# Skeletal Considerations for Movement

## Mechanical Functions of the skeletal system:

Support & protection
System of levers for movement

### Materials of Bone

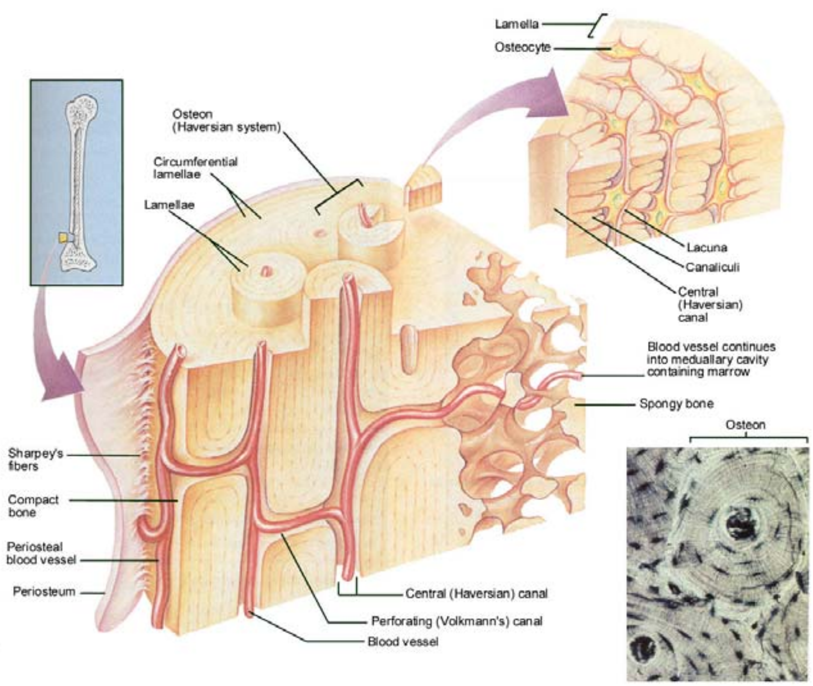
| Material | % of Weight | Primary Function(s) |
|---|---|---|
| Calcium carbonate<br>Calcium phosphate | ~ 60 - 70% | stiffness & compressive strength |
| Collagen | ~ 5 - 10% | flexibility & tensile strength |
| Water | ~ 25 - 30% | strength |

### Types of Bone Tissue

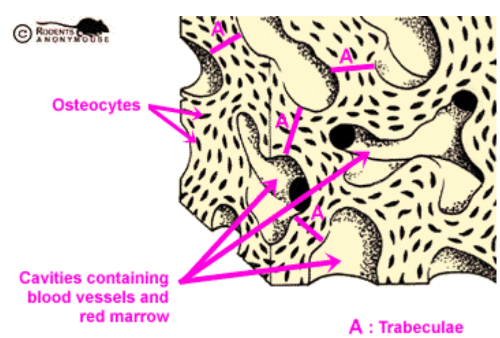
| Tissue | a.k.a. | Construction | Porosity* | Strength |
|---|---|---|---|---|
| Compact | Cortical | Hollow tubes (columns) | 5 - 30% | High |
| Spongy | Cancellous<br>Trabecular | Lattice structure | 30 - 90% | Low |

Both types of bone tissue are found in ALL bones. It is the relative proportion of one to the other that determines the strength and stiffness (flexibility) of an individual bone.

* Values represent the % of non-mineralized tissue present. As porosity increases, the amount of calcium salts decreases. In other texts, porosity values reflect the amount of "dead space", or space not occupied by bony tissue.




