C. Introduction to Multicellularity

1. Regulation of Organism Size by Cell Mass
2. Regulation of Extracellular Structure
3. Regulation of Cell Adhesion
4. Regulation of the Internal Aqueous Environment
5. Regulation by Intercellular Communication
6. Regulation by Cell Specialization

1. Regulation of Organism Size by Total Cell Mass

Cell mass determines the size of an organism and is a combination of cell size and number

a. The size of cells varies with gene dosage and a common nucleus-to-cytosol ratio

b. Cell number is a balance between cell division and cell death

a. The size of cells varies with gene dosage and a common nucleus-to-cytosol ratio

- Most mature cells have a N:C ratio of 1:1 or 2:1 (early differentiating cells as high as 4:1)
- Multiple copies of chromosomes can increase the size of the nucleus and total cell size

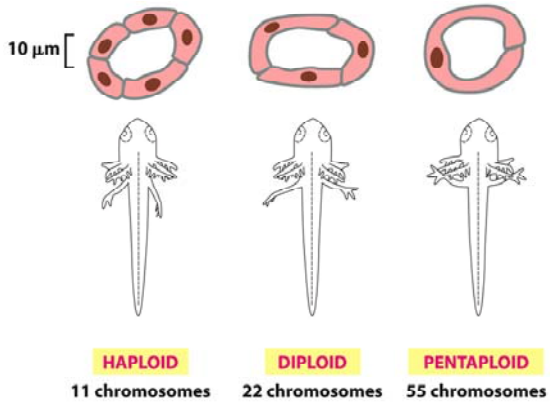


Figure 17-70 *Molecular Biology of the Cell* (© Garland Science 2008)

b. Numbers in a Cell Population

- Cell number is a combination of....
  - Cell divisions – Cell deaths (necrotic + programmed)
  - Necrosis is premature cell death
    - disease, injury, starvation, toxicity, excitotoxicity
  - Programmed cell death is death by design
    - apoptosis, anoikis, cornification, autophagy
- Same for an organism, system, organ or tissue, and for single cell populations in an ecosystem

We've even learned to control it.....

A mutation in a signal molecule that limits muscle cell division has been bred in.

Figure 17-69 *Molecular Biology of the Cell* (© Garland Science 2008)

2. Regulation of Extracellular Structure

- These extracellular materials are produced and organized by the cells themselves.
- Extracellular structures keep the organism intact and allow coordinated function
  - Mechanical support and defense
  - Adhesion for cells and tissues
  - Substrate for cell and organismal movement
  - Regulation of cell growth and function

- Animal cells secrete an elaborate "ECM"
  - Vertebrate four compound ECM
  - Exoskeletal carapace in many arthropods
- Plants, fungi and prokaryotes cells secrete a "cell wall"
  - Cellulose cell wall in plant cells
  - Chitin in fungi
  - (Pseudo-) peptidoglycan in prokaryotes
- Bacterial cells secrete "plaques"
  - Extracellular polymeric substance: DNA, protein and polysaccarides (including cellulose)

b. Variations in Animal ECM

- 4 basic components of vertebrate ECM
  - glycosaminoglycans
  - proteoglycans (add Ca^{2+}-apatite for bone)
  - fibrous proteins
  - elastic proteins
- Fibrous Proteins: collagen, fibronectin, laminin
- Elastic Proteins: elastin

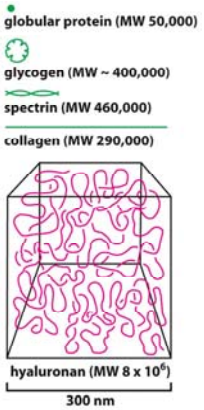


Figure 19-56 *Molecular Biology of the Cell* (© Garland Science 2008)

