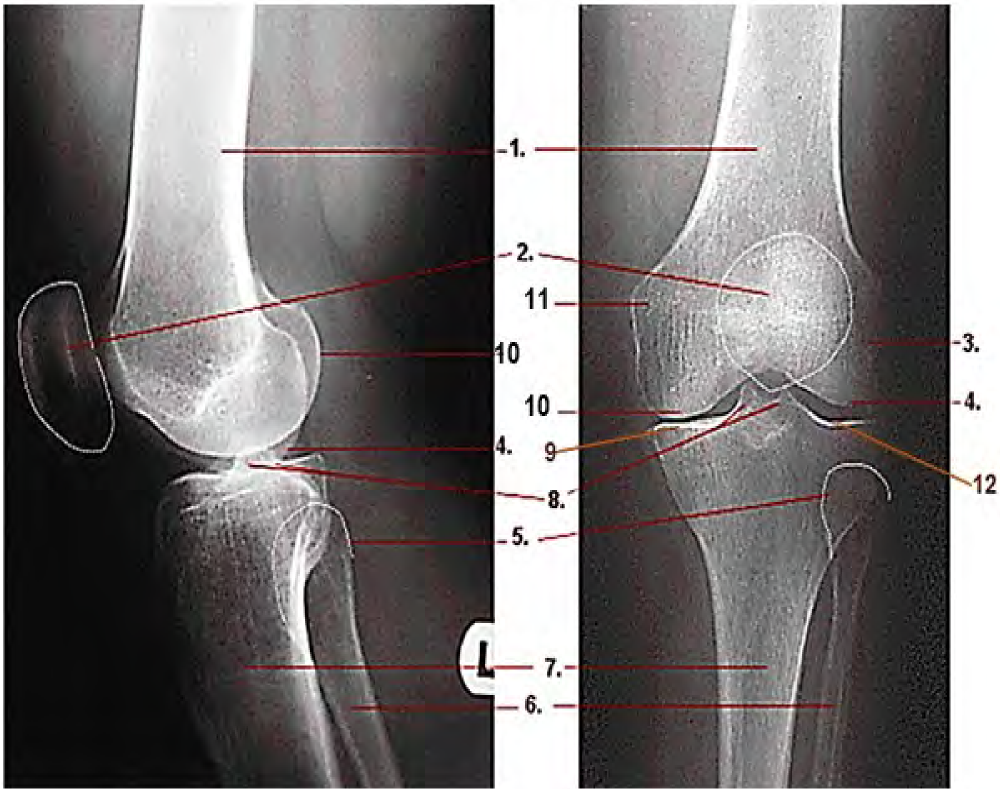
1. How do coax vara and valga differ from anteversion and retroversion?
2. How do the three femoral ligaments similar and how do they differ?
3. How much hip ROM is needed to perform most ADLs?
4. How are the arthrokinematics of the hip similar to that of the glenohumeral joint?
5. What is position of the support (pivot) hip during the following positions ofthe pelvis?
   a. anterior pelvic tilt
   b. non-support side pelvic lateral drop
   c. non-support side forward pelvic rotation
6. What are the mechanical and compensatory positions of the lumbar spine during the following positions of the pelvis?
   a. anterior pelvic tilt
   b. non-support side pelvic lateral drop
   c. non-support side forward pelvic rotation
7. During weight bearing, what strains occur at the femoral shaft and the neck?
8. What muscles produce the following hip movements?
   a. hip flexion
   b. hip extension
   c. hip abduction and internal rotation

4.2 THE KNEE

4.2.1 ANATOMY OF THE TIBIOFEMORAL JOINT

- **BONES OF THE TIBIOFEMORAL JOINT**

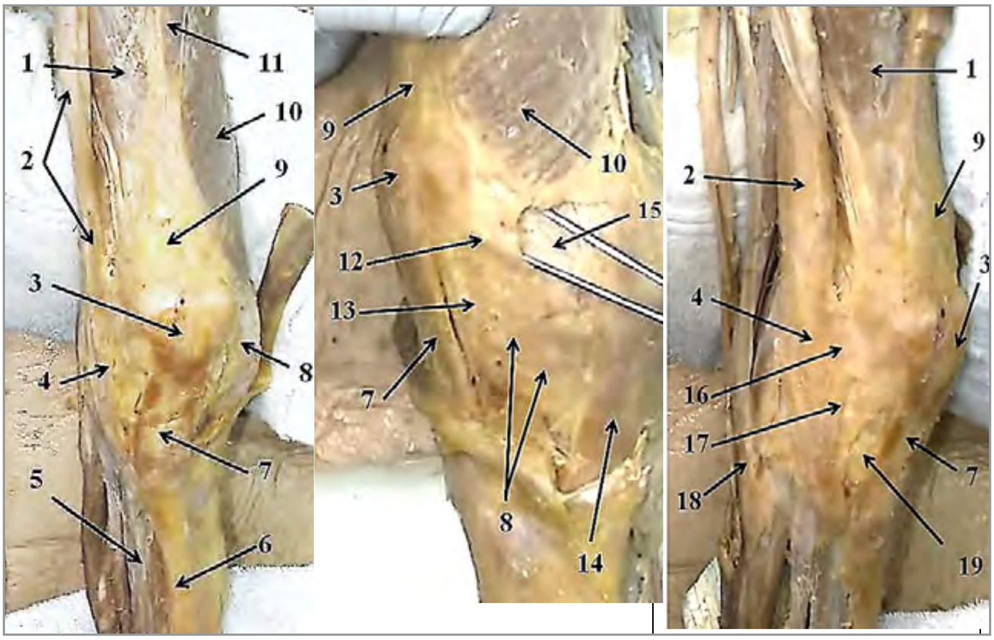
  - Medial and lateral condyles of the femur articulate with the medial and lateral condyles of the tibial plateau.



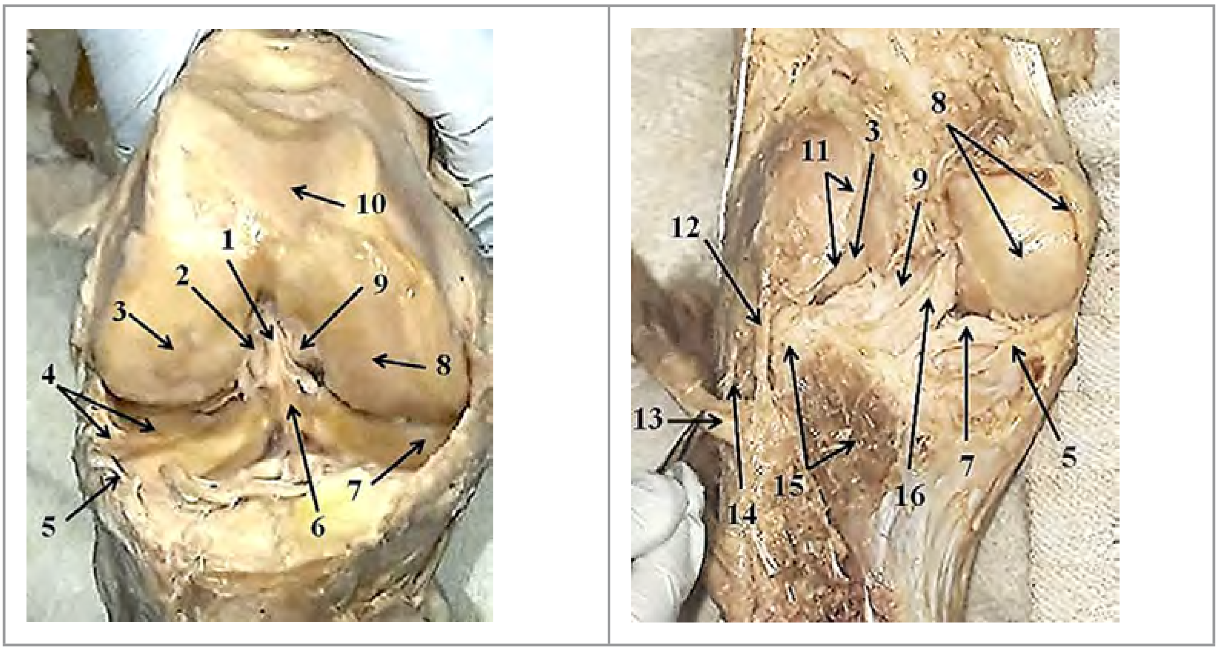
Lateral and AP radiographs of the knee. 1. Shaft of femur, 2. patella, 3. lateral epicondyle of femur, 4. lateral condyle of femur, 5. head of fibula, 6. shaft of fibula, 7. shaft of tibia, 8. intercondylar notches, 9. medial condyle of tibia, 10. medial condyle of femur, 11. medial epicondyle of femur, 12. lateral condyle of tibia.

- **LIGAMENTS OF THE KNEE**

- MEDIAL AND LATERAL COLLATERAL LIGAMENTS
  - These ligaments become tense during extension and are slack during flexion.
  - Slackness in flexion allows increases in rotation, abduction and adduction at the tibiofemoral joint.



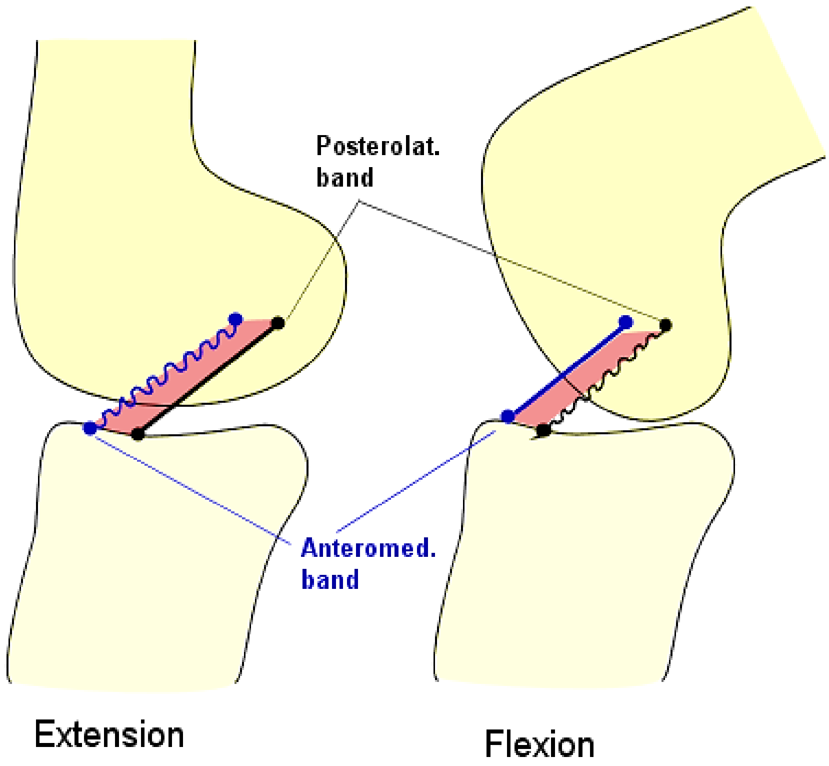
Dissection of the superficial knee in anterior view (LEFT), medial view (MIDDLE) and in lateral view (RIGHT). 1. Vastus lateralis, 2. Iliotibial band, 3. Patella, 4. Lateral retinaculum, 5. Tibialis anterior, 6. Crest of tibia, 7. Patella lig., 8. Medial retinaculum, 9. Quadraceps tendon, 10. Vastus medialis, 11. Rectus femoris, 12. Medial petellofemoral lig., 13. Medial patellotibial lig., 14. Medial collateral lig., 15. Joint capsule, 16. Lateral Patellofemoral lig., 17. Lateral petellotibial lig., 18. Tendon of biceps femoris, 19. Patella fat pad.



Dissection of knee joint. (TOP LEFT) Anterior view of the tibiofemoral articulation. (BOTTOM LEFT) Posterior view of tibiofemoral articulation. (BOTTOM RIGHT) Close up of the posterior lateral aspect of the tibiofemoral articulation. 1. Anterior medial band of the anterior cruciate lig. 2. Posterior lateral band of the anterior cruciate, 3. Wear on the lateral femoral condyle, 4. Lateral meniscus, 5. Coronary lig., 6. Intercondylar eminence, 7. Medial meniscus, 8. Medial femoral condyle, 9. Posterior cruciate, 10. Central groove for patella, 11. Joint capsule (cut), 12. Arcuate lig., 13. Tendon of biceps femoris (reflected), 14. Lateral collateral lig., 15. Popliteus, 16.Posterior meniscofemoral

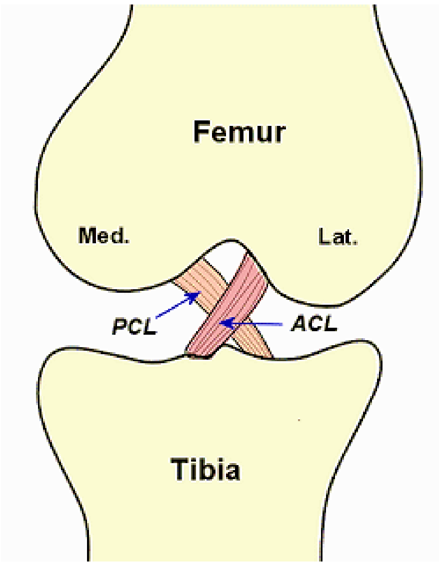
- ANTERIOR CRUCIATE LIGAMENT (ACL)
  - The anterior cruciate consists of an anteromedial band and a posterolateral band.
  - These bands function differently during knee flexion and extension.
  - Anteromedial band
    + Flexion with tibia fixed: this band is taut with maximum tension at 70 degrees of flexion.
    + Flexion with femur fixed: this band is taut.
    + Extension with tibia fixed: this band is slightly lax.
    + Extension with femur fixed: thsi band is lax.

  - Posterolateral band
    + Flexion with tibia fixed: this band is lax.
    + Flexion with femur fixed: this band is lax.
    + Extension with tibia fixed: this band is taut.
    + Extension with femur fixed: this band tightens as full extension is reached.



Drawing showing the strain on the anteromedial and posterolateral bands of the anterior cruciate ligament during extension and flexion.

- ACL limits tibial rotation
  + During knee flexion, the ACL limits medial tibial rotation by becoming tense as it winds around PCL.
  + During knee flexion, the ACL limits lateral tibial rotation by becoming tense as it stretches over lateral femoral condyle.



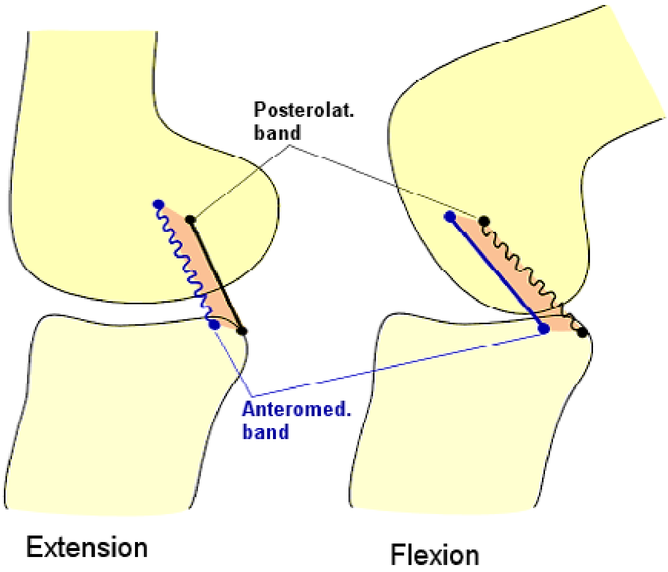
Drawing of a frontal view of the anterior cruciate ligament (ACL) and Posterior cruciate ligament (PCL) showing the crossing arrangement of the ligaments and the position to the ligament relative to the femoral condyles.

- ACL injuries
  + Anteromedial band can be injured with the knee flexed and with medial or lateral rotation of tibia.
  + Posterolateral band can be injured with the knee hyperextended.

• POSTERIOR CRUCIATE LIGAMENT (PCL)
- The posterior ccruciate also has an anteromedial band and posterolateral band that function differently.

- Anteromedial band
  + Flexion with tibia fixed: this band is taut with maximum tension at 80–90 degrees.
  + Flexion with femur fixed: this band is taut.
  + Extension with tibia fixed: this band is lax.
  + Extension with femur fixed: this band is lax.

- Posterolateral band
  + Flexion with tibia fixed: this band is lax.
  + Flexion with femur fixed: this band is lax.
  + Extension with tibia fixed: this band is taut.
  + Extension with femur fixed: this band is taut.



Drawing showing the strain on the anteromedial and posterolateral bands of the posterior cruciate ligament during extension and flexion.

TABLE SHOWING THE STAINS OF THE BANDS OF THE CRUCIATE LIGAMENTS DURING FLEXION AND EXTENSION

	Anterior cruciate	Posterior cruciate
Anteromedial Band	Flexion tight Extension lax	Flexion tight Extension lax
Posteriolateral Band	Flexion lax Extension tight	Flexion lax Extension tight

- PCL resists tibial rotation in either direction.
- PCL resist valgus and varus stress at knee.
- Tightness of posteriolateral band during extension can laterally rotate the tibia and may be important in locking the knee (screw home mechanism).
- PCL injuries
  + Anteromedial band can be injured with the knee flexed.
  + Posteriolateral band can be injured with the knee extended.

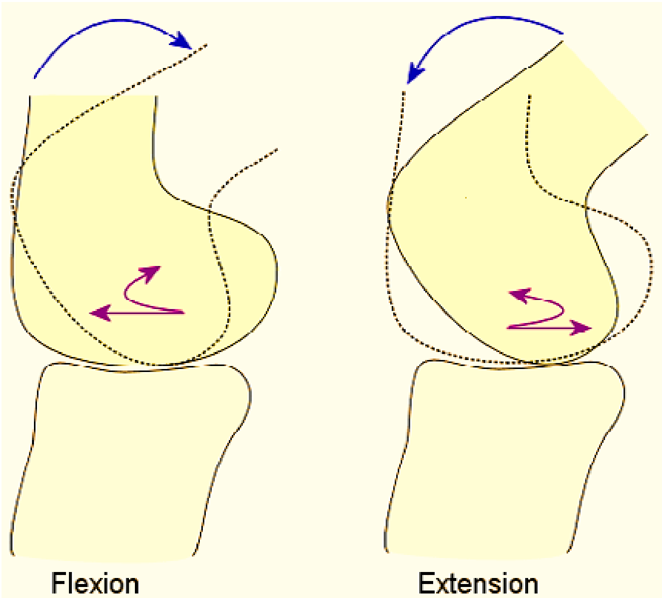
4.2.2 MOVEMENTS

- **OSTEOKINEMATICS MOVEMENTS OF THE TIBIOFEMORAL JOINT**

  - Osteokinematic ranges of motion vary depending on the reference (Norkin, White, Malone 2009; Reese and Bandy 2013).
  - The ranges shown below are commonly used ranges.
    - flexion: 0–140 degrees
    - hyperextension: 5–10 degrees are WNL but >10 degrees is genu recurvatum
    - internal and external rotation
    - at full knee extension
      + No rotation occurs as the knee is locked.
      + The fit of the matching tibial and femoral condyles mechanically locks the joint.
      + The collateral ligaments are also tight restricting rotation.
    - at 90 degrees of knee flexion
      + external rotation = 40 degrees
      + internal rotation = 30 degrees
    - at knee flexion > 90 degrees
      + Internal and external rotation decrease because of soft tissue restriction.

- during walking
  + Maximal rotation at the tibiofemoral joint is 9–10 degrees in either direction.
- abduction and adduction
  - total movement is 11 degrees
  - Most movement occurs when the knee is flexed at 30 degrees.
  - When the knee is flexed > 30 degrees, movement decreases because of soft tissue restriction.
- ROM needed for most ADLs
  - 115–120 degrees of flexion
  - good function with -5 and even -10 degrees of knee extension

- **ARTHROKINEMATIC MOVEMENTS OF THE TIBIOFEMORAL JOINT**



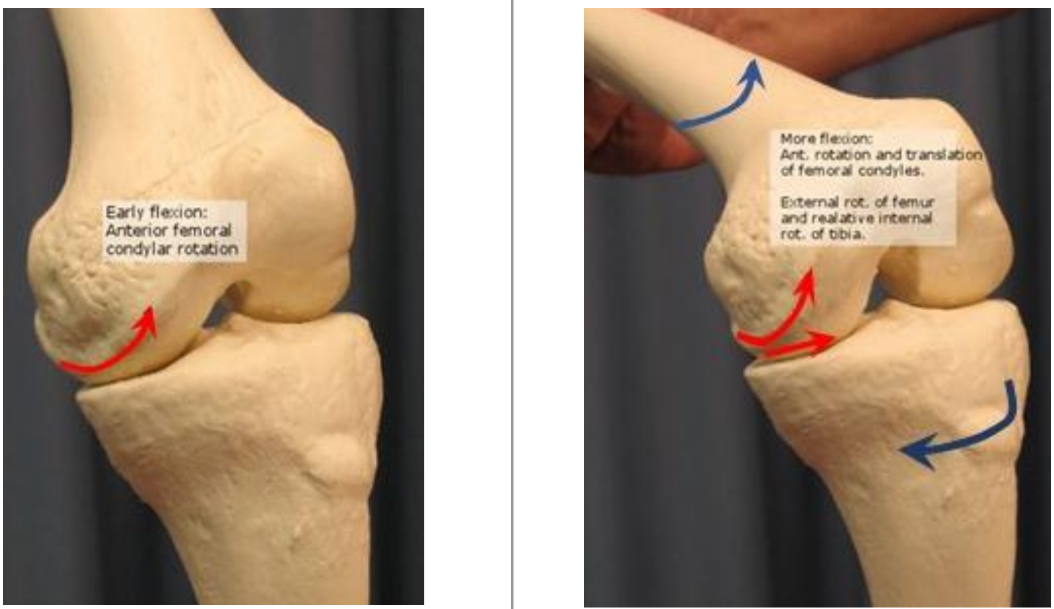
Drawing showing the arthrokinematics of the femoral condyles moving on the fixed tibia during knee flexion and extension.

- CLOSED CHAIN FLEXION or weight bearing movement occurs when the femoral condyles moving on the fixed tibia.

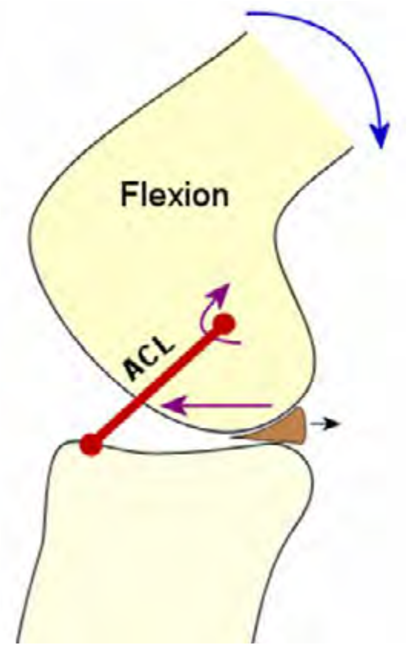
  - 0–25 degrees: anterior rotation of the articular surface of the femoral condyles (posterior roll of the femur)
  - 25–140 degrees: anterior rotation of articular surface and anterior glide of condyles
    + Anterior glide due to ACL tension.
    + Condyles slide anteriorly on the wedge shaped posterior horns of the menisci.
    + Menisci move posteriorly during flexion to keep the posterior horns of the menisci from wedging between femoral and tibial condyles.

+ Posterior horns of the menisci return to neutral position during extension when the menisci move anteriorly.
+ Loss of posterior movement of the menisci will limit flexion of the knee.

- CLOSED CHAIN FLEXION FROM FULL EXTENSION



Photographs of closed chain flexion during early flexion (LEFT) and after 45 degrees of flexion (RIGHT).

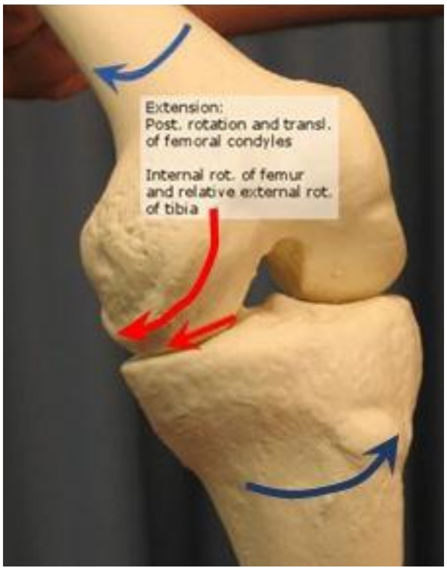


Drawing showing the arthrokinematic movements of the femoral condyles and meniscus during closed chain flexion.

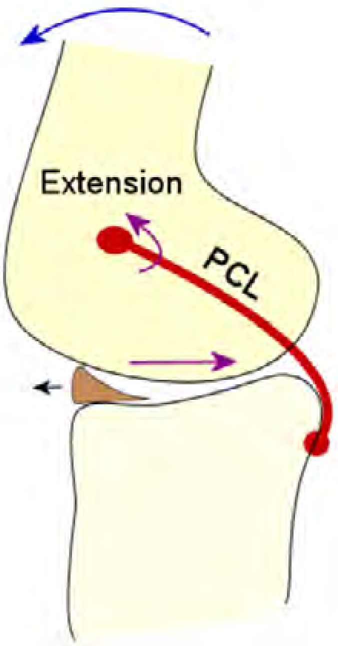
- CLOSED CHAIN EXTENSION or weight bearing movement with the femoral condyles moving on the fixed tibia.

    - 140–115 degrees (initial 25 degrees): posterior rotation of the articular surface of the femoral condyles (anterior roll of the femur).
    - 115–0 degrees: posterior rotation of the articular surface and posterior glide of the femoral condyles.
        + Posterior glide due to PCL tension.
        + The menisci move anteriorly during extension to prevent the anterior horns from wedging between the tibial and femoral condyles.
        + Anterior movement of the posterior horns will blockexcessive posterior femoral glide, preventing hyperextension.
        + Loss of anteriormovement of the menisci will limit extension of the knee.

- CLOSED CHAIN EXTENSION FROM FULL FLEXION



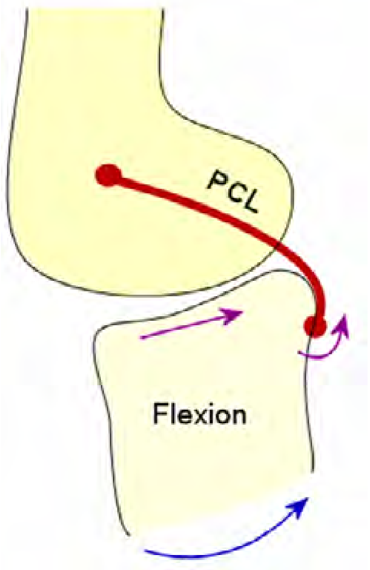
Photographs of closed chain extension starting at 90 debrees of flexion (LEFT) and extending past 45 degees (RIGHT).



Drawing showing the arthrokinematic movements of the femoral condyles and meniscus during closed chain extension

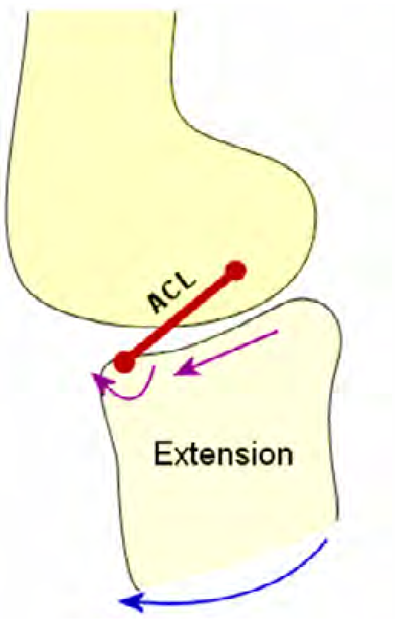
- OPEN CHAIN or non-weight bearing FLEXION and EXTENSION movements occur when the tibia moving on the fixed femoral condyles.

- OPEN CHAIN FLEXION
  - The tibia rotates and glides posteriorly.
  - PCL blocks excessive posterior glide.



Drawing showing the arthrokinematic movements of the tibia during open chain flexion

- OPEN CHAIN EXTENSION
  - The tibia rotates and glides anteriorly.
  - ACL blocks excessive anterior glide of the tibia.



Drawing showing the arthrokinematic movements of the tibia during open chain extension

- closed pack position:
  - tibiofemoral: full extension
- loose pack position:
  - tibiofemoral: 10–20 degrees of flexion

- **SCREW HOME MECHANISM**
  - This mechanical locking mechanism occurs during last 5 degrees of extension.
  - The mechanism results in maximum bilateral surface area contact between femoral and tibial condyles.
  - Because medial femoral condyle is longer than the lateral femoral condyle, either internal rotation of the femur or external rotation of the tibia is needed to attain this maximum surface contact and produce this mechanical lock.
    - Internal rotation of femur relative to a fixed tibia with closed chain or weight bearing activities.
    - External rotation of tibia relative to fixed femur with open chain activities.

