Questions

1. *Compare and contrast cortical and cancellous bone.*

Cortical or compact bone contains a higher mineral content and is, thus, a denser bone material, while cancellous or spongy bone has less dense bone material and is more spongy. Typically cortical bone is found at the outer edges of the bone, while cancellous bone comprise the internal structure of bone.

2. *Describe the structural composition of bone. Give an example of a similar synthetic material*.

Bone structure consists of an extracellular matrix of fibers and a ground substance. The combined effect of the fibers and ground substance provide a additive effect for strength. An apt analogy is reinforced concrete with the concrete producing compressive strength and the rebars providing structural support.

3. *Describe the stress-strain characteristics of bone. How do they compare to those of synthetic materials*.

To better distribute stress in this less dense region, a three dimensional lattice-like structure of fibers, the *trabeculae*, has evolved. This is one of the very dynamic aspects of bone, with the trabeculae structure adapting to external stress in very visible patterns.

4. *What is Wolff's Law? Give several examples of where it may apply to bone*.

Wolff's law states that form follows function; i.e. bone mass is deposited or reabsorbed as necessary at the critical locations due to external stresses. Examples of bone loss occurs in astronauts in space with the loss of gravity or in elderly individuals or hospital patients who are bed ridden for extended time periods.

5. *Describe the basic structure of connective tissue*.

Connective tissue, similar to bone, is composed of cells and an extracellular matrix of fibers and a ground substance, typically a proteoglycan, a polysaccharide with a protein core, some lipids and water. The fibers can be of three main types: collagen, elastin and reticulin. Collagen fibers provide strength and stiffness to the tissue, elastin fibers provide elasticity, while reticulin merely provides bulk.

6. *What are the differences between ligaments, tendons, fascia, and cartilage*?

Ligaments connect bone to bone and provide stability at joints. They are typically 90% collagen with relatively straight arrangement of fibers with minimal elasticity. Tendons connect muscle to bone, transmitting the muscle force. They are composed almost completely of parallel bundles of collagen fibers with no elasticity. Fascia covers organs and muscles. It is very elastic (high percentage of elastin) with a very irregular arrangement of fibers, allowing elasticity in all directions. Cartilage covers articular bony surfaces and is found also in the ear, nose and intervertebral discs.

7. *Compare and contrast the three types of joints*.

An articulating joint is found between the two articulating surfaces of bones. Because a layer of synovial fluid overlays these joints, they are sometimes also called synovial joints. If there is fibrous tissue connecting the two bones, then these are termed fibrous joints. If the tissue is cartilage such as in the intervertebral discs, then these are termed cartilaginous joints.

8. *Describe the structure of an articular joint*?

In an articular joint, the articulating ends of the bones are coved with a 1 to 5 mm thick layer of cartilage and is surrounded by a synovial membrane (to contain the synovial fluid) and a joint capsule of ligaments. Many joints (such as the knee) have a disc of fibrocartilage called a meniscus to better distribute forces and protect the bones. In fact, the main purpose of articular cartilage is to spread loads over a larger area and to allow relative movements of the opposing surface with minimum friction and wear.

9. *Describe the structure of hyaline cartilage. How does it compare to the basic structure of bone*.

Hyaline cartilage is primarily composed of an extracellular matrix with relatively few cells. The extracellular matrix is quite high in water content (60 to 80%), leaving only 20 to 40% solid material widely distributed. Of the solid part, 60% is collagen fibers and 40% is the proteoglycan gel, the ground substance composed of hyaluronic acid protein. The chondrocyte cells comprise less than 2% of the material and are arranged in a layered zones within the proteoglycan gel. In the superficial tangential zone, the chondrocytes are oblong with their long axes aligned parallel to the articular surface. In the middle zone, the chondrocytes are round and randomly distributed, while in the deep zone the chondrocytes are columnar in arrangement and are perpendicular to the tide mark, which acts as a boundary to calcified cartilage and the bone. The collagen fibers are similarly distributed in the cartilage layer: densely packed parallel to the surface in the superficial tangential zone, randomly oriented in the middle zone, and perpendicular to the surface in the deep zone.

10. *Explain why synovial joints have such low coefficients of friction, with respect to joint lubrication*.

Synovial joints have an extremely low coefficient of friction (μ=0.003-0.005) due to the simultaneous application of three different lubrication mechanisms (hydrostatic, hydrodynamic, and squeeze film lubrication) for the synovial fluid.