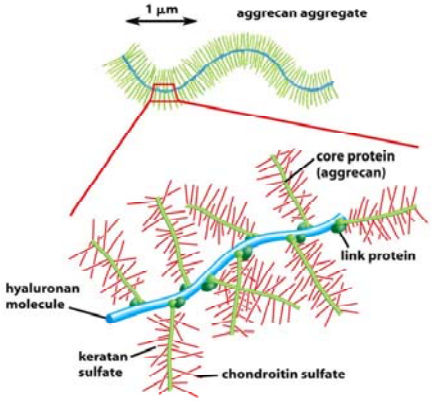


Figure 19-60b *Molecular Biology of the Cell* (© Garland Science 2008)

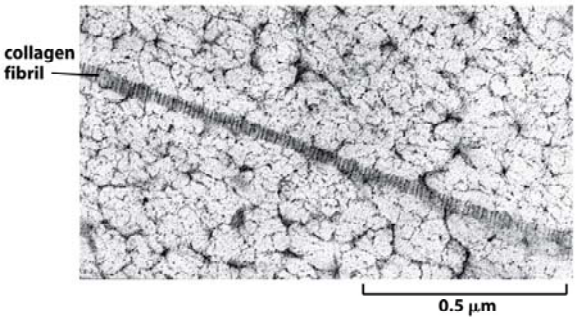
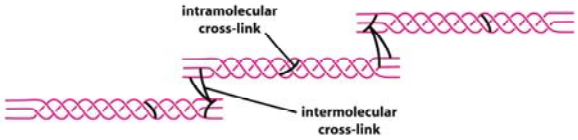


Figure 19-61 *Molecular Biology of the Cell* (© Garland Science 2008)



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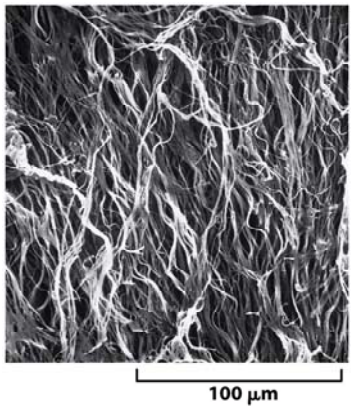

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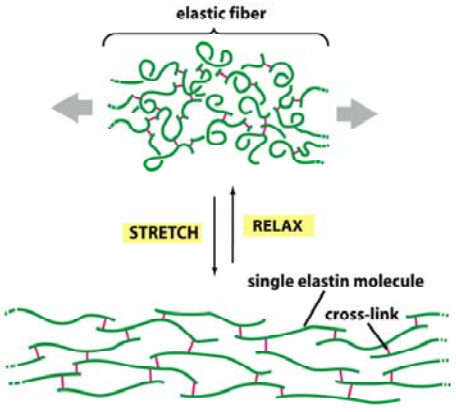


Figure 19-71 *Molecular Biology of the Cell* (© Garland Science 2008)

- Different kinds of ECM vary in the relative concentrations of these basic components
  - Basal lamina in epithelial tissues and specialized basal lamina in blood vessels
  - Elastic tissues that transfer force
  - Fibrous capsules in nearly all organs
  - The non-cellular portion of the blood and extracellular fluid

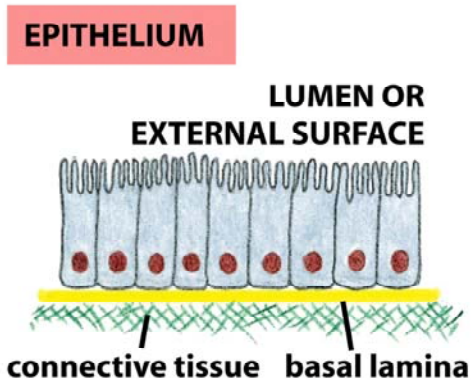


Figure 19-39 (part 2 of 3) *Molecular Biology of the Cell* (© Garland Science 2008)

