Overview of Lecture: Animal Form & Function; Nutrition

Read: Text pgs 850-851, ch 40 & 41

Bullet Points:
- form & function
- tubes: bulk flow & diffusion
- germ Layers
- tissues
- epithelium
- connective
- muscle & nerve
- skeletal muscle
- Eat Food!
- teeth & guts
- glucose regulation; negative feedback
- fat regulation
Form Follows Function - constrained by physical laws in particular environments.

Multicellular organisms are big, aggregated lineages of cells (clones) (plus various symbionts, parasites, mutants etc.). Each cell is plasma-membrane bound aqueous system, with homeostatic mechanisms to maintain stasis (or growth) by regulating exchange: energy, nutrients ‘raw materials’ etc IN & wastes, hormones, ‘products’ etc OUT.

Diffusion through tissues is very slow & inefficient.

Large animals are masses of tubes w/ ↑ surface/vol & ↓ diffusion dist. Bulk flow through tubes (gut, lungs, arteries & veins, lymph etc) minimizes diffusion distances. {most cells <~200µm from capillary}
In mammals the coelom is divided by the diaphragm into the
peritoneal cavity – contains stomach, intestines, liver
thoracic cavity – subdivided into pleural cavities – lungs
pericardial cavity - heart

The endoderm gut tube passes through the mesoderm coelom

The vertebrate body is a tube within a tube

http://www.madsci.org/~lynn/VH/transverse.html

The Visible Human Project
Projects Based on the Visible Human Data
Sources of images and animations

http://www.madsci.org/~lynn/VH/transverse.html
The cells of the embryo differentiate into 3 germ layers
{see ch 47; note: in many vert’ s the hollow sphere becomes a flat disk}

Skin, Neural tissue
Adrenal medulla, Pituitary gland
Connective tissue of the head and face, Eyes, ears

Bone marrow (blood), Adrenal cortex, Lymphatic tissue
Skeletal, smooth, & cardiac muscle, neural crest
Connective tissues (including bone, cartilage)
Urogenital system, Heart & blood vessels

Thymus, Thyroid, parathyroid glands, Larynx, trachea, lung
Urinary bladder, vagina, urethra
Gastrointestinal (GI) organs (liver, pancreas)
Lining of the GI tract & the respiratory tract
Animals are multicellular organisms with their specialized cells grouped into tissues. Tissues are integrated groups of cells with a common structure and function. Combinations of various tissues make up functional units called organs, and groups of organs that work together form organ systems {Table 40.1}

All organs are made of the four basic tissue types. {from various germ layers}

http://mindquest.net/biology/histology/index.html

Epithelial tissue is derived from all 3 germ layers;
- covers the outside of the body; lines internal organs & cavities;
secrete material (e.g. glands), or absorb material (e.g. intestine).

Connective tissue (mainly ectoderm & mesoderm)
connects body parts, Many subtypes of connective tissue, including bone, cartilage, ligaments & tendons, adipose (fat) tissue, areolar (loose irregular) connective tissue, and blood (connective tissue because it derives from bone marrow).

Muscle cells (from mesoderm) have the ability to contract/shorten. This allows muscle tissue to function for providing movement …
There are three subtypes of muscle tissue:
skeletal muscle, smooth muscle, and cardiac (heart) muscle.

Nerve cells, known as neurons, (from ectoderm) are specialized for conducting electrical signals in the body.
Epithelial tissue is derived from all three germ layers; functions to protect surfaces (eg skin), secrete material (eg glands), absorb material (eg intestine).

Epithelial tissue lines all body surfaces... the mouth, esophagus, uterus and vagina, ducts of the pancreas and liver, urethra and ureters, blood vessels (where it is called endothelium), tubules of the kidney, air sacs (alveoli) of the lungs ...

Epithelial tissue is classified according to
(1) the shape of the outermost cell layer
   squamous [flat]: linings - diffusion
   cuboidal: glands & tubules - transport
   columnar: linings – secretion & absorption
   or transitional, {discrete categorization is an ‘ideal’}
(2) whether or not the tissue is
   one layer thick (simple): lungs & capillaries
   or multiple layers (stratified): skin, mouth
   or ‘pseudostratified’: glands & mucous membranes and
(3) whether or not the cells are
   ciliated
   or secrete (glandular, ex: goblet cell) ...
Characterisitcits of epithelial cells:

They are contiguous (connected w/ tight junctions). Epithelia are avascular … blood vessels do not penetrate up between these cells … {ex: blood-brain barrier}

Unlike muscle and connective tissue, they can be derived from any of the three embryologic germ layers (endoderm, mesoderm, ectoderm).

