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From Nordin & Frankel (1989)

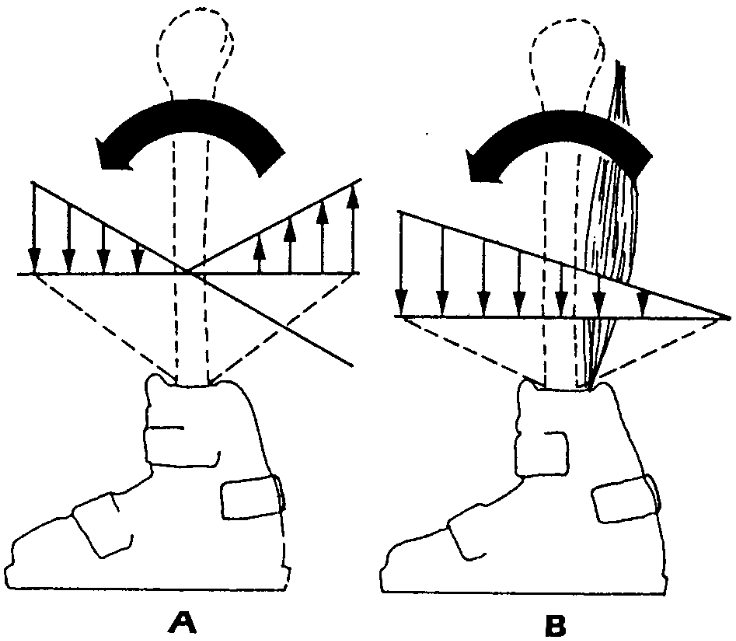

FIG. 1–31
A. Distribution of compressive and tensile stresses in a tibia subjected to three-point bending. **B.** Contraction of the triceps surae muscle produces high compressive stress on the posterior aspect, neutralizing the high tensile stress.

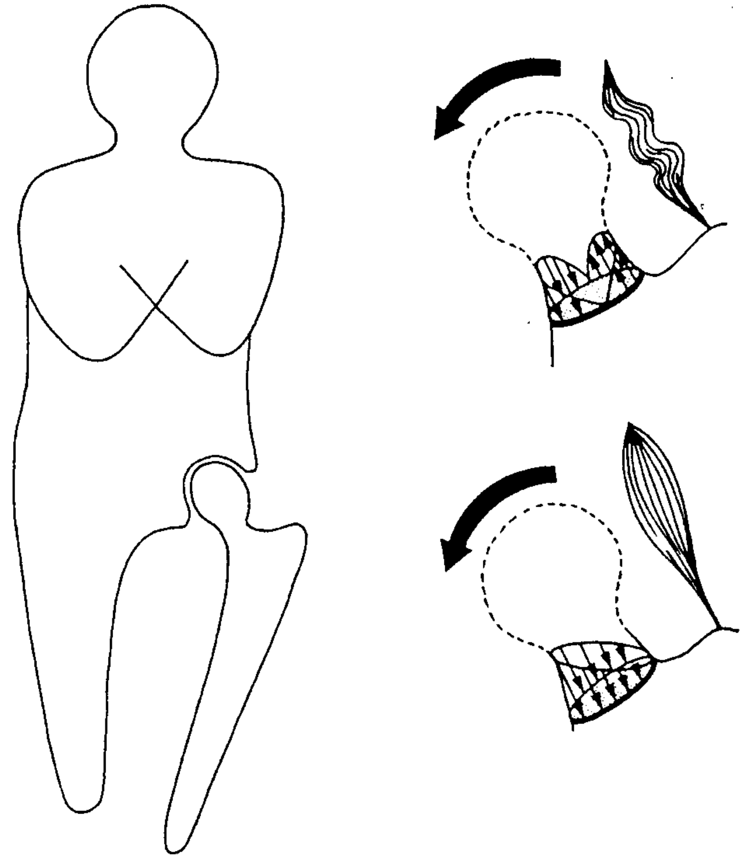

FIG. 1–32
Stress distribution in a femoral neck subjected to bending. When the gluteus medius muscle is relaxed (top), tensile stress acts on the superior cortex and compressive stress acts on the inferior cortex. Contraction of this muscle (bottom) neutralizes the tensile stress.