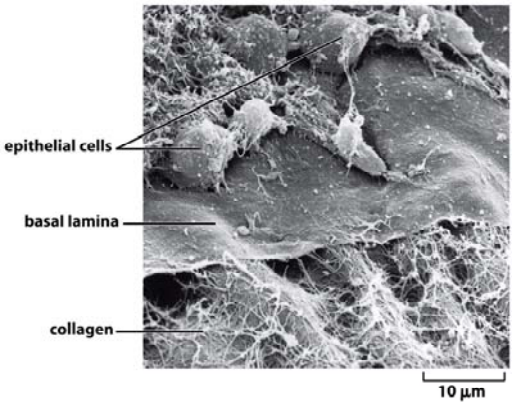


Figure 19-40 *Molecular Biology of the Cell* (© Garland Science 2008)

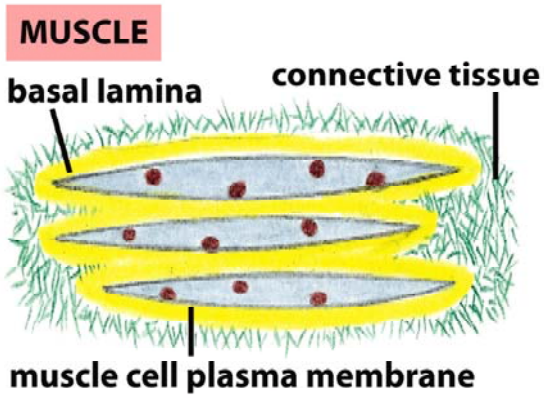


Figure 19-39 (part 1 of 3) *Molecular Biology of the Cell* (© Garland Science 2008)

Degradation and Secretion of ECM are the twin sides of ECM Regulation

- Bound proteases act right at the cell surface, while secreted proteases act near cell surface
  - Matrix metalloproteases and serine proteases
- They must be tightly controlled
  - Secreted as inactive precursors
  - Bound by cell-surface receptors
  - Controlled by secreted inhibitors

ECM in Invertebrates

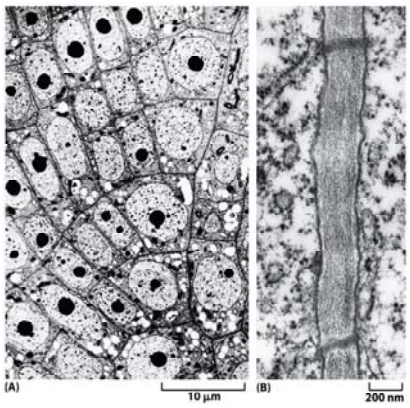
- Chitin ($C_8H_{13}O_5N)_n$, is a long-chain polymer of a *N*-acetylglucosamine, a derivative of glucose.
- It is the main component of the exoskeletons of arthropods such as crustaceans (e.g., crabs, lobsters and shrimps) and insects, the radulas of mollusks, and the beaks of cephalopods, including squid and octopuses.

Chitin ECM can also vary in structure

- In arthropods chitin is often modified, becoming embedded in a hardened proteinaceous matrix.
- In its pure form, it is leathery, but, when encrusted in calcium carbonate, it becomes much harder.
- The difference between the unmodified and modified forms can be seen by comparing the body wall of a caterpillar (unmodified) to a beetle (modified).

The Cellulose Cell Wall

- Cellulose is a polysaccharide consisting of a linear chain of several hundred to over ten thousand β(1→4) linked D-glucose units.
- Cellulose is the structural component of the primary cell wall of green plants, many forms of algae and the oomycetes.
- Cellulose is the most common organic compound on Earth. About 33% of all plant matter is cellulose (the cellulose content of cotton is 90% and that of wood is 40–50%).



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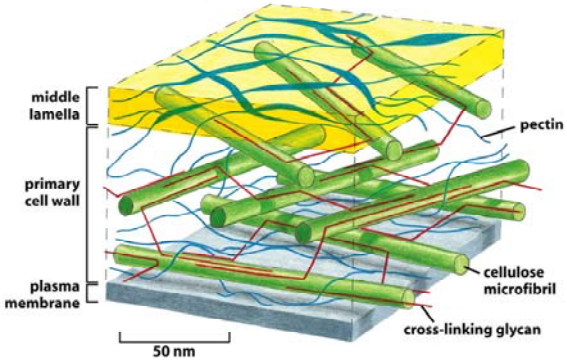


Figure 19-79 *Molecular Biology of the Cell* (© Garland Science 2008)

- Some animals, particularly ruminants and termites, can digest cellulose with the help of symbiotic micro-organisms that live in their guts. Humans can digest cellulose to some extent,[6][7] however it is often referred to as 'dietary fiber' or 'roughage' (e.g. outer shell of maize) and acts as a hydrophilic bulking agent for feces.

