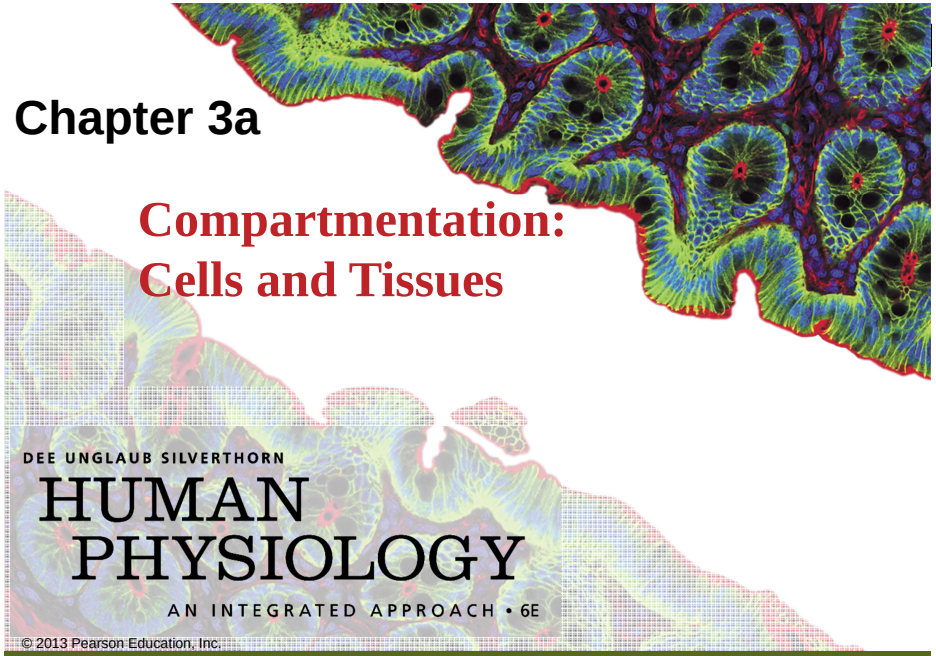


About This Chapter

- Compartments
- Biological membranes
- Intracellular compartments
- Tissues of the body
- Tissue remodeling
- Organs

Figure 3.1a ESSENTIALS – Levels of Organization: Body Compartments

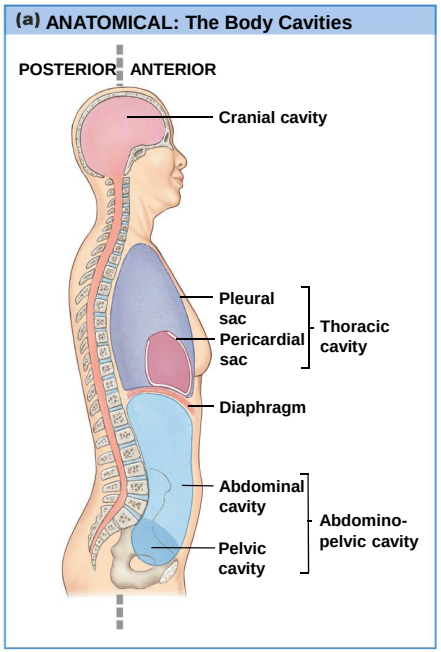
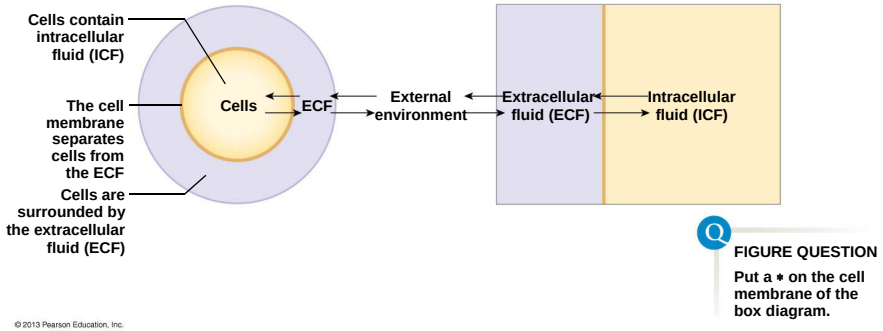


Figure 1.4 The body's internal and external environments



Cells: The first living compartments

- Compartments and life
  - While no one may ever know exactly how life began, it seems likely that compartmentalization was a key component
  - Advantages:
    - Internal environment can differ from external environment
    - Initially maybe hoarding of nutrients
    - As cells evolved, internal compartments allowed for further separation of biochemical processes
      - Increased concentration of materials involved in related functions such as enzymes involved in a metabolic pathway
  - Disadvantages:
    - Barriers to materials – surface of barrier influences rate of transfer between compartments
    - Often requires active processes to shuttle materials from one compartment to another

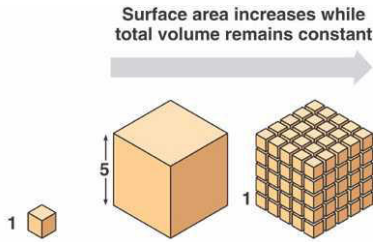
Compartments: Surface Area to Volume Ratio