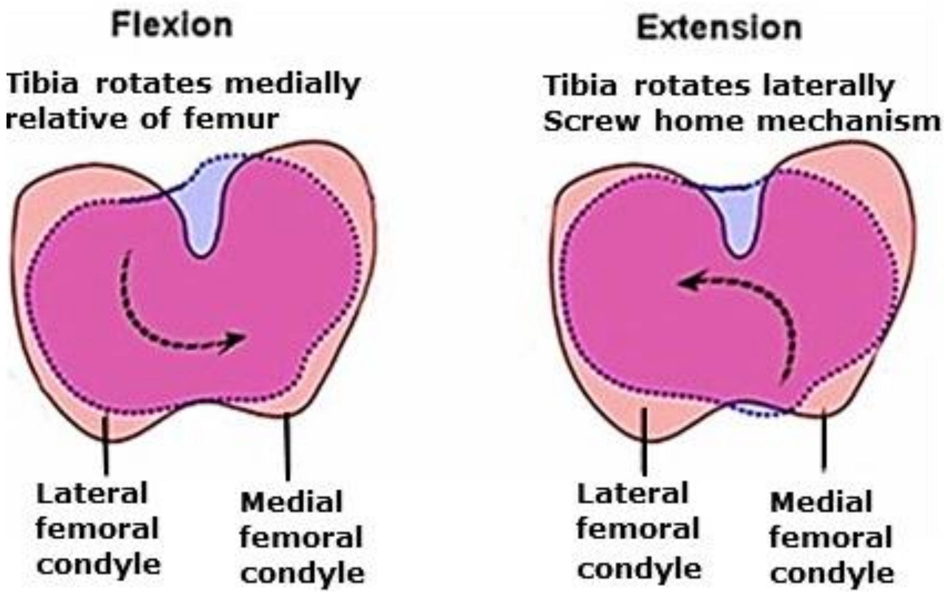
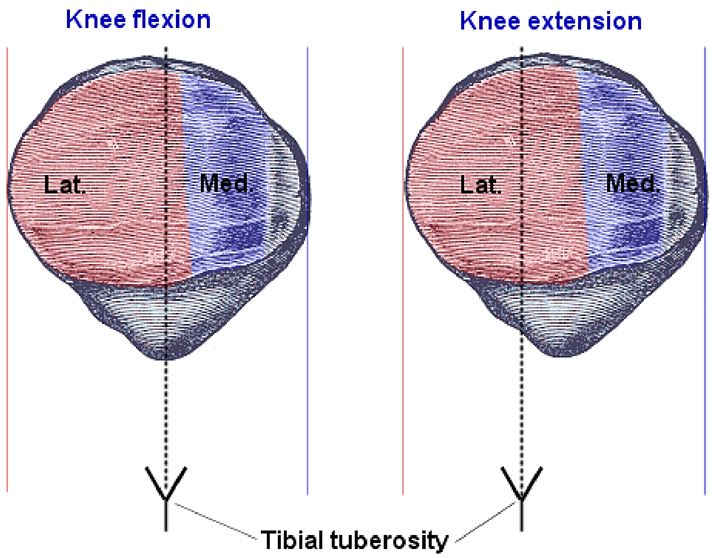


Diagram showing the position of the tibia (dotted lines) relative to the femoral condyled during flexion and with the screw home mechanism at the end of extension.

- unlocking the scew home mechanism
  - an external rotation of the femur relative to fixed tibia with closed chain or weight bearing activities
  - an internal rotation of the tibia relative to fixed femur with open chain activities
  - popliteus muscle unlocks knee with closed or open chain activities
    - + The muscle runs from the posterior medial tibia to the lateral femoral epicondyle.
    - + This arrangement enables the muscle to externally rotate the femur or internally rotate the tibia to unlock the knee.

- Helfet test
  - This test is used to determine the amount of external rotation of the tibia relative to the femur during tibiofemoral extension.
  - This is procedure for this test
    1. The patient is sitting with the hip at 90 degrees of flexion and the knee flex so that the lower leg is hanging free.
    2. Mark the medial and lateral borders of the patella and the midline of the patella and tibial tuberosity.
    3. Have the patient extend the knee fully and observe movement of the tibial tuberosity relative to the midline of the patella.

- Normally, the tibial tuberosity moves laterally during extension and realigns with the midline of the patella during flexion.



Drawing of the results of the Helfet Test showing the lateral shift of the tibial tuberosity relative to the midline of the patella during knee extension.

ACTIVITIES: 1) Sit with your right knee flexed at 90 degrees. Place the palms of your hands on the sides of your right knee. Now rotate your tibia medial and laterally by rotating your right foot medially and laterally on the floor. Can you feel the amount of tibial rotation there is at 90 degrees of knee flexion? 2) Remain seated with your right knee full extended. Again place your hands on the sides of your right knee and rotate your foot medially and laterally. Does the tibia rotate or does your lower limb rotate? What do you think is the better position of the knee, 90 degrees of flexion or full extension, to access tibial rotation? 3) While still sitting, located the midline of your right patella and your right tibial tuberosity. Now flex and extend your knee. Can you feel the tibial tuberosity moving medially during flexion and laterally during extension?

4.2.3 MUSCLES OF THE KNEE

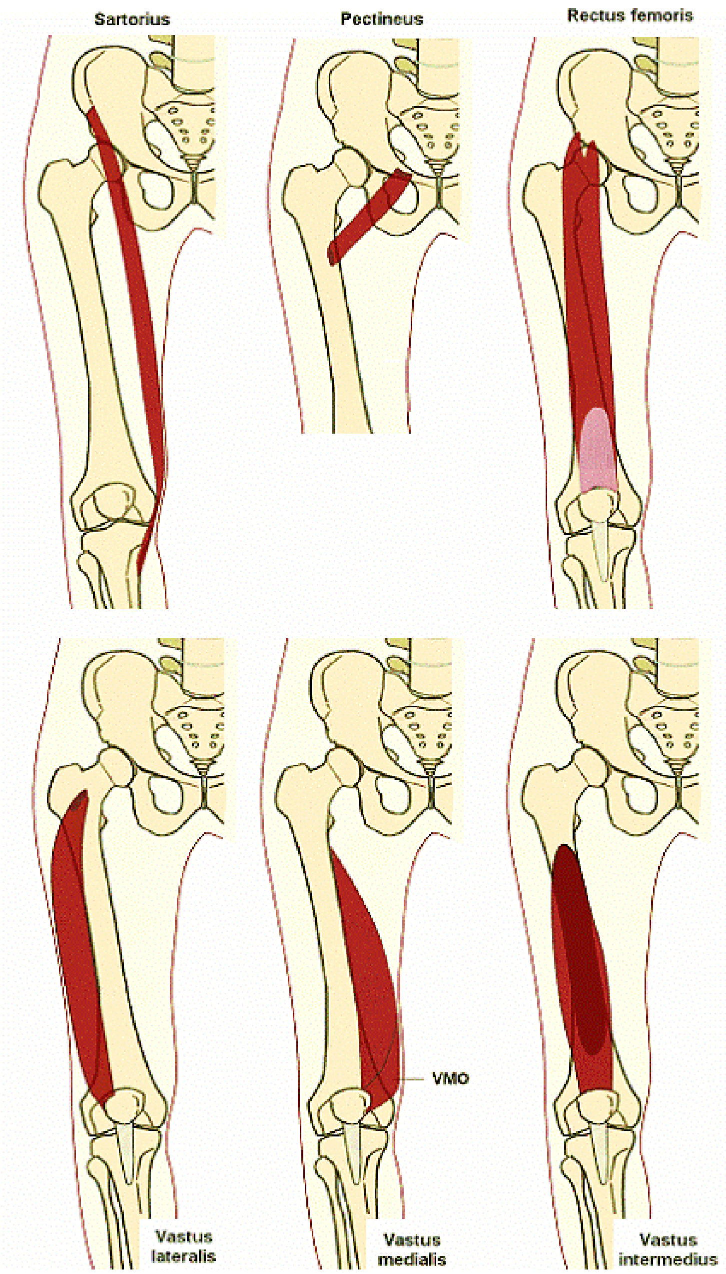
- **EXTENSORS OF THE KNEE**
  - quadriceps (rectus femoris, vastus lateralis, vastus medialis, vas intermedius)
    - The rectus femoris also flexes the hip and it's extension force is affected by hip position.
    - The vastus lateralis is the largest of the quadriceps and extends to the posterior lateral aspect of the thigh.
    - The vastus lateralis forms part of lateral patellar retinaculum with iliotibial band.

        - The vastus medialis has a distal part called the vastus medialis obliquus because of its inwardly slanting muscle fibers.
        - The vastus medialis obliquus forms the medial patellar retinaculum.
        - Vastus intermedius is deep to the vastus lateralis and medialis and lies above the articularis genu muscle.
        - The articularis genu muscle maintains the position of the suprapatellar bursa.
    - Peak quadriceps isometric torque occurs when the knee is in 50–80 degrees of flexion.
    - During the last 15 degrees of knee extension, the quadriceps must produce 60% more force than when the knee is at 90 or 45 degrees of flexion.
    - Removal of patella decreases force production by the quadriceps by 30% .

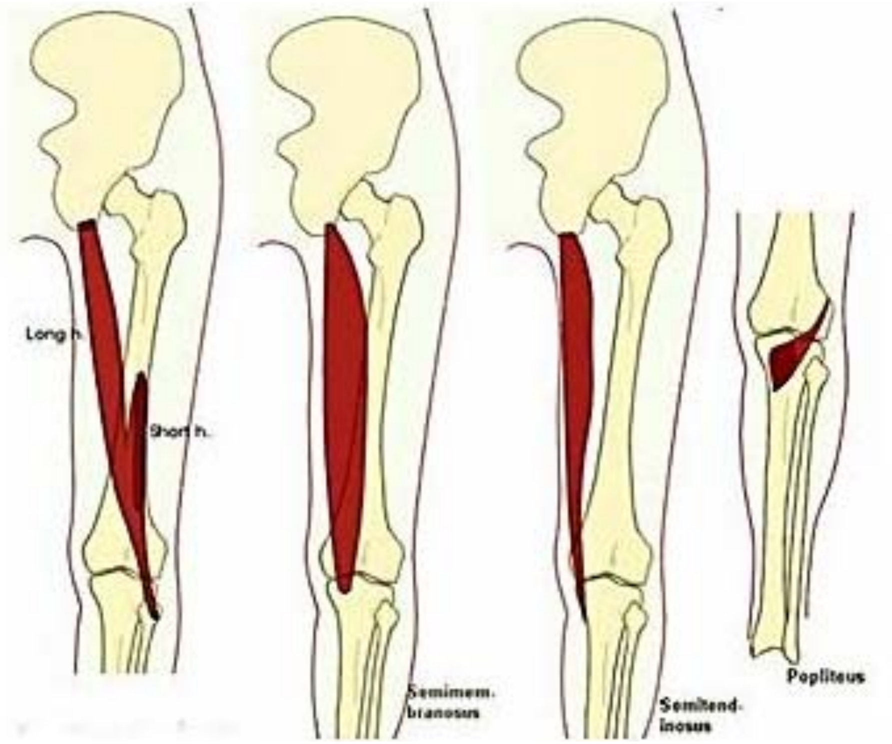
- **FLEXORS OF THE KNEE**
    - hamstrings
        - biceps femoris (lateral hamstring)
        - semitendinosus (medial hamstring)
        - semimembranosus (medial hamstring)
    - gastrocnemius
    - plantaris
    - popliteus

- **EXTERNAL ROTATORS** of the tibia relative to femur
  - biceps femoris
  - tensor fascia lata

- **INTERNAL ROTATORS** of the tibia relative to femur
  - semitendinosus
  - semimembranosus
  - popliteus
  - gracilis
  - sartorius



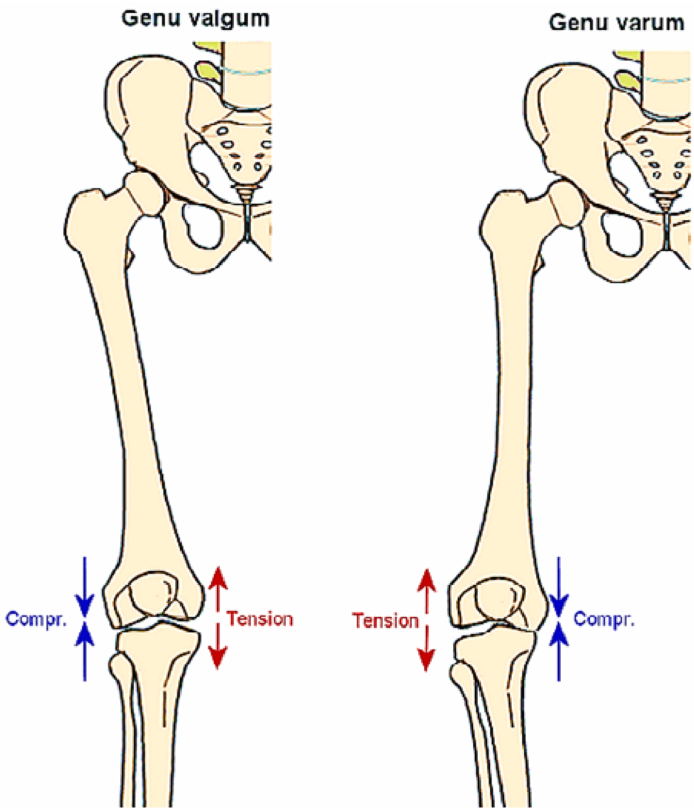
Drawing of the sartorius, pectineus and quadriceps muscles.



Drawing of the hamstrings and popliteus muscles.

4.2.4 FORCES ON THE TIBIOFEMORAL JOINT

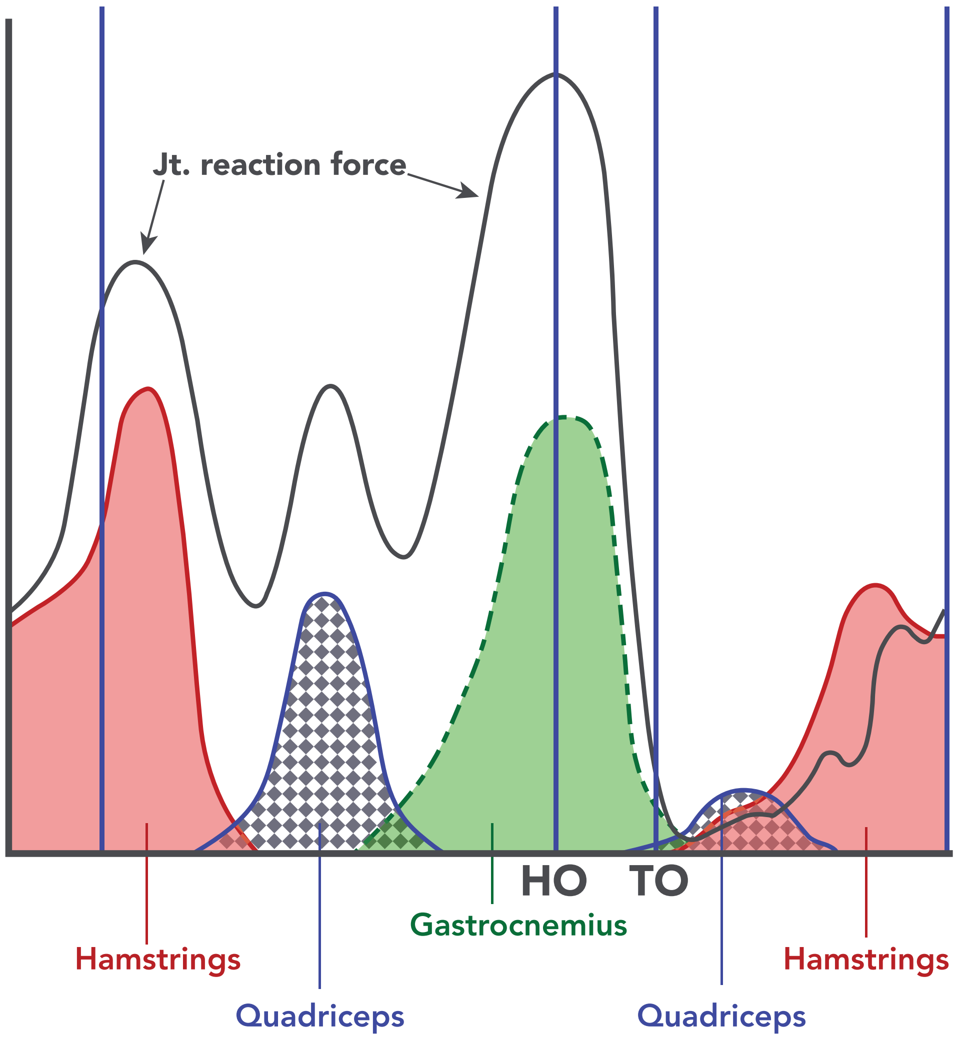
- **GENU VALGUM** (knock knees) and **GENU VARUM** (bow legs)
  - GENU VALGUM
    - The medial ligaments and joint capsule of the knee are strained in tension which results in potential tearing and elongation of these structures.
    - The lateral ligaments and joint capsule are lax and can remodel so they shorten and weaken.
    - The lateral femoral and tibial condyles are compressed which over time increases erosion of the lateral meniscus and articular cartilage with weight bearing.
    - In patients with this deformity, medial knee pain would most likely involve the medial ligaments and capsule while lateral knee pain would most likely involve articular structures.



Drawing of genu valgum and genu varum showing the forces at the knee.

- GENU VARUM
  - The strains are opposite those of genu valgum.
  - The medial ligaments and capsule would be lax and with time shorten and weaken and the medial articular surfaces compressed with increased erosion.
  - The lateral ligaments and capsule would be strained in tension and vulnerable to tearing and elongation.
  - Medial knee pain would likely involve articular structures and lateral knee pain involve the lateral ligaments and capsule.

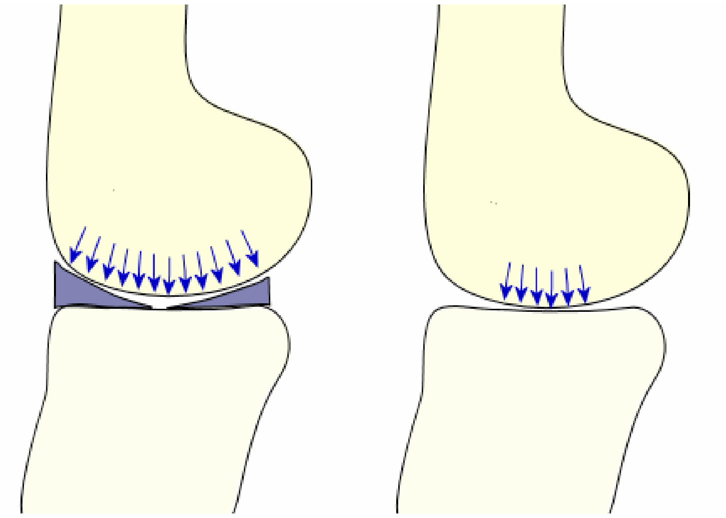
- **WALKING**



Graph showing the compression joint (jt.) reaction forces at the knee during the stance phase at heel strike (HS), midstance, heel off (HO), toe off (TO) and during the swing phase. The muscles shown contribute to the compression forces at the knee during walking (Norkin and Frankel, 2001).

- At heel strike, compression force at the knee is high because of body weight and contraction of the hamstrings acting to decelerate and control knee extension and stabilize the knee for heel contact with the ground.
- At foot flat, compression force is high because of body weight and eccentric contraction of the quadriceps controlling the degree of knee flexion to resist buckling of the knee.
- At heel off, compression force is highest because of body weight and the contraction of the gastrocnemius and soleus producing plantar flexion of the ankle to raise the heel.
- During initial swing, the compression force at the knee is low but the force increases during terminal swing as the hamstrings eccentrically contract to decelerate the extending knee.

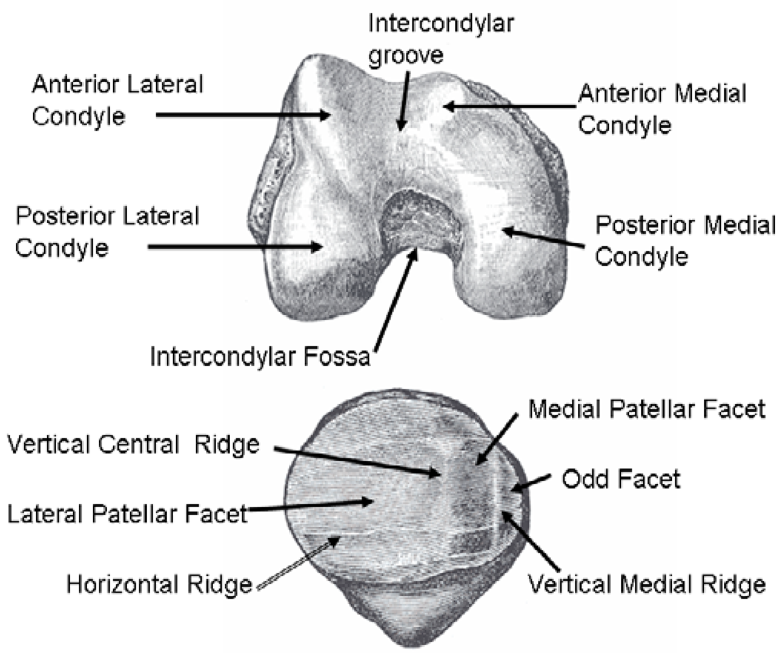
- **ROLE OF MENISCI**



Drawing showing the forces (arrows) from the femoral condyle distributing (LEFT) along the menisci and (RIGHT) when the menisci are removed. Notice that the forces are more concentrated when the menisci are removed.

- The wedge shaped menisci contour the flat tibial condyles to match the rounded femoral condyles.
- The wedge shape of the menisci increases the contact surface area for force distribution between tibial and femoral condyles and provides for an increase in joint stability (left figure).
- The increase in force distribution, decreases the unit forces on the condyles.
- The menisci are **not** shock absorbers but it is the underlying subchondral bone that absorbs compression forces at the tibiofemoral joint.
- Removal of a meniscus will produce areas of high force concentration (right figure) that can damage the articular cartilage, resulting in osteoarthritis.

4.2.5 ANATOMY OF THE PATELLOFEMORAL JOINT



Drawing of the femoral condyles (TOP) and the articular surface of the patella (BOTTOM). The patella moves in the intercondylar groove of the femur with the medial and odd patellar facets articulating with the medial femoral condyle and the large lateral patellar facet articulating with the lateral femoral condyle.

- **Q – ANGLE** (quadraceps angle)

    - This angle is measured between a line connecting the anterior superior iliac spine (ASIS) to the center of the patella and another line running from the tibial tuberosity through the center of the patella.

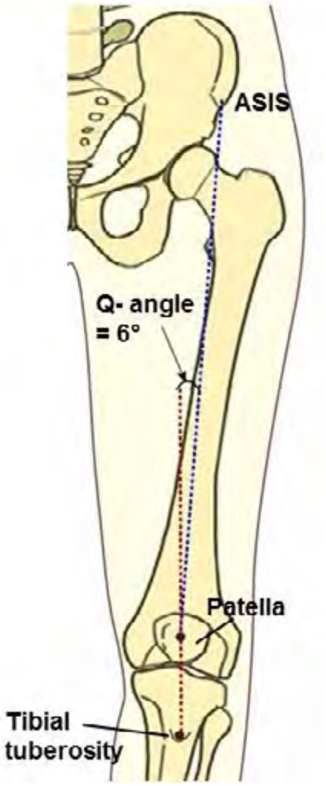


Diagram showing the lines used to measure the Q-angle.

    - A normal angle for males = 12 degrees and for females = 15 degrees.
    - An angle > 20 degrees is abnormal and results in an increase in lateral forces on patella.
    - These increase the Q-ANGLE
        - genu valgus (knock knee)
        - femoral anteversion
        - external tibial torsion
        - lateral displacement of tibial tuberosity

4.2.6 MOVEMENTS AT THE PATELLOFEMORAL JOINT

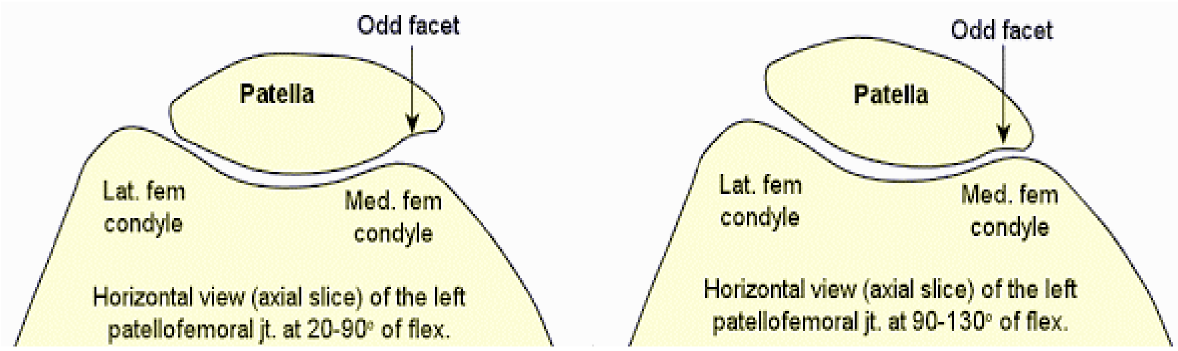


Diagram showing the horizontal movements of the patella from (LEFT) 20 -90 degrees of knee flexion and (RIGHT) from 90–130 degrees of flexion.

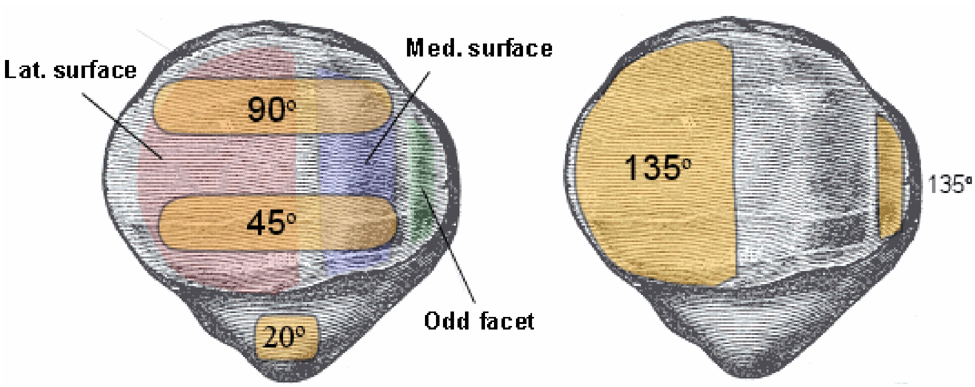
- **0–20 DEGREES OF FLEXION**
  - The tibia internally rotates, decreasing lateral pull on the patella.
  - The patella moves into intercondylar groove and follows in the groove until 90 degrees of knee flexion.
  - The contact area is mainly at the inferior pole of patella.

- **20–90 DEGREES OF FLEXION**
  - The patella moves in intercondylar groove.
  - The contact areas are along lateral and medial patellar facets with lateral and medial condyles.
  - From 70–90 degrees the quadriceps tendon contacts the region of the intercondylar groove of the femur and becomes a weight bearing structure which decreases the compressive joint reaction forces at the patellofemoral joint.

- **90–135 DEGREES OF FLEXION**
  - At > 90 degrees the patella moves laterally and tilts medially into intercondylar groove.
  - Odd facet contacts medial femoral condyle at about 135 degrees of knee flexion.
  - At full flexion, lateral femoral condyle is completely covered by the patella.
  - At full flexion, the medial femoral condyle is almost totally exposed.

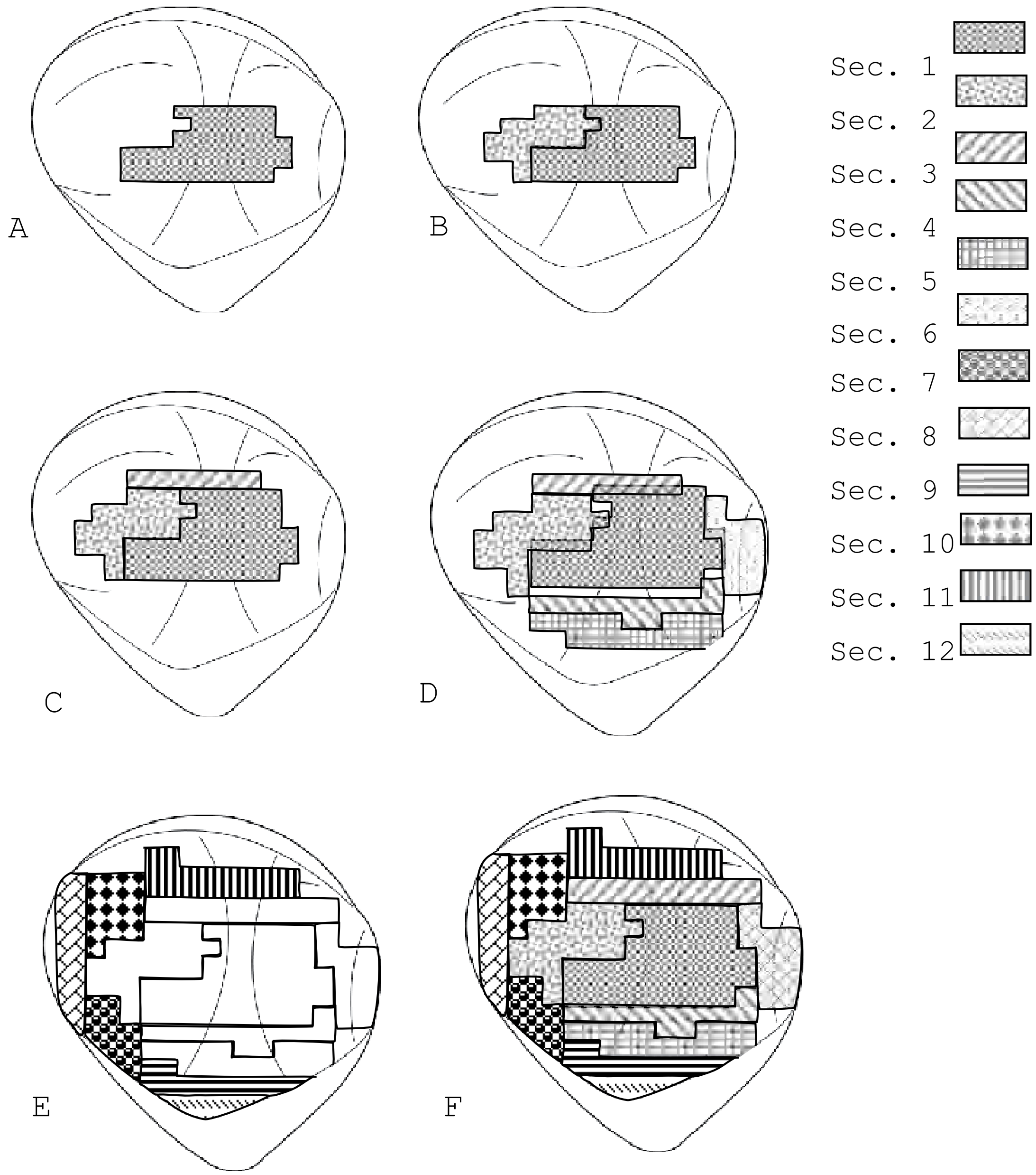
- **PATELLAR CONTACT AREAS**

20–90 DEGREES **90–135 DEGREES**

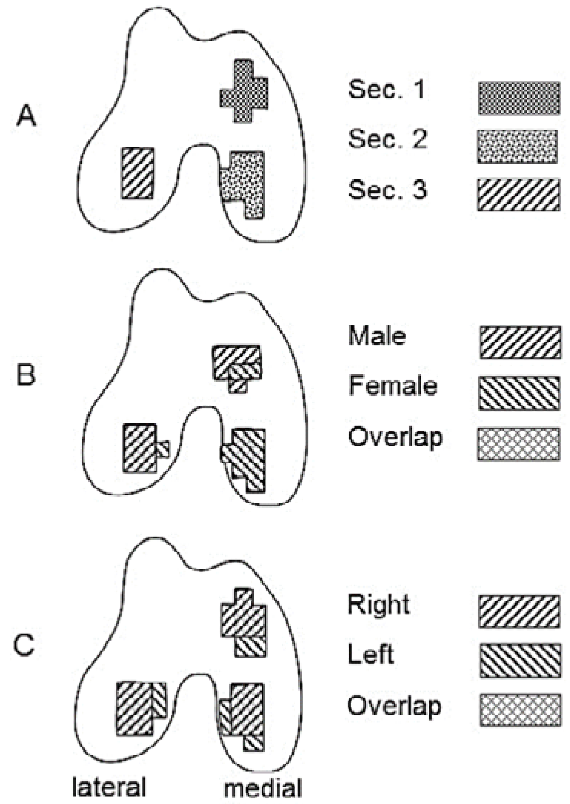


Drawing showing the ccontacts area on the patella (LEFT) at 20, 45, and 90 degrees and (RIGHT) at 135 degrees.

