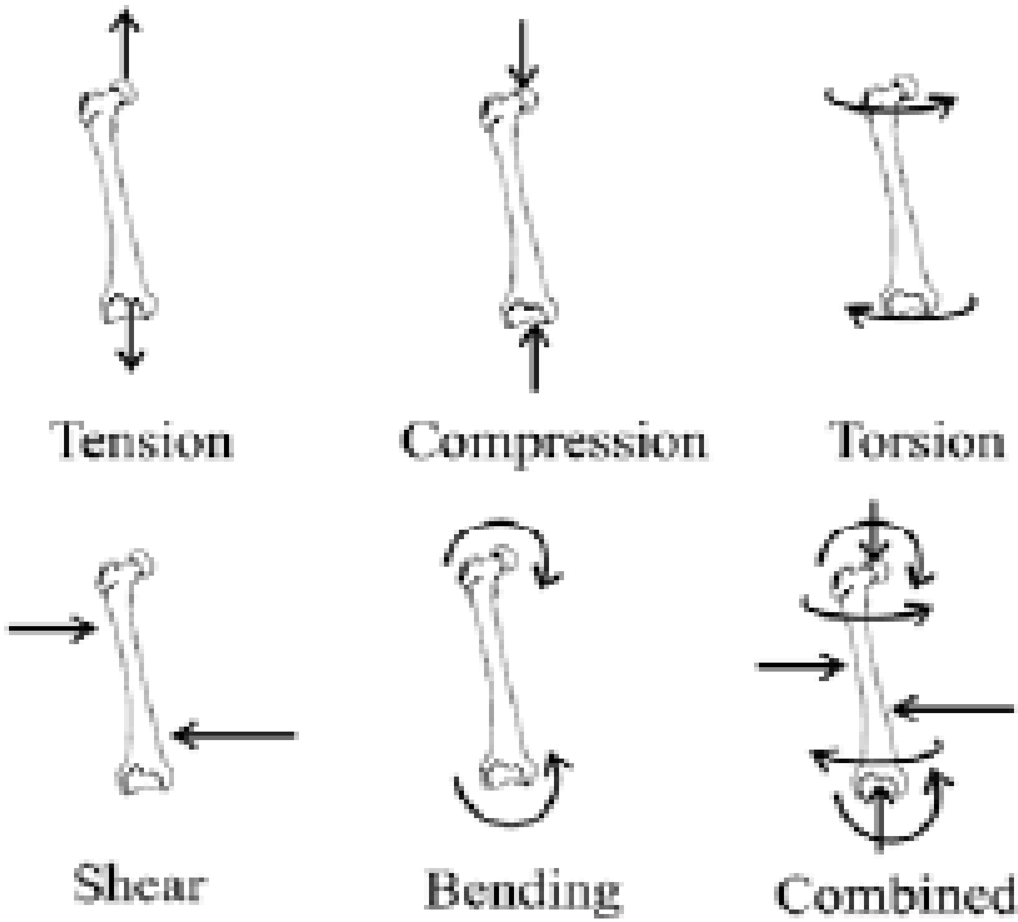
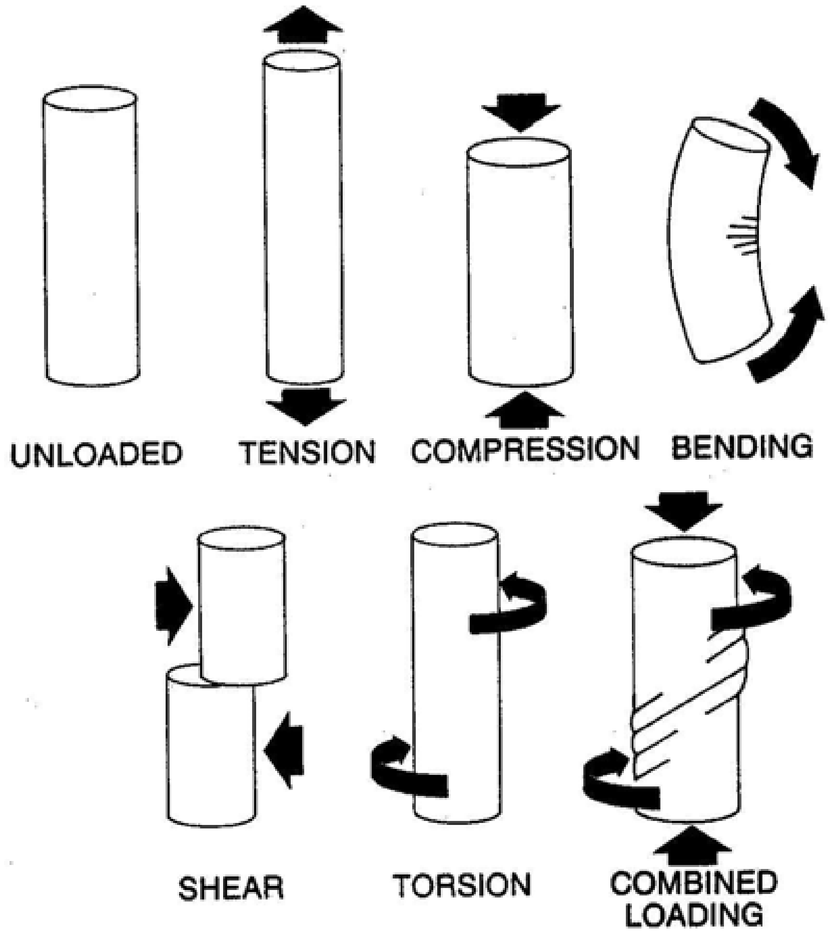
Section 18: Mechanical Properties of Bone