- Barrier is both good and bad
  - To move between compartments, materials have to cross the barrier.
- Surface area to volume ratio
  - As a sphere increases in volume, it's surface area also increases but at a slower rate:
    - Surface Area = $4 \cdot \pi \cdot r^2$
    - Volume = $4/3 \cdot \pi \cdot r^3$
    - SA/Vol = $3 \cdot r^2 / r^3$
      - Key point is the relationship between numerator (squared) and denominator (cubed)
  - Spheres have the lowest surface area to volume ratio of any shape (water droplet in air, fat droplets in water)
- For a given volume:
  - Perfect spheres have the least surface area, perfect cubes have more, but long, thin and/or folded structures have even more

Compartments: Surface Area to Volume Ratio

Sphere
- Surface Area (m^2) = $4 \cdot \pi \cdot r^2$
- Volume (m^3, l) = $4/3 \cdot \pi \cdot r^3$

Cube
- Surface Area (m^2) = $6 \cdot L^2$
- Volume (m^3, l) = L^3



Total surface area (height × width × number of sides × number of boxes)	6	150	750
Total volume (height × width × length × number of boxes)	1	125	125
Surface-to-volume ratio (surface area / volume)	6	1.2	6

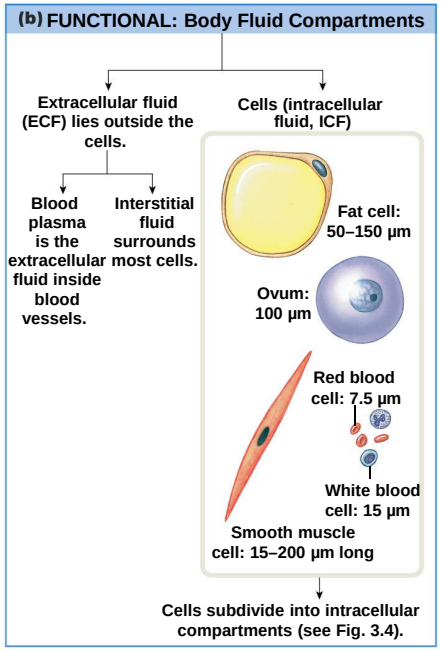
Lumens of Hollow Organs

- Hollow organs
  - Heart
  - Lungs
  - Blood vessels
  - Intestines
- Lumen
  - For some organs, not the internal environment
    - GI tract, *Escherichia coli*

Functional Compartments

- Extracellular fluid
  - Plasma
  - Interstitial fluid
- Intracellular fluid

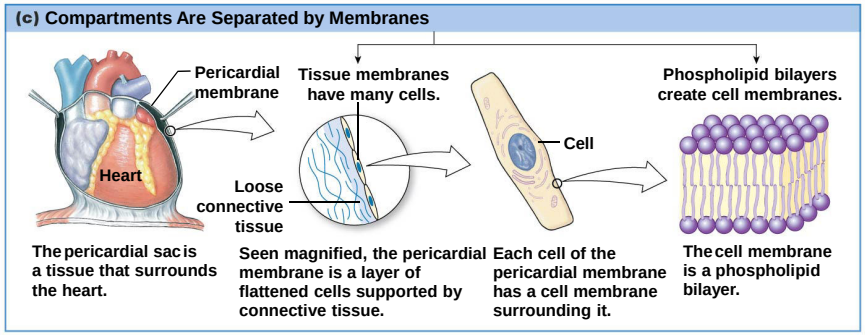
Figure 3.1b ESSENTIALS – Levels of Organization: Body Compartments



Membranes

- Two meanings in biology:
  - Tissue membranes
  - Cell membranes
- Tissue membranes
  - Historically first, predated microscopes, visible with naked eye
  - Tissue that lined a cavity or separated two compartments
- Cell membranes
  - Thin layer of lipids separating intracellular fluid and external environment

Figure 3.1c ESSENTIALS – Levels of Organization: Body Compartments



Cell Membrane: Function

13

- Physical isolation
- Regulation of exchange with the environment
- Communication between the cell and its environment
- Structural support

Table 3.1 Composition of Selected Membranes

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Composition of Selected Membranes — Table 3.1

Membrane	Protein	Lipid	Carbohydrate
Red blood cell membrane	49%	43%	8%
Myelin membrane around nerve cells	18%	79%	3%
Inner mitochondrial membrane	76%	24%	0%

Cell Membrane: Composition

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- Lipids
  - Phospholipids
  - Sphingolipids
  - Cholesterol
- Proteins
  - Integral
    - Transmembrane
    - Lipid-anchored
  - Peripheral
- Carbohydrates
  - Glycoproteins
  - Glycolipids

Figure 3.2a ESSENTIALS – The Cell Membrane

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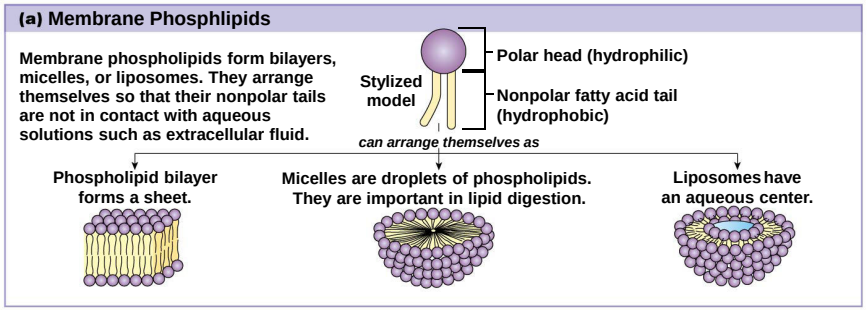