*Human Anatomy & Physiology*, Marieb, 1995




http://www.zoology.ubc.ca/~biomania/tutorial/bonets/anc05.htm
Department of Zoology, University of British Columbia



From: Christopher

## Types of Bones

| Type | Structure | Functions | Examples |
|---|---|---|---|
| Long | Longer than wide, thick layer of compact bone surrounding marrow cavity; ends are thin layer of compact bone covering inner spongy bone | Support, levers & linkages that allow for movement | Clavicle, humerus, radius, ulna, femur, tibia, fibula, metatarsals, metacarpals, phalanges |
| Short | Spongy bone covered with thin layer of compact bone | Shock absorption, force transmission | Carpals, tarsals |
| Flat | Two layers of compact bone with spongy bone and marrow in between - think "bone sandwich" | Protect internal organs, provide broad surfaces for muscle attachment | Ribs, ilium, sternum, scapula, skull |
| Irregular | Spongy bone with thin compact bone exterior; each has specialized shape and function | Support weight, dissipate loads, protect spinal cord and brain, provide sites for muscle attachment | Skull, pelvis, vertebrae |
| Sesamoid | Short bone embedded in a tendon or joint capsule | Alter the angle of insertion of a muscle | |

## Wolff's Law

"Every change in the form and function of a bone or of their function alone is followed by certain definitive changes in their internal architecture, and equally definite secondary alteration in their external conformation, in accordance with mathematical laws."
(Wolff JD: *Das geretz der transformation der knochen*, Berlin, 1892, Hirschwald.)

## Huh?

"The form of a bone being given, the bone elements place or displace themselves in the direction of functional forces and increase or decrease their mass to reflect the amount of the functional forces."

## What?

Bone has the ability to remodel, by altering its size, shape, and structure, to meet the mechanical demands placed on it.
(Buckwalter et al., 1995, *Journal of Bone and Joint Surgery*, **77A**, 1256-1289.)

# Consequences of Wolff's Law

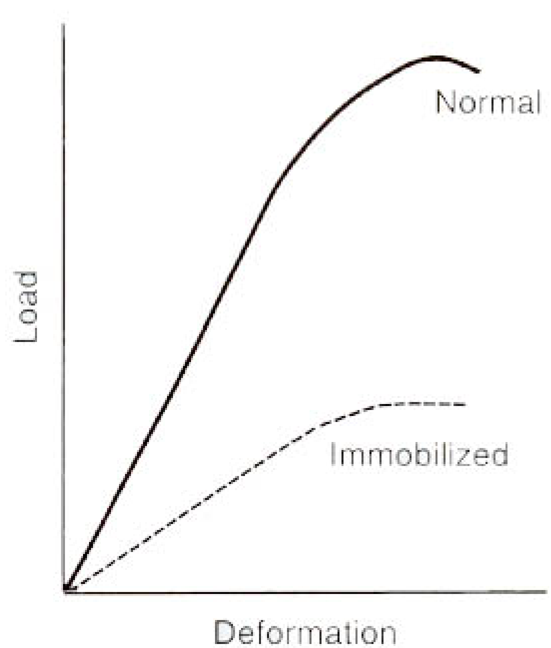
## Physical Activity

- Bones require mechanical stress in order to grow and strengthen.
- Physical activity is important to develop and maintain bone integrity and strength.
- Bone must experience DAILY stimulus to maintain its health.

## Inactivity

Spaceflight
- Significant bone loss in short time.
- Bone loss begins to occur immediately upon leaving gravity.
- Effects:
    - Bones less rigid
    - More bending displacement
    - Decrease in bone length
    - Decrease in cross section of cortical bone
    - Slowing of bone formation

Bed rest
- Similar effects as spaceflight.