11. *Describe the structure of intervertebral discs.*

Intervertebral discs consist of the annulus fibrosus, an outer onion like fiber casings, and the nucleus pulposus, a gel-like center. As the disc is loaded the nucleus pulposus distributes the force uniformly to the outer annulus fibrosus, whose fibers can withstand the axial tensile stresses. Both surfaces of the disc are covered by cartilage endplates, which are sufficiently porous to allow the diffusion of fluid across the endplate. Since the disc has no internal blood supply, this diffusion is its only means for receiving nutrients and eliminating wastes. This diffusion is accentuated by pressures created by loading of the vertebral column. Under high loading fluid is forced out, while under decreased loading, fluid returns to the disc.

Problems

1. *In addition to being hollow tubes, the long bones typically have larger diameters and thicker walls at the ends. Show the effect these characteristics have on bone strength (i.e. deflection). Note, the comparable characteristic used in bicycle frame tubes is termed 'double butted'.*

Consider three different cases:

i) A basic hollow tube of outer radius of 1.1 cm and inner radius of 1.0 cm (i.e. tube thickness of 0.1 cm) has a moment of inertia equal to π $(1.1^4 - 1^4)/4$ or 0.365

ii) A slightly thicker hollow tube at the end, with tube thickness of 0.2 cm (but the same outer radius) has a moment of inertia equal to π $(1.1^4 - 0.9^4)/4$ or 0.635. This gives a 1.74 greater resistance to a bending moment at a junction where greater stress is expected.

iii) A tube with a slightly larger outer diameter of 1.2 cm, but with the same thickness (0.1 cm) has a moment of inertia equal to π $(1.2^4 - 1.1^4)/4$ or 0.479. This gives a 1.31 greater resistance to a bending moment at the critical junction.

In each case, the center section is either thinner or with a smaller radius, saving material and weight, where the resistance to bending is not needed.

2. *Most support structures (bones, trees, etc.) seem to have a circular cross section. This would imply that a circular cross section is more resistant to bending than other shapes for a given amount of material. Compare the resistance to bending for a hollow square tube to a hollow circular tube of the same weight. The moment of inertia for a hollow square tube is given by:* $I = (r_1^4 - r_2^4)/12$ *where:* r_1 *= outer width and* r_2 *= inner width*

Consider a square and circular hollow cross section with the same amount of material. The square tube has outer width of 1.2 cm and an inner width of 1.0 cm (i.e. a wall thickness of 0.1 cm). The cross sectional area of material is $1.2^2 - 1^2 = 0.44$ cm^2. The same amount of material expended in a hollow circular tube with 0.1 cm wall thickness would be found as follows

$$\pi[(x + 0.1)^2 - x^2] = 0.44$$

x = 0.65 yielding an outer radius of 0.75 cm

The moment of inertial for the square tube is:

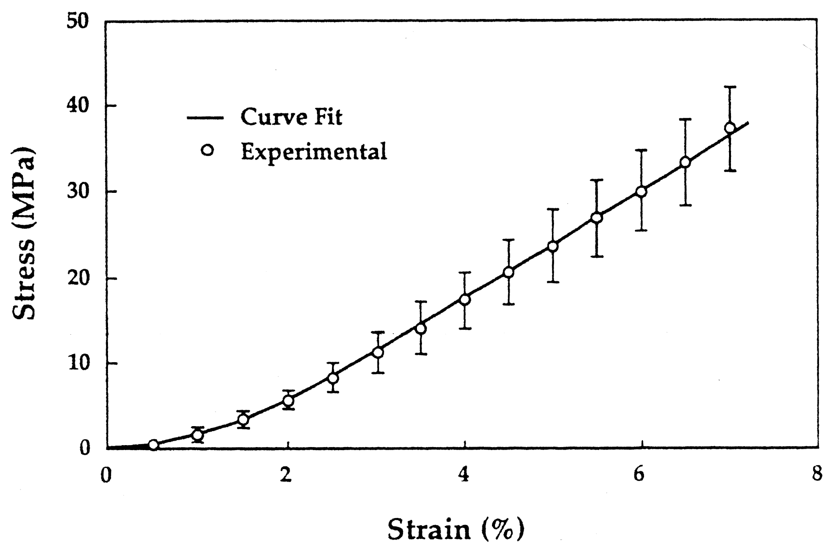
$$I = (1.2^4 - 1^4)/12 = 0.089$$

while the moment of inertial for the circular tube is:

$$I = \pi\,(0.75^4 - 0.65^4)/4 = 0.108$$

and a 21% greater resistance to bending.

3. *The stress-strain curve for a material obeying Hooke's law is a line with a positive slope. Draw the experimentally-determined stress-strain curve for a tendon. Explain the physiological basis for the differences this curve shows from that of the Hookean material.*



The tendon stress-strain shows a toe region at low strains with a different slope and, therefore, different elastic element. The model could also possible include a dashpot to allow for phasic properties.