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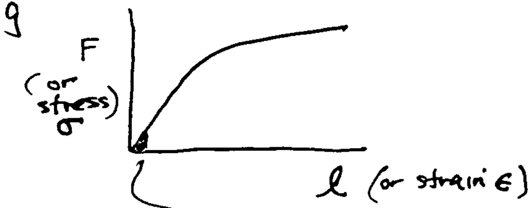
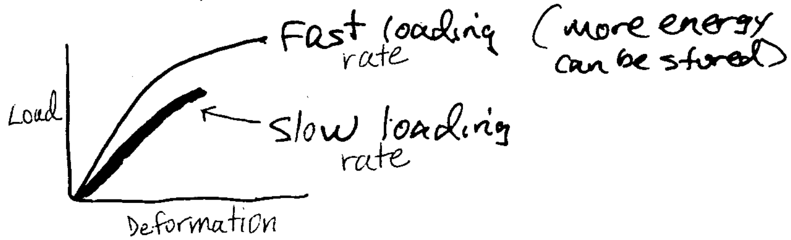
"__________" in bone during loading



In Normal daily activities, the energy stored is a small fraction of what is needed to fracture a bone.

Faster __________ — bone is stiffer and stronger and can absorb more energy



Risk from fractures at high speed loadings of small bone fragments injuring neighboring soft tissue as all this energy is released.

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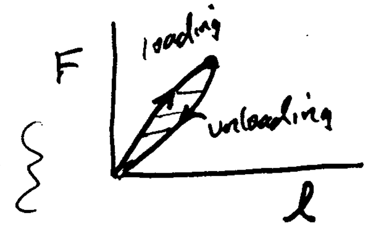
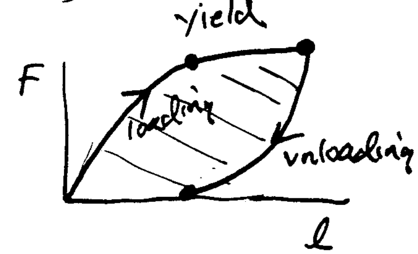
This does not occur as much in slow speed loading of bones. Here there tends to be a single crack with little displacement of bone pieces.

__________ - energy loss during loading & unloading





below yield point

Hysteresis loop ⇒ area inside the loop represents the energy lost during the loading & unloading process

When loading is all the way to fracture, none of the energy is recovered and is lost to heat and permanent deformation as well as kinetic energy of bone fragments

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Fatigue of bone under repetitive loading

The amount of load that can be tolerated before injury occurs gets as the number of reps increases

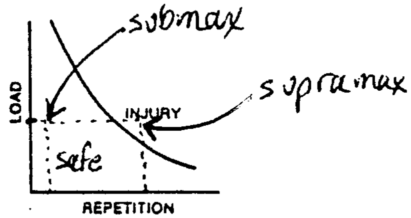
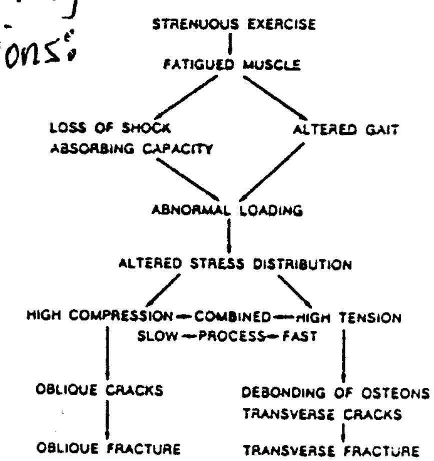


FIG. 1–36
The interplay of load and repetition is represented on a fatigue curve.

Theoretical chain of events leading to injury during fatigue situations:



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Wolff's Law: A bone will adapt to the loads that are placed on it (if given sufficient recovery time). The bone will become ________ (and be able to store ________ before failure) in response to the loads placed on it. Conversely – inactivity will do just the reverse. Take away the loads and over time the bone will get

____

Influence of bone size & shape on strength & stiffness

In tension & compression, cross-sectional area (X-sectional area) is the determining factor. Note stress = force/area ($\sigma = F/A$)

so ________ (________)

so for a given level of stress – increasing x-sectional will increase the force that the bone will tolerate.