*Basic Biomechanics of the Musculoskeletal System*
Nordin & Frankel, 2001

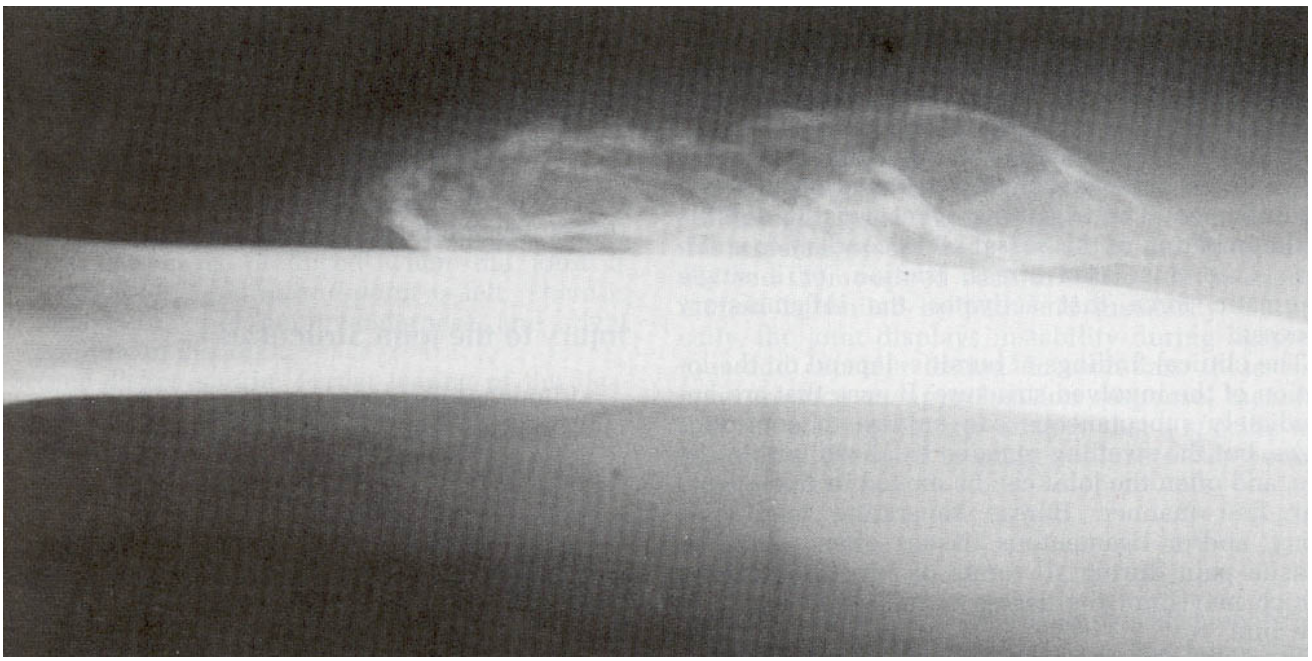
## Bony Deposit in Soft Tissue

### Myositis Ossificans

Myo = muscle
itis = inflammation
Oss = bone

- Bony growth in muscle tissue due to impact injury
  - Contusion to a large muscle
  - Blood (hematoma) pools adjacent to bone
  - If bone (periosteum) is damaged
    - Bone tries to "repair" itself