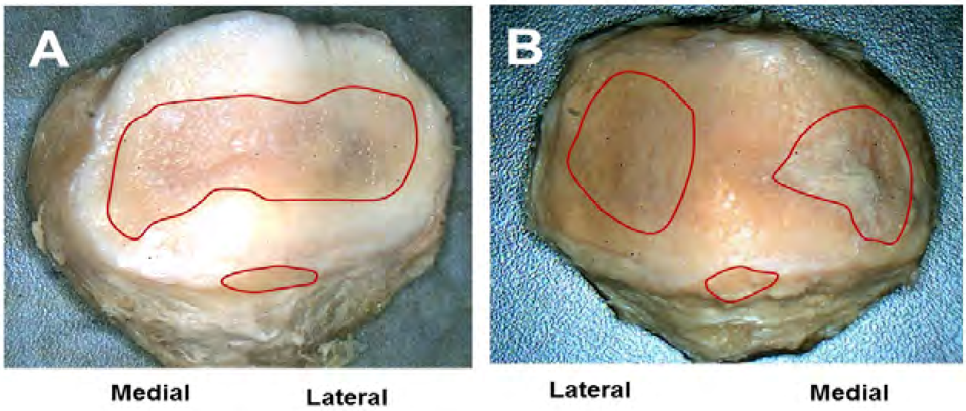
- 0–20 degrees: there is little to no contact between the patella and the femoral condyles so patellofemoral compression forces are zero to very low.
- 20 degrees: the inferior pole of the patella is in contact with the intercondylar groove of the femur but the compression forces at the joint are still relatively low.
- 45–90 degrees: the medial and lateral facets of the patella are in contact with the anterior aspect of the medial and lateral condyles of the femur and joint compression forces are higher than at 20 degrees but they are distributed over a larger surface area than at 20 degrees.
- 90 degrees: the contact with the posterior aspects of the femoral condyles and the compression forces are high but they are distributed over a large surface area which reduces the unit forces.
- 130–135 degrees: the lateral facet of the patella is in full contact with the posterior lateral condyle and compression forces there are high but distributed over a large surface area whereas the small odd facet is in contact with the medial femoral condyle where the high forces are distributed over a small area resulting in high unit forces.

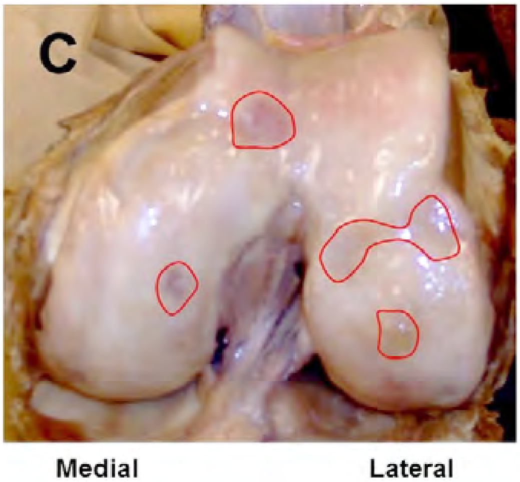


Wear patterns of the patella. Medial side of each patella is on the right. A) Section 1 is the most common area of wear. B) Sections 1 and 2 combine the 2 most common areas of wear. C) Sections 1, 2, and 3 combine the 3 most common areas of wear, D) Sections 1 through 6 combine the 6 most common areas of wear. E) Sections 7 through 12 combine the 6 least common areas of wear. F) Sections 1 through 12 combine all the sections of wear.



Drawing showing the main wear areas on the femoral condyles





Photographs showing the wear areas, encircled in red, on two patellas (A,B) and on the femoral condyles (C).

4.2.7 FORCES AT PATELLOFEMORAL JOINT

- **PATELLOFEMORAL JOINT REACTION FORCE**

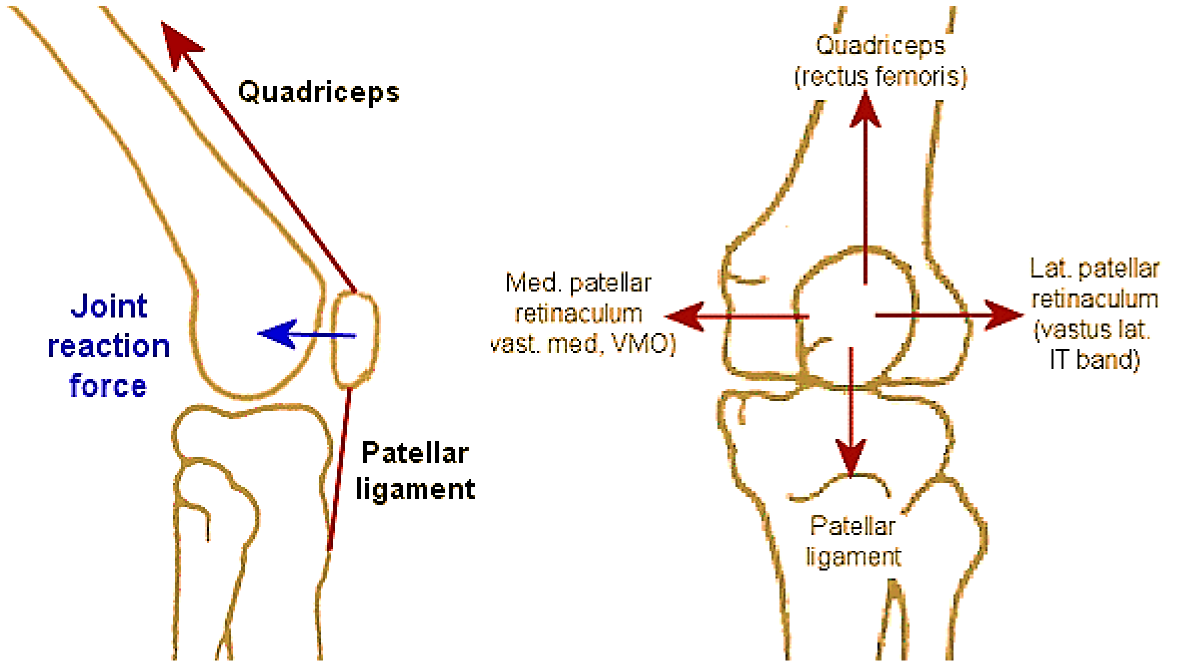


Diagram showing (LEFT) the joint reaction force between the patella and femoral condyles produced at the patellofemoral joint during flexion and (RIGHT) the directions of vertical and horizontal tension on the patella.

- As the knee flexes, quadricep tension and patellar ligament tension increase.
- Increase in quadricep and patellar ligament tension is proportional to an increase in compressive joint reaction force at the patellofemoral joint.
- From full extension to 5 degrees of flexion, compressive joint reaction forces are near 0.
- There is a significant increase in compressive joint reaction force between 45–90 degrees of knee flexion with the highest forces occurring above 90 degrees of flexion.
- As quadriceps forces increase so do compressive forces.
- Quadriceps torque forces on the patellofemoral joint during
  - level walking = 0.5 × BW
  - stair climbing = 3–4 × BW
  - squatting = 7–8 × BW

- **FORCES ACTING ON PATELLA**
  - normal forces
    - Rectus femoris and vastus intermedius pull the patella upward (cranially).
    - Lateral patellar retinaculum formed by the vastus lateralis and IT band pull the patella laterally.
    - Medial patellar retinaculum formed by the vastus medialis obliquus pull the patella medially.
    - Patella ligament attaching the patella to the tibia pulls the patella downward (caudally).

  - factors producing abnormal patellar motion
    - Tightness of IT band will shift patella excessively laterally.
    - Weakness of vastus medialis obliquus will cause a muscle imbalance between vastus medialis and vastus lateralis and shift the patella excessively laterally.
    - Tightness of the rectus femoris will hold the patella cranially increasing inferior patella compression and anterior femoral condylar compression and increase the patellofemoral joint compression forces as knee flexion increases.

- Shift in the insertion site of the patella ligament
  + factors increasing external tibial rotation and Q-Angle
    i. IT band tightness
    ii. biceps femoris tightness
    iii. semimembranosus and semitendinosus weakness
  + Increasing the Q-Angle will increase lateral compression force causing an increase in lateral patellar facet and lateral femoral condylar wear.
  + factors increasing femur internal rotation and Q-Angle
    i. femoral anteversion
    ii. excessive pronation of the foot which internally rotates tibia and femur
- change in the length of the patellar ligament
  + patella alta
    i. ligament 20% longer than patella (ligament length should be equal to patella length)
    ii. mainly observed in females
    iii. results in subluxation and dislocation of the patella
  + patella baja
    i. ligament 20% shorter than patella
    ii. problem that can occur with ACLR when a central patella ligament graft used as the ligament can shorten as it heals

ACTIVITIES: 1) Sit with your right leg relaxed and supported at the ankle and the right knee fully extended. Grasp the sides of your patella and move your patella medially and laterally. Does it move fairly easily? In this position the ground reaction forces at the patellofemoral joint are zero or very little so the patella should be easy to move. 2) Remain seated but now flex your right knee to 90 degrees and relax. Again grasp the sides of the patella and move it medially and laterally. Are the movements greater or lesser than in activity #1? In this position the joint reactions are greater than in #1 and so the movements should be less. 3) Now stand and position both of your lower limbs in a knocked knee position. Can you see that the structures on the medial sides of your knees are stretched in tension and the structures on the lateral sides compressed? Do you think this position would also increase compress at the lateral tibiofemoral joint and accelerate lateral joint wear? Look at you ankles and notice the position of your ankles when your foot is flat on the ground. Is the medial side of the ankle compressed and lateral side stretch? Do your think that a patient with knocked knees may also have ankle problems? 4) Repeat activity #3 but now position your knees in a bow-legged position. What are the forces at the knees? How about the position of your ankles?

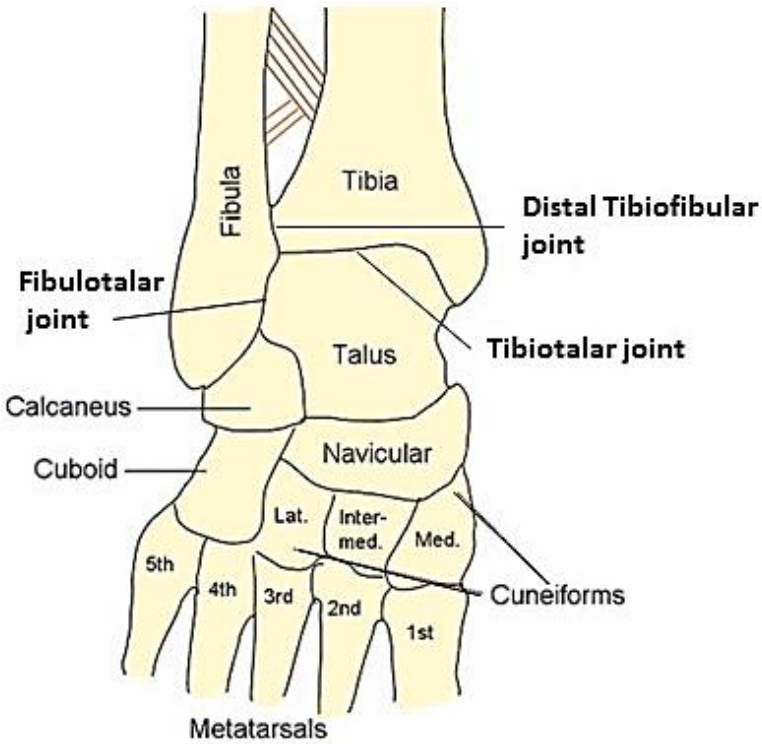
Study Question (knee)

1. What are the functions of the collateral and cruciate ligaments?
2. How do closed chain and open chain flexion differ?
3. How do closed chain and open chain extension differ?
4. How does the tibiofemoral joint lock in extension and unlock?
5. What muscles acting on the knee have multiple actions?
6. Explain the forces occurring at the knee during heel strike (HS), midstance, and heel off (HO)?
7. How do the functions of the menisci and cruciate ligaments differ?
8. How do the following increase the Q-angle and why?
   a. genu valgus
   b. femoral anteversion
   c. external tibial torsion
9. How does movement of the patella during knee flexion relate to the areas of contact between the patellar and femoral condyles?
10. How do the patellar retinacula affect patellar movement and forces?

4.3 THE ANKLE (TALOCRURAL) JOINT

4.3.1 ANATOMY OF THE ANKLE JOINT COMPLEX

- **JOINTS OF THE ANKLE**



Drawing showing the distal tibiofibular, fibulotalar and the tibiotalar joints that form the ankle complex.

- DISTAL TIBIOFIBULAR JOINT
  - a fibrous type joint
  - It lies just superior to ankle joint.
  - The articulation is between a triangular roughened area on the medial distal fibula and the fibular notch on the lateral distal tibia.

- FIBULOTALAR JOINT
  - lateral part of the synovial ankle joint
  - The articulation is between the malleolar articular surface on the medial aspect of the lateral malleolus with the lateral surface of the trochlea of the talus.

- TIBIOTALAR JOINT
  - superior and medial part of the ankle joint
  - The articulation is between the inferior articular surface of the tibia and the malleolar articular surface on the lateral aspect of the medial malleolus with the superior and medial surfaces of the trochlea of the talus.

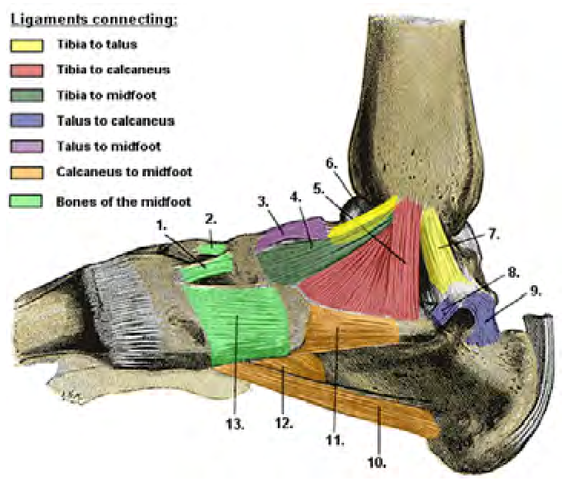
- THE MORTISE
  - This is the inverted "U" shaped cup formed by the articular surfaces of the lateral and medial malleoli and the inferior surface of the tibia.
  - It forms a cup over the trochlea of the talus and is important in ankle stability in dorsiflexion.

- **LIGAMENTS OF THE ANKLE**

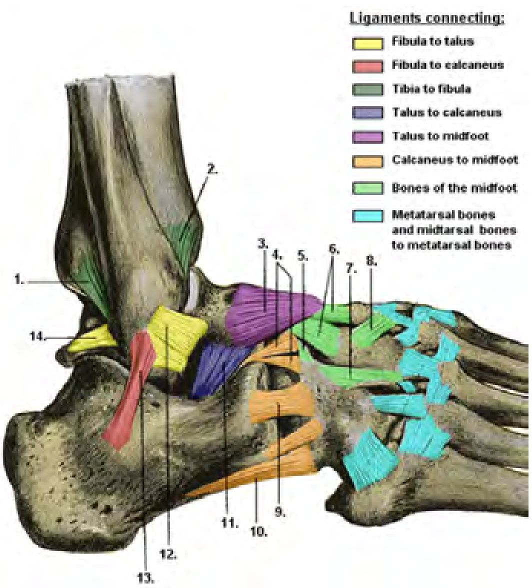
  - TIBIOFIBULAR JOINT LIGAMENTS
    - anterior tibiofibular ligament
    - posterior tibiofibular ligament
    - interosseous tibiofibular ligament

  - FIBULOTALAR JOINT LIGAMENTS
    - lateral collateral ligament
    - This ligament has 3 parts:
      1. anterior talofibular ligament
      2. posterior talofibular ligament
      3. calcaneofibular ligament

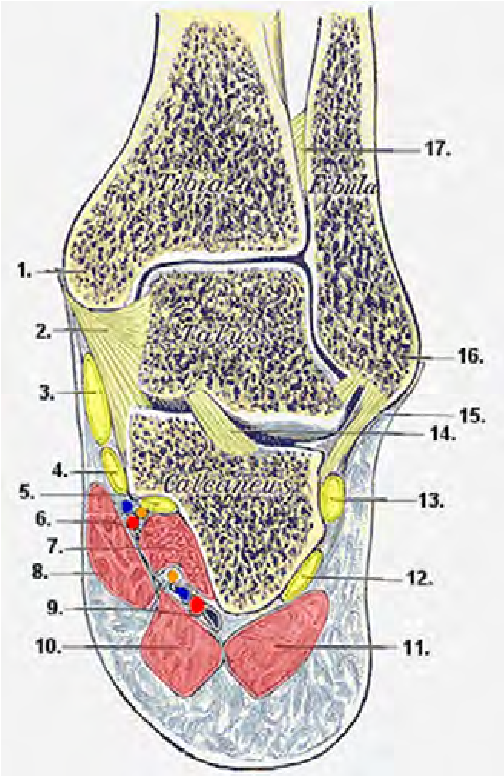
  - TIBIOTALAR JOINT LIGAMENTS
    - medial collateral or deltoid ligament
    - This ligament has 4 parts:
      1. anterior tibiotalar ligament
      2. posterior tibiotalar ligament
      3. tibionavicular ligament
      4. tibiocalcaneal ligament



Foot and ankle ligaments: Medial aspect of foot and ankle. 1. 1st dorsal cuneonavicular ligament, 2. 2nd dorsal cuneonavicular ligament, 3. talonavicular ligament, 4. tibionavicular ligament, 5. tibiocalcaneal ligament, 6. anterior tibiotalar ligament, 7. posterior tibiotalar ligament,, 8. medial talocalcaneal ligament, 9. posterior talocalcaneal ligament, 10. long plantar ligament, 11. plantar calcaneonavicular (spring) ligament, 12. calcaneocuboid ligament (short plantar) and 13. cuneonavicular ligament (Modified from Gray 1918)



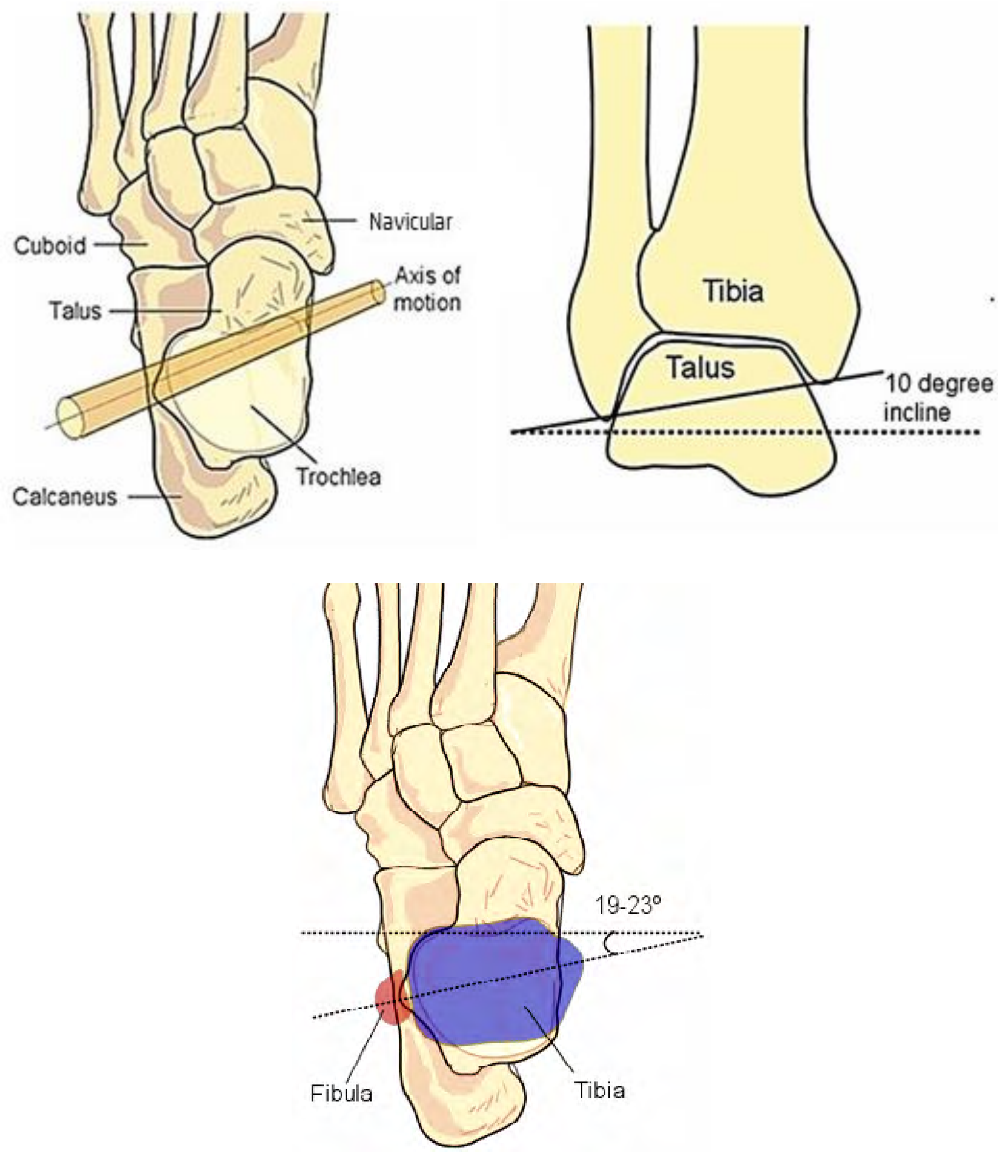
Foot and Ankle Ligaments: Lateral aspect of foot and ankle. 1. Posterior and 2. anterior tibiofibular ligament, 3. dorsal talonavicular ligament, 4. bifurcate ligament, 5. dorsal cuboideonavic. ligament, 6. dorsal cuneonavic. ligaments, 7. dorsal cuneocuboid ligament, 8. dorsal intercuneiform ligament, 9. dorsal calcaneocuboid ligament, 10. long plantar ligament, 11. interosseous talonavicular ligament, 12. anterior talofibular ligament, 13. calcaneofibular ligament, and 14. posterior talofibular ligament. (Modified from Gray 1918)



Cross section through the inferior tibiofibular, ankle, and subtalar joints. 1. Medial malleolus, 2. medial tibiocalcaneal ligament. Tendons of: 3. tibialis posterior, 4. flexor digitorum longus, and 5. flexor hallucis longus. 6. medial plantar nerves and vessels, 7. quadratus plantae, 8. abductor hallucis, 9. lateral plantar nerve and vessels, 10.flexor digitorum brevis, 11. abductor digiti quinti, 12. tendon of fibularis longus, 13. tendon of fibularis brevis, 14. interosseus talocalcaneal ligament, 15. calcaneofibular ligament, 16. lateral malleolus, and 17. tibiofibular syndesmosis. (Modified from Gray 1918)

4.3.2 MOVEMENTS

- **AXIS OF ANKLE JOINT MOTION**
  - Ankle movement occurs about an axis that is at an angle to all three cardinal planes.
    - This axis runs anterior to posterior from the medial to the lateral side of the trochlea of the talus in the sagittal and transverse planes.
    - It also runs at a 10 degree decline from the medial malleolus superiorly to the lateral malleolus inferiorly.



Drawing showing the axis of motion of the sagittal, transverse and frontal planes. Notice that the axis is at an angle to all three cardinal planes so the ankle has a component of flexion and extension in the sagittal plane, inversion and eversion in the frontal plane, and rotation in the transverse plane. (Modified from Norkin and Frankle 1989, 2001)

- This angulation results in the lateral malleolus of the fibula moving a greater distance in an anterior and posterior direction than the medial malleolus of the tibia during sagittal plane movement (see bottom picture above).
- This angulation also results in sagittal plane dorsiflexion and plantar flexion being coupled with internal and external rotation in the transverse plane and inversion and eversion in the frontal plane.
- This simultaneous movement in all three cardinal planes is called **triplanar movement**.

- **OSTEOKINEMATIC MOVEMENTS**
  - Osteokinematic ranges of motion vary depending on the reference (Norkin, White, Malone 2009; Reese and Bandy 2013).
  - The ranges shown below are commonly used ranges.
  - The primary osteokinematic movements at the ankle joint are dorsiflexion and plantar flexion.
  - Because dorsiflexion and plantar flexion are coupled with other movements, these terms are inaccurate.
  - The terms pronation and supination are used to describe these triplanar movements.

  - PRONATION is the combination of
    - dorsiflexion
    - external rotation or abduction
    - eversion

  - SUPINATION is the combination of
    - plantar flexion
    - internal rotation or adduction
    - inversion

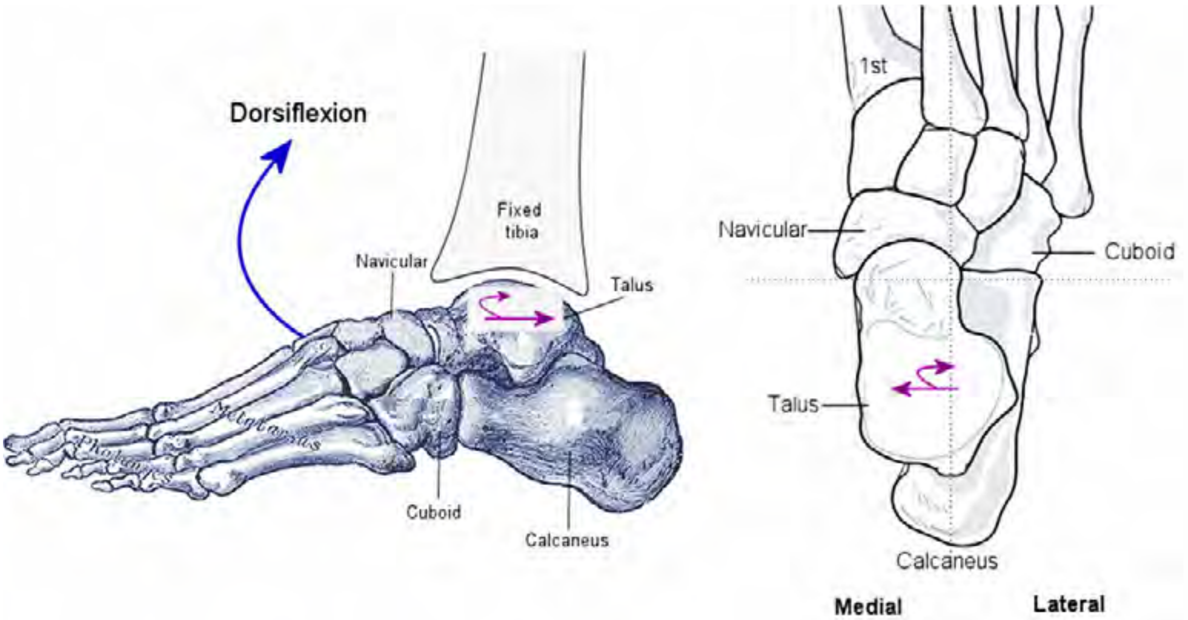
  - DEGREES OF MOTION in each plane
    - dorsiflexion in the sagittal plane = 20 degrees
    - plantar flexion in the sagittal plane = 50 degrees
    - rotation in the transverse (IR or ER of tibia on talus) = 11 degrees maximum
    - Eversion and inversion in the frontal plane is slight; most foot inversion and eversion occurs at the subtalar and midtarsal joints of the foot.

- **ARTHROKINEMATIC MOVEMENTS**

    - As in the knee, the ankle also has open and closed chain movements.
    - Because of the complex triplannar movements of the ankle, the descriptions of arthrokinematic movements will start with open chain pronation and supination.