Rapid replacement: stomach epithelium replaced ~2-3 days; epidermis ~2 weeks;

A major cytoskeletal component of skin epithelia is the filament called keratin {the main component of: mammal hair, reptile scales, bird feathers, claws (including nails and hooves), horn (but not antlers), & the enamel of the teeth}.

… rest on an extracellular matrix which they produce … the basement membrane.

… basement membrane … is a thin sheet of collagen {dense connective tissue Fig 40.5}

Cancer biology: Breaking and entering


To spread, or metastasize, cancer cells must escape from their site of origin. Doing so requires crossing the basement membrane, a barrier of connective tissue. S Weiss and colleagues have identified three enzymes that allow tumors to degrade proteins in the basement membrane, allowing cancer cells to escape. Knowing the enzymes … could enable future cancer therapies to target this process.
Glandular epithelia, absorb or secrete chemical solutions.

**Endocrine** glandular epithelia secrete hormones **into the blood** (ch 45)

**Exocrine** glands channel product **to epithelial surface**.
- ex: tear, sweat and sebaceous glands to skin; liver to gut.

Glandular epithelia that line the digestive & respiratory tracts form **mucous membrane**; they secrete a slimy solution called **mucus** that lubricates the surface.

**The epithelium of our respiratory tract has beating cilia**
- that move the film of mucus along the surface:
  - helps keep our lungs clean by trapping dust, ‘germs’ and other particles and sweeping them back up the trachea (windpipe) – to esophagus.

Vertebrate glands (ch 45) develop from invaginated epithelium

**Glandular epithelia**
- absorb or secrete chemical solutions.

**Endocrine** glands secrete hormones **into the blood** (ch 45)

**Exocrine** glands channel product **to epithelial surface**.
- ex: tear, sweat and sebaceous glands to skin; liver to gut.

Glandular epithelia that line the digestive & respiratory tracts form **mucous membrane**; they secrete a slimy solution called **mucus** that lubricates the surface.

**The epithelium of our respiratory tract has beating cilia**
- that move the film of mucus along the surface:
  - helps keep our lungs clean by trapping dust, ‘germs’ and other particles and sweeping them back up the trachea (windpipe) – to esophagus.

Vertebrate glands (ch 45) develop from invaginated epithelium

Water-soluble:
- spilled out
In the inactive mammary gland, the glandular elements consist only of ducts: lined by cuboidal or columnar epithelium ... Dramatic changes in the mammary gland occur during pregnancy. Ducts proliferate and secretory alveoli sprout from them. Alveoli are collections of cuboidal or columnar epithelial cells that become active milk-secreting structures.

The lipid \{water insoluble\} component of milk is released in an envelope of plasma membrane by apocrine secretion. \{homogenization breaks up large globules\}.

The protein \{water soluble\} component of milk is released into solution by merocrine secretion.

During the menstrual cycle slight development of secretory alveoli may begin ...

... an increasing number of menstrual cycles \{fewer pregnancies\} increases the stimulation of breast ductal epithelial cells and one’s risk of breast cancer.

... the risk for breast cancer is associated with lifetime exposure to estrogen.

Breast Cancer Risk Factors: Estrogens

Menstrual and reproductive factors and endometrial cancer risk ...

**Connective Tissue** derives from embryonic *mesoderm*, … has a sparse population of cells scattered through an extracellular matrix.

The most widespread connective tissue in the vertebrate body is *loose connective tissue*. Collagenous, elastic, and reticular fibers in this tissue type bind epithelia to underlying tissues and hold organs in place.

**Cartilage** has an abundance of collagenous fibers embedded in a rubbery matrix made of a protein-carbohydrate complex called chondroitin sulfate. Cells called chondrocytes secrete the collagen and chondroitin sulfate that make cartilage a strong yet flexible support material. Many vertebrate embryos have cartilaginous skeletons, but most of the cartilage is replaced by bone as the embryo matures. Cartilage is retained in some locations, such as the disks that act as cushions between vertebrae.

**Fibrous connective tissue** is dense with collagenous fibers. The fibers form parallel bundles, which maximize nonelastic strength. Fibrous connective tissue is found in tendons, which attach muscles to bones, and in ligaments, which connect bones at joints.