Figure 3.2b ESSENTIALS – The Cell Membrane

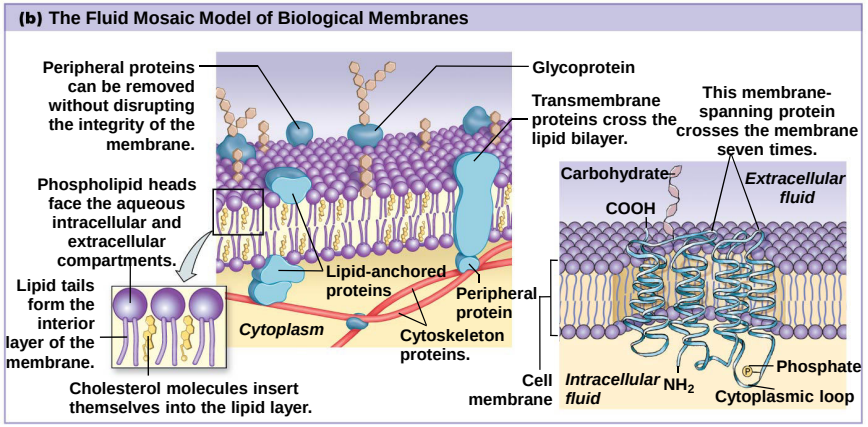
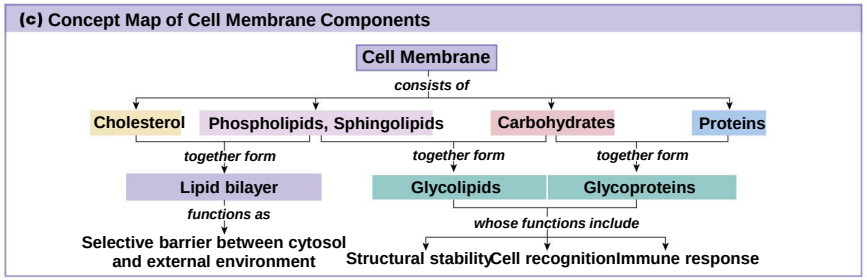


Figure 3.2c ESSENTIALS – The Cell Membrane



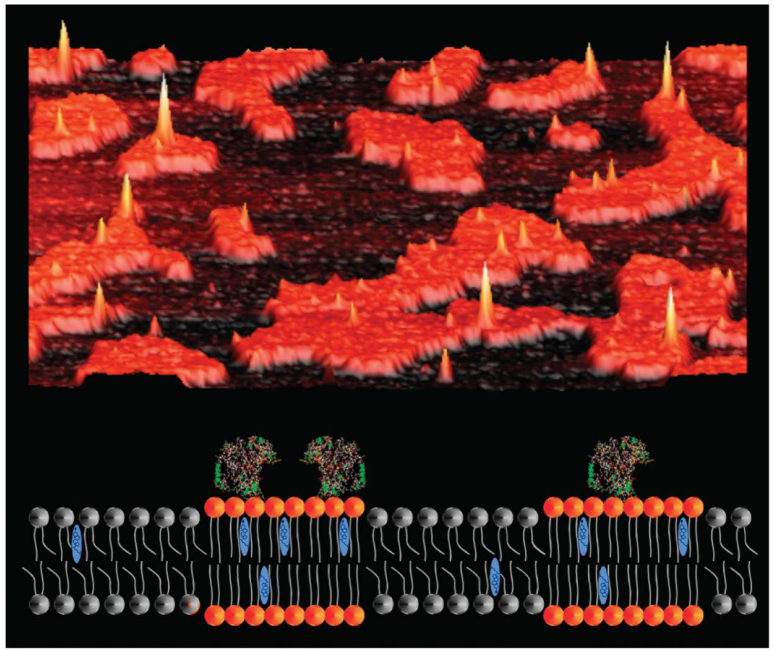
Membrane Associated Proteins

- Integral
  - Transmembrane
    - Proteins with 7 transmembrane segments are common
  - Lipid anchored
- Peripheral
  - Covalently attached but can be separated chemically

Co-localization

- Sometimes cells group materials together forming a “virtual compartment”
  - Due to rates of diffusion, the concentration of materials can be greater in a localized area even if not separated by a physical barrier.
  - E.g. Lipid rafts
    - Will concentrate particular proteins together involved in similar function such as enzymes involved in the same metabolic or signaling pathway.