Loading of Bones



From: Vanwanseele

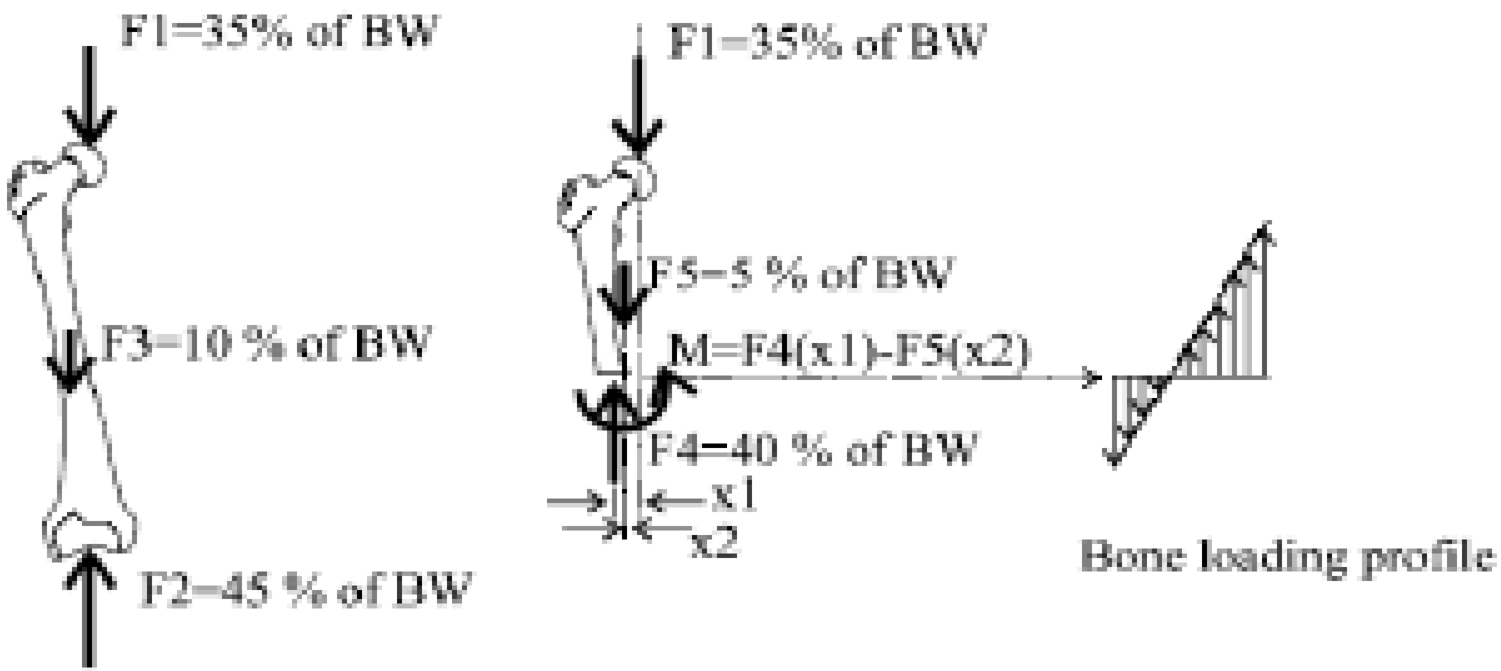
Load-deformation Relationships



Schematic representation of various loading modes.