**Adipose tissue** is a specialized loose connective tissue that stores fat in adipose cells distributed throughout its matrix. Adipose tissue pads and insulates the body and stores fuel as fat molecules (see Figure 4.6). Each adipose cell contains a large fat droplet that swells when fat is stored and shrinks when the body uses that fat as fuel.

The skeleton of most vertebrates is made of *bone*, a mineralized connective tissue. Bone-forming cells called osteoblasts deposit a matrix of collagen. Calcium, magnesium, and phosphate ions combine into a hard mineral within the matrix. The combination of hard mineral and flexible collagen makes bone harder than cartilage without being brittle. The microscopic structure of hard mammalian bone consists of repeating units called osteons. Each osteon has concentric layers of the mineralized matrix, which are deposited around a central canal containing blood vessels and nerves.

**Blood**, which functions differently from other connective tissues, has a liquid extracellular matrix called plasma. Consisting of water, salts, and dissolved proteins, plasma contains erythrocytes (red blood cells), leukocytes (white blood cells), and cell fragments called platelets. Red cells carry oxygen; white cells function in defense, and platelets aid in blood clotting.
Fibrous connective tissue is dense, due to its large numbers of collagenous fibers.

In **tendons**, which attach muscles to bones, and in **ligaments**, which join bones together at joints, the fibers are organized into parallel bundles …

The “unhappy triad” is where the ACL is torn at the same time as the MCL and the lateral meniscus (one of the shock absorbing **cartilages** in the knee).

**Cartilage** has collagenous fibers embedded in a rubbery matrix of **chondroitin sulfate**, a protein-carbohydrate complex. … secreted by cells called **chondrocytes**.

… **articular (meniscus) cartilage** lining the bones of your knee joint has limited ability to heal itself. Blood capillaries do not penetrate the **joint capsule**.

**Synovial fluid**, secreted by **synovium** (membranes), lubricates the joint and carries nutrients to the cartilage.
Rheumatic diseases are connective tissue diseases. Arthritis means joint inflammation. … arthritis is a kind of rheumatic disease. **Osteoarthritis affects cartilage**, the tissue that cushions the ends of the bones within the joints. **Rheumatoid arthritis is an autoimmune disease** … the immune system attacks a person's own synovium, the tissue inside the joint capsule. 

*Rheumatoid factor is an autoantibody against IgG antibodies* - ch 43

http://en.wikipedia.org/wiki/Rheumatoid_arthritis

In theory, RA requires susceptibility to the disease through genetic endowment with specific markers *and* an infectious event that triggers an autoimmune response. The "mistaken identity" theory suggests that an infection triggers an immune response; then, there is an auto-immune attack because the host molecule "looks like" the infectious antigen - this phenomenon is called molecular mimicry. Epidemiological studies have confirmed a potential association between RA and two herpesvirus infections ... \{a GXE interaction\}
Adipose tissue has long been viewed as a harmless tissue in the pathogenesis of chronic inflammatory connective tissue and joint diseases ... However, three discoveries have completely changed this point of view ...

1. A number of molecules released by adipocytes ("fat cells") – the adipokines – are also produced by various cells of a similar connective tissue origin such as fibroblasts.

2. Adipocytes can actively secrete additional proinflammatory factors operative in the pathophysiology of inflamed joints ... tumor necrosis factor (TNF), interleukin (IL)-6, components of the ... immune system

3. These adipokines target well-known immune system effector cells operative in the pathophysiology of chronic rheumatic diseases. The key prototype molecule in this scenario is adiponectin, a central mediator of inflammation with well-known deleterious effects in arthritis.

Fat cells use immune signal Nature 495, 413 (28 March 2013)
In obese individuals, fat cells may act like inflammatory white blood cells by using communication machinery once considered to be exclusive to immune cells.
Bone is an extracellular mineralized connective tissue (from mesoderm). Bone-forming cells called osteoblasts deposit a matrix of collagen. Calcium, magnesium, and phosphate ions combine and harden within the matrix into the mineral hydroxyapatite – rigid but brittle.

The surface enamel of teeth is composed of a form of hydroxyapatite: Ca$_5$(PO$_4$)$_3$(OH). The OH- ion can be replaced by fluoride. Fluorapatite is "harder" and more resistant to damage caused by acids ... more resistant to tooth decay.

The structure of hard mammalian bone consists of repeating units called osteons (or Haversian systems). Each osteon has concentric layers of the mineralized matrix, which are deposited around a central canal containing blood vessels and nerves that service the bone. Mature osteocytes maintain, remodel and repair mineral bone.