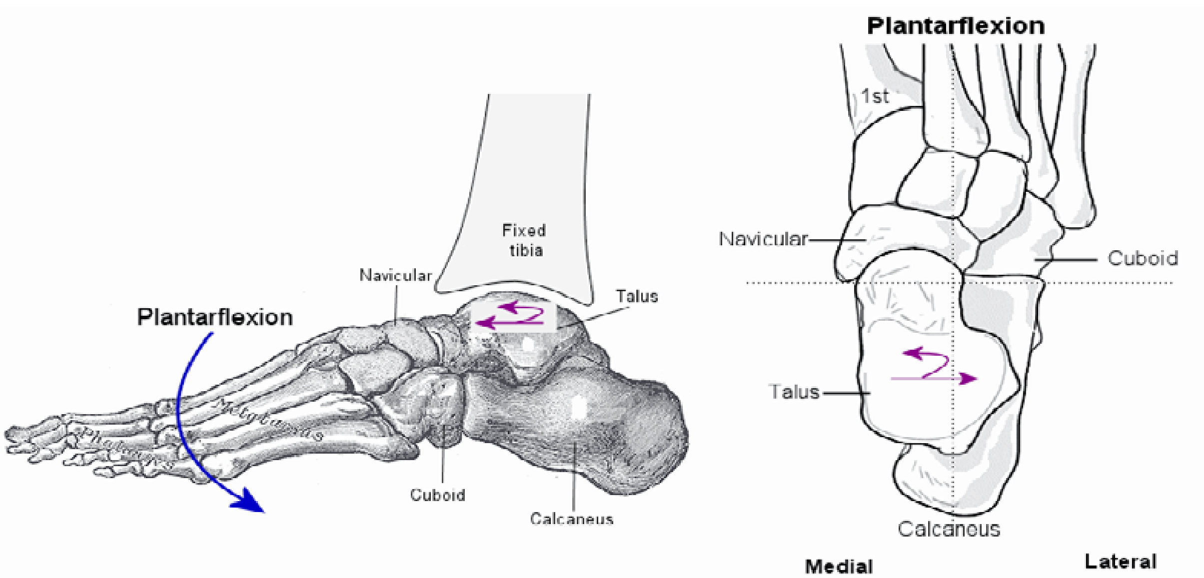
    - OPEN CHAIN MOVEMENTS
        - In open chain movements, the talus is moving on fixed tibia/fibula.
        - Open chain pronation and supination will describe movements of the talus relative to the tibia/fibula.

    - OPEN CHAIN PRONATION
        - Dorsiflexion is the result of
          + posterior rotation of talus couples with posterior glide of talus
        - External (lateral) rotation of talus
        - Eversion is produced by medial glide of talus relative to the tibia
        - **Dee** is a way to remember these 3 components of pronation.



Drawing showing the components of open chain pronation for dorsiflexion (LEFT) and rotation and eversion (RIGHT).

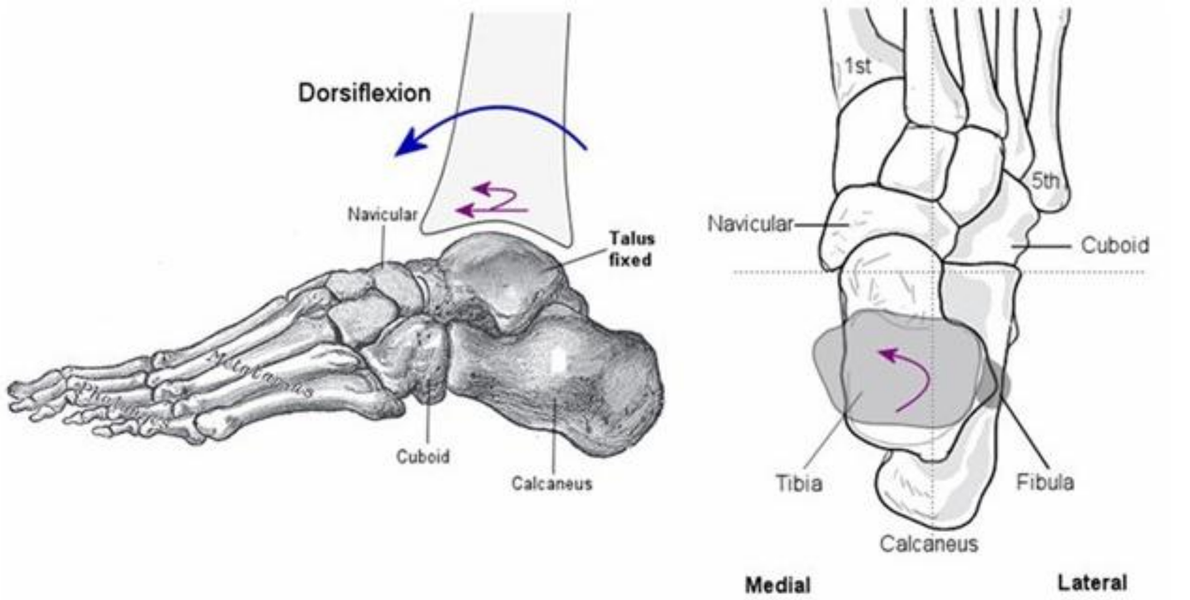
- OPEN CHAIN SUPINATION
  - Plantar flexion is the result of
    + anterior rotation of talus coupled with an anterior glide of talus
  - Internal rotation of talus
  - Inversion is produced by lateral glide of talus.
  - **Pii** is a way to remember these components of supination.



Drawing showing the components of open chain supination for plantar flexion (LEFT) and rotation and inversion (RIGHT).

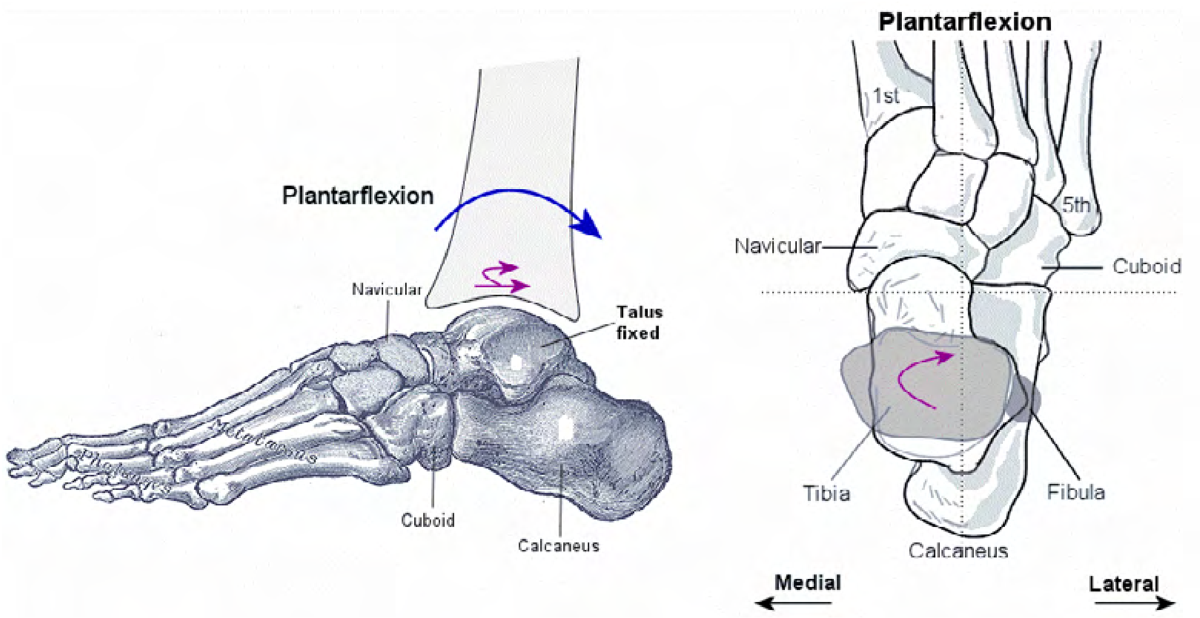
- CLOSED CHAIN MOVEMENTS
  - In closed chain or weight bearing ankle motion, the tibia/fibula move on a fixed talus.
  - All movements below describe movements of the tibia/fibula relative to the talus which is opposite that for the open chain movements described above.
  - Because the reference points have reversed with closed chain movements, the directions of arthrokinematic movements are also reversed compared to the open chain movements.
  - However, this difference in the reference points does not change the actual movements that are occurring at the ankle.
  - The actual movements are the same for both open and closed chain movements and it is only the description of motion that changes because the reference points for describing the movement are different.

- CLOSED CHAIN PRONATION
  - Dorsiflexion is the result of
    + Anterior rotation of the tibia/fibula couples with an anterior glide of tibia/fibula
    + In both open and closed chain pronation, there is a dorsiflexion component of movement.
  - Internal rotation of tibia/fibula
  - Inversion is produced by lateral glide of the tibia/fibula which is slight to none due to joint compression.



Drawing showing the components of closed chain pronation for dorsiflexion (LEFT)and rotation (RIGHT). The inversion component is not shown as it is negligible.

- CLOSED CHAIN SUPINATION
  - Plantar flexion is the result of
    + posterior rotation of the tibia couples with posterior glide of the tibia
  - External rotation of tibia
  - Eversion is produced by medial glide of the tibia/fibula which is slight to none due to joint compression.

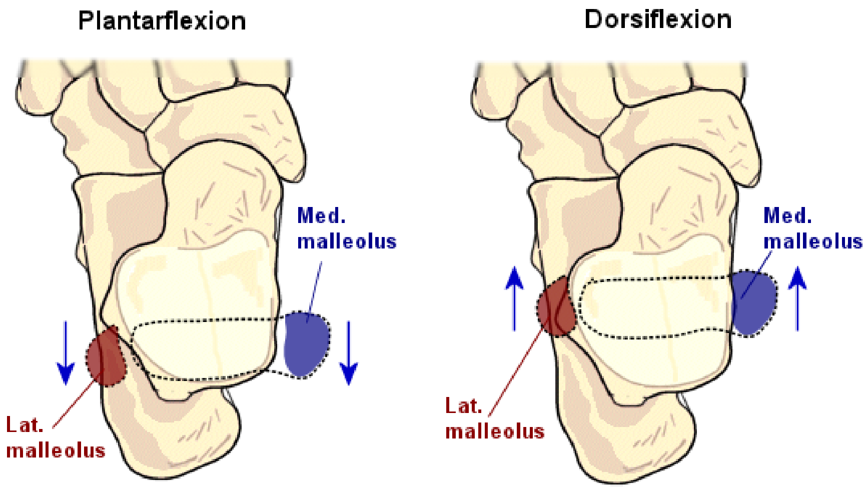


Drawing showing the components of closed chain supination for plantar flexion (LEFT) and rotation (RIGHT). The eversion component is not shown as it is negligible.

- **ANKLE STABILITY**

  - DORSIFLEXION AND PLANTAR FLEXION STABILITY

    - The wide anterior part of the talus results in a tight fit of mortise over the trochlea and stability of the ankle in dorsiflexion.
    - The narrow posterior part of the talus results in a loose fit of mortise over the trochlea in plantar flexion.
    - Because of the fit of the mortise on the trochlea, the ankle is more stable in dorsiflexion than plantar flexion.



Drawing of the position of the lateral and medial malleoli relative to the talus when the ankle is in planter flexion (LEFT) and dorsiflexion (RIGHT). The dotted area represents the mortise. Notice the tight position of the malleoli and mortise during dorsiflexion and compared to plantar flexion.

- Ankle stability during dorsiflexion and plantar flexion is dependent also on tibiofibular joint integrity.
  + Looseness of tibiofibular joint because of a fracture of fibula or tearing of the interosseous membrane may increase the size of the mortise and reduce ankle stability.
  + Restriction or fusion of tibiofibular joint because of a malleolar fracture repair may reduce the size of the mortise and restrict dorsiflexion.

o INVERSION AND EVERSION STABILITY
- During closed chain or weight-bearing activities, stability of the ankle in inversion and eversion is provided mainly by compression of the matching articular surfaces.
- During open chain or non-weight-bearing activities, inversion and eversion stability of the talus relative to the tibia/fibula is provided mainly from collateral ligaments.
  + inversion stability
    i. 87% of the stability is provided by lateral collateral ligaments.
    ii. The calcaneofibular ligament ranks first for providing stability.
    iii. The anterior talofibular ligament ranks 2nd for stability.
    iv. The posterior talofibular ligament provides the least amount of stability.
  + eversion stability
    i. 83% of the stability is provides by the medial (deltoid) ligament.

- INTERNAL AND EXTERNAL ROTATION STABILITY
  - During open and closed chained internal and external rotation, stability is provided mainly by parts of the lateral and medial collateral ligaments.
  - During open chain or non-weight bearing activities, internal rotation of the talus relative to the tibia/fibula is stabilized mainly by the
    + the anterior talofibular ligament (LCL)
    + the posterior tibiotalar ligament (MCL)
  - During open chain or non-weight bearing activities, external rotation of the talus relative to the tibia/fibula is stabilized mainly by the
    + posterior talofibular ligament (LCL)
    + anterior tibiotalar ligament (MCL)
  - During closed chain or weight bearing activities, internal rotation of the tibia/fibula relative to the talus is stabilized mainly by the
    + posterior talofibular ligament (LCL)
    + calcaneofibular ligament (LCL)
    + anterior tibiotalar ligament (MCL)
    + tibionavicular ligament (MCL)

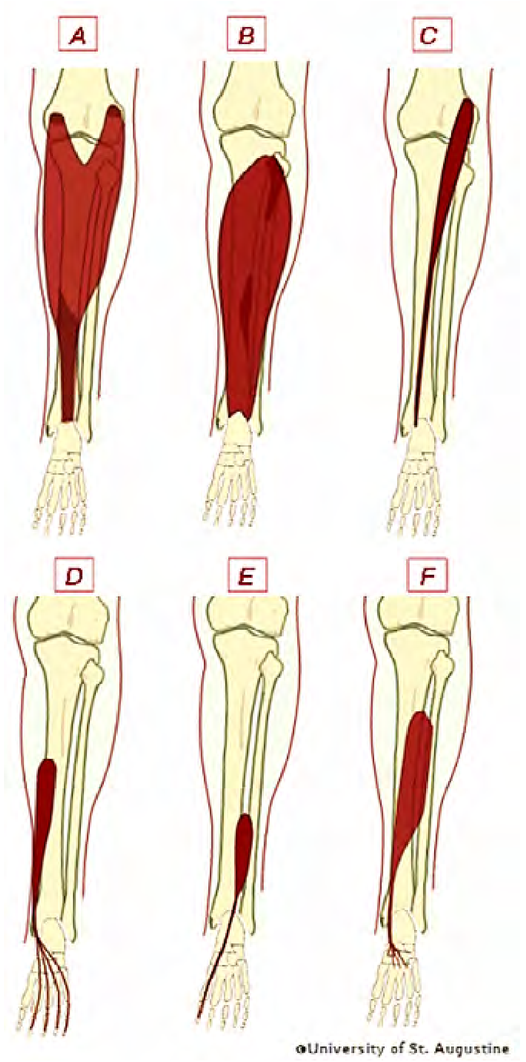
  - During closed chain or weight bearing activities, external rotation of the tibia/fibula relative to the talus is stabilized mainly by the
    - anterior talofibular ligament (LCL)
    - posterior tibiotalar ligament (MCL)
    - tibiocalcaneal ligament (MCL)

- TALAR TILT assessment of the lateral collateral ligament
  - Medial movement of the talus and calcaneus away from fibula produces a tilting of the talus
  - This maneuver is useful in the non-weight bearing assessment of the ankle to determine the integrity of the anterior and posterior talofibular and calcaneofibular ligaments by changing the position of the ankle joint and moving the talus with calcaneus away from the fibula.
    - In ankle plantar flexion, the talar tilt is limited mainly by the anterior talofibular ligament.
    - In ankle neutral, talar tilt is limited mainly by anterior and posterior talofibular ligaments.
    - In ankle dorsiflexion, talar tilt is limited mainly by calcaneofibular and posterior talofibular ligaments.
  - Most lateral ankle sprains occur when the ankle is loaded in a planter flexed position and the ligament that is usually damaged is the anterior talofibular ligament.
  - As described earlier, when the ankle is in planter flexion, the mortise is loose and the ankle mobile and the anterior talofibular ligament is limiting plantar flexion.
  - It is this combination that usually results in a sprain of the anterior talofibular ligament during plantar flexion.

ACTIVTIEIS: 1) Take a relaxed sitting position with your right knee in about 30 degrees of flexion. Look at the position of your relaxed right foot. For most people, the foot is plantar flexed, inverted and internally rotated because the ankle is in open chain supination. Now dorsiflex the ankle and watch the movement of the foot as the ankle dorsiflexes. It should dorsiflex, externally rotate and evert. The ankle is moving in open chain pronation. Remember Pii for open chain supination and Dee for open chain pronation. 2) The hands and the wrist make go visual images for the ankle and foot. Position your right hand so that you see the dorsum of the hand and the fingers are extended and the thumb adducted. Notice that the metacarpal area of the dorsum of the hand is wider at the metacarpophalangeal joints than at the ankle. This is a shape similar to the trochlea of the talus. Now with your left thumb and index finger form a "C" as in the shape of the mortise. Place your left hand "mortise" over the dorsum of your right hand in the area of the metacarpophalangeal joints of the fingers and let the palmar surfaces of the left index finger and thumb contact the sides of the dorsum of the hand. Next, maintain the size of your left hand "mortise" and side your left hand along the dorsum of the right hand to the wrist. Are the palmar surfaces of the left hand "mortise" still in contact with the sides of the dorsum of the right hand or is there room for movement? Remember that when the ankle is in dorsiflexion, the mortise is at the wide distal side of the trochlea of the talus but in plantar flexion the mortise is at the narrow part of the trochlea. So can you see why the ankle in dorsiflexion is more stable than the ankle in plantar flexion? 3) Keep your right hand in the same position as for #2. Now imitate the movements for ankle open chain supination by moving your right hand at the wrist in palmar flexion, inversion and internal rotation (Pii). Do the same for ankle open chain pronation (Dee). Next, place your left hand "mortise "over the right dorsum of the hand and repeat the open chain supination and open chain pronation movements. Describe the movements of the dorsum of the right hand relative to the left hand "mortice". 4) Continue to keep your right hand in the same position as in #2 and #3 but know place your left hand "mortise" over the dorsum of the right hand as you did in #2. Now without moving your right hand, move your left hand "mortise" posteriorly and rotate it externally (laterally) mimicking ankle closed chain supination. Next, move the left hand "mortise" anteriorly and rotate it internally (medially) mimicking ankle closed chain pronation.

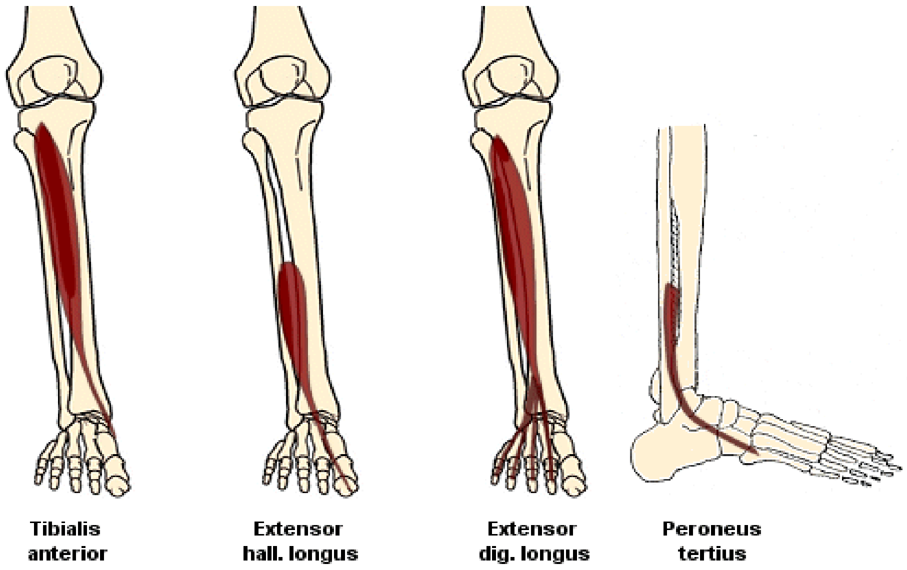
4.3.3 MUSCLES OF THE ANKLE

- **ANKLE PLANTAR FLEXORS (SUPINATORS)**
  - These muscles can also control ankle dorsiflexion by eccentric contraction.
  - gastrocnemius
  - soleus
  - tibialis posterior
  - other muscles that can assist
    - flexor digitorum longus
    - flexor hallucis longus
    - fibularis longus and brevis



Drawing showing the plantar flexors (supinators) of the ankle joint. A) astrocnemius, B) soleus, C) plantaris, D) flexor digitorum longus, E) flexor hallucis longus, and F) posterior tibialis

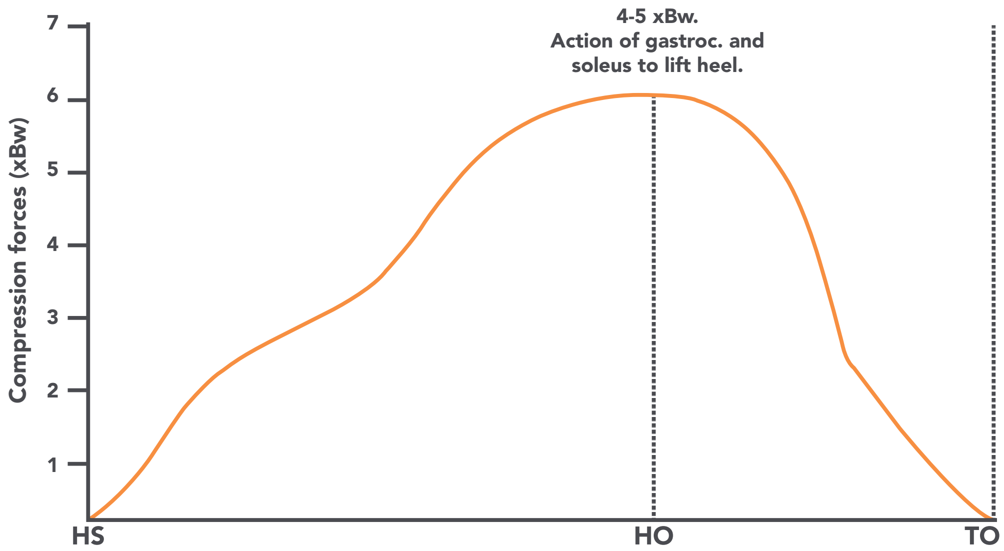
- **ANKLE DORSIFLEXORS (PRONATORS)**
  - These muscles can also control plantar flexion by eccentric contraction.
  - tibialis anterior
  - other muscles that assist
    - extensor digitorum longus
    - extensor hallucis longus



Drawings showing the dorsiflexors (pronators) of the ankle joint.

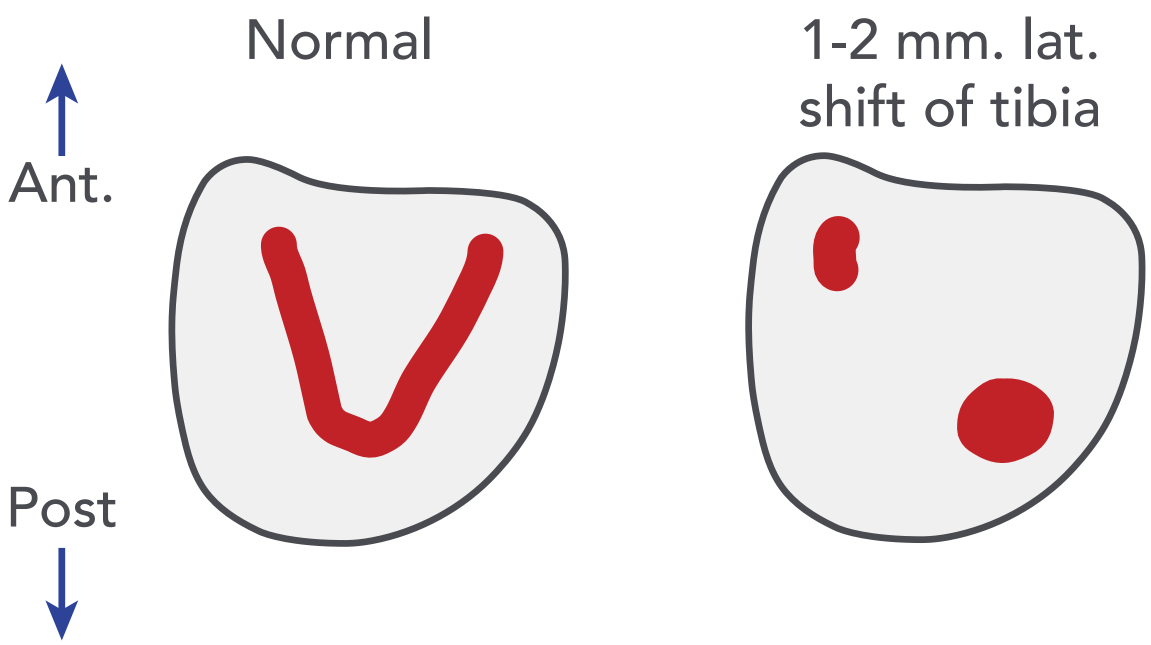
4.3.4 FORCES AT THE ANKLE JOINT

- **WALKING**
  - Compression forces at the ankle gradually increase from heel strike to heel off.
  - At heel off, compression reach a maximum of 4–5 times body weight due to the weight of the body and the contraction of the gastrocnemius and soleus muscles.
  - Compression forces then rapidly decrease from heel off to toe off as the body weight decreases by shifting to the opposite stance leg.
  - Compression forces at the ankle during the swing phase are low.



Graph showing the compression forces on the stance side ankle from heel strike (HS) to heel off (HO) and then toe off (TO).

- **COMPRESSION FORCE DISTRIBUTION ON TALUS WITH WEIGHT BEARING**



Drawing of the trochlea of the talus showing normal compression forces (LEFT) and compression forces when the tibia shifts slightly laterally.

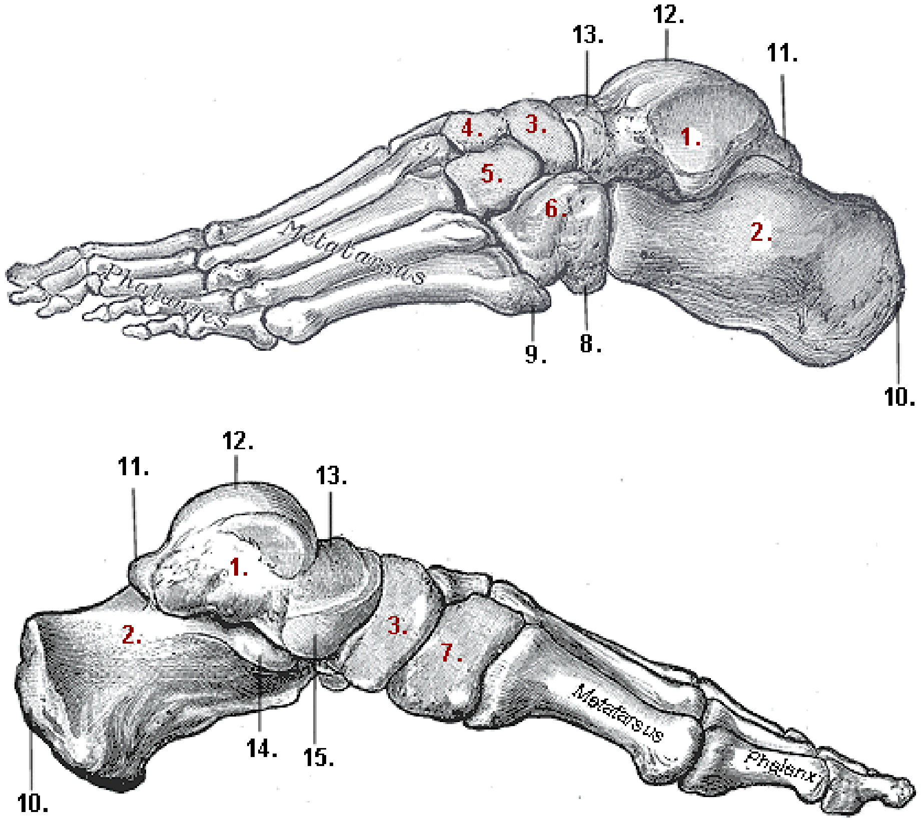
- With normal standing, compression forces on the trochlea of the talus are distributed in a "V" shaped pattern to decrease the unit forces on the articular cartilage (Norkin and Frankle 1989, 2001).
- With just a slight shift of the tibia, the distribution of compression forces changes and forces are now concentrated in two small areas (Norkin and Frankle 1989, 2001).
- This re-distribution of forces results in high unit forces in these two areas and increases the likelihood of articular cartilage damage.

Study Questions (ankle)

1. What is the difference between open and closed chain pronation?
2. What is the difference between open and closed chain supination?
3. What structures stabilize the ankle during the following movements:
   a. dorsiflexion
   b. inversion
   c. internal rotation
4. How can the integrity of the anterior talofibular and calcaneofibular ligaments be tested?