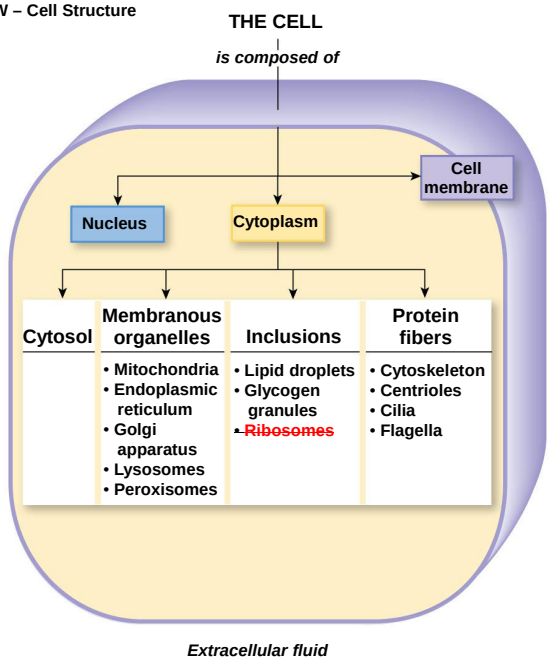
Figure 3.3 Lipid rafts are made of sphingolipids



Intracellular Compartments

- Cytoplasm
  - Cytosol
  - Inclusions: No membranes, aggregates of materials
    - Text includes ribosomes and proteins, but that may not be universal definition. Text also refers to various “insoluble proteins” which many others would consider soluble
    - Usually inclusions are defined as not metabolically active: Fat, Glycogen, Pigments, etc.
  - Cytoskeleton
  - Organelles
- Organelles: Nucleus, Mitochondria, Golgi Aparatus, Endoplasmic Reticulum, Cytoplasmic vessicles

Figure 3.4-1a REVIEW – Cell Structure



Cytoplasmic Protein Fibers

- Actin (microfilaments)
- Intermediate filaments
  - Keratin
  - Neurofilaments
- Microtubules
  - Centrioles, cilia, flagella

Table 3.2 Diameter of Protein Fibers in the Cytoplasm

Table 3.2

Diameter of Protein Fibers in the Cytoplasm

	Diameter	Type of Protein	Functions
Microfilaments	7 nm	Actin (globular)	Cytoskeleton; associates with myosin for muscle contraction
Intermediate filaments	10 nm	Keratin, neurofilament protein (filaments)	Cytoskeleton, hair and nails, protective barrier of skin
Microtubules	25 nm	Tubulin (globular)	Movement of cilia, flagella, and chromosomes; intracellular transport of organelles; cytoskeleton

Microtubule Function

- Centrosome
  - AKA microtubule organizing center
  - Assembles tubulin monomers into microtubules
  - Contains 2 Centrioles
    - Direct DNA movement in cell division, mitotic spindle (but experiments show it they are not required)
- Cilia
  - Fluid movement across cells
- Flagella
  - Cell (sperm) movement through fluid

Figure 3.4-1e REVIEW – Cell Structure

(e) Centrioles

Centrioles are made from microtubles and direct DNA movement during cell division.

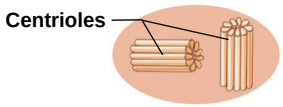
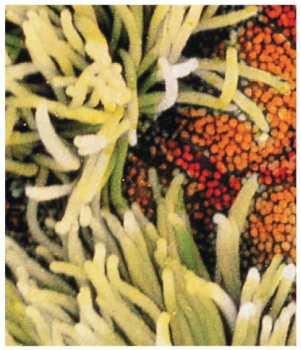
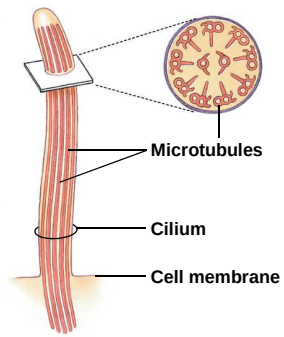


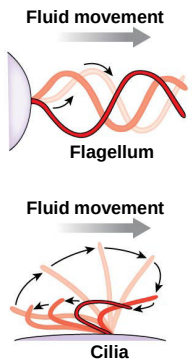
Figure 3.5 Centrioles, cilia, and flagella



(a) Cilia



(b) Cilia and flagella have 9 pairs of microtubules surrounding a central pair.



(c) The beating of cilia and flagella creates fluid movement.

Cytoskeleton: Function

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- Dynamic (i.e. changing) Scaffold
- Cell shape
- Internal organization (organelles, protein co-locolization, etc)
- Intracellular transport
- Assembly of cells into tissues
- Movement

Figure 3.4-1b REVIEW – Cell Structure

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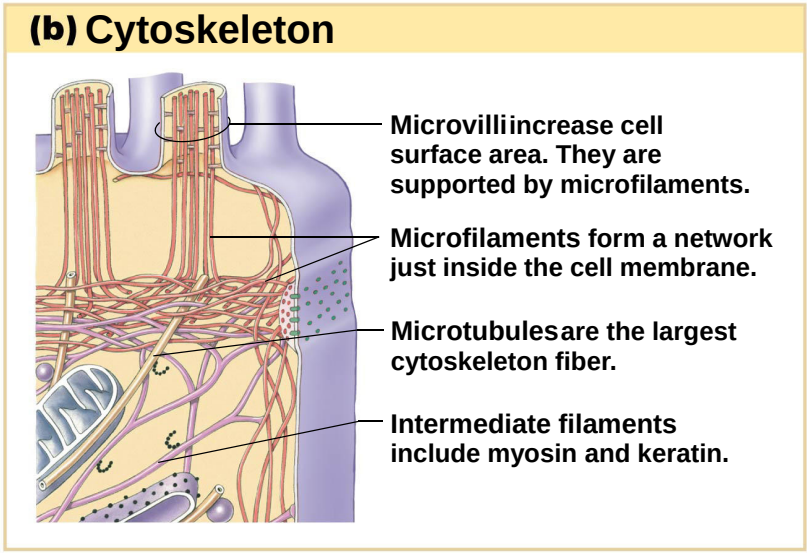