Bony tissue is laid down in hematoma



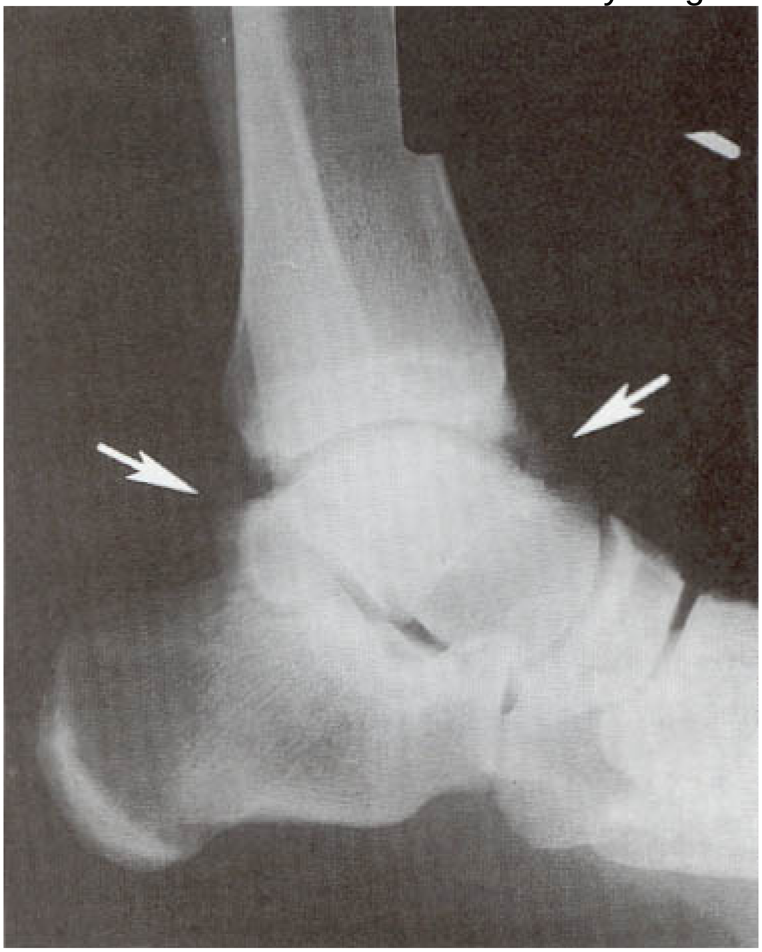
*Evaluation of Orthopedic and Athletic Injuries*,
Starkey & Ryan, 1996



From: Christopher

# Exostoses (Osteophytes)

Bony outgrowths



*Evaluation of Orthopedic and Athletic Injuries*,
Starkey & Ryan, 1996

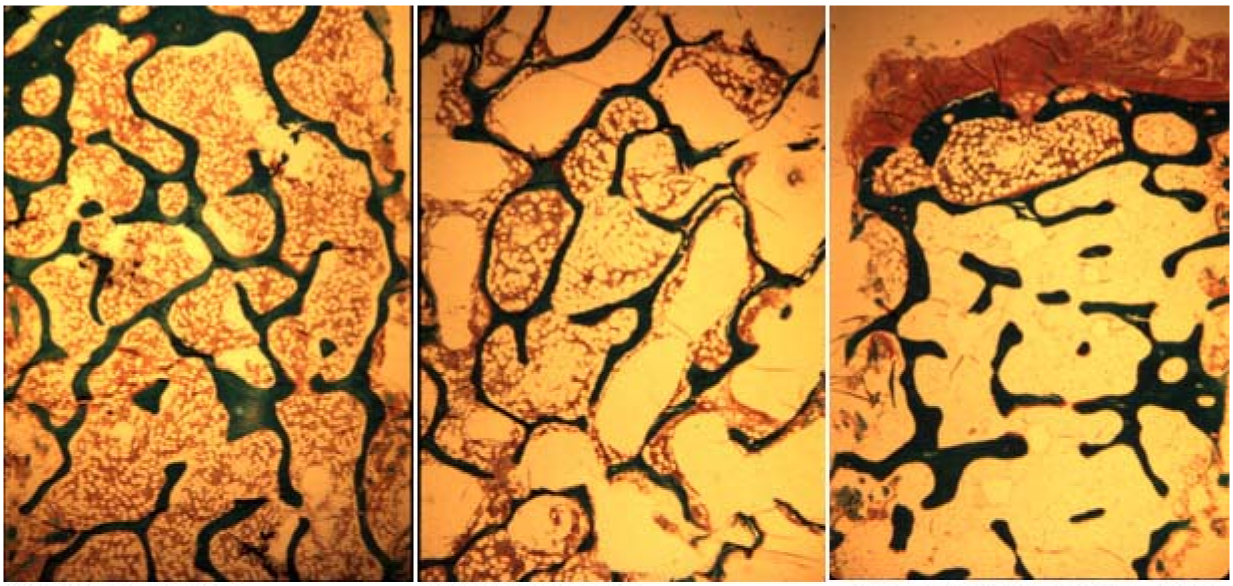
Exostoses of subtalar joint

Exostoses (osteophytes) occur due to stress reaction from injury or from irregular forces on bone