In bending: Here the relevant factor is called ___ ___ ___ ___. This quantity takes into account both x-sect. area and the distribution of material about

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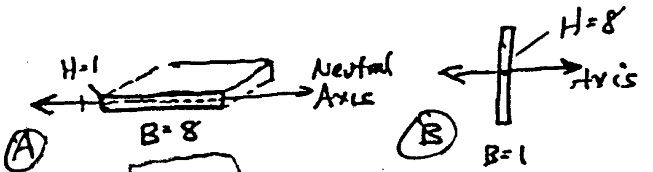
the neutral axis.



$I = \boxed{\quad\quad}$ for a rectangular x-section.

Case A:
$$I = \frac{8\times(1)^3}{12} = \frac{8}{12}$$

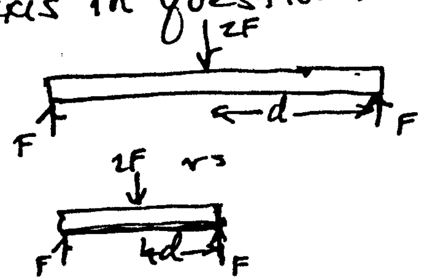
Case B
$$I = \frac{1\times(8)^3}{12} = \frac{512}{12}$$

= 64 times as large as case A.

This area moment of inertia represents the ______________________________

____

However the strength of the whole bone against bending moments also depends on the ______________. The longer the bone is, the ________ the moment arm of a force applied distal to the joint axis in question.



larger moment applied from forces

smaller moment applied from forces

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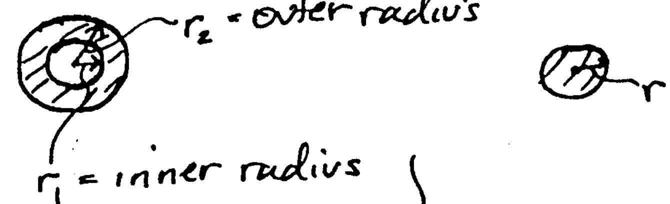
Tubular material



(Hollow)
$$I = \underbrace{\frac{\pi}{4} r_2^4}_{\text{equiv. solid x-section}} - \underbrace{\frac{\pi}{4} r_1^4}_{\text{hollow space}} = \_\_\_\_\_\_\_\_\_\_$$

(Solid)
$$I = \frac{\pi}{4} r^4$$

For a given bending moment M applied to a structure the stress depends on both the ________ and on the ______________

____

$$\underbrace{\sigma}_{\text{stress}} = \frac{\overbrace{M}^{\text{moment}}\ \overbrace{a}^{\text{distance from neutral axis}}}{\underbrace{I}_{\text{area moment of inertia}}}$$

Note: as "a" increases, σ ________
" M " , σ ________
" I " , σ ________

holding all else constant

Maximum stress (σ_0) produced by a bending moment

$\sigma_0 = \boxed{}$

(for a round x-section)

where r = outside radius or maximum distance from neutral axis

for rectangular — $\updownarrow \frac{1}{2}H$ $\sigma_0 = \frac{M(\frac{1}{2}H)}{I} = \frac{MH}{2I}$

max value of a = ____

General: $\sigma = \frac{Mc}{I}$

where c is the max value of a

See example of solid vs hollow bone problem

Torsion: similar factors affect strength & stiffness in bones – However the relevant variable is called ____ ____ – ____ ____. This describes how the material is distributed away from the neutral axis for torsion see Fig 1-59

I_p = polar moment of inertia

Fracture healing –

After fracture – during the healing process – a cuff of callus forms around the site – increasing ________ (and hence strength to resist tension & compression loads), ____ moment of inertia (hence increasing strength to resist bending loads) and ____ moment of inertia (hence increasing strength to resist torsional loads). Then as healing is completed, the cuff is progressively ________.

Aging: with progressing age, there is a marked decrease in the total amount of bone tissue and a slight decrease in actual size of bones. Result: reduced strength ________ and decrease in the length of the plastic region on the stress-strain curve (bone becomes ________).

Osteoporosis is a major problem with the elderly (from reduction in ________ ________). Weight bearing loads are necessary to reduce the chances of osteoporosis. Exercise alone is ________.