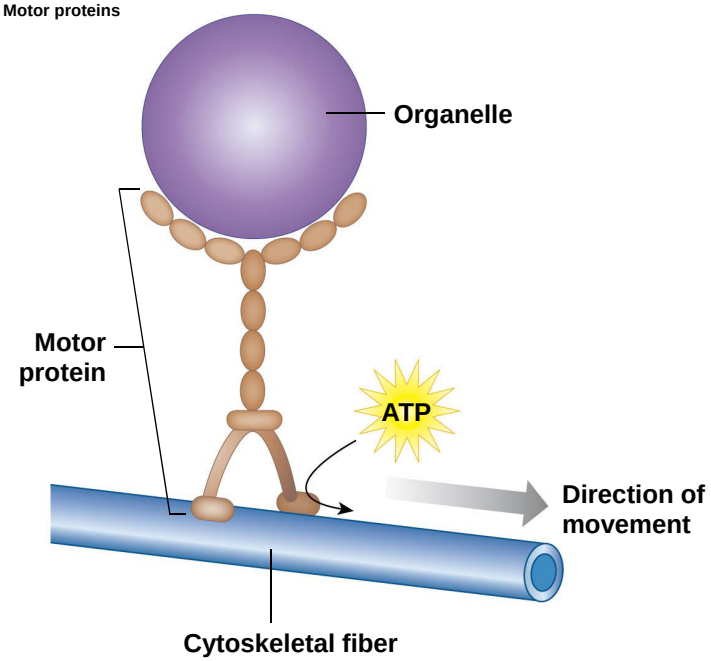
Motor Proteins: Function

31

- Myosins
  - Muscle contraction
- Kinesins and dyneins
  - Movement of vesicles along microtubules
- Dyneins
  - Movement of cilia and flagella

Figure 3.6 Motor proteins

32



Mitochondria

33

- Two membranes create two compartments
  - Mitochondrial matrix
    - Unique DNA (evidence of endosymbiotic theory)
  - Intermembrane space
    - Cellular ATP production

Figure 3.4-2g REVIEW – Cell Structure

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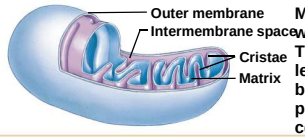
(g) Mitochondria



Mitchondria are spherical to elliptical organelles with a double wall that creates two separate compartments within the organelle. The inner matrix is surrounded by a membrane that folds into leaflets called cristae. The intermembrane space, which lies between the two membranes, plays an important role in ATP production. Mitochondria are the site of most ATP synthesis in the cell.

Endoplasmic Reticulum (ER)

35

- Rough ER
  - Ribosomes attached
  - Protein assembly and modification
- Smooth ER
  - Synthesis of fatty acids, steroids, lipids
  - Modified forms in liver, kidney, muscles
  - Calcium ion storage (neurons, muscle)

Figure 3.4-2i REVIEW – Cell Structure

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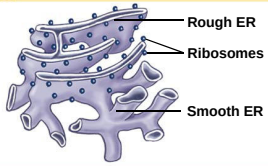
(i) Endoplasmic reticulum (ER)



The endoplasmic reticulum (ER) is a network of interconnected membrane tubes that are a continuation of the outer nuclear membrane. Rough endoplasmic reticulum has a granular appearance due to rows of ribosomes dotting its cytoplasmic surface. Smooth endoplasmic reticulum lacks ribosomes and appears as smooth membrane tubes. The rough ER is the main site of protein synthesis. The smooth ER synthesizes lipids and, in some cells, concentrates and stores calcium ions.

Golgi Apparatus (Golgi Complex)

37

- Stacked membranes surrounded by vesicles
- Modifies protein from rough ER
- Packages proteins into vesicles

Figure 3.4-2h REVIEW – Cell Structure

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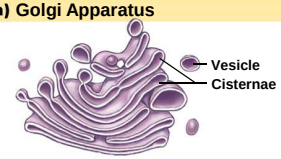
(h) Golgi Apparatus



The Golgi apparatus consists of a series of hollow cured sacs called cisternae stacked on top of one another and surrounded by vesicles. The Golgi apparatus participates in protein modification and packaging.

Cytoplasmic Vesicles

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- Secretory vesicles
  - Released from cell
- Storage vesicles
- Lysosomes
  - Enzymes to degrade bacteria or old organelles
  - Acidic interior
- Peroxisomes
  - Enzymes to degrade long-chain fatty acids and toxic foreign molecules
  - Generate hydrogen peroxide

Figure 3.4-1d REVIEW – Cell Structure

40

(d) Lysosomes

Lysosomes are small, spherical storage vesicles that contain powerful digestive enzymes.