From: Brown

Normal Standing

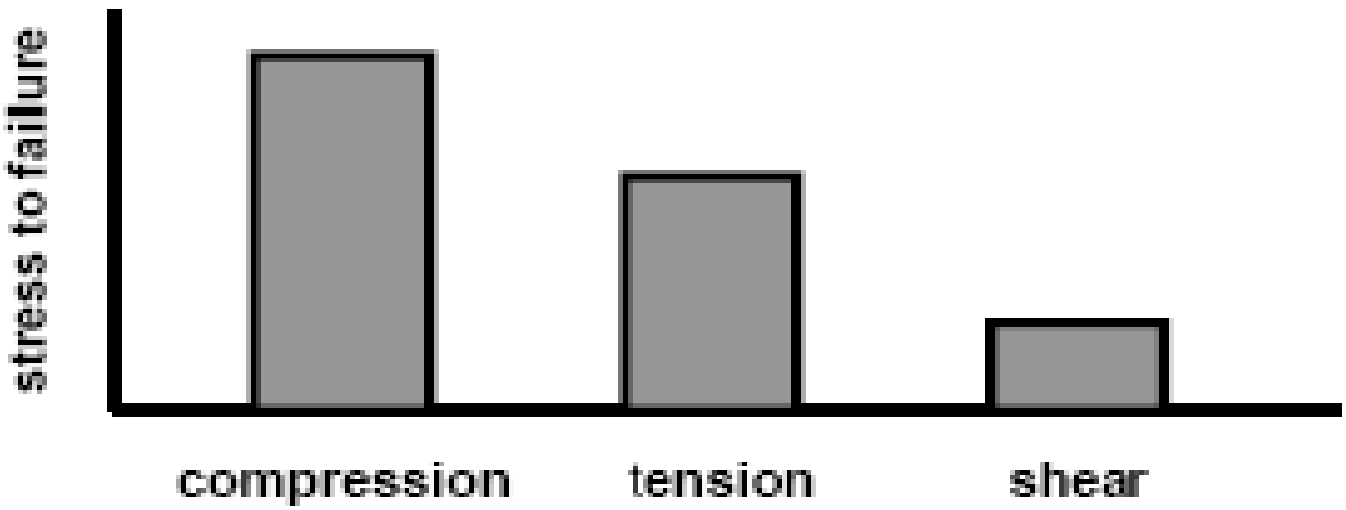


Normal standing
Femur supports ~ 35% of BW

From: Vanwanseele

Resistance to Mechanical Load

Bone is strongest in compression and weakest in shear…how do you suppose we know this?



From: Seeley

Bone Biomechanics

- Bone is anisotropic - its modulus is dependent upon the direction of loading.
- Bone is weakest in shear, then tension, then compression.
- Ultimate Stress at Failure Cortical Bone