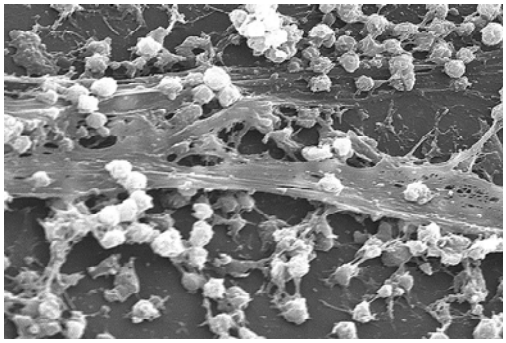
- The cell wall of fungi and the bulk of the fruiting body is chitin

Prokaryotic ECM

- Peptidoglycan, also known as murein, is a polymer consisting of sugars and amino acids that forms a mesh-like layer outside the plasma membrane of bacteria (but not Archaea), forming the cell wall.
- Some Archaea have a similar layer of pseudopeptidoglycan or pseudomurein, where the sugar residues are β-(1,3) linked *N*-acetylglucosamine and *N*-acetyltalosaminuronic acid. That is why the cell wall of Archaea is insensitive to lysozyme.

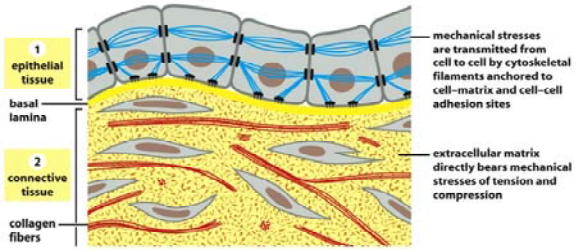
- The peptidoglycan layer is substantially thicker in Gram-positive bacteria (20 to 80 nanometers) than in Gram-negative bacteria (7 to 8 nanometers), with the attachment of the S-layer.
- Peptidoglycan forms around 90% of the dry weight of Gram-positive bacteria but only 10% of Gram-negative strains. Thus, presence of high levels of peptidoglycan is the primary determinant of the characterisation of bacteria as gram-positive.[3]

- A biofilm is an aggregate of microorganisms in which cells adhere to each other on a surface. These adherent cells are frequently embedded within a self-produced matrix of extracellular polymeric substance (EPS).
- Biofilm EPS, which is also referred to as slime (although not everything described as slime is a biofilm), is a polymeric conglomeration generally composed of extracellular DNA, proteins, and polysaccharides. Some species of bacteria secrete cellulose to form biofilms.



3. Regulation of Cell Adhesion

- Most of the cells of multicellular organisms must adhere to survive – VERY few are free
- Cells adhere to other cells, the ECM or, quite commonly, to both
- It is also common for cells that lose their appropriate attachments to undergo anoikis



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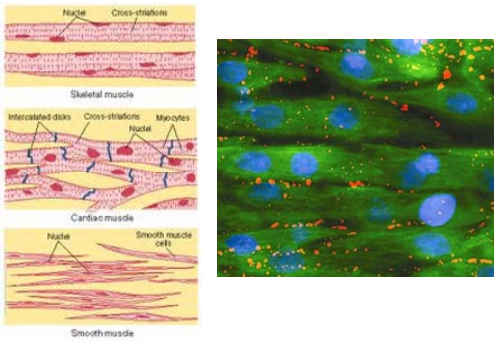


4. The Internal Aqueous Environment

- All multicellular organisms on Earth maintain an aqueous environment
- Most animals have the roughly the same pH and ion concentrations as sea water
- Plants are more dependent on their external environment for these
- Some of us maintain the water temperature, others rely on solar energy