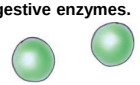
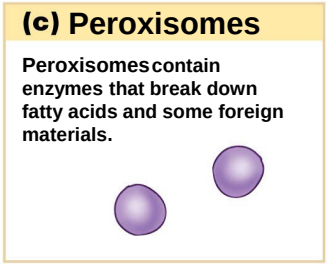


Figure 3.4-1c REVIEW – Cell Structure



Nucleus

- Nuclear envelope: two membranes
- Nuclear pore complex
- Chromatin: DNA and associated proteins
- Nucleoli
  - Control RNA synthesis for ribosomes

Figure 3.4-2j REVIEW – Cell Structure

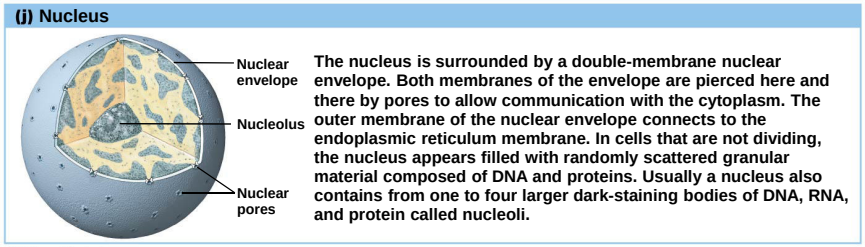
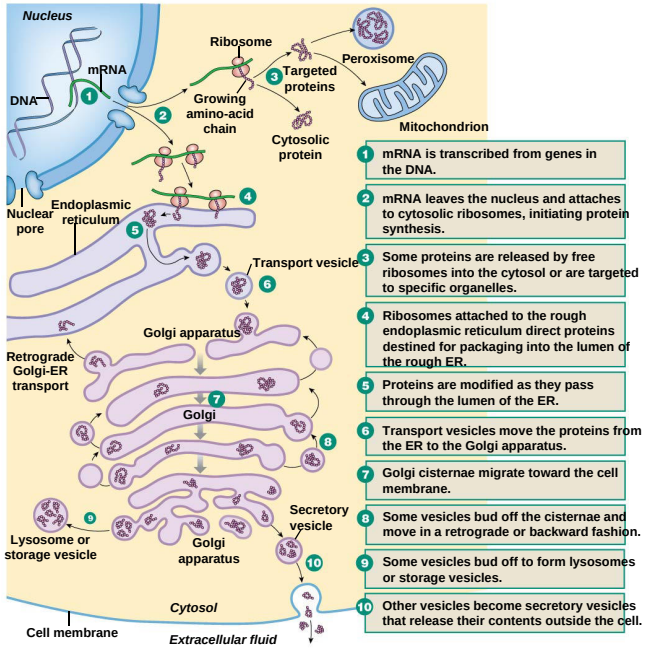


Figure 3.7 Protein synthesis



Tissues of the Body

45

- Primary Tissue Types
  - Epithelial
  - Connective
  - Muscle
  - Neural/nerve
- Held together by specialized connections called **cell junctions** and other support structures

Extracellular Matrix

46

- Synthesized and secreted by cells
- Proteoglycans
  - Glycoproteins
- Protein fibers
  - Examples: collagen, fibronectin, laminin
  - Strength
  - Anchor cells to matrix for communication
- Varies in composition, density and total volume in different tissue types

Cell Junctions and CAMs

47

- Cell to cell
  - Gap junction (communicating junction)
  - Tight junction (occluding junction)
  - Anchoring junction
    - Cell–cell with cadherins
      - Adherens junctions
      - Desmosomes
    - Cell–matrix with integrins
      - Hemidesmosomes
      - Focal adhesions

Table 3.3 Major Cell Adhesion Molecules (CAMs)

48

Table 3.3 Major Cell Adhesion Molecules (CAMs)

Name	Examples
Cadherins	Cell-cell junctions such as adherens junctions and desmosomes. Calcium-dependent.
Integrins	Primarily found in cell-matrix junctions. These also function in cell signaling.
Immunoglobulin superfamily CAMs	NCAMs (nerve-cell adhesion molecules). Responsible for nerve cell growth during nervous system development.
Selectins	Temporary cell-cell adhesions.