Compression	< 212	N/m^2
Tension	< 146	N/m^2
Shear	< 82	N/m^2

From: Le

Material Properties

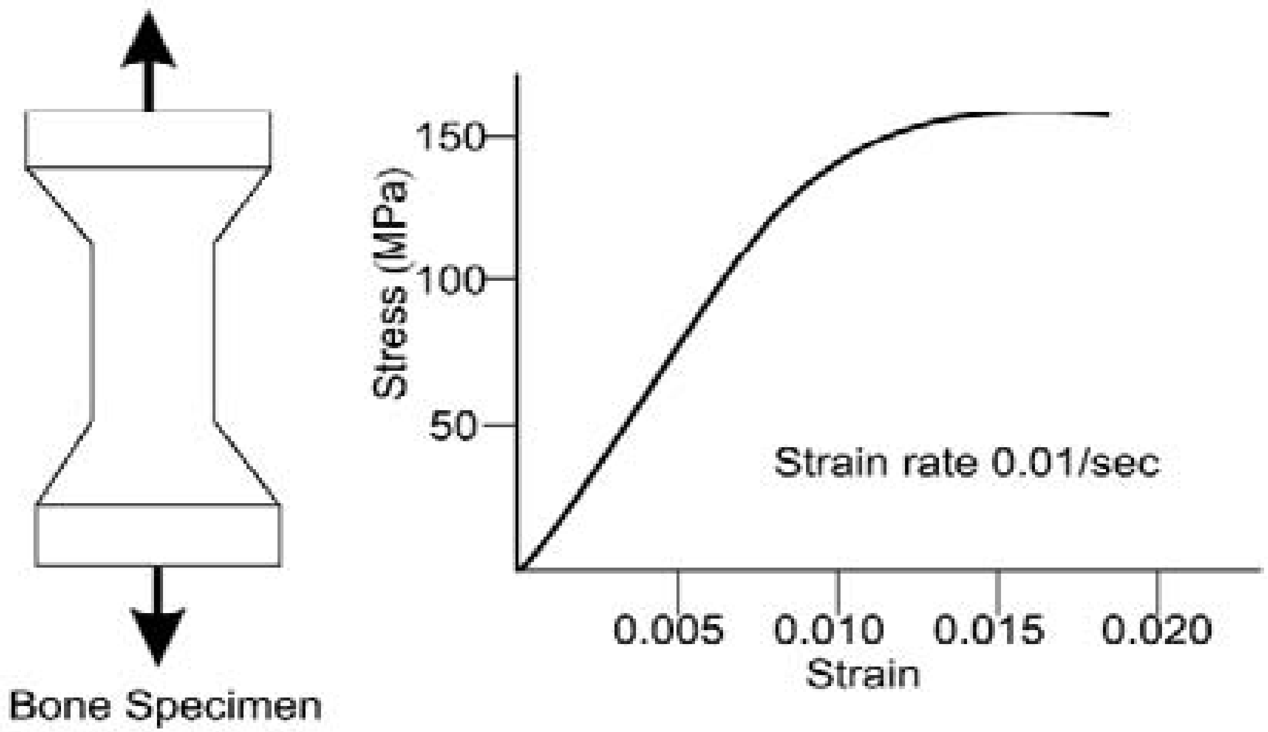


Figure 3 - Illustration of a bone test specimen and a stress-strain curve resulting from a tensile test.

From: Vanwanseele

Load Deformation Testing

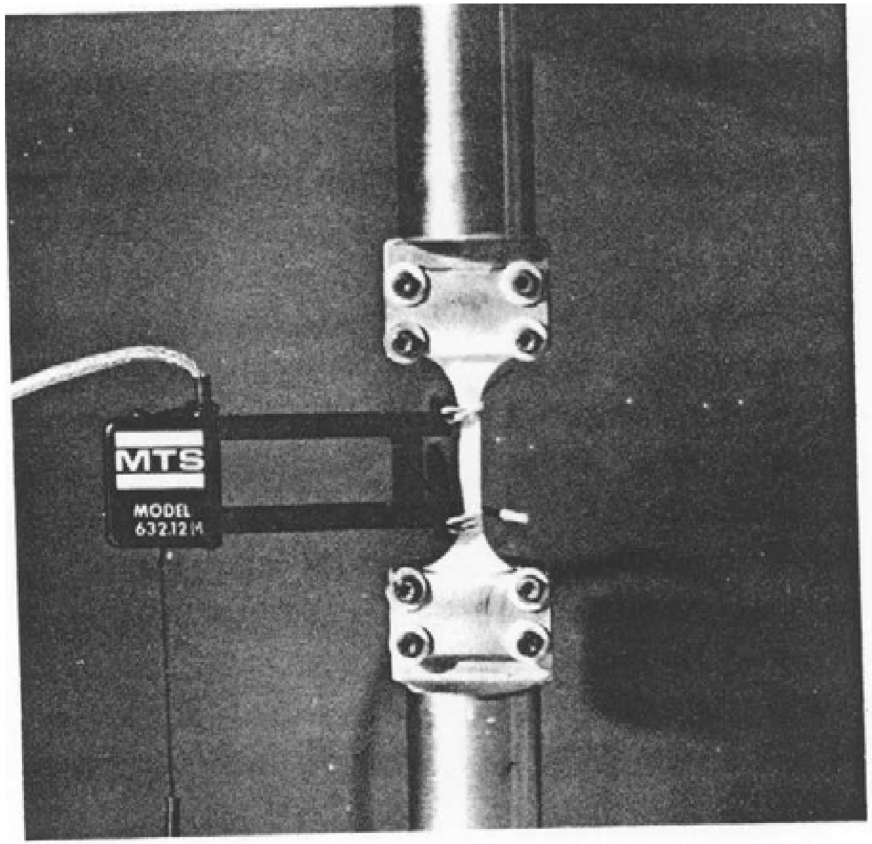


FIG. 1–5

Standardized bone specimen in a testing machine. The strain in the segment of bone between the two gauge arms is measured with a strain gauge. The stress is calculated from the total load measured. (Courtesy of Dennis R. Carter, Ph.D.)