## Osteoporosis

Osteo = bone
poros = full of holes

- Pathologic condition of decreased bone mass and density
- Bone resorption exceeds bone deposition
- Decrease of bone mineral mass & density
  - Loss of bone stiffness
  - Loss of trabecular integrity
  - Higher incidence of fractures (2 - 2.5 x more than in non-osteoporotic individuals)



Normal bone structure.
Bone volume/tissue volume = 22%

Thinning trabeculae.
Bone volume/tissue volume = 13%
This may be seen with prednisone.

Bone volume/tissue volume = 22%
However, trabeculae are thicker and not as well connected.
This would not be as strong as normal bone.

http://courses.washington.edu/bonephys/Gallery/structures.jpg

Trabecular structure: three biopsies showing (l. to r.)
normal structure, thin trabeculae, and poor connectivity



From: Christopher

http://encarta.msn.com/encnet/refpages/RefArticle.aspx?refid=761567424

A portion of a bone showing signs of osteoporosis (*right*)
is contrasted with a portion of a healthy bone (*left*).

Related to:

- Hormonal factors
    - Post-menopausal hormone replacement therapy - this is a double-edged sword:
        - helps decrease bone loss,
        - linked to increased risk of cervical cancer.
- Nutritional imbalance - anorexia, elite athletes
- Lack of exercise - elderly, sedentary

At Risk:

- Post-menopausal women
- Elderly (>70) men & women
- Anorexic women
- Female Athlete Triad
    - Disordered Eating
        - NOT just female problem
    - Amenorrhea
        - Low body fat
        - Excessive training
    - Leading to osteoporosis

Other risk factors (note that all but one of these are LIFESTYLE factors - i.e., within YOUR control):

- Inactivity
- Smoking
- Deficiencies in
  - Estrogen, calcium, and vitamin D
- Excessive consumption of
  - Protein, caffeine, and alcohol

Easier to prevent than to treat.

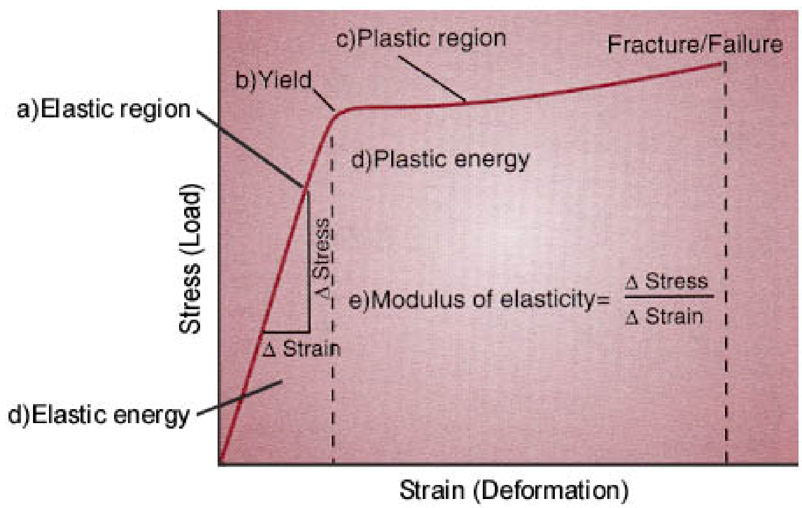
American College of Sports Medicine makes the following recommendations:

1. Weight bearing physical activity
2. Strength exercises
3. Increase in physical activity for the sedentary
4. Postmenopausal hormone replacement (questionable)
5. Appropriate exercise program for elderly, with focus on improving strength, flexibility, and coordination