**Optimization of bone growth and remodeling in response to loading ...**

Limb bones initially optimize \{growth\} responses to loading ...
In juveniles, exercise induces higher rates of \{remodeling\} ... \{but less so in adults\}
Blood functions differently from other connective tissues (mesoderm) but it has an extensive extracellular matrix: a liquid called plasma, consisting of water, salts, and a variety of dissolved proteins. Suspended in the plasma are two classes of blood cells, erythrocytes (red blood cells) and leukocytes (white blood cells), and cell fragments called platelets. Blood will be discussed later (Chapters 42, 43 & 44).

Nervous tissue (from ectoderm) senses stimuli and transmits signals from one part of the animal to another, & stores memories. The functional unit of nervous tissue is the neuron, or nerve cell, Discussed later in ch 48

Archeo-Cell Biology: Carbon Dating Is Not Just for Pots and Dinosaurs
In this issue of Cell, Spalding et al. (2005) describe a clever strategy for birth dating human cells in vivo, based on incorporation of 14C during a peak in atmospheric levels resulting from above-ground nuclear arms testing in the 1950s. The amount of 14C in neurons of the human cerebral cortex corresponds to the amount in the atmosphere at the time of birth ...

occipital neurons are as old as the individual {new connections, not new cells}
**Muscle** tissue (from mesoderm) is composed of long cells called muscle fibers that are capable of contracting when stimulated by nerve impulses. Arranged in parallel within the cytoplasm of muscle fibers are large numbers of myofibrils made of the proteins actin and myosin. Recall actin in eukaryotic cytoskeleton (see ch 6)

**Smooth muscle** is found throughout animals. In vertebrates – ‘visceral’ muscle, sheets surround larger blood vessels and bronchia, gut, iris of eye. Not striated (lined up) Not ‘voluntary;’ spontaneous waves in gut;

**Skeletal muscle** is usually attached to tendons & bones at origin & insertion; antagonists flex & extend. Lined up in orderly, multinucleate myofibrils – ‘striated.’ ‘Voluntary;’ excited at neuromuscular synaptic junctions

**Cardiac (heart) muscle** ‘striated’ but single cells (& nuclei) linked by gap junctions into single functioning myocardium Specialized ‘autogenic’ cells maintain rhythmic contractions; modified by sympathetic (+) and parasympathetic (-) nerves
**Sliding filament mechanism** (see text ch 50.5)
Each *skeletal muscle* is an nested hierarchy of filaments.

**Contraction:**
Somatic motor neurons release **acetylcholine Ach** *(blocked by Botox)*
Ach depolarizes muscle ... starting the power cycle

**Power cycle:**
(a) myosin splits ATP
(b) cross-bridges w/ actin,
(c) myosin head bends  
(power stroke - rowing)
(d) new ATP releases bridge,  
straightens →(a)
*Rigor mortis* – no ATP to break bridges

actin Z bands get closer, Sarcomeres shorten muscle contracts
From venoms to toxins to drugs:
Toxins have been used to elucidate physiological mechanisms; the pure alkaloid, tubocurarine, isolated from the arrow poison curare, has been used as a muscle relaxant to accompany general anaesthetic. {blocks Ach binding at neuromuscular junction}

Another toxin used for its muscle relaxant properties is **botulinum toxin**, from bacteria Clostridium botulinum. The toxin gets into motor nerve terminals and prevents the release of acetylcholine {presynaptic vesicle can’t fuse w/ membrane} ...

... botulinum toxin is often regarded as one of the most toxic substances known ...

However, its specificity and irreversibility have been useful ...

When **Botox** is injected into a muscle, it blocks the release of acetylcholine; the lack of stimulation & activity weakens the muscle. ... the skin overlying the muscle relaxes and the wrinkles in the skin often disappear.
Essentially We Have Two Fibre Types: \{there are intermediate types; less common\}

**Fast-twitch (Type 2) & Slow-twitch (Type 1)**

High intensity, anaerobic, short-burst activity, engages the fast-twitch fibres, which are lighter in coloring than slow-twitch fibres due to the low levels of myoglobin (stores oxygen for use in cell respiration) and mitochondria they possess – **quickly fatigue**.

Slow-twitch fibres, on the other hand, possess more mitochondria and myoglobin, and are red in coloring as a result. **Fatigue resistance**, at the expense of fast rate force production, is the hallmark of these fibres.