From: Brown

Material Properties

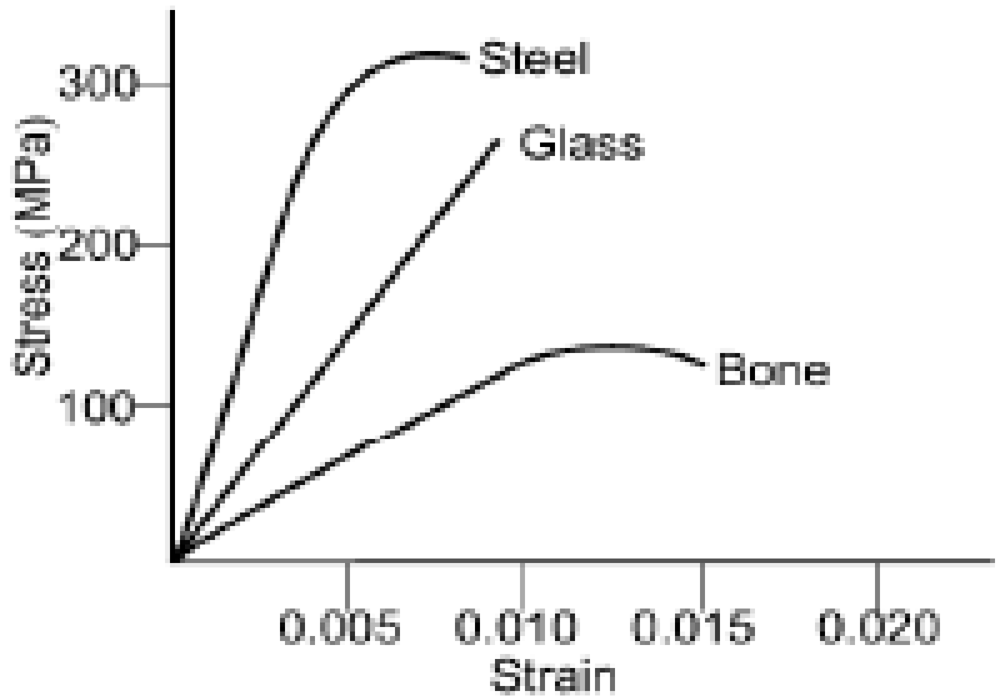


Figure 4 - Material properties of bone relative to other common materials.

From: Vanwanseele

Material and stuctural behavior

- A : cross-sectional area
- L_0 : original length of the cylinder
- Only valid for bone with the same microstructure and in the same environment as the test specimen

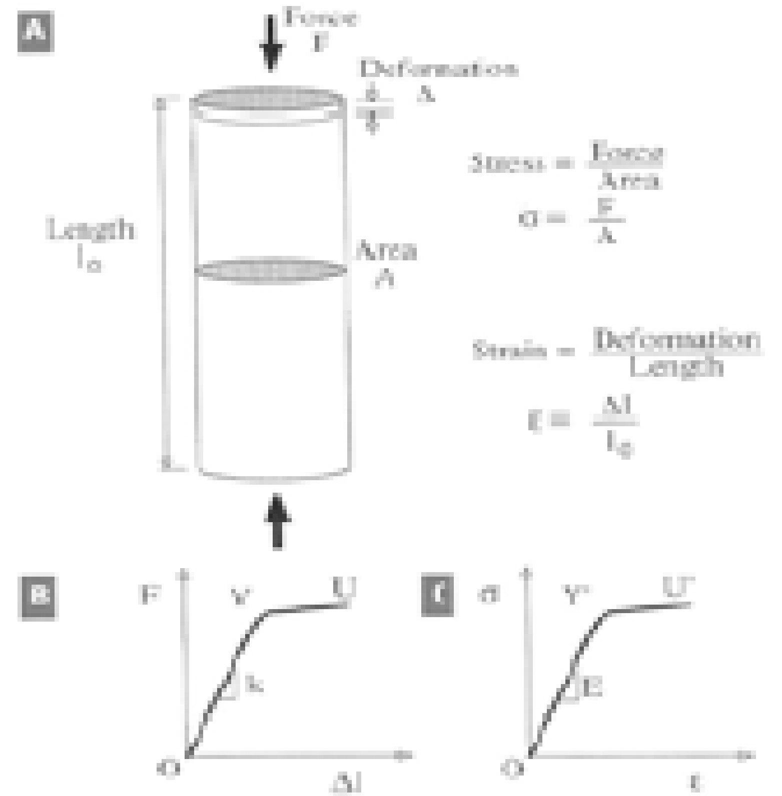


Figure 18

A, Cylindrical specimen used in uniaxial compression tests of human bone. Stress and strain are calculated from the force, deformation, and dimensions of the specimen. **B,** The force-deformation plot describes the structural behavior of the specimen. The linear region (also known as the elastic region) is from 0 to Y. At Y, "yielding" occurs, with internal rearrangement of the structure, often involving damage to the material. In the region Y-U (also known as the postyield region), nonelastic deformation occurs until finally, at U, fracture occurs. **C,** The stress-strain plot describes the material behavior of the tissue which makes up the specimen. The elastic behavior occurs up to Y', and the postyield behavior occurs after Y'. The yield strength is at Y' and the ultimate strength is at U' where fracture occurs. The Young's modulus E is the slope of the linear region of this plot. (Reproduced with permission from Keaveny TM, Hayes WC: Mechanical properties of cortical and trabecular bone. In Hall BK (ed): Bone. Boca Raton, FL, CRC Press, vol 7, pp 285–344.)