Figure 3.8a ESSENTIALS – Cell Junctions

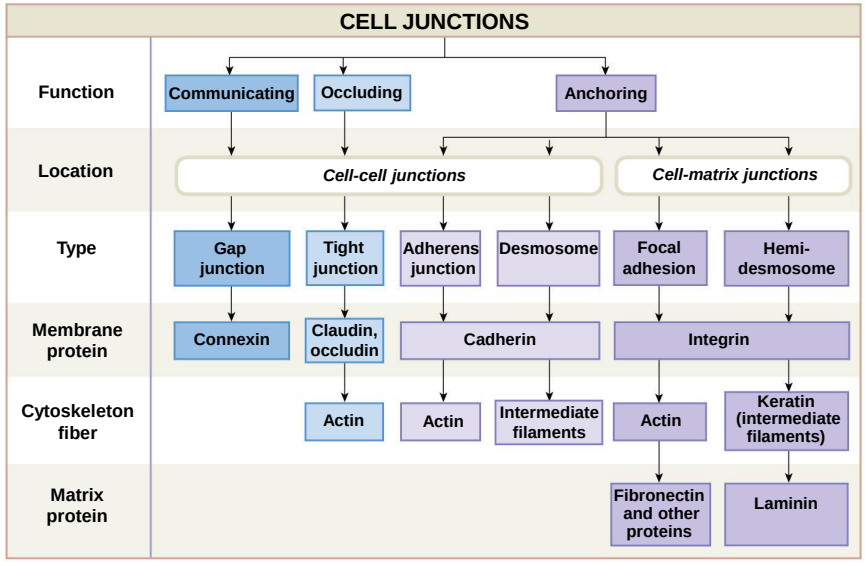


Figure 3.8b ESSENTIALS – Cell Junctions

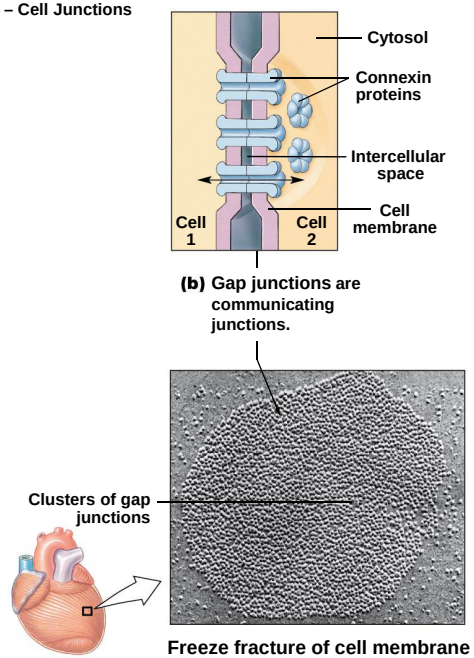


Figure 3.8c ESSENTIALS – Cell Junctions

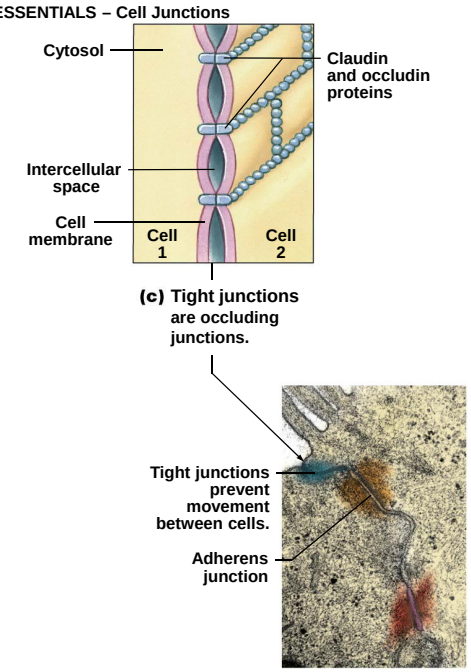
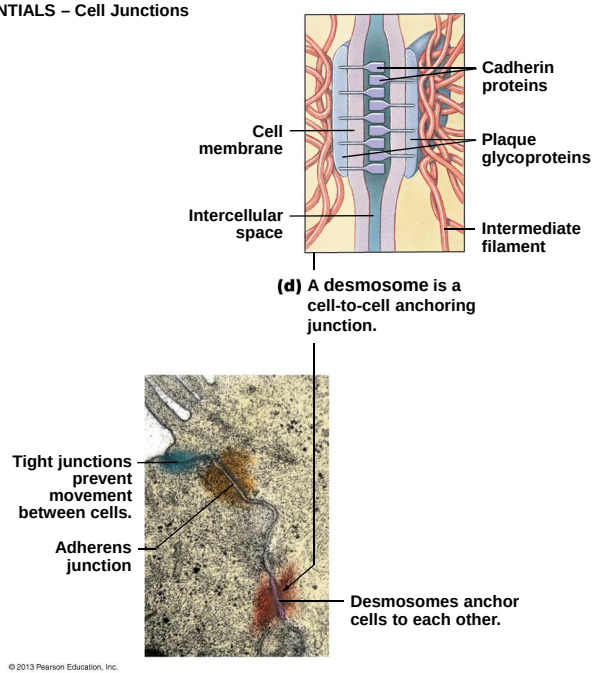


Figure 3.8d ESSENTIALS – Cell Junctions



Epithelial Tissue: Structure

53

- One or more layers of epithelial cells
- Separated from underlying tissue by basal lamina or basement membrane
  - composed of a network of collagen and laminin filaments embedded in proteoglycans.
- Two types
  - Sheets of cells lining internal and external body surfaces
  - Secretory epithelia

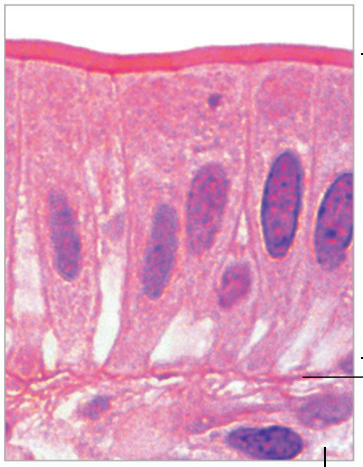
Transport of materials across epithelium

54

- Epithelium can be leaky (most capillaries) or tight (kidney)
- Types of transport
  - Paracellular transport
    - Passage of substances through a tissue in the spaces between cells (little or few tight junctions)
  - Transcellular transport
    - Passage through the cell (only way in very tight epithelium)

Figure 3.9c ESSENTIALS – Epithelial Tissue

55



(c) Most epithelia attach to an underlying matrix layer called the basal lamina or basement membrane.