4.4 THE FOOT

4.4.1 ANATOMY OF THE FOOT



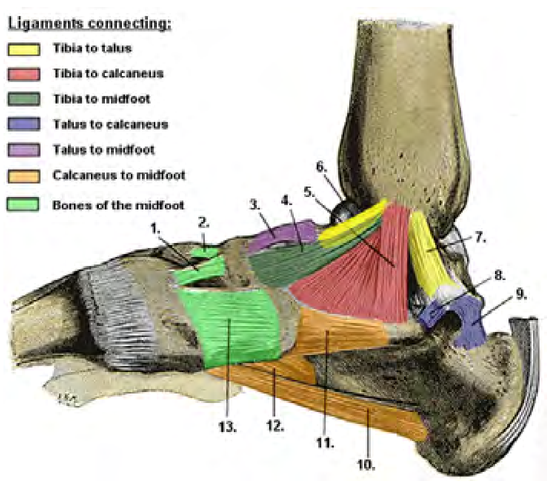
Drawing of the lateral (above) and medial (below) views of the foot. 1. Talus, 2. calcaneus, 3. navicular, 4. middle cuneiform, 5. lateral cuneiform, 6. cuboid, 7. medial cuneiform, 8. tuberosity of cuboid, 9. tuberosity at the base of the 5th metatarsal, 10. tuberosity of calcaneus, 11. posterior tubercle of talus, 12. trochlea of talus, 13. neck of talus, 14. sustentaculum tali, and 15. anterior articular surfaces of talus. (Modified from Gray 1918)

- **DIVISION OF THE FOOT**
  - the **rearfoot** or **hindfoot** consists of the calcaneus, talus and the subtalar joint
  - the **midfoot** consists of the navicular, cuboid, 3 cuneiform bones and the midtarsal joint
  - the **forefoot** consists of the metatarsals, phalanges, metatarsophalangeal joints and interphalangeal joints

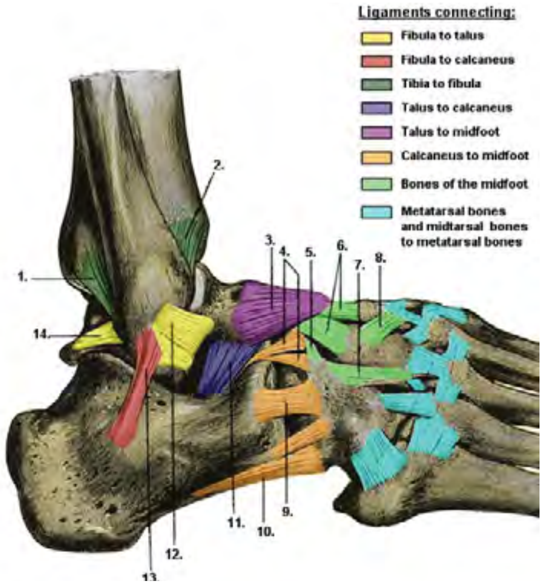
4.4.2 JOINTS AND LIGAMENTS OF THE FOOT

- **SUBTALAR JOINT**
  - This is a plane type synovial joint.
  - The articulations are between the posterior calcaneal articulation facet on the inferior body of the talus and the anterior, middle, and posterior talar articulation surfaces on the superior body of the calcaneus.
  - This joint allows mainly the inversion and eversion components of foot pronation and supination.
  - The ligaments stabilizing this joint are the
    - medial talocalcaneal
    - lateral talocalcaneal
    - posterior talocalcaneal
    - calcaneofibular
    - tibiocalcaneal
    - interosseous talocalcaneal

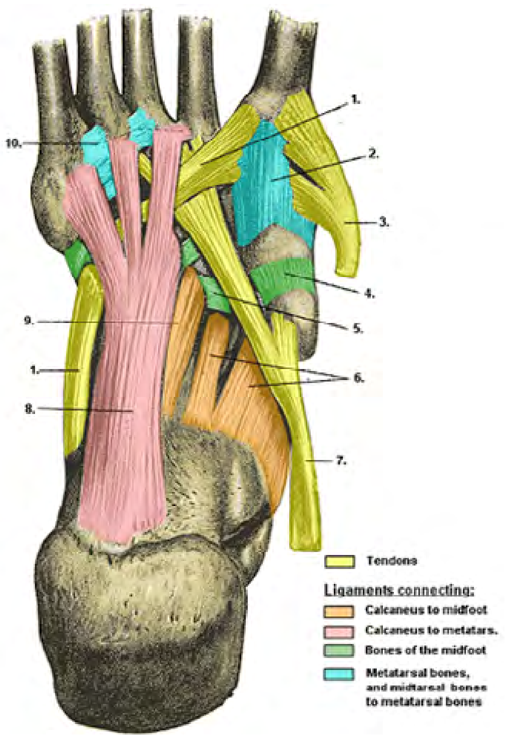
- **MIDTARSAL JOINT** (transverse tarsal or Chopart's)
  - o The calcaneocuboid and talonavicular joints form the midtarsal joint.
    - ▪ calcaneocuboid joint
      - + This joint is a plane type synovial joint.
      - + The articulation is between the posterior cuboid articular surface and the anterior body of the calcaneus.
    - ▪ talonavicular joint
      - + This is a shallow ball and socket type synovial joint.
      - + The articulation is between the oval convex articular surface on the talar head and the oval concave articular surface on the posterior navicular.
  - o The calcaneocuboid allows mainly the inversion and eversion components of foot pronation and supination.
  - o The talonavicular allows the dorsiflexion, plantar flexion, external rotation (abduction) and internal rotation (adduction) components of foot pronation and supination.
  - o Ligaments stabilizing the calcaneocuboid joint are the
    - ▪ dorsal calcaneocuboid
    - ▪ calcaneocuboid part of the bifurcate
    - ▪ plantar calcaneocuboid (short plantar)
    - ▪ long plantar
  - o Ligaments stabilizing the talonavicular joint are the
    - ▪ dorsal talonavicular
    - ▪ tibionavicular
    - ▪ plantar calcaneonavicular (spring ligament)



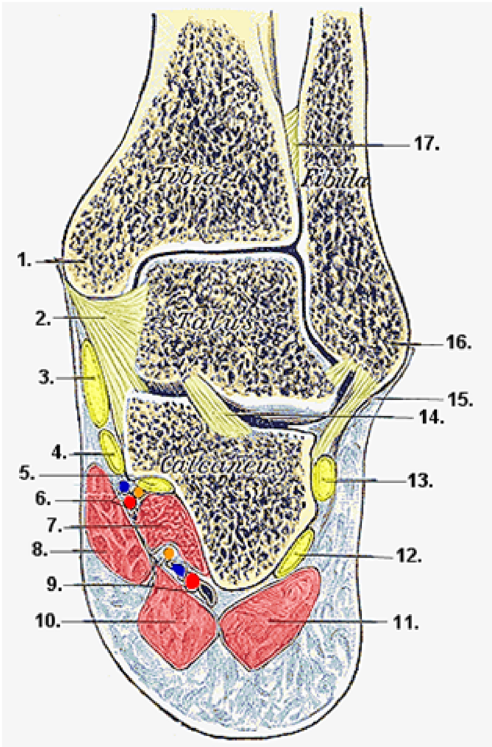
Foot and ankle ligaments: Medial aspect of foot and ankle. 1. 1st dorsal cuneonavicular ligament, 2. 2nd dorsal cuneonavicular ligament, 3. talonavicular ligament, 4. tibionavicular ligament, 5. tibiocalcaneal ligament, 6. anterior tibiotalar ligament, 7. posterior tibiotalar ligament, 8. medial talocalcaneal ligament, 9. posterior talocalcaneal ligament, 10. long plantar ligament, 11. plantar calcaneonavicular (spring) ligament, 12. calcaneocuboid ligament (short plantar) and 13. 3rd dorsal cuneonavicular ligament. (Modified from Gray 1918)



Foot and Ankle Ligaments: Lateral aspect of foot and ankle. 1. Posterior and 2. anterior tibiofibular ligament, 3. dorsal talonavicular ligament, 4. bifurcate ligament, 5. dorsal cuboideonavicular ligament, 6. dorsal cuneonavicular ligament, 7. dorsal cuneocuboid ligament, 8. dorsal intercuneiform ligament, 9. dorsal calcaneocuboid ligament, 10. long plantar ligament, 11. interosseous talonavicular ligament, 12. anterior talofibular ligament, 13. calcaneofibular ligament, and 14. posterior talofibular ligament. (Modified from Gray 1918)



Inferior aspect of the foot and ankle. 1. fibularis longus, 2. plantar tarsometatarsal ligament, 3. tibialis anterior, 4. plantar cuneobuboid ligament, 5. plantar cuboideonavicular ligament, 6. plantar calcaneonavicular (spring) ligament, 7. tibialis posterior, 8. long plantar ligament, 9. plantar calcaneocuboid (short plantar) ligament, and 10. intermetatarsal ligaments. (Modified from Gray 1918)



Cross section through the inferior tibiofibular, ankle, and subtalar joints. 1. Medial malleolus, 2. medial tibiocalcaneal ligament. Tendons of: 3. tibialis posterior, 4. flexor digitorum longus, and 5. flexor hallucis longus. 6. medial plantar nerves and vessels, 7. quadratus plantae, 8. abductor hallucis, 9. lateral plantar nerve and vessels, 10.flexor digitorum brevis, 11. abductor digiti quinti, 12. tendon of fibularis longus, 13. tendon of fibularis brevis, 14. interosseus talocalcaneal ligament, 15. calcaneofibular ligament, 16. lateral malleolus, and 17. tibiofibular syndesmosis. (Modified from Gray 1918)

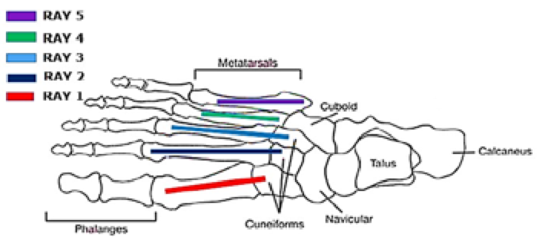
- **TARSOMETATARSAL JOINTS**
    - These are plane type synovial joints.
    - The articulations for these 5 joints are
        - anterior articular surface of the medial cuneiform and the base of the first metatarsal
        - anterior articular surface of the intermediate cuneiform and the base of the second metatarsal
        - anterior articular surface of the lateral cuneiform and the base of the third metatarsal
        - anterior medial articular facet of the cuboid and the base of the fourth metatarsal
        - anterior lateral articular facet of the cuboid and the base of the fifth metatarsal
    - These joints allow flexion and extension.
    - The ligaments stabilizing the tarsometatarsal joints are the
        - dorsal tarsometatarsal
        - plantar tarsometatarsal
        - interosseous tarsometatarsal
        - plantar and dorsal metatarsal ligaments stabilize the articulations between adjacent metatarsal bases

- **METATARSOPHALANGEAL JOINTS**
    - These are condyloid type synovial joints.
    - The articulation for each joint is between the articular convex surface of the metatarsal head and the slightly concave articular surface of the base of the proximal phalanx.
    - These joints allow for flexion, extension, slight abduction, slight adduction and slight circumduction.
    - The ligaments stabilizing the metatarsophalangeal joints are the
        - medial collateral
        - lateral collateral
        - plantar ligament (plate)
        - deep transverse metatarsal ligament stabilizes the heads of the adjacent metatarsals for movement of the proximal phalanges

- **INTERPHALANGEAL JOINTS**
    - These are hinge type synovial joint.
    - The articulation for each joint is between the articular surface of the head of the proximal phalanx with the articular surface of the base of the more distal phalanx.
    - These joints allow flexion and extension

- The ligaments stabilizing the interphalangeal joints are the
  - medial collateral
  - lateral collateral
  - plantar ligament (plate)

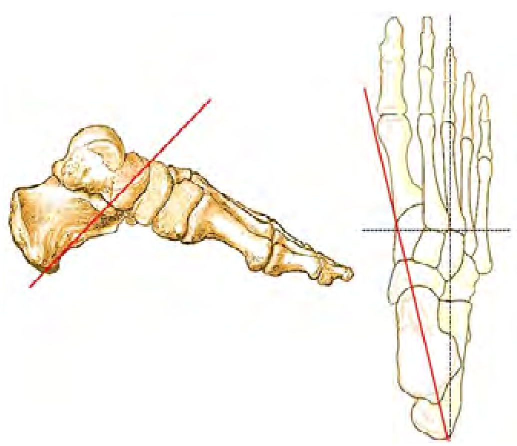
- **RAYS OF THE FOREFOOT**
  - These are functional units of the forefoot.
  - Rays 1–3 = the cuneiform bone and the articulating metatarsal.
  - Rays 4 and 5 = metatarsal 4 and 5.



Drawing showing the 5 rays of the foot

4.4.3 MOVEMENTS OF THE JOINTS OF THE FOOT

- **SUBTALAR JOINT**
  - MOVEMENTS AT THE SUBTALAR JOINT occur about an axis that is oblique to sagittal, frontal and transverse planes.
    - The axis runs from the anteromedial talus to the posterolateral end of calcaneus.
    - Because of this oblique axis the movements of this joint triplanar movements.
    - There are open and closed chain pronation and supination of the subtalar joint.



Drawings showing the axis of subtalar motion in lateral view (LEFT) relative to the transverse plane and in dorsal view (RIGHT) relative to the sagittal and frontal planes (dotted lines) (Modified from Norkin and Frankle 1989, 2001).

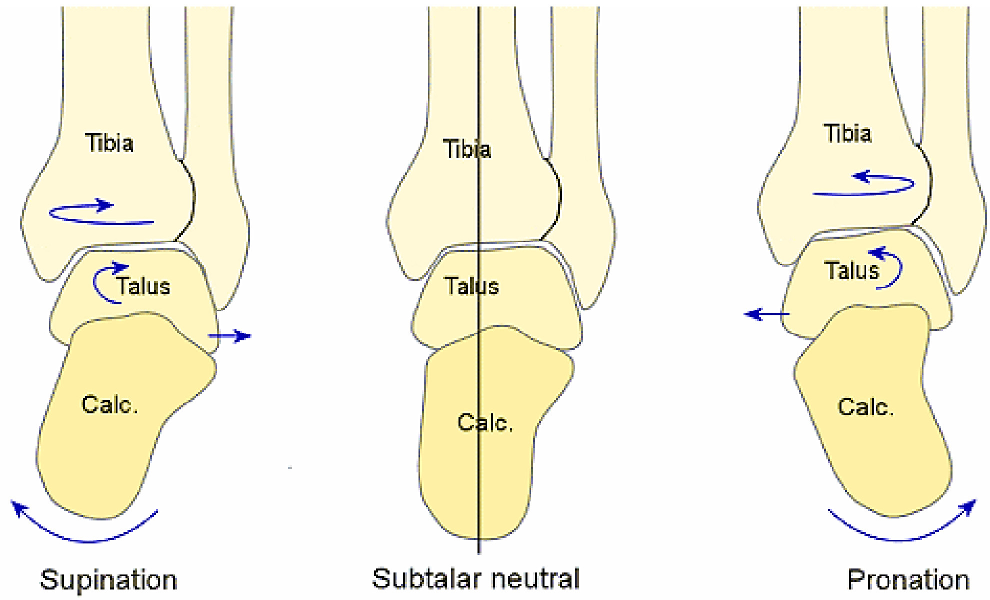
- SUBTALAR PRONATION
  - Eversion is the main movement and it is coupled with abduction (external rotation) and dorsiflexion (**Dee**).
  - Clinically, subtalar pronation is measured by calcaneal eversion.
  - Normal calcaneal eversion is about 10 degrees.
  - The loose packed position of the subtalar joint is neutral to 5 degrees of pronation.

- SUBTALAR SUPINATION
  - Inversion is the main movement and it is coupled with adduction (internal rotation) and plantar flexion (**Pii**).
  - Clinically, subtalar supination is measured by calcaneal inversion.
  - Normal calcaneal inversion is about 20 degrees.
  - The closed pack position of the subtalar joint is full supination.

- SUBTALAR OPEN CHAIN PRONATION
  - calcaneal eversion
  - calcaneal abduction (external rotation)
  - calcaneal dorsiflexion

- SUBTALAR OPEN CHAIN SUPINATION
  - calcaneal inversion
  - calcaneal adduction (internal rotation)
  - calcaneal plantar flexion

- SUBTALAR NEUTRAL POSITION
  - This position is the starting position from which subtalar movement is measured.
  - From this position the calcaneus inverts 2 times more than the number of degrees it everts.
  - To locate this position,
    + first measure the degrees of calcaneal movement from full supination to full pronation
    + multiply this full range by 2/3
    + finally, measure this 2/3 range from full supination to attain subtalar neutral



Drawing showing the subtalar neutral position (CENTER) and the closed chain subtalar supination (LEFT) and closed chain subtalar pronation (RIGHT). The arrows show the direction of movement of the calcaneus (calc.), talus and tibia. Notice that the talus and tibia go in the opposite direction as the calcaneus.

- CLOSED CHAIN PRONATION (heel strike to midstance)
  - calcaneal eversion (valgus)
  - talar adduction (med. rotation)
  - talar plantar flexion
  - tibial/fibular internal (medial) rotation

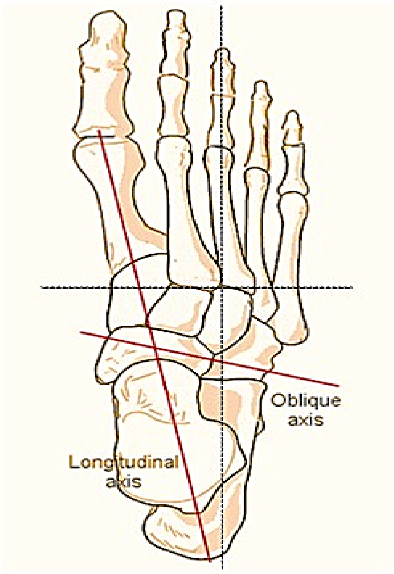
- CLOSED CHAIN SUPINATION (midstance to toe off)
  - calcaneal inversion (varus)
  - talar abduction (lat. rotation)
  - talar dorsiflexion
  - tibial/fibular external (lateral) rotation

- SUBTALAR STABILITY
  - structures limiting inversion of the subtalar joint
    - + calcaneofibular ligament
    - + lateral talocalcaneal ligament
    - + interosseous talocalcaneal ligament
    - + tendons of the fibularis longus and brevis
    - + sustentaculum tali (bone)
    - + medial talar tubercle (bone)

  - structures limiting eversion of the subtalar joint
    - + tibiocalcaneal part of the deltoid ligament
    - + medial talocalcaneal ligament
    - + interosseous talocalcaneal ligament
    - + tendons of the posterior tibialis, flexor digitorum longus and the flexor hallucis longus muscles
    - + lateral process of the talus on the calcaneus (bone)

  - Static subtalar stability is from bone and the subtalar ligaments.
  - Dynamic subtalar stability is from tendons of the posterior tibialis, flexor hallucis longus, flexor digitorum longus, fibularis longus and brevis muscles.
  - Subtalar instability can occur with damage to the bones and ligaments of the static stabilizing structures that limit subtalar inversion and eversion.
  - Subtalar instability can also occur with damage and physiological changes in the tendons and muscles forming the dynamic stabilizing structures.

- **MIDTARSAL JOINT OF THE FOOT**
  - This joint is formed by the calcaneocuboid and talonavicular joints.
  - This two joint arrangement has two axes of motion about which movements of the talus and calcaneus produce supination and pronation movements.
  - Movements about these axes produce 1/3 to 1/2 as much supination and pronation as the subtalar joint.



Drawing of the dorsum of the foot showing the 2 axes of the midtarsal joint relative to the sagittal and frontal plans (dotted lines) (Modified from Norkin and Frankle 1989, 2001).

- LONGITUDINAL AXIS of the midtarsal joint
  - Predominately inversion and eversion occurs about this axis with slight plantar flexion or dorsiflexion and internal or external rotation.
  - Clinically during gait, midtarsal inversion is seen as the medial arch of the foot rises and eversion as the medial arch of the foot falls.

- OBLIQUE OR TRANSVERSE AXIS of the midtarsal joint
  - Predominately dorsiflexion, plantar flexion, abduction (external rotation) and adduction (internal rotation) occur about this axis with slight inversion/eversion.

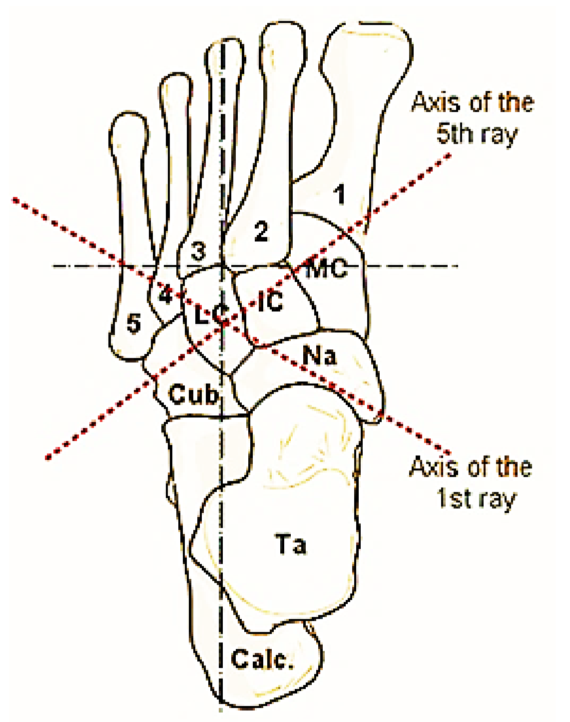
- MIDTARSAL JOINT MOVEMENTS
  - Movements are triplanar and referred to as pronation and supination
    + pronation: eversion, abduction (external rotation) and dorsiflexion **(Dee)**
    + supination: inversion, adduction (internal rotation) and plantar flexion **(Pii)**
  - Midtarsal movements are controlled by movements at the subtalar joint

- HINDFOOT (SUBTALAR) PRONATION AND MIDTARSAL JOINT MOVEMENTS
  - With subtalar pronation, the midtarsal joint also pronates.
  - Pronation of the midtarsal joint results in the longitudinal and oblique axes becoming more parallel to each other.
  - With the axes in this position, the midfoot is mobile and free to adjust and conform to surface changes or irregularities of the substrate.
  - During heel strike or initial loading, the subtalar and midtarsal joints are pronated which allows the foot to contour to the substrate.

- HINDFOOT (SUBTALAR) SUPINATION AND MIDTARSAL JOINT MOVEMENT
  - With subtalar supination, the midtarsal joint is also supinated.
  - Supination of the midtarsal joint results in the longitudinal and oblique axes becoming more crossed.
  - With the axes in this position, midfoot movements are restricted to provide a solid base of support for the transfer of the weight from the hindfoot to the tarsometatarsal joints of the forefoot.
  - The subtalar and midtarsal joints are supinated throughout late midstance, heel off and toe off.

- **FOREFOOT**

  - MOVEMENTS OF RAYS 1 AND 5 OF THE HINDFOOT
    - Axes of motion for ray 1 & ray 5 are oblique to the 3 cardinal planes resulting in triplanar movement.
    - The axis of motion for ray 1 passes through the navicular and lateral cuneiform bones in a posteriomedial to an anteriolateral direction.
    - The axis of motion for ray 5 passes through the cuboid and all three cuneiform bones in a posteriolateral to an anteriomedial direction.



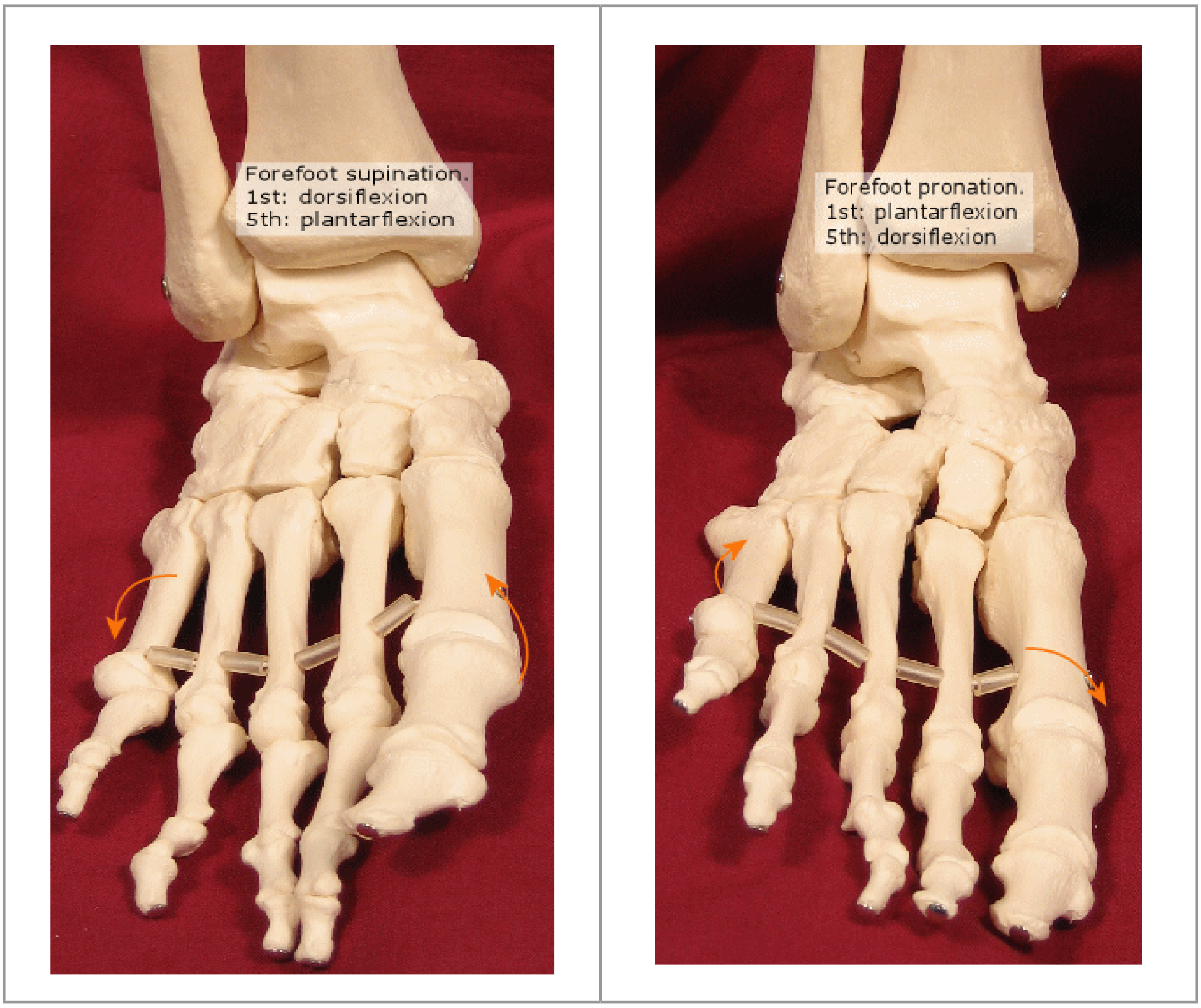
Drawing showing the axes of motion for the first and fifth rays relative to the tarsal bones (Modified from Norkin and Frankle 1989, 2001).

  - RAY 1 MOVEMENT
    - pronation
      + mainly dorsiflexion (extension)
      + inversion
      + slight adduction (internal rotation)
    - supination
      + plantar flexion
      + eversion
      + slight abduction (external rotation)

- RAY 5 MOVEMENT
  - pronation
    - \+ dorsiflexion
    - \+ eversion
    - \+ slight abduction (external rotation)
  - supination
    - \+ plantar flexion
    - \+ inversion
    - \+ slight adduction (internal rotation)

- MOVEMENTS RAYS 2,3,4
  - ray 2 movement
    - \+ mainly dorsiflexion, slight inversion
    - \+ mainly plantar flexion, slight eversion
  - ray 3 movement
    - \+ dorsiflexion
    - \+ plantar flexion
  - ray 4 movement
    - \+ mainly dorsiflexion, slight eversion
    - \+ mainly plantar flexion, slight inversion

- FOREFOOT SUPINATION AND PRONATION TWIST
  - Movements of the forefoot during walking to maintain foot to ground contact and to distribute the forces over the plantar surface of the foot
  - Supination twist
    + rays 1 & 2 dorsiflex
    + rays 4 & 5 plantar flex
    + forefoot inverts
  - Pronation twist
    + rays 1 & 2 plantar flex
    + rays 4 & 5 dorsiflex
    + forefoot everts



Photograph showing the movements of the first ray and fifth ray (arrows) during the supination twist of the forefoot (LEFT) and the pronation twist of the forefoot (RIGHT).

- FOREFOOT MOVEMENTS DURING GAIT
  - heal strike to midstance
    - + The subtalar and midtarsal joints are moving from pronation to neutral.
    - + The forefoot is moving from supination to neutral.
  - heel off to toe off
    - + The subtalar and midtarsal joints are moving in supination.
    - + The forefoot is moving in pronation.

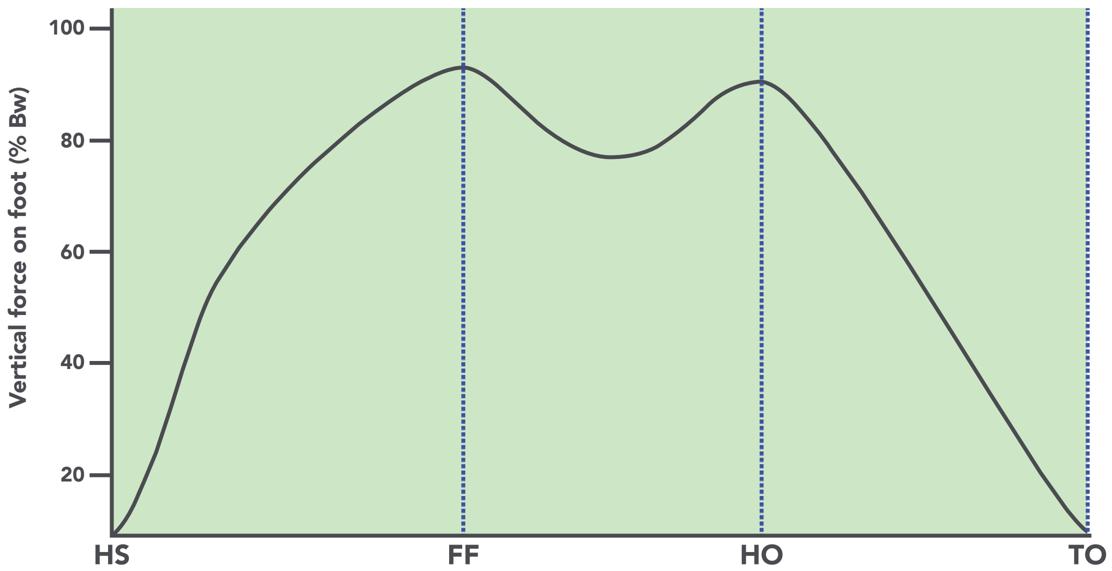
- WITH EXCESSIVE HINDFOOT PRONATION (abnormal)
  - The midtarsal joint is mobile and can compensate partially by supinating.
  - The forefoot can also compensates by supinating.

- WITH EXCESSIVE HINDFOOT SUPINATION
  - The lateral side of the foot is the major weight bearing surface.
  - The midtarsal movement is restricted because the axes of motion are crossed and the midfoot is unable to compensate by pronating.
  - The forefoot can compensate by pronating excessively but high weight bearing forces remain on the lateral side of the foot.

4.4.4 FORCES ON THE FOOT

- **FORCES ON THE FOOT DURING STANDING**
  - DISTRIBUTION OF COMPRESSION FORCES
    - 60.5% of the force is across heel
    - 7.8% of the force is on the midfoot
    - 28.2% of the force is on the forefoot
    - 3.6% of the force is on the toes

- **FORCES OF THE FOOT DURING WALKING**



Graph showing the vertical forces on the foot during heel strike (HS), foot flat (FF), heel off (HO) and toe off (TO) of gait.