From: Gillet

Cortical bone : elastic behaviour

- Poisson's ratio

~0.6 for cortical bone !!!!
compared to ~0.3 for metals

- E in the longitudinal direction ~ 1.5 E in the transverse direction

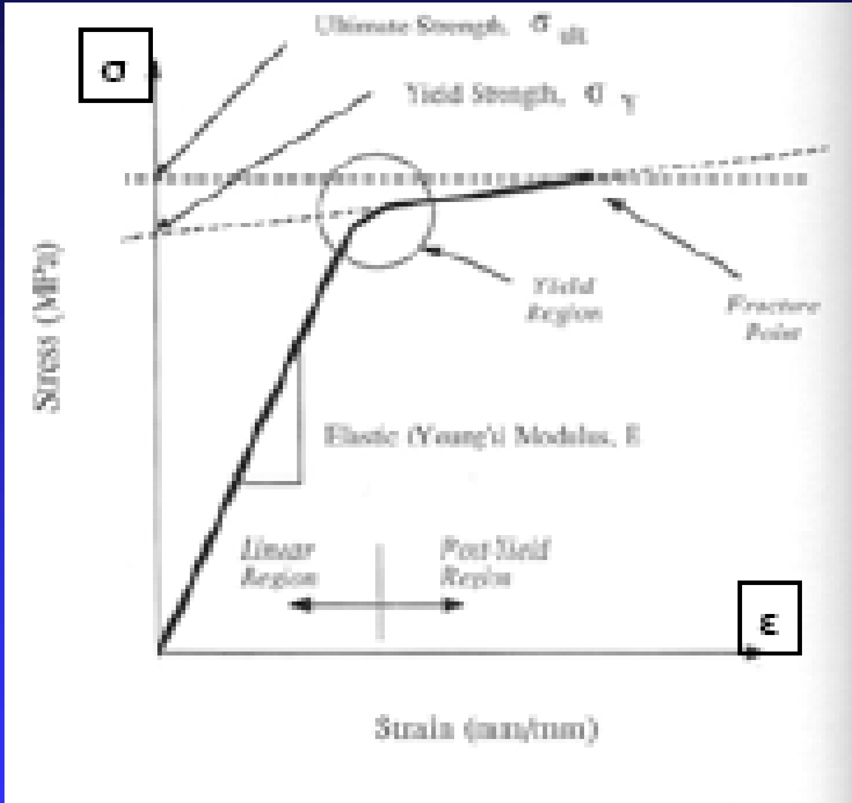


Figure 1.9

Typical stress-strain plot for cortical bone in tension, showing the linear, yield, and postyield regions. Note that the yield and ultimate strengths are similar. Reproduced with permission from Keaveny TM, Hayes WC: Mechanical properties of cortical and trabecular bone. In Hall BK (ed): Bone. Boca Raton, FL, CRC Press, vol 7, pp 285–344.)

From: Gillet

Cortical bone: age effects

- The longitudinal *E* and tensile yield strength of cortical bone decrease by ~2% per decade after age 20
- The slope of the stess-strain curve after yielding increases by 8% per decade
- There is reduction in energy absorption ~ 7% per decade, mainly due to reduction in the ultimate strain
- => less strong, less stiff, more brittle with aging

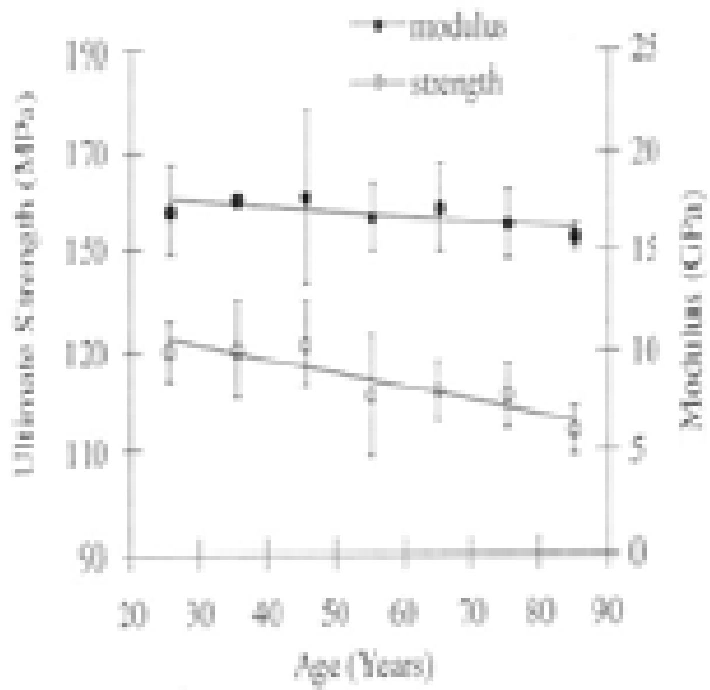


Figure 27

Age-related effects on longitudinal modulus and ultimate tensile strength of human femoral cortical bone. (Reproduced with permission from Burstein AH, Reilly DT, Martens M: Aging of bone tissue: Mechanical properties. J Bone Joint Surg 1976;58A:82-86.)