- All plants and animals have water in their cells and in the extracellular matrix
- Some also have water in a vascular system that can exchange that water with tissues
- Animals with a GI or respiratory systems also exchange water with those systems
- Vertebrate animals also have a specialized cerebrospinal and lymphatic fluid systems

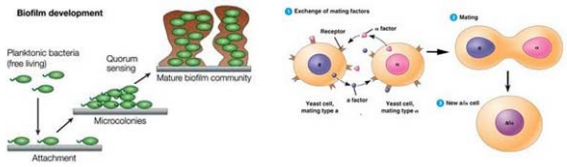
5. Regulation by Intercellular Communication

Single celled organisms use intercellular signals to coordinate such things as gene expression, mating, sporulation and cell death in response to population density, nutrients, stress and other cues.

Multicellular organisms use intercellular communications to coordinate the activities of their component cells.

- The overall purpose is to coordinate the activities of multiple cells in response to the needs of the organism and changes in its environment.

- We have evolved very complex cell communications systems to regulate our 100 trillion cells
- These pathways are similar to and likely arose from those that single celled organisms use to molecularly sense their environments.
- Much of our genetic energy is spent on cell signaling and control.



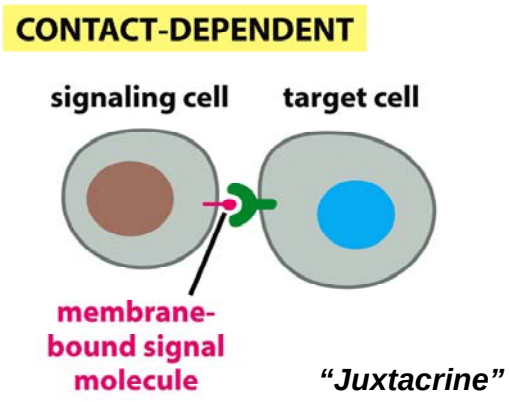
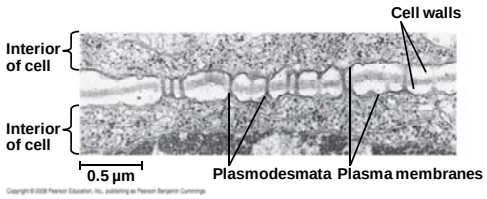


Figure 15-4a *Molecular Biology of the Cell* (© Garland Science 2008)

Fig. 6-31

Plasmodesmata in Plant Cells



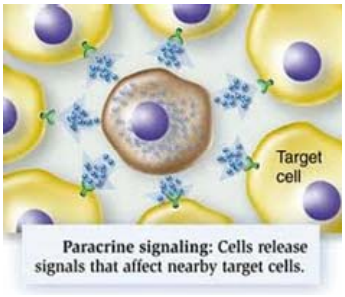
Gap Junctions in Animal Cells

Soluble Molecule Signaling

1. Paracrine signaling
2. Endocrine signaling
3. Synaptic signaling

2. Paracrine Signaling

- Local secretion into extracellular fluid affects nearby cells within a tissue or organ
- Very selective and VERY powerful
- Allows local coordination of cells that share the same or closely related jobs
- Autocrine signals are paracrine signals where the same type of cell both secretes and responds to the signal



Paracrine signaling: Cells release signals that affect nearby target cells.

1. Endocrine Signaling

- Cells must be within diffusing range of our capillaries so that they have access to oxygen and nutrients.
- Hormones come from the Endocrine System/Glands: ductless glands that secrete into the blood
- Every cell in the body is exposed to all of the hormones that are running through our blood stream.
- Cell must express receptors specific for those hormones if they are to respond to them.