- VERTICAL FORCES are highest at flat foot but then decrease slight at midstance only to increase again at heel off.
- VERTICAL FORCES decrease rapidly after heel off and are low at toe off and during the swing phase.

- **FORCES TRANSMITTED ACROSS THE FOOT DURING WALKING**

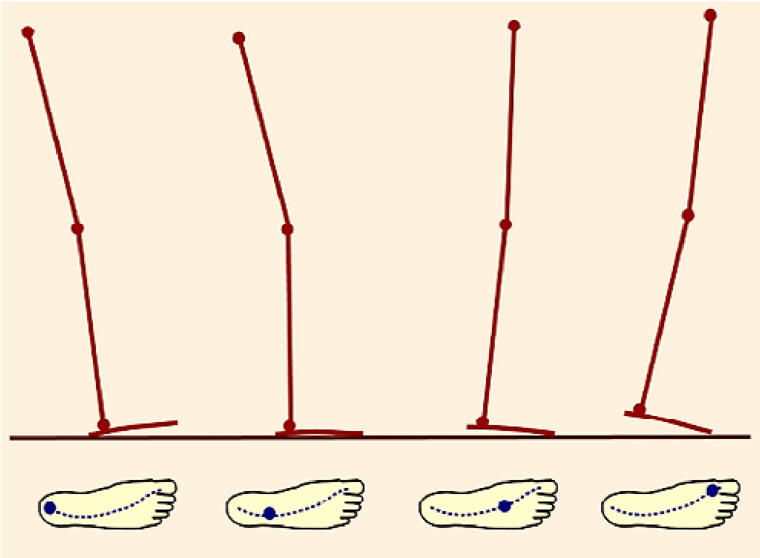
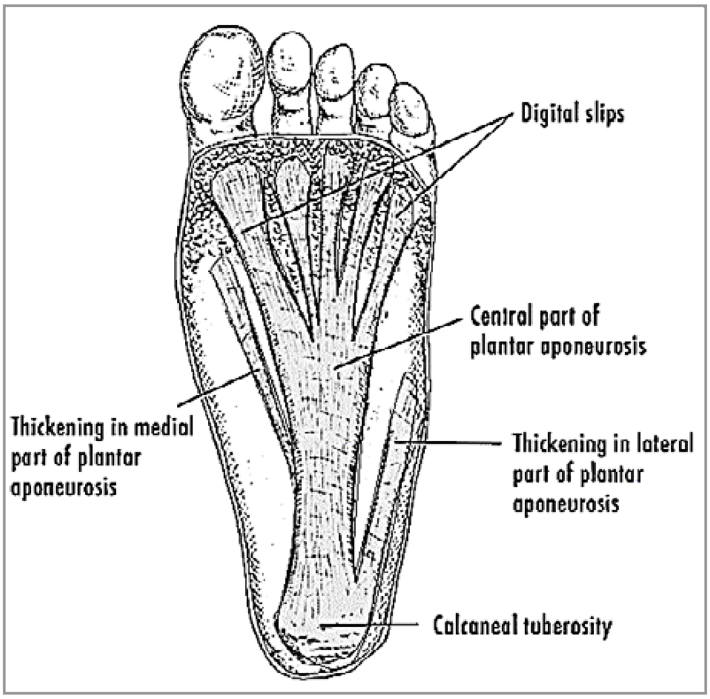


Diagram showing the pattern of force transmission across The foot from heel strike to toe off

- PATH OF THE GREATEST force transmission across the foot
  - The greatest forces are transmitted across the highest part of the longitudinal arch on the medial side of the foot where the bones are the largest.
  - The forces travel from the heel to the talonavicular joint to the naviculocuneiform joint to the first (1st) metatarsal head.

- PATH OF THE LEAST FORCE transmission across the foot
  - The least forces are transmitted along the lateral side of the foot where the bones are smaller than on the medial side of the foot.
  - The force travels through the cuboid to fifth (5^{th}) metatarsal head.

- **PLANTAR FASCIA (aponeurosis) OF THE FOOT**
    - This fascia extends along the longitudinal arch of the foot from the calcaneus to the metatarsal heads.



Drawing of the plantar aponeurosis of the foot

    - This fascial band acts like a tie-rod between two trusses.

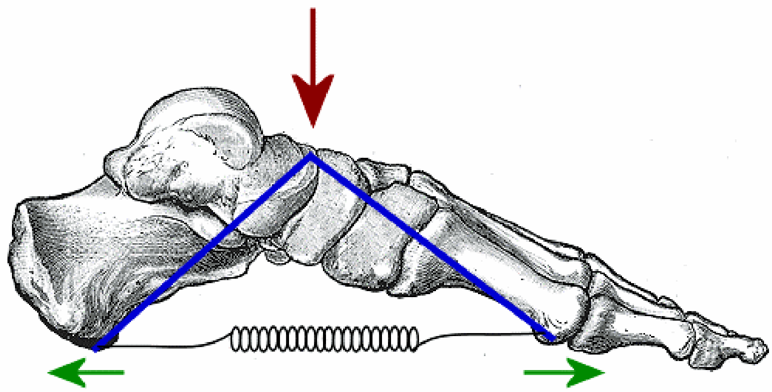


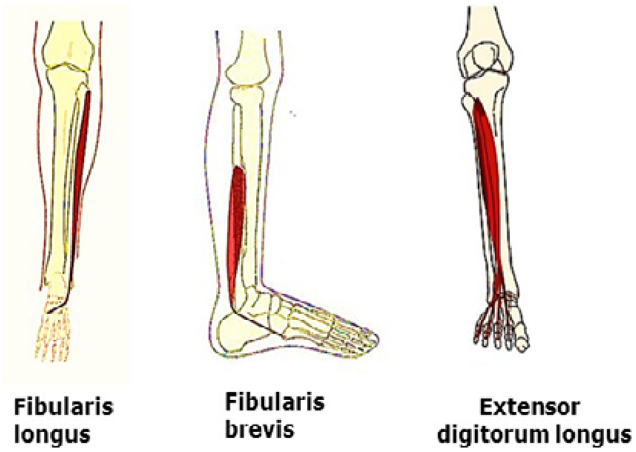
Diagram showing the plantar fascia acting like a tie-rod. When the foot is loaded (red arrow), the fascia stretches as the calcaneus moves posteriorly and the toes move anteriorly (green arrows). (Modified from Norkin and Frankle 1989, 2001).

- When foot is loaded, the distal and proximal ends to the plantar fascia move apart which tense the fascia.
- When the foot is unloaded, tension on the plantar fascia decreases and its ends move toward each other.
- This decrease in plantar fascia tension passively returns the tarsal bones to a flexed position.
- Functions of the plantar fascia are
  - shock absorber
  - distribution of forces
  - stabilizes midfoot esp. during running, climbing types of activities

- Inflammation of plantar fascia
  - This inflammation is called plantar fasciitis.
  - It may be associated with bone spurs and overuse.
  - An arch supports may help.

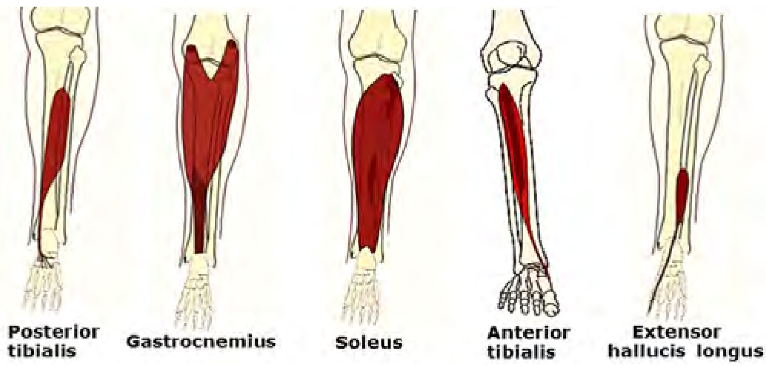
4.4.5 MUSCLES OF THE FOOT

- **PRONATORS OF THE FOOT**
  - FIBULARIS LONGUS
    - pronates foot but supinates ankle
  - FIBULARIS BREVIS
    - pronates foot but supinates ankle
  - EXTENSOR DIGITORUM LONGUS (weak)
    - weak pronator of the foot and ankle



Drawing of the muscles that pronate the foot

- **SUPINATORS OF THE FOOT**
  - POSTERIOR TIBIALIS
    - supinator of the foot and the ankle
    - active at heel strike to eccentrically control pronation of subtalar joint
  - GASTROCNEMIUS
    - supinator of the foot and the ankle
  - SOLEUS
    - supinator of of the foot and the ankle
  - ANTERIOR TIBIALIS (weak)
    - supinator of the foot but pronator of the ankle
    - active at heel strike to eccentrically control pronation of subtalar joint along with the tibialis posterior
  - EXTENSOR HALLUCIS LONGUS (weak)
    - weak supinator of the foot and pronator of the ankle



Drawing of the supinators of the foot

ACTIVITIES: 1) Position your right forearm in neutral supination-pronation. Your thumb should be medial to your index finger. Now make a fist so that your thumb is on the superior and medial side of the fist. This will be that start position for this and the next activity. The thumb represents the big toe and medial side of the foot and the fist is the calcaneus. With your hand in this starting position, move the bottom of your fist medially (inversion), rotate your fist medially, and bend your fist downward (plantar flexion). This combination of movements is open chain subtalar supination. Returning to the start position, move the bottom of your fist laterally (eversion), rotate your fist laterally, and bend your fist upward (dorsiflexion). This combination is open chain subtalar pronation. 2) Place your right hand in the same start position as in activity #1. Now make a fist with your left hand and press it palm side down on the top of your right hand fist. The right hand fist still represents the calcaneus. The left hand fist represents the talus. Move the bottom of your right fist medially (calcaneal inversion) and rotate it medially (internal calcaneal rotation) and finally bend it downward (calcaneal plantar flexion) to mimic subtalar supination and watch what happens to the left hand representing the talus. Your left hand should move laterally and rotate laterally. This activity mimics closed chain subtalar supination. 3) Now repeat the #2 activity but move the bottom of your right fist laterally (calcaneal eversion) and rotate it laterally (external calcaneal rotation) and finally bend it upward (calcaneal dorsiflexion) to mimic subtalar pronation. The left hand representing the talus should move medially and rotate medially mimicking closed chain subtalar pronation. 4) Place your right hand so the dorsum of the hand is up, the thumb is medial and the fingers are extended to mimic the dorsum of your foot. The proximal palmar area (area of the thenar and hypothenar eminences) represents the calcaneus, your thumb represents the big toe, and your fingers the other toes. Rotate your right hand medially (calcaneal inversion) and press the proximal palmar part of your right hand against a hard surface. Your hand represents the position of the foot when the subtalar joint is in supination. Notice the position of the fingers (toes). The lateral part of the hand (foot) is in contact with the surface but not the medial part of the hand (foot). To get all of the fingers (toes) to contact the surface, you need to twist the fingers (toes) laterally. This movement mimics the pronation twist of the forefoot when the subtalar and midtarsal joints are in supination. 5) Repeat activity #4, but rotate your right hand laterally (calcaneal eversion) and press the proximal palmar part of your right hand against a hard surface. Your hand represents the position of the foot when the subtalar joint is in pronation. In this position the medial part of the hand (foot) is in contact with the surface but not the lateral part of the hand (foot). To get all of the fingers (toes) to contact the surface, you need to twist the fingers (toes) medially. This movement mimics the supination twist of the forefoot when the subtalar and midtarsal joints are in pronation.

Study Questions (foot)

1. What ligaments of the ankle joint are also stabilizers of the subtalar joint?
2. What do the ligaments stabilizing the calcaneocuboid joint have iscommon? What about the talonavicular joint?
3. What is the difference between open and closed chain subtalar pronation?
4. What is the difference between open and closed chain subtalar supination?
5. How does the subtalar joint movement affect midtarsal movement and how does this affect the midfoot?
6. During a supination twist, what are the movements of the big toe and little toe?
7. With excessive subtalar supination, what muscles might need to be strengthened or stretched and how will this affect the loads on the foot during walking?
8. When are vertical forces on the foot high during the stance phase of gaitand how does this compare with high forces at the hip, knee, and ankle?

4.4.6 BIOMECHANICS OF GAIT (WALKING)

- **GENERAL TERMINOLOGY**
  - STANCE TIME: time of stance phase
  - STRIDE LENGTH: distance from heel strike of one leg to the next heel strike of the same leg (heel strike to heel strike distance of the same leg
  - STRIDE DURATION: time of one stride
  - STEP LENGTH: distance from heel strike of one leg to the successive heel strike of the opposite leg
  - STEP DURATION: time of one step
  - CADENCE: number of steps per minute
    - males: 110 steps per minute
    - females: 116 steps per minute
  - WALKING VELOCITY: distance walked per unit time
  - WIDTH OF SUPPORT BASE: horizontal distance between the middle heel of one foot and the middle heel of the opposite foot

- **PHASES OF GAIT**
  - Gait is divided into the STANCE PHASE when the foot is on the ground and SWING PHASE when the foot is not on the ground.
  - The stance phase is divided into 5 subdivisions and the swing phase is divided into 3 subdivisions.
  - Because the movements between the lower limbs are opposite in that one limb is in the stance phase and the other limb is in the swing phase, the descriptions of gait usually specify the side of the limb being described.
  - There two widely used descriptions of the two phases of gait.
  - Both need to be learned as some clinicians intermix these descriptions.
  - THE STANCE PHASE OF GAIT

Table listing the Traditional and Rancho Los Amigos terms used to describe the parts of the stance phase

TRADITIONAL TERMS	RANCHO LOS AMIGOS TERMS
HEEL STRIKE	INITIAL CONTACT
FOOT FLAT	LOADING RESPONSE
MIDSTANCE	MIDSTANCE
HEEL OFF	TERMINAL STANCE
TOE OFF	PRESWING

- THE SWING PHASE OF GAIT

Table listing the Traditional and Rancho Los Amigos terms used to describe the parts of the swing phase

TRADITIONAL TERMS	RANCHO LOS AMIGOS TERMS
ACCELERATION	INITIAL SWING
MIDSWING	MIDSWING
DECELERATION	TERMINAL SWING

Below are a series of photographs showing the parts of gait while an individual walks on a treadmill. Traditional terms are used with the matching Rancho Los Amigos terms in parenthesis. Pictures from Alec Stenhouse.

Right foot at heel strike (initial contact) and Left foot at toe off (preswing)

Right foot at foot flat (loading response) and Left foot at end of toe off and start of acceleration (initial swing)

Right foot at midstance (midstance) and Left foot at acceleration (initial swing)

Right foot at the end of midstance and the start of heel off (terminal stance) and Left foot at midswing (midswing)

Right foot at heel off (terminal stance) and Left foot at end of deceleration (terminal swing)

Right foot at toe off (preswing) and Left foot at heel Strike (initial contact)

Right foot at the start of acceleration (initial swing) and Left foot at foot flat (loading response)

Posterior view of the Right foot at midstance and in subtalar neutral and the left foot at midswing with the subtalar joint in pronation

Posterior view of the Right foot at heel off with the subtalar joint in supination and the LEFT foot going into heel strike (initial contact) with the subtalar joint in pronation

Posterior view of the Right foot at toe off (preswing) with the foot in subtalar supination and the Left foot at heel strike (initial contact) with the subtalar joint in pronation

- **GROUND REACTION FORCES (GRF) DURING GAIT**

  - When the foot is in contact with the ground, the ground transmits a force up the lower extremity in response to the forces being applied by the body downward to ground.
  - The force transmitted up the lower extremity is called the **ground reaction force (GRF) shown below by the dotted line with arrowhead.**

STANCE PHASE

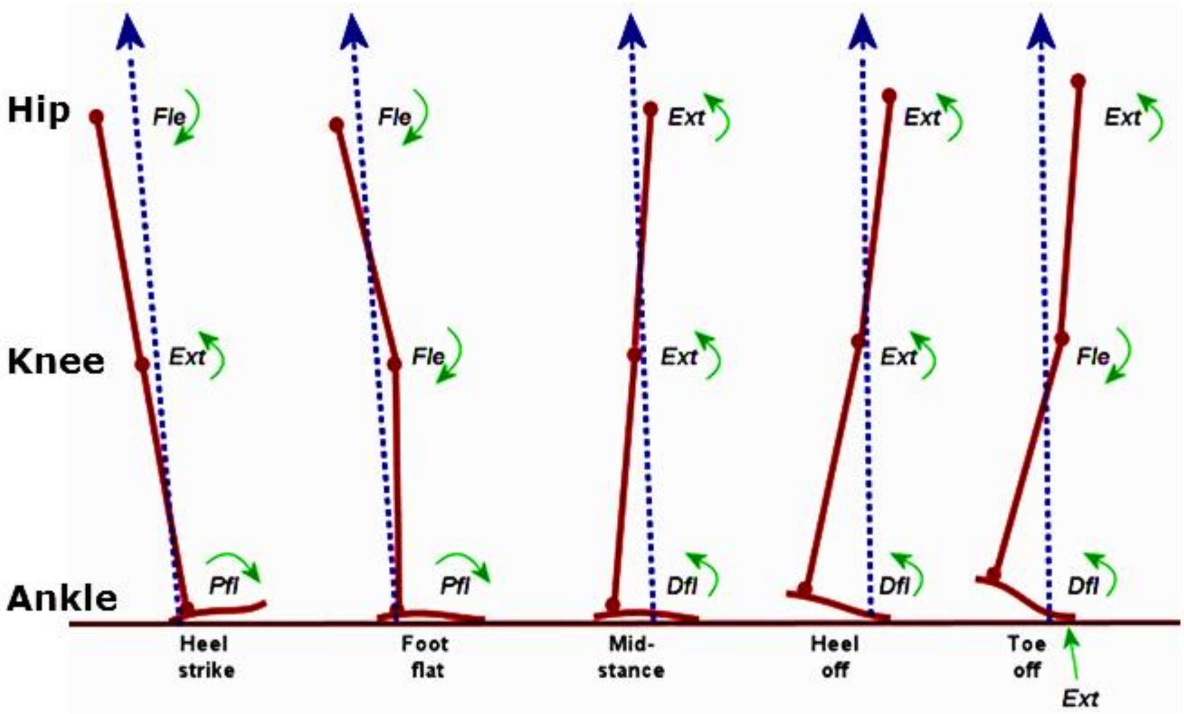


Diagram showing the ground reaction force (dotted line) relative to the hip, knee and ankle during the parts of the stance phase of gait. The arrows show the directions of force produced at each joint by the ground force. Fle = flexion, Ext = extension, Pfl = plantar flexion, Dfl = dorsiflexion

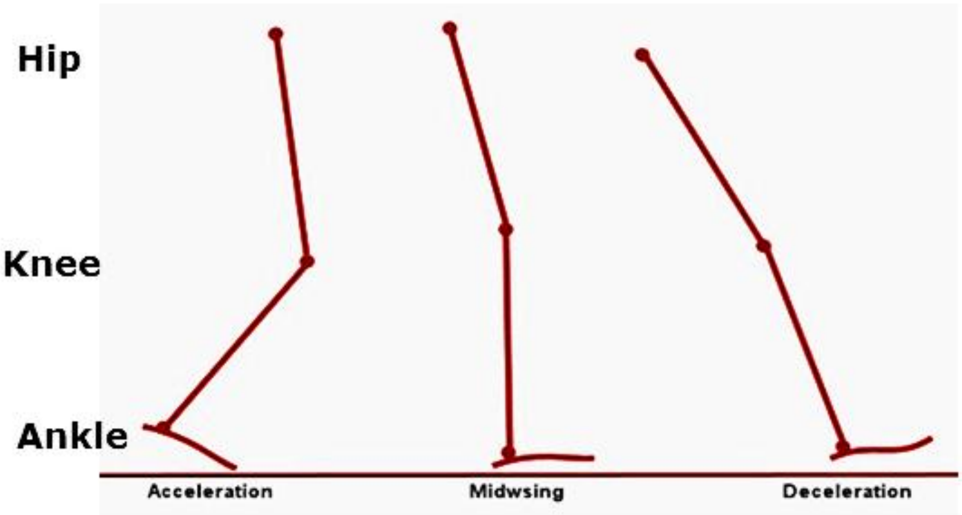


Diagram showing the movements of the hip, knee, and ankle during the swing phase. As there is no contact of the lower limb with the ground, there are no grounds reaction forces.

- The ground reaction force (GRF) lies anterior or posterior to the hip, knee or ankle applying a flexion or extension *moment* (a rotational force) to that joint.
- In other words, the force of the ground is trying to move the joint in a particular direction.
- For example
  - If the GRF lies anterior to the hip joint, it is applying a force or moment that will flex the hip.
  - If the GRF lies posterior to the hip joint, it is applying a moment that will extend the hip.
  - If the GRF lies anterior to the knee, it is applying a moment to extend the knee.
  - If the GRF lies posterior to the ankle joint, it is applying a moment to plantar flex the ankle.
- As the lower limb changes position during the stance phase of gait so does the relative position of the ground reaction force change relative to a joint.
- During the stance phase of gait, movements that occur at each joint can be produced by the GRF or by concentric muscle contraction.
- By comparing the action of the GRF with the movement of the joint, one can determine if the muscles are producing the movement or if the movement is being produced by the GRF and controlled by eccentric activity of muscle.

Two helpful concepts to remember for determing if the movement at a joint during the stance phase of gait is produced by the GRF, produced by concentric muscle contration, and controlled by eccentric muscle contraction.
1. If the movement of a joint is the same as the moment applied by the GRF at the joint, then concentric muscle action is not needed to produce the movement but eccentric muscle action may be needed to control the movement.
2. If the movement of a joint is opposite the moment applied by the GRF at the joint, then concentric muscle action is needed to move the joint and overcome the GRF.

Below are a series of tables for the hip, knee and ankle that show the Range of Motion (ROM), Movements, the GRF Moments, the Muscles associated with the movements, and the type of muscle Contractions during the parts of the stance and swing phases of gait. After the table for the hip joint, there is also a table showing the movements of the Pelvis, hip joint using the Acetabulum as the reference structure, and the Femur during the parts of the stance and swing phases of gait.

4.5 THE HIP

Table showing the Range of Motion (ROM) of the hip, hip Movements, the GRF Moments, the Muscles associated with the movements, and the type of muscle Contractions during the stance and swing phases of gait.

PHASE OF GAIT	ROM	MOVEMENTS	MOMENTS	MUSCLES	CONTRACTIONS
Heel Strike to Foot Flat	30 deg. to 25 deg.	extension	flexion	adductors glut. max.	concentric concentric
Foot Flat to Midstance	25 deg. to 0 deg.	extension extension	flexion extension	adductors glut. max. glut. max.	concentric no activity
Midstance to Heel Off	0 deg. to 10–20 deg.	backward extension	 extension	adductors hip flexors	concentric eccentric
Heel Off to Toe Off	10–20 deg. to 0 deg	flexion	extension	iliopsoas add. long. add. mag.	concentric concentric concentric
Acceleration to Midswing	0–20 deg. to 30 deg.	flexion	none	iliopsoas gracilis sartorius	concentric concentric concentric
Midswing to Deceleration to Heel Strike	30 deg.	flexion	none	glut. max. hamstrings	eccentric eccentric

deg. = degree, long. = longus, mag. = magnus, max. = maximus

4.5.1 PELVIS, HIP JOINT, AND FEMUR MOVEMENTS

Table showing the movements of the Pelvis, hip joint using the Acetabulum as the reference structure, and the Femur during the parts of the stance and swing phases of gait.

PHASE OF GAIT	PELVIS	ACETABULUM	FEMUR
Heel Strike to Foot Flat	forward	internal rotation adduction	external rotation neutral to adduction
Foot Flat to Midstance	forward to neutral	internal rotation adduction	external rotation adduction
Midstance to Heel Off	neutral to backward	internal to external rotation adduction	external to internal rotation adduction
Heel Off to Toe Off	backward	external rotation abduction	internal rotation abduction
Acceleration to Midswing	backward to neutral	external rotation abduction	internal rotation abduction
Midswing to Deceleration to Heel Strike	forward	external to internal rotation abduction to adduction	internal to external rotation abduction to neutral

4.6 THE KNEE

Table showing the Range of Motion (ROM) of the knee, knee Movements, the GRF Moments, the Muscles associated with the movements, and the type of muscle Contractions during the stance and swing phases of gait.

PHASE OF GAIT	ROM	MOVEMENTS	MOMENTS	MUSCLES	CONTRACTIONS
Heel Strike to Foot Flat	0–5 deg to 15 deg	flexion	extension flexion	quads	eccentric (prevent knee buckeling)
Foot Flat to Midstance	15 deg to 5 deg	extension extension	flexion extension	quads quads	concentric no activity
Midstance to Heel Off	5 deg to 0 deg	extension	extension	no activity	none
Heel Off to Toe Off	0 deg to 30 deg	flexion flexion	extension flexion	quads popliteus quads	no activity concentric eccentric
Acceleration to Midswing	30 deg to 60 deg 60 deg to 30 deg	flexion extension	none none	hamstrings sartorius graclis quads	concentric concentric
Midswing to Deceleration to Heel Strike	30 deg to 5 deg	extension	none	quads hamstrings	concentric eccentric

deg. = degree, quads = quadriceps femoris

4.7 THE ANKLE

Table showing the Range of Motion (ROM) of the ankle, ankle Movements, the GRF Moments, the Muscles associated with the movements, and the type of muscle Contractions during the stance and swing phases of gait.

PHASE OF GAIT	ROM	MOVEMENTS	MOMENTS	MUSCLES	CONTRACTIONS
Heel Strike to Foot Flat	0 deg to 15 deg	plantar flexion	plantar flexion	ant. tib. ext. dig. long. ext. hal. long.	eccentric
Foot Flat to Midstance	15 deg to 5–10 deg	plantar flexion to dorsiflexion	plantar flexion to dorsiflexion	soleus gastroc. plantar flexors	eccentric
Midstance to Heel Off	5 deg to 0 deg	dorsiflexion to plantar flexion	dorsiflexion	soleus gastroc. post. tib. plantar flexors	eccentric to concentric
Heel Off to Toe Off	0 deg to 20 deg toes	plantar flexion extension	dorsiflexion extension	soleus gastroc. post. tib. fibularis long. and brev. FDL, AbH, interossei lumbricles FDB, FHL	concentric to no activity eccentric
Acceleration to Midswing	20 deg to neutral	dorsiflexion	none	ant. tib. ext. dig. long. ext. hal. long.	concentric
Midswing to **Deceleration to Heel Strike**	remains in neutral	none	none	ant. tib. ext. dig. long. ext. hal. long.	concentric

AbH = Abductor hallucis , FDB = flexor digitorum brevis, FDL = flexor digitorum longus, FHL = flexor hallucis longus, Ant. = anterior, dig. = digitorum, deg. = degree, ext. = extensor, gastroc. = grastrocnemius, hal. = hallucis, long. = longus, post. = posterior, tib. = tibialis

4.8 ANKLE AND FOOT POSITIONS DURING GAIT

Table listing the position of the ankle, subtalar joint, midtarsal joint and forefoot during the parts of the stance and swing phases.

PHASE OF GAIT	ANKLE	SUBTALAR	MIDTARSAL	FOREFOOT
Heel Strike to Foot Flat	supination (PF)	pronation (EVERT)	pronation (EVERT)	supination (INVERT)
Foot Flat to Midstance	supination (PF) to pronation (DF)	pronation (EVERT) to neutral	pronation (EVERT) to neutral	supination (INVERT) to neutral
Midstance to Heel Off	pronation (DF) to supination (PF)	neutral to supination (INVERT)	neutral to supination (INVERT)	neutral to pronation (EVERT)
Heel Off to Toe Off	supination (PF)	supination (INVERT)	supination (INVERT)	pronation (EVERT)

Acceleration to Midswing	supination (PF) to neutral	supination (INVERT) to neutral	supination (INVERT) to neutral	pronation (EVERT) to neutral
Midswing to Deceleration	neutral	neutral	neutral	neutral

DF = dorsiflexion, EVERT = eversion, INVERT = inversion, PF = plantar flexion

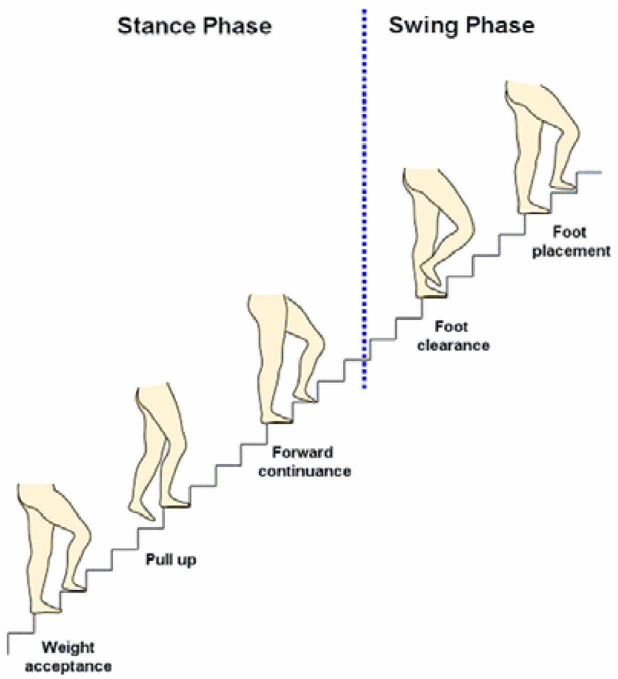
The best way to learn all the interacting components of walking is to repeat the movements often in a mirror and with colleagues. Also, these descriptions of the mechanics of gait are for a typical gait pattern, but not very one walks with a typical gait pattern. So while you are learning these components of gait on yourself or others keep in mind the gait pattern you are studying may not be typical and coincide with the material in this section.