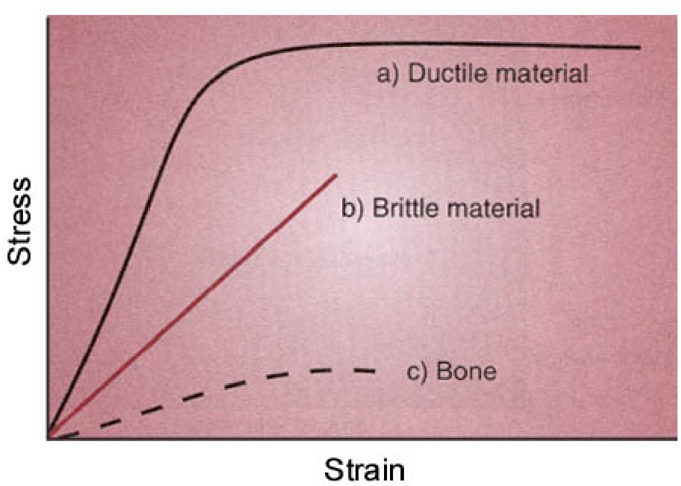
Increased dietary calcium - particularly important during teens. Unfortunately, most American girls fall below the recommended daily calcium intake by age 11!

# Material Science

| | |
|---|---|
| Load | Applied force |
| Deformation | Change of shape of material under load |
| Stress | Normalized load - force per unit area.<br>Typical units - lb/in$^2$, kPa, MPa (1 Pa = 1 N/m$^2$)<br><br>Allows comparisons of different materials |
| Strain | Normalized deformation - length change divided by initial length, or change of angle<br><br>Allows comparisons of different materials |




*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995

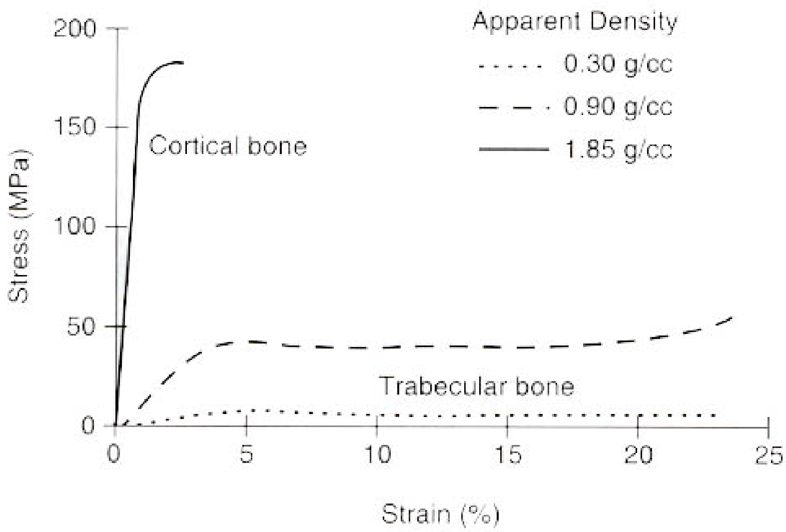



*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995

Ductile materials – gold, copper, silver, lead, steel, plastics, rubber

In some ductile materials, brittle behavior can be observed below a certain temperature (particular to the material).

Brittle materials – glass, steel, plastics, rubber

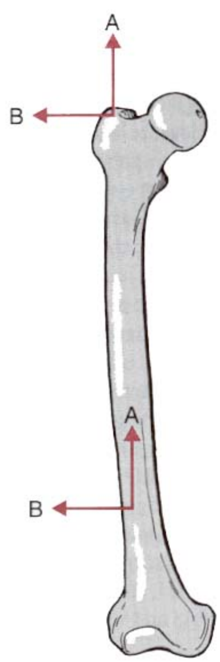



*Basic Biomechanics of the Musculoskeletal System*,
Nordin & Frankel, 2001

Cortical bone can withstand greater load, but will not deform very much before failure.