The average person has about 50% slow & 50% fast fibres in locomotory muscles. You can almost guarantee that the 100-meter Olympic sprint champion has around 80% fast twitch fibres in his quadriceps muscles. \{the proportions change with age and training, and possibly vary across genotypes\}

To simplify things somewhat, a nice analogy can be used to explain the various actions of these two fibre types.

**Chickens**, like us, have both fast and slow-twitch fibres: their darker \textcolor{red}{(red) meat} is composed of slow-twitch fibres, and the \textcolor{white}{white meat} of fast-twitch fibres.

Chickens use their legs \textcolor{red}{(red meat)} for walking and standing for large periods of time, while their wings & breasts \textcolor{white}{(white meat)} are used for brief bursts of activity. \{wild, migratory ducks have “red meat” breasts\}
All animals eat other organisms dead or alive, whole or by the patty

An adequate diet must satisfy three nutritional needs:

1 **fuel** (chemical energy) for all cellular work of the body;
   
   *{empty calories in junk food serve this purpose OK}*

2 the **organic raw materials** animals use in biosynthesis;
   
   Given a source of **organic carbon** (such as sugar) & **organic nitrogen** (usually amino acids in protein), animals can fabricate a great variety of organic molecules - carbohydrates, proteins, and lipids;

3 **essential nutrients** - substances that the animal cannot make for itself:
   
   - vitamins, and minerals (Table 41.1)

**An Evolutionary Perspective on Amino Acids**

**complementary foods** *{not complimentary}*

balance essential nutrients across plant foods

**Glyphosate Roundup** herbicide inhibits the synthesis of three essential *{to animals}* aromatic amino acids synthesized only in plants, therefore … only toxic to plants …
Teeth and Guts are great indicators of diet

The vestigiality of the human vermiform appendix

... as is the number of copies of the gene coding for the salivary enzyme amlayse, which digests complex starches into simple sugars ... 

news@nature  Ewen Callaway, Published online: 9 September 2007;

Ability to digest starch could have spurred human evolution.

Compared with chimpanzees, humans boast many more copies of the salivary amylase – a saliva enzyme that breaks down starch into digestible sugars. And carbohydrate-loving societies carry more copies of the gene than those that follow low-carbohydrate diets, says a new study in Nature Genetics1.

Dog's dinner was key to domestication - dogs possess genes for digesting starches, setting them apart from their carnivore cousins — wolves.

Blood Glucose Regulation as an Example of \{push-pull –FB\} Homeostasis

When an animal takes in more calories than it needs ...
the liver and muscle cells store energy in the form of glycogen,
a polymer made up of many glucose units.

If the body’s glycogen depots are full the excess is usually stored as fat.

When fewer calories are taken in than are expended ...
the body expends liver glycogen, then muscle glycogen and fat.
\{released as glucose, into blood\}

Blood glucose levels are regulated by complementary ‘push-pull’
negative feedback systems:
insulin pulls high blood glucose down
glucagon pushes low glucose up
(Figs 40.8 & 41.21)

Type 1 diabetes mellitus:
loss of insulin-producing beta cells;
autoimmune, juvenile onset

Type 2 diabetes is often due to reduced responsiveness to insulin, associated w/ obesity in adults
Over the long term, homeostatic mechanisms, involving hormones in feedback circuits to a “satiety center” in the brain {a group of cells in the ventromedial hypothalamus} control the body’s storage and metabolism of fat.

... plus many other neural and chemical signals from guts
Both of these mice have a defect in a gene called *obese* (*ob*). This mutation results in a marked increase in the amount of fat. Administration of the protein encoded by the *ob* gene, called *leptin*, {Greek – "thin"} reduced the body weight of the *ob* mice. {In obese humans, defective receptor}

By modulating the hypothalamo-pituitary-gonadal axis both directly and indirectly, **leptin may thus serve as the signal from fat to the brain** about the adequacy of fat stores for pubertal development and reproduction. Normal leptin secretion is necessary for normal reproductive function to proceed and leptin may be a signal allowing for … progression toward puberty.

**Role of leptin in reproduction.**

Bajari et al. CURRENT OPINION IN LIPIDOLOGY 15 (3): 315-319 JUN 2004

The development of therapeutic agents against obesity must consider the consequences of treatment on the bioactivity of **leptin** in the context of growth, glucose homeostasis, fertility {and inflammation}