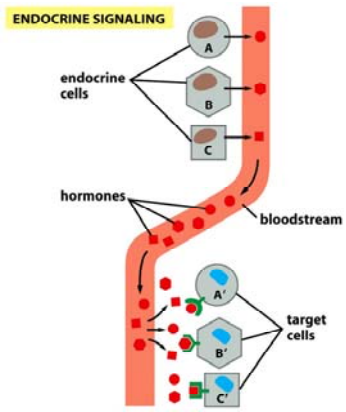


Figure 15-5a *Molecular Biology of the Cell* (© Garland Science 2008)

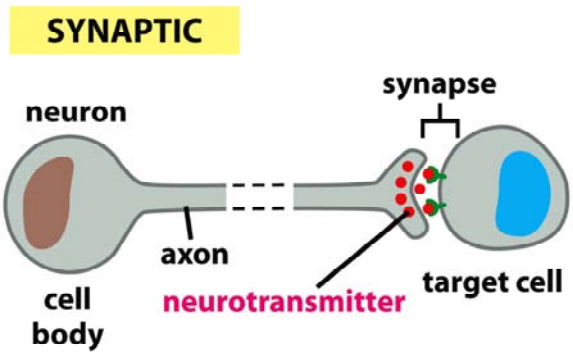


Figure 15-4c *Molecular Biology of the Cell* (© Garland Science 2008)

d. The Structure of Signaling Systems in Multicellular Organisms

- All systems have 4 primary components
  - Ligand
  - Receptor
  - 2nd Messengers
  - Target Mechanisms

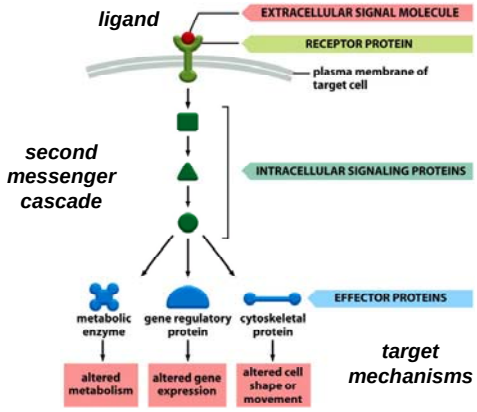


Figure 15-1 *Molecular Biology of the Cell* (© Garland Science 2008)

Target Mechanisms

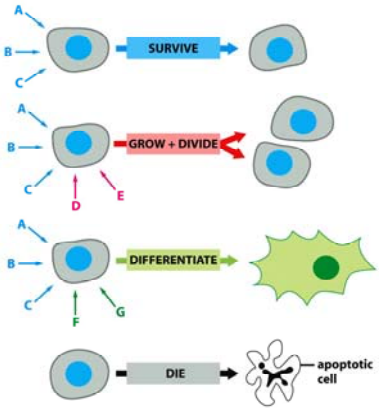


Figure 15-8 *Molecular Biology of the Cell* (© Garland Science 2008)

6. Regulation by Cell Specialization

Cells of an organism share the exact same DNA but they can be very different

a. There are over 200 cell types in adult humans

b. Cell types are determined by differential gene expression

Anatomical Organization in Multicellular Organisms is Based on Cell Functions

Tissues are made up of multiple cell types

Organs are made up of multiple tissue types

Systems are made up of multiple organs

Anatomical Organization in Multicellular Organisms is Based on Cell Functions

- Characteristic Types of Cells
  - epithelial vs. mesenchymal
  - parenchymal vs. support
  - stem cells vs. adult cells

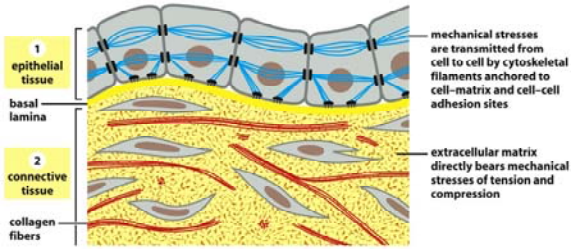


Figure 19-1 *Molecular Biology of the Cell* (© Garland Science 2008)

A variety of mechanisms can change a cell's gene expression and, thus, its phenotype

a. Changes can occur due to developmental stage

a. Changes can occur due to age

b. Changes can occur due to injury

b. Changes can occur due to infection

b. Changes can occur due to disease state