Trabecular bone can deform significantly, but will fail at much lower load.

## Characteristics of Bone



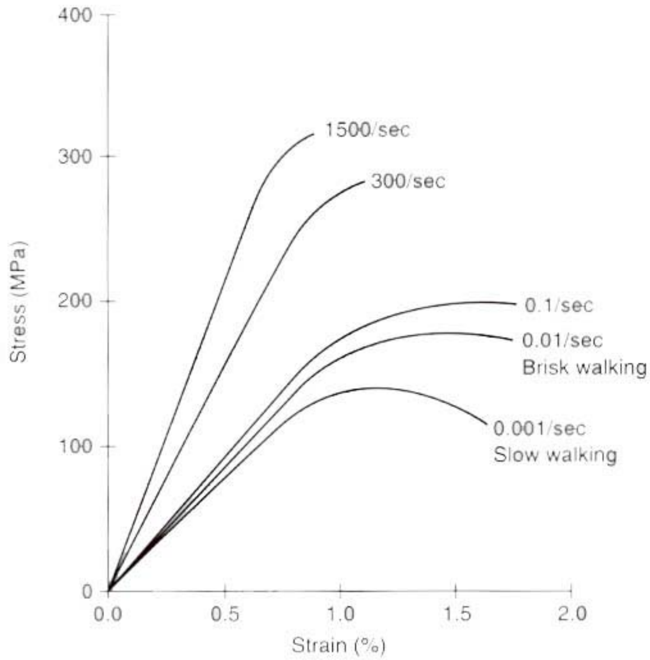

*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995

### Anisotropic

Responds differently to different types of loads; response depends upon orientation of load

Bone can handle longitudinal loads better than transverse loads

- Strongest in compression
- ~1/2 as strong in tension
- ~1/5 as strong in shear (sideways force)




*Basic Biomechanics of the Musculoskeletal System*, Nordin & Frankel, 2001

## Viscoelastic

Responds differently to different loading rates (speeds)

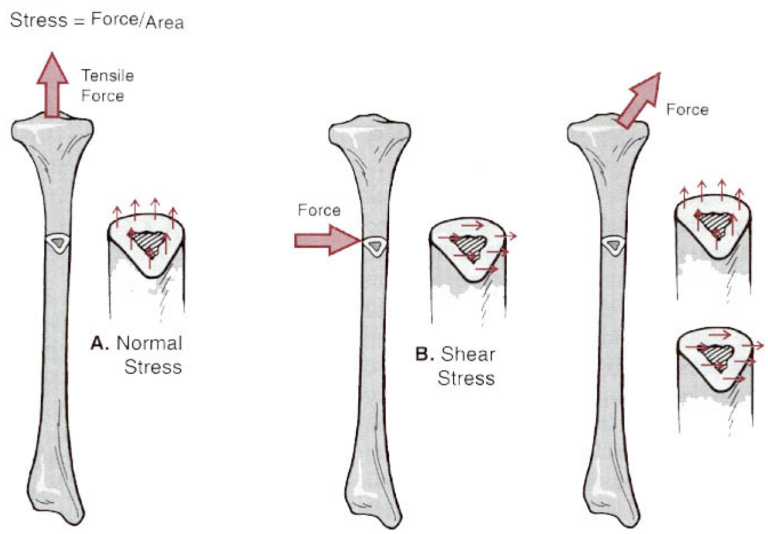
- Rapid loading, bone responds with more stiffness (steeper slope in elastic region); can sustain higher load before fracture
- Slow loading, bone not as stiff; fracture occurs at much lower applied load as rapidly loaded bone