ACTIVITIES: 1) Find a meter stick or long handle that you can use to align the outside of your right lower limb from your hip to your ankle. While looking at the stick diagrams that show the ground reaction forces (GRF), place the stick/handle along the side of your leg so the it matches the GRF at the hip, knee and ankle at heal strike. Do not look at the tables at this time. At the hip, knee, and ankle, write down the moment and then move your limb to the foot flat position. Here write down the moment and the movement of each joint. Continue this activity for midstance, heel off and toe off. When you have the moments and movements for each joint from heel strike to toe off, compare your descriptions with those of the table. If you were incorrect, figure out why and repeat this activity until you have it perfected. 2) Beginning at toe off, move your right lower limb through the swing phase. At each part of swing, write down the position and movements of the hip, knee, and ankle. Compare your descriptions with the tables on the swing. 3) Repeat activities #1 and #2 but this time add the muscles and contractions at each joint and each part of the stance and swing phases. 4) As in a previous activity on the foot where your hand was used to mimic the foot, place your right palm on a flat surface and your fingers extended like toes and your thumb adducted to the side of the index finger. This flat hand position represents the midstance position of the stance phase. Remember before the palmar aspect of the hand between the thenar and hypothenar eminences represented the "calcaneus". Now pronate the hand placing the "calcaneus" is in the position of subtalar pronation at heel strike. Next begin to supinate the hand until it is flat on the surface. This movement of the "calcaneus" represents the movement of the subtalar joint from heel strike, to foot flat and to midstance. From this flat hand position, continue to supinate the hand. This movement of the "calcaneus" represents the movement of the subtalar joint from midstance to heel off to toe off. Do this movement sequence several times and then add the corresponding movements at the midtarsal joint and forefoot.

5 MECHANICS OF ASCENDING AND DESCENDING STAIRS

- **ASCENDING STAIRS**

  - PHASES IN ASCENDING STAIRS
    - As with gait, the ascending of stair has a stances phase where the foot is in contact t with the stair and the swing phase where the foot is not contact with the stair.
    - stance phase
      + weight acceptance
      + weight acceptance to pull up
      + pull up to forward continuance
    - swing phase
      + foot clearance
      + foot placement
    - During the stance phase, the GRF is opposite to the movement at the hip, knee, and ankle so the muscles need to concentrically contract to produce the movements.



Drawing showing the position of the right lower limb during the parts of the stance and swing phases. (Modified from Norkin and Frankle 1989, 2001).

5.1 THE HIP

Table listing the Range of Motion (ROM) of the hip, hip Movements, the Muscles associated with the movements, and the type of muscle Contractions during the stance and swing phases of ascending stairs.

PHASE	ROM	MOVEMENTS	MUSCLES	CONTRACTIONS
Weight acceptance to pull-up	60 deg flexion to 30 deg flexion	extension	gluteus max. gluteus med.	concentric
Pull-up to forward continuance	30 deg flexion to 5 deg flexion	extension	gluteus max. gluteus med.	concentric
Foot clearance to foot placement	5 deg flexion to 60 deg flexion	flexion	iliopsoas	concentric

deg. = degree, max. = maximus, med. = medius

5.2 THE KNEE

Table listing the Range of Motion (ROM) of the knee, knee Movements, the Muscles associated with the movements, and the type of muscle Contractions during the stance and swing phases of ascending stairs.

PHASE	ROM	MOVEMENTS	MUSCLES	CONTRACTIONS
Weight acceptance to pull-up	80 deg flexion to 35 deg flexion	extension	rectus fem. vastus lat. (quads)	concentric
Pull-up to forward continuance	35 deg flexion to 10 deg flexion	extension	rectus fem. vastus lat. (quads)	concentric
Foot clearance to foot placement	10 deg flexion to 90–100 deg	flexion	hamstrings	concentric
	90–100 deg flexion to 85 deg flexion	extension	rectus fem. vastus lat. (quads)	concentric

deg. = degree

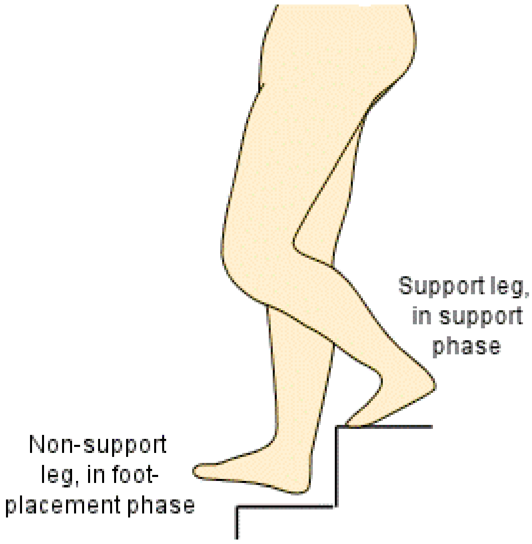
5.3 THE ANKLE

Table showing the Range of Motion (ROM) of the ankle, ankle Movements, the GRF Moments, the Muscles associated with the movements, and the type of muscle Contractions during the stance and swing phases of gait.

PHASE	ROM	MOVEMENTS	MUSCLES	CONTRACTIONS
Weight acceptance to pull-up	20–25 deg dorsiflexion to 15 deg dorsiflexion	plantar flexion	gastrocnemius soleus acting on tibia	concentric
Pull-up to forward continuance	15 deg dorsiflexion to 10–15 deg plantar flexion	plantar flexion	gastrocnemius soleus acting on tibia and then foot	concentric
Foot clearance to foot placement	10 deg plantar flexion to 20 deg dorsiflexion	dorsiflexion	anterior tibialis	concentric

deg. = degree

- **DESCENDING STAIRS**
  - There are no subdivided stance and swing phases as with gait and ascending stairs.
  - The stance or support phase is the support lower limb in contact with the stair.
  - The swing or foot-placement phase is the non-support lower limb reaching to the next stair.
  - During the stance or support phase, the support limb lowers the non-support limb and the muscles at the hip, knee and ankle contract eccentrically.



Drawing of the support limb during the support phase of descending stairs lowering the non-support limb duringthe foot-placement phase

5.4 SUPPORT LIMB

Table listing the Movements, Muscles associated with the movements and the Muscle Actions of the hip, knee, ankle and toes during the support phase of descending stairs.

JOINTS	MOVEMENTS	MUSCLES	MUSCLE ACTIONS
Hip	flexion	gluteus max.	eccentric to control hip flexion
Knee	flexion	quads	eccentric to control knee flexion
Ankle	dorsiflexion	gastrocnemius soleus plantar flexors	eccentric to control ankle dorsiflexion
Toes	extension	FDL, FDB, FHL, FHB, AbH, interossei lumbricals	eccentric to control toe extension

AbH = Abductor hallucis, FDB = flexor digitorum brevis, FDL = flexor digitorum longus, FHL = flexor hallucis longus, quads = quadriceps femoris

5.5 NON-SUPPORT LIMB

Table listing the Movements, Muscles associated with the movements and the Muscle Actions of the hip, knee, ankle and toes during the non-support foot-replacement phase of descending stairs

JOINTS	MOVEMENTS	MUSCLES	MUSCLE ACTIONS
Hip	extenion	gluteus max.	concentric to extend flexed hip
Knee	extenion	quads	concentric to extend knee to reach step below
Ankle	plantar flexion to dorsiflexion	gastrocnemius soleus plantar flexors	concentric plantar flexion to reach step below then eccentric to control dorsiflexion for full foot loading
Toes	Neutral to slight flexion	FDL, FDB, FHL, FHB, AbH, interossei lumbricales	no activity to concentric for toe to step contact

AbH = Abductor hallucis, FDB = flexor digitorum brevis, FDL = flexor digitorum longus, FHL = flexor hallucis longus, quads = quadriceps femoris

- **RUNNING**

  - Running is also divided into stance and swing phases.
  - In the stance phase the foot is in contact with the ground.
  - In the swing phase the foot is off the ground.
  - STANCE PHASE
    - foot strike
    - foot strike to midsupport
    - midsupport to toe off
  - SWING PHASE
    - forward swing
    - deceleration

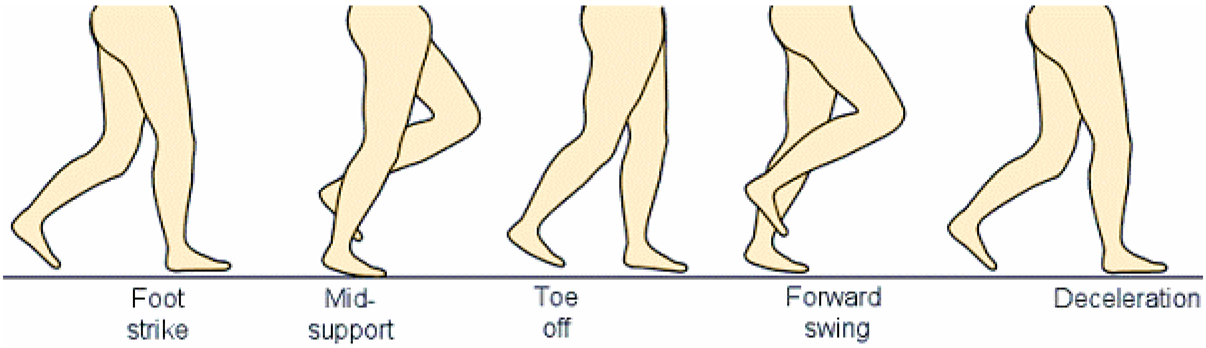


Diagram showing the position of the hip, knee and ankle during the stance andswing phases of running. (Modified from Norkin and Frankle 1989, 2001).

  - RUNNING MOVEMENTS
    - At foot strike of running, as at heel strike of walking, the calcaneus everts (subtalar pronation), the midtarsal joint pronates, and the midfoot is mobile and the forefoot is supinated.
    - At midsupport of running, as at midstance of walking, the calcaneus is inverting (subtalar supination)and passing through subtalar neutral and the midtarsal joint is supinating, the midfoot is becoming rigid and the forefoot is moving from neutral and into pronation.
    - At toe off of running, as in walking, the subtalar and midtarsal joints are inverted (supinated) and the midfoot is ridged and the forefoot is pronated.
    - During running from foot strike to midsupport, there is rapid ankle dorsiflexion.
    - During running from midsupport to toe off, there is rapid ankle plantar flexion.
    - During the stance phase of running, the hip adducts and as running speed increases, the magnitude of hip adduction increases.

- GENERAL MUSCLE ACTIVITY
  - Muscle actions associated with walking are similar for running although there is more overlap of muscle activity.
  - During running, especially between the hamstrings and quadriceps, as the phases of movement are shorter in running than walking.
  - In running, muscle groups are active over 70–80% of the stance phase (note: the time of the stance phase decreases during running so muscles are active over a high percentage of the phase).
  - In walking, muscle groups are active over < 50% of the stance phase (note: the time of the stance phase is longer in walking than in running so the muscles are active over a low percentage of the phase in walking).

- RUNNING SPEED
  - As speed increases, the period of the stance phase decreases and the period of the swing phase increases.
  - At high speeds, there is a period of non-support called the FLOAT PHASE in which both feet are off the ground.

- FORCES
  - vertical forces
    - + Vertical forces are greater during running than walking.
    - + During walking, vertical forces are 110–120% body weight.
    - + During running, vertical forces reach 200% body weight.
  - fore and aft shear forces
    - + These forces increase by 50–100% during running as compared to walking.
  - medial and lateral shear forces
    - + These forces increase by 150–200% during running as compared to walking.

- REPETITIVE STRESS ON THE FOOT
  - walking
    - + a 150 lb. male with a step length of 2.5 ft andwalking at 2110 steps per mile shows on averagevertical forces of 80% body weight at heel strike
    - + for a 1 mile walk, the repetitive forces total 253,440lbs (127 tons) = 63.5 tons per foot
  - running
    - + a 150 lb male with a step length of 3.5 ft and a rate of 1175 steps per mile shows on average vertical forces of 250% body weight at foot strike
    - + for a 1 mile run, the repetitive forces total 440,625lbs (220 tons) = 110 tons per foot

Study Questions (gait)

1. What is the ground reaction force and does it affect joint movement andmuscle activity during stance?
2. For the hip and knee, what are the movements, moments and muscle actions occurring during the following:
    a. heel strike to foot flat
    b. foot flat to midstance
    c. heel off to toe off
3. For the ankle and foot, what are movements, moments and muscle actions occurring during the following:
    a. heel strike to foot flat
    b. foot flat to midstance
    c. heel off to toe off
4. What are the movements and muscles actions occurring at the hip, knee and ankle for midswing to deceleration?
5. What are the actions of the following muscles on the support side during ascending stairs?
    a. gluteus maximus
    b. gluteus mdius
    c. quadriceps
    d. plantar flexors
6. What are the actions of the following muscles on the support side duringdescending stairs?
    a. gluteus maximus
    b. quadriceps
    c. plantar flexors
7. How do the actions of the above muscles in questions 5–6 differ betweenascending and descending stairs?

6 BIOMECHANICS STUDY QUESTIONS

Study Questions (Newton's Laws and Forces)

1. Apply Newton's First Law to the movements of the glenohumeral joint.
2. Apply Newton's Second Law to an exercise for increasing elbow flexion strength.
3. Apply Newton's Third Law to gripping and holding an object in your hand.
4. What is the difference between total and unit force?
5. What is the difference between loads and stresses?
6. What are the stresses occurring in a tendon when a tensile load isapplied by the contraction of a muscle?
7. What are the stresses occurring in a vertebral disc when a compression load is applied by the vertebral bodies?
8. What is the difference between stress and strain?
9. What strains occur at a tendon when a tensile load is applied?
10. What strains occur when a long bone is bending?
11. What is the difference between work and power?

ANSWERS

1. Force is needed to start a movement at the joint and the movement will continue in the same direction unless another force is applied to change the direction of movement. If the shoulder flexors activate flexion at the glenohumeral joint, flexion will continue until another force, say by the deltoid, applies an abduction force on the glenohumeral joint. The movement direction will then change with the addition of this second force.
2. If it is necessary to accelerate elbow flexion motion during an exercise than greater force will be needed. If a weight is added to the hand, then the mass increases and this increase in mass will decelerate the motion unless more force is added. Rapid elbow flexion requires more force and if the mass is also increased then even force is required.
3. In lifting an object off the ground, the lifting forces of the arm are equal and opposite to the forces holding the object in position. As the mass of the object is much less than the mass of the ground (earth), the lifting force of the arm will accelerate the object and the object will move.

4. Total force is the total amount of force being applied to a surface while unit force is the force being applied per unit area on the surface. So if there is a total force of 100 Newtons on a surface with an area of 100 mm2 then the unit force would be 100 N divided by 100 MM2 or 1N per mm2.
5. Loads are externally applied to a structure while stress is the force that occurs within that structure due to the external load.
6. With a tensile (tension) load on the tendon, there are tensile stresses being transmitted with in the tendon, compressive stresses within the tendon resisting the tensile stresses and shear stresses resulting from the tensile – compression forces.
7. With a compression load on a vertebral disc, there are compressive stresses being transmitted in the disc, tensile stresses resisting the compression stresses, and shear stresses resulting for the tensile – compression forces.
8. Stresses are internal forces within a structure while strain is the deformation of the structure due to these stresses.

9. When a tensile load is applied to a tendon, the tensile stresses produce tensile strain (elongation) of the tendon. At the same time, the resisting compressive stresses in the tendon produce compressive strain (contraction, squeezing) in the tendon and these two stresses produce shear stresses which produces shear strain (cutting, tearing) in the tendon. The relative magnitude of the stresses determines what the overall strain is on the structure. If the tensile stresses are greater than the compressive stresses than the structure will elongate.
10. When a long bone bends, the concave side of the bend shows compressive stress and strain and the convex side show tension stress and strain. The forces for both are greatest at the periphery and decrease as the neutral axis in the center of the bone is reached.
11. Work is a function of the amount of force times the distance over which that force is applied. Work has no time component. However, Power is work divided by time. Unlike Work, as the time interval changes the amount of power changes.

Study Questions (vectors and torque)

1. How would you determine the final resultant force and movement of a bone when three different muscles are applying forces (F1, F2, F3) at three different angles to the bone?
2. How can the component forces be determined from the line of actionof a muscle?
3. What is the difference between fixed and movable pulleys?
4. What is the difference between type I and type III levers?
5. What is toque and how is it calculated?
6. With a type I lever, what would the Force be if dW=6 cm and dF=2 cm? What if the dW=3 cm and dF=9 cm?
7. With a type III lever, what would the Force be if dW=10 cm and dF=2cm? What if the dW=20 cm and dF=2 cm?
8. How can the distance that the weight arm moves be increased relative to the distance that the force arm moves in a Class I lever? How about in a Class III lever?
9. How does movement of the force arm only a short distance affect muscle contraction force?

ANSWERS

1. By using a parallelogram, the resultant force FR1,2 can be determined for the combined action of F1 and F2 on the bone. After FR1,2 is resolved, this resultant force and F3 can be combined to find the overall resultant force FR1,2,3.
2. Represent the line of action of a muscle as a vector and then construct a X and a Y axis for that vector. The X axis is always along the bone that is moving and the Y axis will be perpendicular to the X axis. Using the line of action of the muscle as the hypotenuse, the X and Y components of muscle action can be derived. Remember, that as the muscle contracts and the bone moves the line of muscle action usually changes and so do the X and Y components.
3. Fixed pulleys change the direction of pull but not the magnitude of the applied force whereas movable pulleys change both the direction of pull and decrease the magnitude of the applied force.
4. Type I lever has a central fulcrum with the weight side of the lever on one side of the fulcrum and the force side of the lever on the opposite side of the fulcrum. With a type III lever, the fulcrum is at one end and the weight at the opposite end of the lever. The force lies between the fulcrum and the weight end. In this lever, the weight arm is always longer than the force arm.
5. Torque is a rotational force and is calculate by multiplying the Force or Weight by the perpendicular distance of the Force or Weight from the center of rotation.
6. If dW=6 and dF=2, the Force (F) = 3W (Weight). If dW=3 and dF=9, the Force (F) = 1/3 W (Weight)
7. If dW=10 and dF=2, the Force (F) = 5W (Weight). If the dW= 20 and dF=2, the Force (F) = 10W (Weight).
8. In a Class I lever, the longer the weight arm relative to the Force arm or the shorter the Force arm relative to the Weight arm, the greater and faster the movement of the Weight end of the lever. In a Class III lever, the same is true. The longer the weight arm or the shorter the Force arm, the greater and faster the movement of the weight end of the lever.
9. With a short Force arm and a long Weight arm, small movement at the force end of the lever produces a large movement at the weight end. Because the movement of the force end is small, the shorten (contraction) of the muscle is also small. This small shortening keeps the muscle near the top of its length-tension curve so force production by the muscle is high.

Study Questions (movement)

1. What is the difference between osteokinematic and arthrokinematic movements?
2. Give an example of the following types of synovial joints and there degrees of freedom.
   a. plane
   b. hinge
   c. condyloid
   d. saddle
5. What is the concave/convex rule?
4. What is the difference between a loose pack and closed pack position of a joint?

ANSWERS

1. Osteokinematic are the movements seen by the bone at a joint. These include flexion, extension, abduction and adduction. Arthrokinematic movements are those that are occurring at the articular surfaces of the bone making up the joint. These movements are usually described as a rotation, translation, or a combination of the these or curvilinear.
2. a. intercarpal joints which can have 1, 2 or 3 degrees of freedom
   b. humeroulnar or interphalangeal joints which have 1 degree of freedom
   c. radiocarpal or metacarpophalangeal joints which have 2 degrees of freedom
   d. carpometacarpal joint of the thumb which has 2 degrees of freedom or the sternoclavicular joint which has 3 degrees of freedom.
3. When a convex surface is moving on a fixed concave surface, arthrokinematic joint translation (glide) is opposite to the direction of osteokinematic movement. However, when a concave surface is moving on a fixed convex surface, arthrokinematic joint translation (glide) is in the same direction a the osteokinematic movement.
4. In a loose pack position, the joint shows minimum congruency between the match joint surfaces, the ligaments and capsule are loose and there is maximum joint space. This position is for good for dynamic joint movement and joint mobilization but poor for static load bearing. In the closed pack position, the joint shows maximum congruency, tightness of the joint capsule and ligaments, minimal joint space. This is a good position for static load bearing but not for joint mobilization.

Study Questions (shoulder complex movements)

1. What movements of the clavicle occur at the sternoclavicular and acromioclavicular joints during the following movements:
   a. clavicular elevation
   b. clavicular posterior rotation
   c. clavicular protraction
2. What are benefits of upward scapular rotation during arm flexion and abduction?
3. What is scapular rhythm?
4. When is phase II of scapular movement and what movements occur during this phase?
5. What can decrease the size of the subacromial space?
6. What are the movements of the shoulder complex structures during flexion?
7. What are the movements of the shoulder complex structures during extension?
8. What are the movements of the shoulder complex structures during external rotation?

ANSWERS

1. a. elevation at the acromioclavicular joint and depression at the sternoclavicular joint
   b. posterior rotation at the sternoclavicular and acromioclavicular joints
   c. anterior translation of the clavicle at the sternoclavicular and acromioclavicular joints
2. Increases ROM in flexion and abduction, maintenance of the subacromial space, permits the deltoid, supraspinatus and coracobrachialis muscles to function near the top of the length-tension curve so that these can produce high forces over a large portion of the motion.
3. Scapular rhythm is the ratio of glenohumeral motion to scapular motion. This ratio is commonly given at 2:1 (2 degrees of glenohumeral to 1 degree of scapular motion) but it is variable. Using the 2:1 ratio, 90 degrees of osteokinematic flexion or abduction is the result of 60 degrees of glenohumeral movement and 30 degrees of scapular movement.
4. Phase II of scapular movement occurs after 90 degrees of shoulder flexion and abduction. During this phase, scapular and clavicular elevation occurring in Phase I stops and the scapula upwardly rotates and the clavicle rotates posteriorly.
5. subacromial bursitis, calcium deposits in the subacromial bursa, thickening of the coracoacromial ligament, inflammation of the rotator cuff or the tendon of the long head of the biceps, thickening or hooking for the acromion process.

6. From 0–60 degrees, the scapula and clavicle elevate, the humeral head glides inferiorly and rotates posteriorly. From 60–90, the humeral head is seated in the glenoid fossa and rotates posteriorly, the clavicle and scapula continue to elevated but the scapula also begins to upwardly rotate. From 90–180, the scapula upwardly rotates, the clavicle rotates posteriorly, and humeral head rotates posteriorly while still seated in the glenoid fossa.
7. From 180–90 degrees, the seated humeral head rotates anteriorly, the scapula downwardly rotates, and the clavicle rotates anteriorly. From 90–60, the seated humeral head continues to rotate anteriorly, the scapula stops it downward rotation and depresses, and the clavicle stops its anterior rotation and depresses. From 60–0, the humeral head rotates anteriorly and glides superiorly, and the scapula and clavicle depress.
8. During external rotation with the arm at the side of the body, the humeral head rotates laterally and glides anteriorly, the clavicle translates posteriorly and the scapula retracts.

Study Questions (shoulder complex movements and muscle actions)

1. What scapular and clavicular movements are produced by the upper trapezius?
2. What muscles produce downward rotation of the scapula?
3. What muscles produce upward rotation of the scapula?
4. What are the actions of the deltoid?
5. What muscles produce glenohumeral adduction and internal rotation?
6. What muscles produce an inferior glide of the humeral head?
7. What muscle is the main glenohumeral abductor from 0–60 degrees? What about abduction over 90 degrees?
8. What are the muscles producing glenohumeral flexion from 0–60 degrees and from 90–180 degrees?
9. What movements and muscles actions producing glenohumeral flexion are common to those during glenohumeral abduction? What are different?
10. What movements and muscle actions are common during glenohumeral extension (180–0 degrees) and adduction (180–0 degrees)? What are different?
11. What are the two strongest groups of shoulder muscles? What are the two weakest groups? How does this relate to muscle testing?
12. Why is the amount of force generated by the deltoid to hold the arm at 90 degrees of abduction so much greater than the weight of the arm? How about the rotator cuff holding the arm in abduction at 60 degrees?

ANSWERS

1. elevation of the scapula and clavicle, posterior rotation of the clavicle, upward rotation of the scapula
2. pectoralis minor, rhomboid major and minor, levator scapulae
3. upper trapezius, lower trapezius, serratus anterior
4. glenohumeral flexion, extension, abduction, internal rotation, external rotation
5. pectoralis major, latissimus dorsi, teres major, subscapularis (slight adduction)
6. infraspinatus, teres minor, subscapularis
7. supraspinatus is the main abductor for 0–60 degrees and the deltoid is the main abductor above 90 degrees.
8. Flexion for 0–60 degrees: the upper trapezius elevates the clavicle and scapula – the subscapularis, infraspinatus, teres minor produce the inferior glide of the humeral head – the coracobrachialis, anterior deltoid and biceps produce the posterior humeral head rotation. Flexion from 90–180 degrees: the upper trapezius, lower trapezius and serratus anterior produce the upward scapular rotation – the rhomboids stabilize the scapula and control upward scapular rotation – the upper trapezius produces the posterior clavicular rotation – the subscapularis, infraspinatus and teres minor hold the humeral head seated in the glenoid fossa – coracobrachialis, anterior deltoid, biceps produce the posterior rotation of the humeral head.
9. In both flexion and abduction, scapular and clavicular elevation are produced by the upper trapezius – upward scapular rotation is produced by the upper trapezius, lower trapezius, serratus anterior and the rhomboids stabilize the scapula and control upward rotation – the upper trapezius produces posterior clavicular rotation – the subscapularis, infraspinatus and teres minor produce the inferior humeral head glide and hold it (seated) in position – deltoid acts to rotate the humeral head. The only differences are the medial direction of humeral head abduction and the muscles producing the rotation.
10. In both extension and adduction, scapular downward rotation is produced by the levator scapulae, rhomboids major and minor and pectoris minor – anterior clavicular rotation by the pectoralis major – subscapularis, infraspinatus, teres minor hold the humeral head seated in the glenoid fossa – pectoralis minor and lower trapezius depress the scapula – pectoralis major and subclavius depress the clavicle. The differences are the direction of humeral head rotation (anterior in extension and lateral in adduction) and the muscles producing these rotations.

11. The strongest groups are the adductors and internal rotators while the weakest groups are the abductors and external rotators. Because of these normal differences in strength, comparisons of strength based on the amount of resistance applied during a movement may be misleading and not provide an accurate measure of function. It is important to remember that some muscles and muscle group are more powerful than others and that relative weakness between these is not necessarily a sign of dysfunction.
12. For both the deltoid and rotator cuff muscles, the high forces are associated with the type of lever involved in these actions. These muscles are acting as the force part of a Class III lever and the force arms are short compared to the weight arms. With this arrangement, the amount of force required is always much higher that the amount of weight or resistance.

Study Questions (elbow)

1. Why is the medial collateral ligament of the elbow more developed than lateral collateral ligament and what movements do the medial collateral ligament resist.
2. What is the best way to test the medial collateral ligament and the joint capsule of the elbow joint?
3. What elbow movements are needed for most ADLs?
4. What arthrokinematic movements are common at the humeroulnar and humeroradial joints during flexion? What movements are not common?
5. What arthrokinematics movements occur at the proximal radioulnar joint during pronation of the forearm?
6. If the musculocutaneous nerve is damaged, what muscles could still flex the elbow?
7. What is the main flexor of the elbow and why?
8. What are the differences in the actions of the three heads of the triceps?
9. What is the main pronator of the forearm and why?

ANSWERS

1. Most ADLs involving the elbow apply a valgus strain that tenses the medial collateral ligament (MCL). This tensile strain stimulates the production of collagen and thus the MCL develops more than the LCL which has less strain applied to it. The MCL has an anterior and a posterior band. The superior fibers of the anterior band resist elbow extension and the inferior fibers of the anterior band resist flexion. The posterior band resists flexion beyond 90 degrees.
2. The way to test the MCL is to place the elbow at 90 degrees of flexion and apply distraction to the joint. The best way to test the joint capsule is to place the elbow in a 0 degrees position and apply distraction to the joint.

3. Flexion between 20 to 130 degrees and 50 degrees of pronation from neutral and 50 degrees of supination from neutral.
4. During elbow flexion, both the ulna and the radius rotate and glide anteriorly, but only the radius moves cranially on the ulna and the ulna guides the forearm in adduction as its trochlear ridge follows the trochlear groove of the humerus.
5. During forearm pronation, only the radius is moving. It rotates medially and the head glides laterally.
6. The brachioradialis, pronator teres, flexor carpi ulnaris and radialis, flexor digitorum superficialis, and extensor carpi radialis longus can flex the elbow.
7. The main flexor of the elbow is the brachialis. It shows the largest strength and work capacity, it is active regardless of should position, and its active during resistive and non-resistive flexion at both rapid and slow elbow flexion.
8. The action of the long head of the triceps is affected by the position of the shoulder but the medial and lateral heads are not. The lateral and long heads are active with resisted but not non resisted movements while the medial triceps is active is active with resisted and non-resisted movements. The long head shows its greatest activity during rapid and high resistive movements.
9. The main pronator of the forearm is the pronator quadratus as it is not affected by elbow position as the pronator teres is and the pronator quadratus is active during resisted and non-resisted movements and during rapid and slow pronation. The pronator teres is active with rapid and resistive pronation but not with slow and non-resistive pronation.

Study Questions (wrist)

1. What are the roles of the intrinsic and extrinsic ligaments of the wrist?
2. What wrist movements are needed for most ADLs?
3. What is the movement sequence during wrist extension (dorsiflexion) and where does most of the movement take place.
4. How does the movement sequence during wrist flexion (palmar flexion) differ from that of dorsiflexion?
5. What is the movement sequence during wrist ulnar deviation?
6. How does radial deviation differ for ulnar deviation?
7. Why are radial and ulnar deviations limited when the wrist is in full extension?
8. How might fractures or dislocations at the wrist affect movement?
9. What muscles produce the following movements:
   a. wrist extension
   b. wrist flexion and ulnar deviation
   c. wrist flexion
   d. wrist extension and radial deviation
10. Which muscles stabilize the following:
    a. ulnar side of the wrist when the wrist is in a neutral position
    b. radial side of the wrist when the wrist is in a neutral position
    c. ulnar side of the wrist when the wrist is in extension

ANSWERS

1. These ligaments provide stability for the radiocarpal, ulnocarpal, midcarpal and intercarpal joints. They also resist movements by tightening and allow movements by loosening. This combination of ligament tightening and loosing allows certain bones to move while at the same time restricts other bones from moving. The results are wrist flexion (palmar flexion), extension (dorsiflexion), radial and ulnar deviation.
2. For most ADLs 10 degrees of palmar flexion and 35 degrees of dorsiflexion are needed.
3. During wrist extension, the distal carpal row moves dorsally and proximal row moves palmarly. At 60 degrees of extension, the scaphoid of the proximal carpal row and the hamate, capitate and trapezoid of the distal carpal row come into a closed pack position, forming a ridged mass. Distal movement of this mass on the palmarly moving proximal row at the radiocarpal joint completes wrist extension. Because of the formation of this closed pack position between the proximal and distal carpal rows, 60–70% of wrist extension occurs at the radiocarpal joint and 30–40% at the midcarpal joint.