From: Gillet

Basic Biomechanics

- Anisotropic
  - Mechanical properties dependent upon direction of loading
- Viscoelastic
  - Stress-Strain character dependent upon rate of applied strain (time dependent).

Anisotropic behaviour of bone

- Anisotropic behaviour of cortical bone: specimens from a femoral shaft tested in tension in four directions

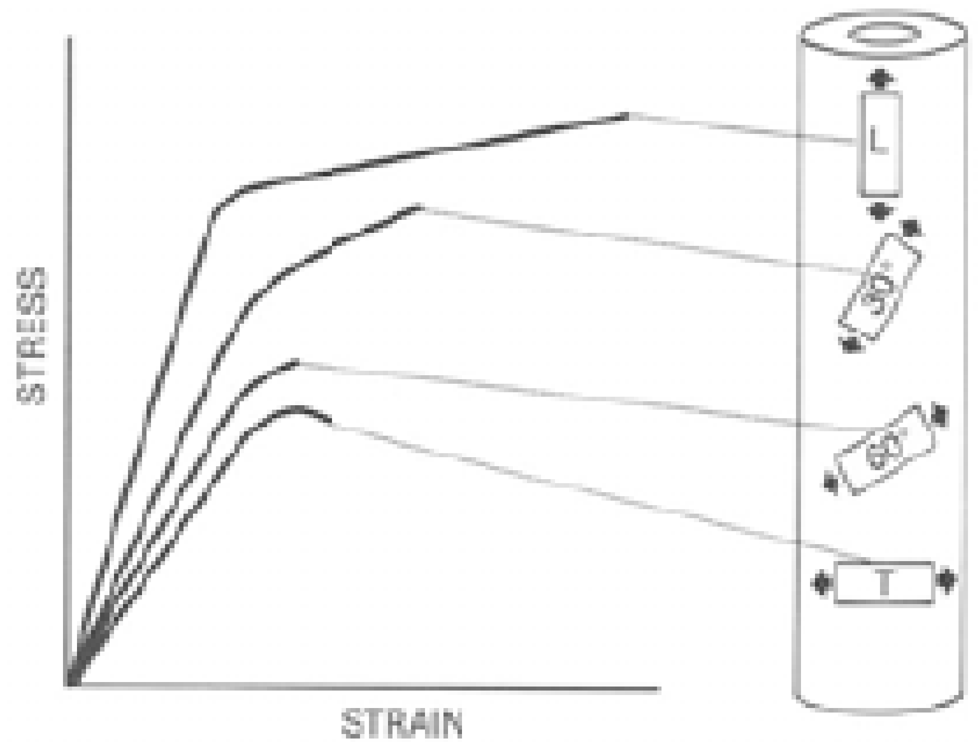


FIG. 1–9

Anisotropic behavior of cortical bone specimens from a human femoral shaft tested in tension (pulled) in four directions: longitudinal (L), tilted 30 degrees with respect to the neutral axis of the bone, tilted 60 degrees, and transverse (T). (Data from Frankel and Burstein, 1970.)

From: Gillet

Wolff's Law (1892)