Rates represent how fast bone is being strained (deformed)

| | |
|---|---|
| Strength | Typically defined by amount of load that can be sustained before fracture. Another measure of material strength is energy absorption (area under the stress-strain curve) |
| Stiffness | Capability of absorbing load with minimal deformation. Determined by the slope of the elastic region of stress-strain curve. |

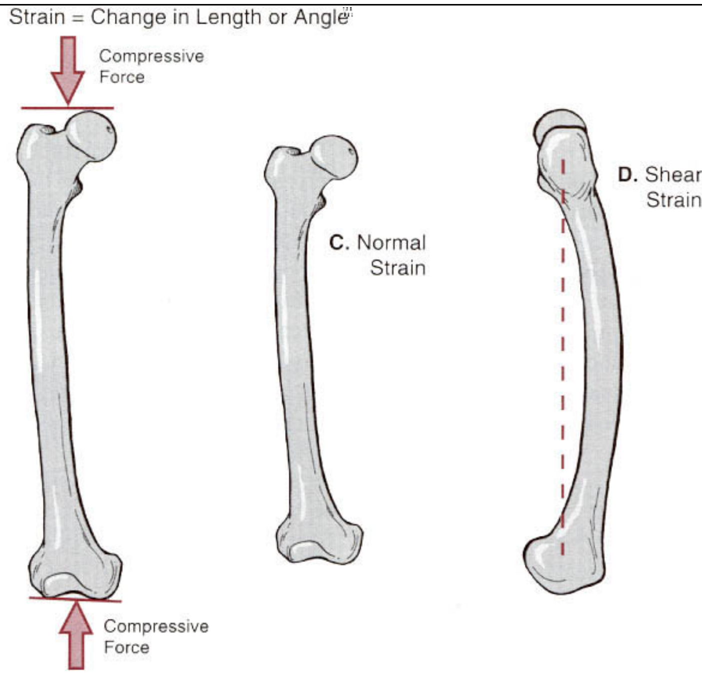
Stress & Strain

| | |
|---|---|
| Normal Stress | Stress applied at right angle to cross section of bone. Normal stress causes normal strain. |
| Shear Stress | Stress applied parallel to cross section of bone. Shear stress causes shear strain. |




*Biomechanical Basis of Human Movement,* Hamill & Knutzen, 1995

| | |
|---|---|
| Normal Strain | Strain involving a change in length of a bone. |
| Shear Strain | Strain involving a change in the angle of a bone. |




*Biomechanical Basis of Human Movement,* Hamill & Knutzen, 1995



From: Christopher

# Bone Loading

| Type | Examples |
|---|---|
| Compression | Normal loading for spine and leg bones<br><br>Injuries - Crush fractures, spinal disk injuries, spondylolysis |
| Tension | Normal loading for attachment points of muscles, tendons, and ligaments; give rise to apophyses<br><br>Injuries - apophysitis, avulsion fractures, muscle strains, tendon ruptures, ligament sprains |

*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995

*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995



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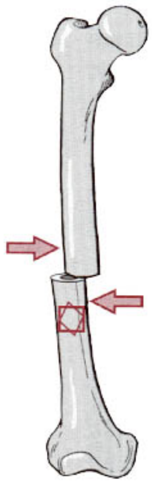
Shear



Injuries - ACL ruptures, epiphyseal plate fractures, spondylolysthesis

*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995

Torsion

Injuries - Spiral fractures; also a feature in some child abuse injuries

*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995



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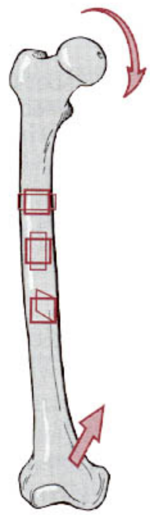
Bending



*Biomechanical Basis of Human Movement*,
Hamill & Knutzen, 1995

Used in spinal bracing

Injuries – fractures

- Three point bending
    - Fracture occurs opposite midpoint load
- Four point bending
    - Fracture occurs at weakest point in bone