4. During wrist flexion, the direction of movement of the proximal and distal carpal rows is opposite that of extension (proximal move dorsally and distal move palmarly). While the scaphoid, hamate, capitate and trapezoid formed a closed packed ridge mass during extension, this formation does not occur during flexion and thus movement of the midcarpal joint is not blocked. In fact, most of the flexion movement that occurs during the last part of flexion is at the midcarpal joint. Because midcarpal movement is allow throughout the range of wrist flexion, more flexion (60%) occurs at the midcarpal joint and less (40%) at the radiocarpal joint which is opposite of that seen during extension where most movement occurs at the radiocarpal joint and less at the midcarpal joint.
5. During ulnar deviation, the distal carpal row moves ulnarly, the proximal row slightly radially and the scaphoid and lunate move dorsally.
6. Movements of the distal and proximal carpal rows and movement of the scaphoid and lunate during ulnar deviation are opposite those occurring during radial deviation.
7. Radial and ulnar deviations require movements between the proximal and distal carpal rows at the midcarpal joint. With the wrist in full extension, the scaphoid, hamate, capitate, and trapezoid form a closed pack ridged mass that blocks movement at the midcarpal joint. With midcarpal movement blocked, radial and ulnar deviations are also blocked and thus very limited or no deviation is permitted.
8. If a fracture of the distal radial occurs, motion at the radiocarpal joint will be affected. Because 60–70% of dorsiflexion (extension) occurs here, there will likely be more restriction and problems with wrist dorsiflexion than with wrist palmar flexion. As radial and ulnar deviations occur mainly at the midcarpal joint, there should be little effect on these movements. If the scaphoid or lunate are fractured or dislocated, both the radiocarpal and midcarpal joints would be involved. In this case, dorsiflexion, palmar flexion and radial and ulnar deviations could be affected. If a fracture or dislocation affected mainly the midcarpal joint, then radial and ulnar deviation would be affected. Palmar flexion would most likely be affected more than dorsiflexion as 60% of palmar flexion occurs at the midcarpal joint whereas only 30–40% of dorsiflexion occurs at the midcarpal joint.
9. a. ext. carpi radialis longus and brevis, ext. carpi ulnaris, ext. digitorum, ext. indicis, ext. digiti minimi
   b. flex. carpi ulnaris
   c. flex. carpi radialis, flex. carpi ulnaris, flex. digitorum superficialis, palmaris longus
   d. ext. carpi radialis longus; ext. carpi radialis brevis (slight radial deviation)
10. a. flex. carpi ulnaris; ext. carpi ulnaris
    b. ext. carpi radialis longus; flex. carpi radialis
    c. flex. carpi ulnaris

Study Questions (hand)

1. In what way does arthrokinematic abduction and adduction of the carpometacarpal joint of the thumb differ from arthrokinematic movements at the other joints of the fingers?
2. What joints are flexed by contraction of the flexor digitorum superficialis?
3. How would you differentiate between the following muscles:
    a. flexor digitorum superficialis and profundus
    b. flexor pollicis longus and brevis
    c. extensor pollicis longus and brevis
4. What muscles are needed to fully extend a finger and why are multiple muscles needed for this action?
5. What are the two main functions of the flexor tendon sheath?
6. How does the extensor assembly extend the PIP and DIP?
7. What are the differences between ulnar nerve palsy and median nerve palsy during active extension of the fingers and why?
8. What are the differences between ulnar nerve palsy and median nerve palsy during active flexion of the fingers and why?
9. What is the difference between a power grip and a precision grip?
10. What is the difference between a tip pinch and a lateral pinch?
11. If you are mobilizing a joint and are applying 5 pounds of compression to the thumb, how much compression force is occurring at each joint of the thumb?

ANSWERS

1. During thumb carpometacarpal abduction and adduction, the direction of rotation and glide are opposite the osteokinematic movement whereas at the other joints the direction of rotation and glide are in the same direction as the osteokinematic movement.
2. wrist, carpometacarpal, metacarpophalangeal, proximal interphalangeal
3. a. The profundus flexes the distal interphalangeal joint but the superficialis does not.
    b. The longus flexes the interphalangeal joint of the thumb and the brevis does not.
    c. The longus extends the interphalangeal joint of the thumb and the brevis does not.
4. The extensor digitorum, ext. indicis (specific to index finger), ext. digiti minimi (specific to little finger), lumbricals, palmar and dorsal interossei are the muscles needed for full extension of the fingers. Because of the strength of the flexor digitorum superficialis and profundus and the lack of strength of the extensors, the lumbricals and interossei are needed.

5. The flexor sheath 1) maintains the proper position of the flexor tendons to the axis of the joint so that there is smooth distal to proximal flexion of the fingers and thus preventing bow stringing by tendons which gives tendons a mechanical advantage at the joint (increasing the force arm) and produces premature bending of the joint and 2) minimizes the amount tendons need to move to produce flexion and thus the amount of muscle shortening so the muscles can work near the top of the length- tension curve.
6. Tension applied to the extensor hood by the extensor digitorum (ext. indicis and digiti minimi), lumbricals and interossei is transmitted to the central slip and the lateral bands. Tension of the central slip produced extension of the PIP. Tension on the lateral bands is transmitted to the terminal tendon to extend the DIP.
7. With ulnar nerve palsy when trying to actively extend the fingers, the PIP and DIP of the little and ring fingers are flexed more than the flexion occurring at the PIP and DIP of the index and middle fingers because of involvement of the interossei and lumbricals of the little and ring fingers. Also the MCPs of all the fingers are extended because the extensor digitorum in intact.

   With median nerve palsy, when trying to actively extend the fingers, extension of the PIP and DIP of the index and middle fingers are less than the extension of the little and ring fingers because of loss of the lumbricals to the index and middle fingers but not the little and ring fingers. Extension of the MCP joints are not involved.
8. With ulnar nerve palsy, when actively trying to flex the fingers, flexion of the ring and index fingers are less than flexion of the index and middle fingers because of involvement of the flexor digitorum profundus and lumbricals to the little and the ring fingers. With median nerve palsy, when actively trying to flex the fingers, flexion of the index and middle fingers will be less than the little and ring fingers because the flexor digitorum superficialis and profundus and the lumbricals of the index and middle fingers are involved but the flexor digitorum profundus and lumbricals of the little and ring fingers are intact.
9. The thumb is adducted in a power grip but abducted in a precision grip.
10. In a tip pinch, the tips of the two fingers are used and the forces are greater at the PIP joint than the MCP joint. With a lateral pinch, the palmar aspect of the distal thumb is pressing an object against the distal radial aspect of the index finger and forces at the MCP are greater than the PIP.
11. 5 pounds of compression force on the thumb will produce 10–15 pounds of force at the IP, 25–30 pounds of force at the MCP, and 30–60 pounds at the CMC joint.

Study Questions (hip)

1. How do coxa vara and valga differ from anteversion and retroversion?
2. How do the three femoral ligaments similar and how do they differ?
3. How much hip ROM is needed to perform most ADLs?
4. How are the arthrokinematics of the hip similar to that of the glenohumeral joint?
5. What is position of the support (pivot) hip during the following positions of the pelvis?
    a. anterior pelvic tilt
    b. non-support side pelvic lateral drop
    c. non-support side forward pelvic rotation
6. What are the mechanical and compensatory positions of the lumbar spine during the following positions of the pelvis?
    a. anterior pelvic tilt
    b. non-support side pelvic lateral drop
    c. non-support side forward pelvic rotation
7. During weight bearing, what strains occur at the femoral shaft and the neck?
8. What muscles produce the following hip movements?
    a. hip flexion
    b. hip extension
    c. hip abduction and internal rotation

ANSWERS

1. From the shaft of the femur, the neck and head angle upward. Normally this upward angle is about 125 degrees, but with coxa valga, the upward angle is greater than 125 degrees and with coxa vara the angle is less than 125 degrees. In addition to this upward angulation, the neck and head of the femur are angled anteriorly relative to the femoral condyles. Normally this anterior angle is 12–15 degrees but in some individuals this anterior angle is greater than 20 degrees and this is called anteversion. In others, the anterior angulation is less than 12 degrees and this is retroversion. Anteversion can rotate the femur medial producing a toes-in position while retroversion can rotate the femur laterally producing a toes-out position. Coxa valga and coax vara are abnormal degrees of upward angulation of the femoral neck and head in the frontal plane while anteversion and retroversion are abnormal degrees of anterior angulation of the femoral neck and head in the transverse plan.
2. All three ligaments resist hyperextension of the hip. The iliofemoral and pubofemoral are anterior ligaments while the ischiofemoral is posterior. The iliofemoral and pubofemoral resist abduction but the iliofemoral also resists adduction.
3. 120 degrees of flexion, 20 degrees of external rotation, 20 degrees of abduction.

4. Both of these ball and socket joints show posterior rotation with flexion, anterior rotation with extension and hyperextension (backward extension), medial rotation in the frontal plane with abduction, lateral rotation in the frontal plane with adduction, medial rotation in the transverse plane with internal rotation, and lateral rotation in the transverse plane with external rotation.
5. a. hip flexed
   b. hip adducted
   c. hip internal rotated
6. a. lumbar spine would mechanically flex and the person would compensate by lumbar extension
   b. lumbar spine would mechanically bend laterally toward the non-support side and the person would compensate by bending lateral toward the support side
   c. lumbar spine would mechanically rotate toward the support side and the person would compensate by rotating toward the non-support side.
7. The femoral shaft and neck both undergo bending strain during weight bearing. Tensile strains occur along the lateral shaft and the superior neck while compression strains occur along the medial shaft and the inferior neck.
8. a. iliopsoas, rectus femoris, sartorius, tensor fascia lata
   b. gluteus maximus, hamstrings
   c. gluteus medius, gluteus minimus, tensor fascia lata

Study Question (knee)

1. What are the functions of the collateral and cruciate ligaments?
2. How do closed chain and open chain flexion differ?
3. How do closed chain and open chain extension differ?
4. How does the tibiofemoral joint lock in extension and unlock?
5. What muscles acting on the knee have multiple actions?
6. Explain the forces occurring at the knee during heel strike (HS), midstance, and heel off (HO)?
7. How do the functions of the menisci and cruciate ligaments differ?
8. How do the following increase the Q-angle and why?
   a. genu valgus
   b. femoral anteversion
   c. external tibial torsion
9. How does movement of the patella during knee flexion relate to the areas of contact between the patellar and femoral condyles?
10. How do the patellar retinacula affect patellar movement and forces?

ANSWERS

1. The medial and lateral collateral ligaments tighten during extension and become slack in flexion. Tightness of the collaterals stabilizes the knee when it extends but allows rotation and adduction and abduction when they are slack. So the tibiofemoral joint is move mobile and less stable in flexion than in extension. The anteromedial bands of the anterior and posterior cruciate are tight in flexion and lax in extension while the posteromedial bands do the opposite. So the anteromedial bands are resisting flexion of the tibiofemoral joint and the posterolateral bands extension. ACL and PCL also resist tibial rotation. The anteromedial bands would tighten and resist rotation when the knee is flexed and the posterolateral band would tighten and resist rotation when the knee is extended. Tightening of the posterolateral band of the PCL also seems to be important in locking the knee.
2. In closed chain flexion the femur is moving on the fixed tibia. The femoral condyles initially rotate anteriorly and then (after 25 degrees) rotate and translate anteriorly with anterior translation due to tightening of the anteromedial band of the ACL. In open chain flexion, the tibia is moving on the fixed condyles and the tibia rotates and translates posteriorly. Posterior translation of the tibia tightens the anteromedial band of the PCL to resist excessive posterior movement. In closed chain flexion, the menisci move posteriorly on the tibia to prevent it from wedging under the condyles. In open chain flexion, the menisci move posteriorly with the tibia rather than being pushed posteriorly on the tibia by the compression of the condyles during closed chain flexion.
3. In closed chain extension, the femur is moving on the tibia. The femoral condyles initially rotate posteriorly and then rotate and translate posteriorly with posterior translation due to tightening of the posterolateral band of the PCL. In open chain extension, the tibia is moving on the fixed condyles and the tibia rotates and translates anteriorly. Anterior translation of the tibia tightens the posterolateral band of the ACL to resist excessive anterior movement. In closed chain extension, the menisci move anteriorly on the tibia to prevent it from wedging under the condyles. In open chain extension, the menisci move anterior with the tibia rather than being pushed anteriorly on the tibia by compression of the condyles during closed chain extension.
4. The locking of the knee is a mechanical event that occur during about the last 5 degrees of extension by external rotation of the tibia relative to the femur (open chain) or by internal rotation of the femur relative to the tibia (closed chain). Unlocking requires the opposite motion to locking and is a main function of the popliteus muscle.

5. Rectus femoris extends the knee and flexes the hip; biceps femoris extends the hip, flexes the knee and externally rotates the tibia; semitendinosus flexes the knee and internally rotates the tibia; semimembranosus flexes the knee and internally rotates the tibia; popliteus flexes the knee and internally rotates the tibia; sartorius flexes the and externally rotates the hip and flexes the knee; gastrocnemius flexes the knee and plantar flexes the ankle; tensor fascia lata flexes, abducts and internally rotates the hip and externally rotates the knee.
6. At heel strike, midstance and heel off, there are compression force occurring at the knee due to the weight of the body and muscle contraction. At heel strike, hamstring contraction increases compression at the knee, while at midstance it is the action of the quadriceps and at heel off the action of the gastrocnemius.
7. The menisci are force distributors. Because of the flatness of the tibial condyles and the roundness of the femoral condyles, the menisci help to spread out the forces at the knee, reducing the unit force. The cruciate ligaments are mainly resistors of movement at the knee during flexion and extension.
8. a. With genu valgus, the tibial tuberosity lies lateral to the patella so that the line connecting the tibial tuberosity with the center of the patella shifts medially and this increases the Q-angle.
   b. With anteversion, the femur internally rotates and this moves the patella medial to the tibial tuberosity. The line connecting the tibial tuberosity and the patella shifts medially and this increases the Q-angle.
   c. With external tibial torsion, the tibial tuberosity lies lateral to the patella and this shifts the line connecting the tibial tuberosity with the patella medially. This medial line shift increases the Q-angle.

9. From 0–20 of flexion, the patella moves distally in the shallow intercondylar groove of the femur and the main contact area is the tip of the patella and the groove. From 20–45 degrees of flexion, the patella continues to move distally in the intercondylar groove and the inferior aspect of the patellar condyles are in contact with the anterior aspects of the femoral condyles. As flexion continues to 90 degrees, the superior aspects of the patellar condyles is now contacting the femoral condyles. As the knee flexes further and the patella moves further distally, the patella tilts medially into the intercondylar groove which is now much wider and contact between the lateral patellar condyle and the posterior aspect of the lateral femoral condyle increases whereas contact between the medial patellar condyle and the posterior an aspect of the medial femoral condyle decreases. At 135 degrees of flexion, the intercondylar groove is at its widest and the patella tilts further medially so that the medial patellar condyle is no longer in contact with the posterior medial femoral condyle. In this position, the odd facet of the patella is in contact with the posterior medial femoral condyle and the lateral patellar condyle is almost entirely in contact with the posterior lateral femoral condyle.
10. Tightness of the lateral patellar retinaculum will shift the movement of the patella laterally and increases the contact and compression force between the lateral patellar and lateral femoral condyles. Weakness of the VMO will decrease the pull of the medial retinaculum on the patella and this will result in an imbalance of pull between the medial and lateral retinaculum. This imbalance shifts the movement of the patella laterally and increases the contact and compression force between the lateral patellar and lateral femoral condyles. Slackness of the lateral retinaculum or tightness of the medial retinaculum will shift the movement of the patella medially and increase medial contact and compression between the medial patellar and medial femoral condyles.

Study Questions (ankle)

1. What is the difference between open and closed chain pronation?
2. What is the difference between open and closed chain supination?
3. What structures stabilize the ankle during the following movements:
   a. dorsiflexion
   b. inversion
   c. internal rotation
4. How can the integrity of the anterior talofibular and calcaneofibular ligaments be tested?

ANSWERS

1. In open chain pronation the talus is moving on the tibia & fibula and in closed chain the tibia & fibula are moving on the talus. In open chain, the dorsiflexion component of pronation is the result of posterior talar rotation and translation while in closed chain pronation the dorsiflexion component is the result of anterior rotation and translation of the tibia & fibula. In open chain pronation, the talus external rotates and glides medially with the medial glide producing talar eversion. In closed chain pronation, the tibia & fibula rotate internally. Compression of the tibia & fibula (mortise) on the anterior talus is believed to block or extensively limit a lateral glide component.
2. In open chain supination, the talus is moving on the tibia& fibula and in closed chain the tibia & fibula are moving on the talus. In open chain, the plantar flexion component of supination is the result of anterior talar rotation and translation while in closed chain supination the plantar flexion component is the result of posterior rotation and translation of the tibia & fibula. In open chain supination, the talus internally rotates and glides laterally with the lateral glide producing talar inversion. In closed chain supination, the tibia & fibula rotate externally. Compression of the tibia & fibula (mortise) on the talus may block or limit the medial glide component.
3. a. mortise
   b. calcaneofibular, anterior talofibular, posterior talofibular
   c. open chain (talus moving) = anterior talofibular, posterior tibiotalar closed chain (tibia & fibula moving) = posterior talofibular, calcaneofibular, anterior tibiotalar, tibionavicular
4. For the anterior talofibular ligament, perform a talar tilt (move talus and calcaneus away from the fibula) with the ankle in plantar flexion or in neutral (neutral not as good because the posterior talofibular involved). For the calcaneofibular, perform a talar tilt with the ankle in dorsiflexion.

Study Questions (foot)

1. What ligaments of the ankle joint are also stabilizers of the subtalar joint?
2. What do the ligaments stabilizing the calcaneocuboid joint have is common? What about the talonavicular joint?
3. What is the difference between open and closed chain subtalar pronation?
4. What is the difference between open and closed chain subtalar supination?
5. How does the subtalar joint movement affect midtarsal movement and how does this affect the midfoot?
6. During a supination twist, what are the movements of the big toe and little toe?
7. With excessive subtalar supination, what muscles might need to be strengthened or stretched and how will this affect the loads on the foot during walking?
8. When are vertical forces on the foot high during the stance phase of gait and how does this compare with high forces at the hip, knee, and ankle?

ANSWERS

1. Calcaneofibular and tibiocalcaneal.
2. Three of the four ligaments stabilizing the calcaneocuboid joint have calcaneocuboid in the name. As for the talonavicular joint, and three ligaments have navicular in the name.
3. In open chain subtalar pronation, the calcaneus is moving on the talus so all three components of pronation (eversion, abduction or external rotation, dorsiflexion) are describes as calcaneal movements. In closed chain subtalar pronation, movements of the calcaneus produces movements of the talus and the tibia & fibula. Thus, calcaneal eversion that occurs during closed chain subtalar pronation produces talar adduction (medial rotation) and plantar flexion as well as tibial & fibular internal (medial) rotation.
4. In open chain subtalar supination, the calcaneus is moving on the talus so all three components of supination (inversion, adduction or internal rotation, plantar flexion) are describes as calcaneal movements. In closed chain subtalar supination, movements of the calcaneus produces movements of the talus and the tibia & fibula. Thus, calcaneal inversion that occurs during closed chain subtalar supination produces talar abduction (lateral rotation) and dorsiflexion as well as tibial & fibular external (lateral) rotation.
5. Subtalar movements are reproduced at the midtarsal joint. If the subtalar joint pronates, the midtarsal pronates and if the subtalar supinates, the midtarsal supinates. Midtarsal pronation allows flexibility at the bones of the midfoot whereas midtarsal supination makes the midfoot ridged.

6. During a forefoot supination twist, the big toe pronates – dorsiflexes, inverts, adducts- and little toe supinates – plantar flexes, inverts, abducts.
7. With excessive subtalar supination, the gastrocnemius, soleus, posterior tibialis, anterior tibialis need to be stretched and the fibularis longus and brevis need to be strengthened. This excessive subtalar supination produces midtarsal supination and this places the midfoot in a ridged position which increases the forces at the midfoot during the first half of gait. A ridged midfoot also means that this area cannot pronate to compensate for the excessive subtalar supination. Thus any compensation must come from the forefoot and it may not be enough to permit the foot to fully contact the ground. As a result, the individual walks on the lateral side of their foot. This places high loads on the lateral foot. As the lateral foot is designed for transmitting small loads along the foot during walking (the medial foot designed for the transmission of the greatest loads), the stresses and strains on the bones, joints and ligaments produced by these high loads result in damage to the lateral foot.
8. The vertical forces on the foot are high at foot flat, midstance and heel off. At the hip, knee and ankle, high forces also occur at heel off. At the hip and foot there are high forces near foot flat. At the knee and foot, there are high forces at midstance. High forces at the knee also occur at heel strike, but not at the hip or foot.

Study Questions (gait)

1. What is the ground reaction force and does it affect joint movement and muscle activity during stance?
2. For the hip and knee, what are the movements, moments and muscle actions occurring during the following:
   a. heel strike to foot flat
   b. foot flat to midstance
   c. heel off to toe off
3. For the ankle and foot, what are movements, moments and muscle actions occurring during the following:
   a. heel strike to foot flat
   b. foot flat to midstance
   c. heel off to toe off
4. What are the movements and muscles actions occurring at the hip, knee and ankle for midswing to deceleration?
5. What are the actions of the following muscles on the support side during ascending stairs?
   a. gluteus maximus
   b. gluteus medius
   c. quadriceps
   d. plantar flexors
5. What are the actions of the following muscles on the support side during descending stairs?
   a. gluteus maximus
   b. quadriceps
   c. plantar flexors
4. How do the actions of the above muscles in questions 5–6 differ between ascending and descending stairs?

ANSWERS

1. The ground reaction force is the force transmitted up the lower limb by the ground when the leg is in contact with the ground. If the leg is not in contact with the ground, there is no ground reaction force. The ground reaction force can pass anterior or posterior to the axis of motion of a joint. This ground reaction force, just like a muscle, produces a moment at the joint. This moment wants to move the joint in a specific direction. If the moment wants to move the joint is the direction that is needed, muscle does not have to contract concentrically to move the joint. The ground reaction force will move the joint. However, the degree of movement produced by the ground reaction force must be controlled. This control is often produced by eccentric contraction of antagonistic muscles. If the moment from the ground reaction force is opposite to the desired movement, then muscle must contract concentrically to produce the movement and override the force (moment) produced by the ground reaction force.

2. a. From heel strike to foot flat, the hip is extending and the knee is flexing. The ground reaction force (GRF) at the hip lies anterior to the axis of motion and wants to flex the hip. As the hip needs to extend, the moments produced by the GRF must be overcome by concentric contraction of the hip extensors (gluteus max.) to produce hip extension. The GRF at the knee move from anterior to the axis of the knee to posterior to the knee axis. The GRF anterior to the knee wants to extend the knee and hold it in an extended position as the weight of the body begins to be supported by the limb. At the same time the quadriceps muscle is still concentrically active as it extends the knee from midswing to deceleration and the hamstrings are eccentrically active decelerating knee extension. The concentric contraction of the quads and the eccentric contraction of the hamstrings along with the anterior position of the GRF stabilize and support the knee for initial contact with the ground. As the weight of the body moves over the leg, the GRF moves behind the knee and produces a flexion moment on the knee. As this moment wants to flex the knee and the knee needs to be held in an extension, the quadriceps muscle must now act to prevent buckling of the knee by eccentrically contracting.

   b. From foot flat to midstance, the hip is extending and the GRF moves from anterior to the axis of the hip to a position posterior to the axis. Initially, the gluteus maximus is concentrically active to extend the hip and override the flexion moment produced by the GRF. Once the hip has extended to the midstance position, the posterior GRF also wants to extend the hip. In this position the contraction of the gluteus maximus can stop and the GRF extend the hip. As the hip subsequently extends backward because of the extension moment by the GRF, the iliopsoas eccentrically contracts to controls this backward extension. From foot flat to midstance, the knee is extending and the GRF moves from a posterior to an anterior position to the knee axis. The quadriceps initially contract concentrically to extend the knee against the flexion moment of the GRF. As the knee extends and the GRF moves anterior to the knee axis, the extension moment by the GRF holds the knee in extension and activity of the quadriceps stops.

c. From heel off to toe off, the hip is flexing and the GRF wants to extend the hip. At this time, the iliopsoas contract concentrically to flex the hip and override the extension moment produced by the GRF. From heel off to toe off, the knee flexes and the GRF moves from an anterior to a posterior position to the knee axis. At the start of heel off, the GRF keeps the knee in its locked extended position so the quadriceps do not have to be active, but the popliteus begins to concentrically contract to unlock the knee and flex it. Flexion of the knee then occurs mechanical because of simultaneous hip flexion and ankle plantar flexion and because of concentric contraction of the popliteus and contraction of the gastrocnemius which is plantar flexing the ankle. With knee flexion, the GRF moves posteriorly to the knee axis to further flex the knee. As the foot is still one the ground, the degree of knee flexion needs to be controlled to prevent buckling of the knee. Eccentric contraction of the quadriceps at this time controls flexion produced by the GRF, popliteus and gastrocnemius, and the mechanical event of hip flexion and ankle plantar flexion.

3. a. From heel strike to foot flat, the ankle in moving in plantar flexion (supination) and the GRF is posterior to the axis of the ankle and wants to move the ankle in plantar flexion (supination). Because the GRF moment can move the ankle in the direction of actual movement, the plantar flexors do not need to be active but the ankle dorsiflexors need to be eccentrically active to control the rate of plantar flexion. These muscles are the anterior tibialis primarily, and to a less extent the extensor digitorum longus and extensor hallucis longus. At this time, the subtalar joint is in a pronated position because of the fit of the matching articular surfaces. This is a mechanical event that is not produced by muscle but the extent of subtalar pronation is controlled by eccentric contraction of the anterior and posterior tibialis muscles. Notice that the anterior tibialis concurrently controls ankle plantar flexion and subtalar pronation. As gait moves towards foot flat, the subtalar remains in a pronated position but is gradually supinating. The pronated position of the subtalar joint results in pronation of the midtarsal joint and supination of the forefoot. Pronation of the midtarsal joint places the two axes of this joint more in parallel to each other and allow mobility in the midfoot. This mobility enables the midfoot to contour to the substrate.

b. From foot flat to midstance, the ankle moves from plantar flexion to dorsiflexion and at the same time the GRF moves from a position posterior to the ankle where it wants to plantar flex it to a position anterior to the ankle where it can produce dorsiflexion. The movement of the GRF anteriorly to produce a dorsiflexion moment on the ankle coincides with the ankle moving in dorsiflexion. Thus the dorsiflexors of the ankle are no longer needed and can cease activity but the plantar flexors of ankle must contract eccentrically to control the amount of dorsiflexion. These muscles are mainly the gastrocnemius, soleus, and posterior tibialis. As the ankle is dorsiflexing, the subtalar is still pronated and still moving in supination. As the gastrocnemius, soleus and posterior tibialis are also supinators of the subtalar joint, the actions of these muscles are concurrently controlling dorsiflexion at the ankle and supinating the pronated subtalar joint. Because the subtalar joint is still pronated, the midtarsal joint is still pronated so the midfoot is still mobile and the forefoot supinated.
c. From heel off to toe off, the ankle is plantar flexing (supinating) and the GRF is anterior to the axis of the ankle and wants to dorsiflex (pronate) the ankle. Because the ankle needs to plantar flex, concentric contraction of the plantar flexors (gastrocnemius, soleus, posterior tibialis) is needed to plantar flex the ankle and override the dorsiflexion GRF moment. At this time, the subtalar joint in supinated and moving in further supination. This action is being produced by the concentric contraction of the plantar flexors. As the subtalar joint is supinated, the midtarsal joint is supinated and the two axes of motion at the midtarsal joint are now crossed, resulting in the midfoot being ridged. The ridge midfoot provides a solid base from which the foot can push off the ground. With the subtalar and midtarsal joints supinated, the forefoot needs to be pronated so that the toe stay in contact with the ground. As gait near toe off, the GRF is anterior to the metatarsal phalangeal joints. This GRF position produces an extension moment on the toe and the toes extend. Extension of the toes must be limited to support foot against the ground. Extension of the toes is limited at this time by eccentric contraction of the FHL, FDL, FDB, FHB, Abd. Hal., Add. Hal., Abd and Fl. digiti minimi, lumbricals, and interossei.

4. From midswing to deceleration, the hip is moving in flexion and the gluteus maximus and hamstrings are active eccentrically to decelerate the flexing hip so that it will not overshoot its position for heel strike. The knee is extending by concentric contraction of the quadriceps. The eccentric contraction of the hamstrings at this time is no only decelerating hip flexion but also controlling knee extension. The ankle is in its neutral position and it is held there against gravity by contraction of the dorsiflexors of the ankle (ant. Tib., EHL, EDL). The actions of these muscles have been described as isometric and as concentric. There are good arguments for both.
5. a. gluteus maximus – This muscle concentrically contracts to extend the hip and vault the body upward over the next step.
   b. gluteus medius – This muscle concentrically contracts to hold the hip level so the swing leg pelvis does not drop and swing leg foot catch the next step.
   c. quadriceps – This muscle concentrically contracts to extend the knee and lift the body upward over the next step in combination with contraction of the gluteus maximus.
   d. planter flexors – These muscles concentrically contract to move the tibia & fibula forward over the fixed foot and producing ankle plantar flexion.
6. a. gluteus maximus – This muscle is eccentrically active to control hip flexion as the body is lowered to place the non-support side foot on the step below.
   b. quadriceps – This muscle is eccentrically active to control knee flexion as the body is lowered to place the non-support side foot on the step below.
   c. plantar flexors – These muscles are eccentrically active to control ankle dorsiflexion as the body is lowered to place the non-support side foot on the step below.
7. These muscles are concentrically active when ascending stairs to lift the body upward on to the next step but eccentrically active when descending stairs to lower the body so that the non-support leg can reach the next step.

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