Properties of Biological Materials

Cells

Cells are the most fundamental structures and functional units in a living body. Depending on their biological characteristics, they can be linked to 5 different kingdoms: Animalia, Plantae, Fungi, Protista and Monera. Eukaryote cells present in the Animalia, Plantae and Fungi are the most complex and the ones that are more often seen grouped in multicellular organisms. Some million years ago, cells started to organize themselves in tissues and later in organs, each one playing a different role in a living system.

Focusing in the animal cells (Fig. 1), they are constituted of the following (main) components: cytoplasmic membrane, mitochondria, ribosomes, lysosome, Golgi apparatus, endoplasmic reticulum (rough and smooth), peroxisomes and a nucleus (inside of it, there can be a nucleolus, associated to genetic material). In a biochemistry point of view, biomolecules are responsible for the functional and structural properties often associated to each organelle. Amino acids, monosaccharides, nucleotides, glycerol and fatty acids are the main blocks that integrate proteins, carbohydrates, DNA/RNA and lipids, respectively.

Until now, only organic materials were considered. An important weight percentage in the human body is due to minerals and water. In fact, the interaction between the previous living structures and inorganic matter are important to assure a lasting homeostasis. Usually, this proximity is regulated by ECM (extracellular matrix) molecules, e.g.: fibronectin and laminin.

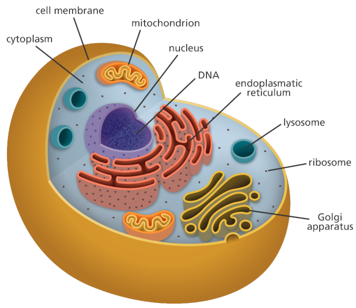

Fig. 1 – Animal cell.

Introduction

When we want to design something to replace some part of the human body, we should know exactly the characteristics of this specific volume. Both Anthropometry and Biomechanics are essential to measure the size and shape of the human body, and to link structural features to a biological function, respectively.

Generally, tissues can be divided in 2 main categories: soft tissues and hard tissues. Inside each of these 2 groups, several ones can be defined based on structural and functional peculiarities, although in a more difficult way, due to sharing of some features:

→ Epithelial tissue – known for lining cavities, blood vessels and organs. Can be organized in many layers of cells w/ different shapes: 1 layer - squamous, columnar, cuboidal or pseudo-stratified columnar; 2 or more - squamous, columnar or cuboidal;

→ Muscle tissue – in an active way (spending energy), it's responsible for conscious and automatic movement. This tissue can be subdivided in 3 main categories: skeletal, smooth and cardiac muscle;

→ Nervous tissue – play an important role in generating and conducting nervous impulses, in response to inner or environmental stimulus;

→ Connective tissue – structural functions are most of the times linked to this tissue.

Material's properties

Some mechanical properties can be used to describe biological materials: isotropy, homogeneity, elasticity and viscosity. Ideal materials are considered isotropic and homogeneous. This means that they have the same properties along the 3 axes and are made of the same material throughout. Biological tissues are viscoelastic materials. These materials possess 4 specific properties: stress-relaxation, creep, strain-rate sensitivity and hysteresis. After straining a sample until a certain value, it's expected that the stresses created will decrease w/ time. Instead of strain it, if it's stressed, it will increase in length along 1 or more directions - creep. Strain-rate sensitivity is a reflex of the viscous component. Time dependent property, which assumes that the material will behave accordingly to the rate at same action is performed (stress or strain – Fig. 3)). Pure elastic materials can stretch and recover their initial conformation w/out energy losses. Viscoelastic will dissipate energy during the cycle.

Finally, elasticity by itself can be described by Young Modulus, which reflects the tendency to strain when a stress is applied (or the inverse). It's simply the slope of the curve in a stress-strain graph for an elastic material.

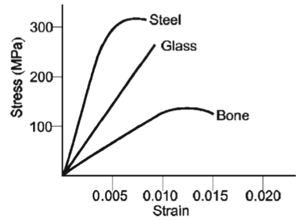

Fig. 2 – Stress-strain curves for different compounds.

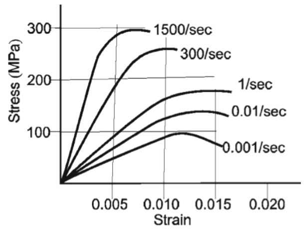

Fig. 3 – Strain-rate sensitivity of cortical bone.

Connective tissues

Bone

It has 2 main phases, one fluid and another solid. The solid can be divided in organic and inorganic. Generally, an extracellular collagenous matrix is impregnated w/ an inorganic compound called hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$. Both complement each other, in a sense that the organic matrix prevents brittle cracking of the stiffest phase (hydroxyapatite). Additionally, GAGs serve to cement together the mineralized collagen fibers.

Bone can be identified as both: cortical or spongy. The main difference between both is related to their degree of porosity. Porosity of cortical bone ranges from 5 to 30%, while spongy bone's porosity ranges from 30 to 90%.

Spongy bone can sustain strains of 75% before failing *in vivo*, but cortical bone will fracture if the strain exceeds 2%. For some reason, if a cortical bone is dryer than supposed, it will present an ultimate yield strength of about 0.4%. This reveals an important role of water present in tissues. Observing Fig. 2, we can easily compare bone E w/ some well-known materials.

Tooth

Tooth (Fig. 4) are covered by an external shell called enamel at the top. And in the bottom composed by cementum. These 2 layers offers protection to a 3rd one – dentin. While enamel is mainly made of hydroxyapatite, dentin is a calcified mesh of collagen fibrils. Generally, tooth is very hard and brittle (not very strong) due to their high mineralization.

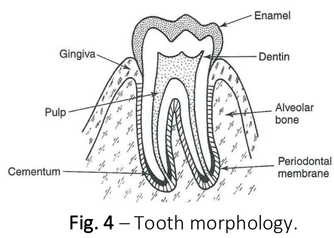

Fig. 4 – Tooth morphology.

Cartilage

Articular cartilage is a multiphasic material, w/ 2 major phases: fluid, composed essentially of water and a solid by type II collagen fibers. Interactions that take place among the sinusoidal fluid, proteoglycan molecules, and various electrostatic charges, provide superior quality of lubrication (coefficient of friction is several times smaller than that between ice and an ice skate) and shock absorption.

Ligaments

Mainly constituted of elastin, collagen and water (60-80% weight). They have a characteristic long turnover rate, of about 400 days, which makes them such a problematic issue when damaged. Ligaments are usually found closely packed, providing motion stabilization for the musculoskeletal system. Moreover, their properties are strongly biased by environment temperature: Fig. 5 exhibits response to cyclic loading and unloading. Peak loads decreased w/ each cycle, indicating ligament softening.

Aging causes a gradual water loss in the ligaments, consequently decreasing their plasticity over time.

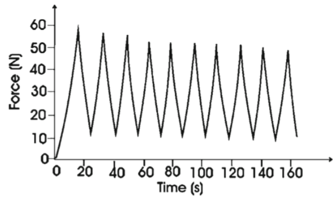

Fig. 5 – Ligament response to cyclic loading and unloading.

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