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…

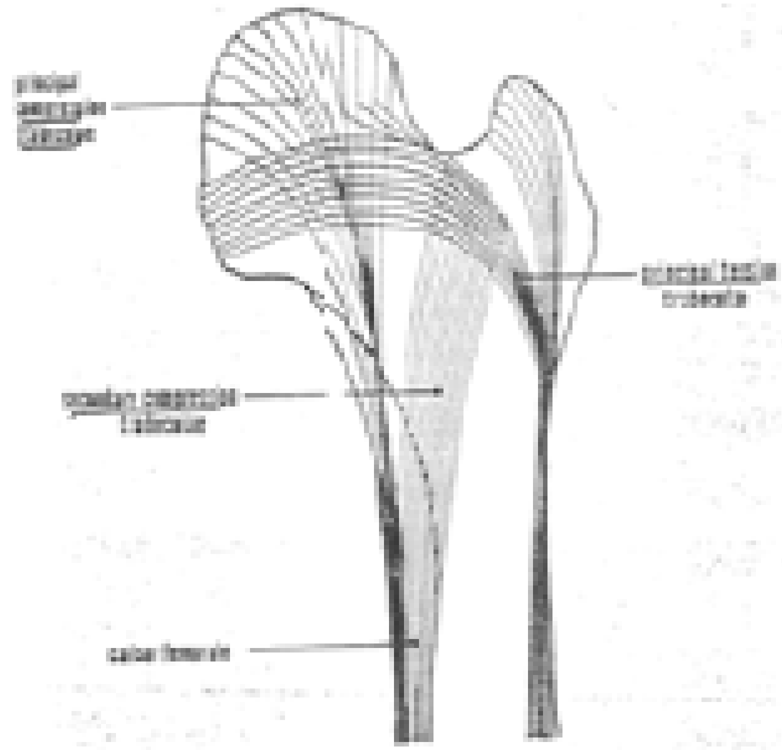


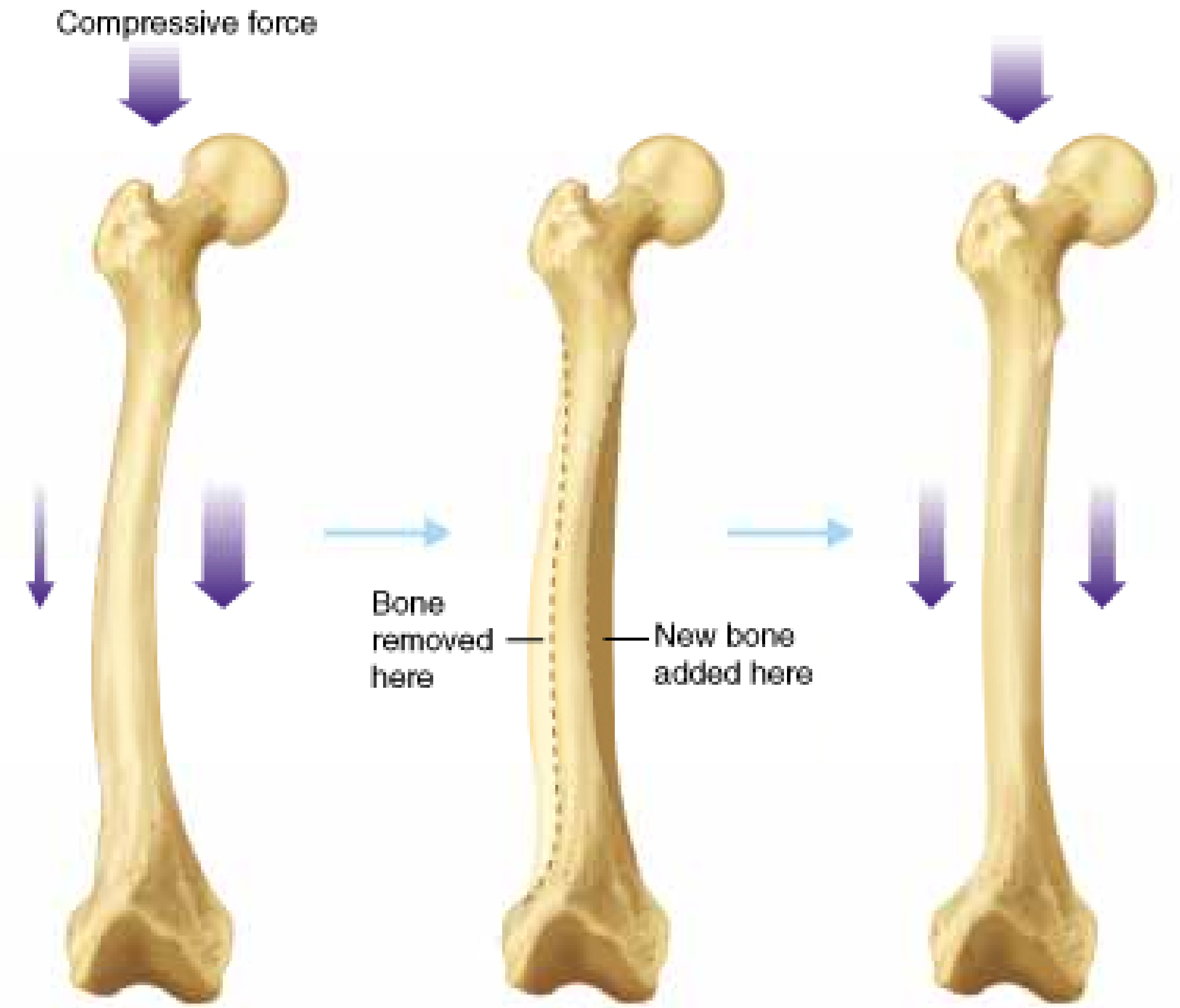
Fig. 4. Diagram of trabecular systems of the proximal femur.

Bone adapts to increased use (e.g., physical activity) or disuse (e.g., bed rest)

Mechanical properties of bone (strength of stiffness) that depend upon form (size, shape) can be altered in response to mechanical demand

From: Seeley

Bone Remodeling



- Bone is a dynamic tissue.
  - *What does that mean?*
- Wolff's law holds that bone will grow or remodel in response to the forces or demands placed on it. *Examine this with the bone on the left.*

18-16

From: Imholtz