Epithelial Tissue: Classified

56

- Layering
  - Simple (one cell thick) or stratified (multiple cell layers)
- Shapes
  - Squamous, cuboidal, columnar
- Function
  - Exchange, transporting, ciliated, protective, secretory

Figure 3.10 ESSENTIALS – Types of Epithelia

57

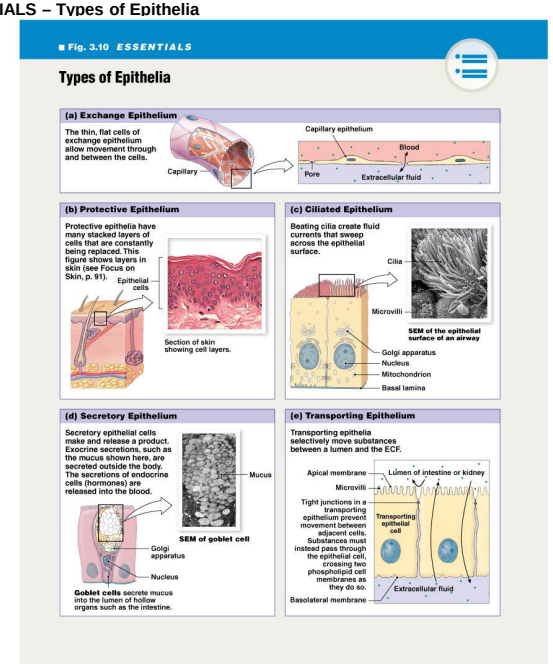
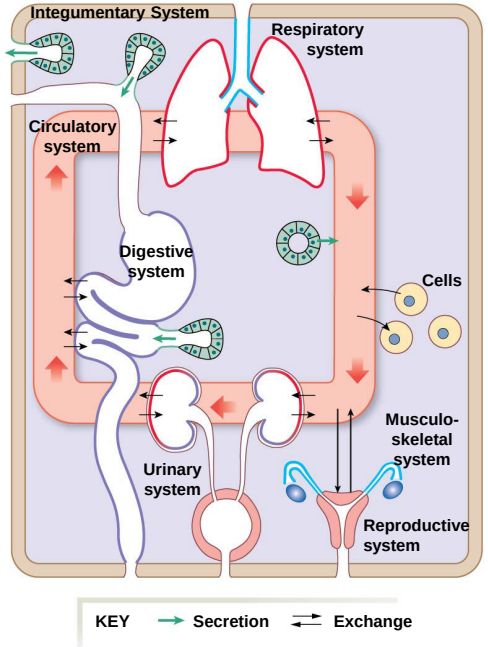


Figure 3.9b ESSENTIALS – Epithelial Tissue

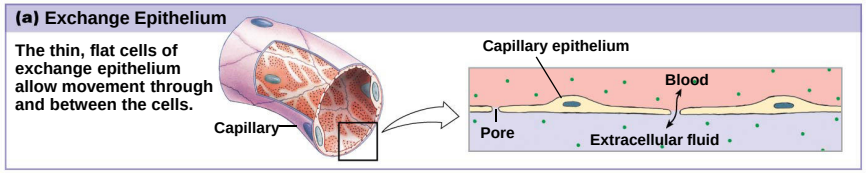
58



(b) This diagram shows the distribution of the five kinds of epithelia in the body outlined in the table above.

Figure 3.10a ESSENTIALS – Types of Epithelia

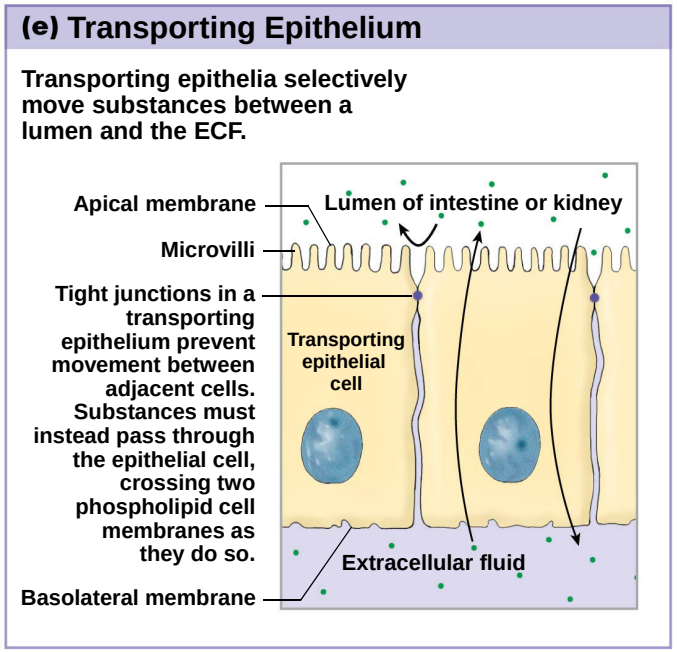
59



- Leaky in capillaries – Allows small molecules and ions to pass between cells but blocks large proteins and cells

Figure 3.10e ESSENTIALS – Types of Epithelia

60



Transporting Epithelium: Characteristics

61

- Cell shape
  - Simple but thicker than exchange epithelia
  - Cuboidal or columnar
- Membrane modification
  - Apical membrane: faces lumen
    - Microvilli increase surface area at least 20 times!
  - Basolateral membrane: faces ECM
- Cell junctions
  - Extensive tight junctions
- Cell organelles
  - Many mitochondria for energy intensive process

Figure 3.10c ESSENTIALS – Types of Epithelia

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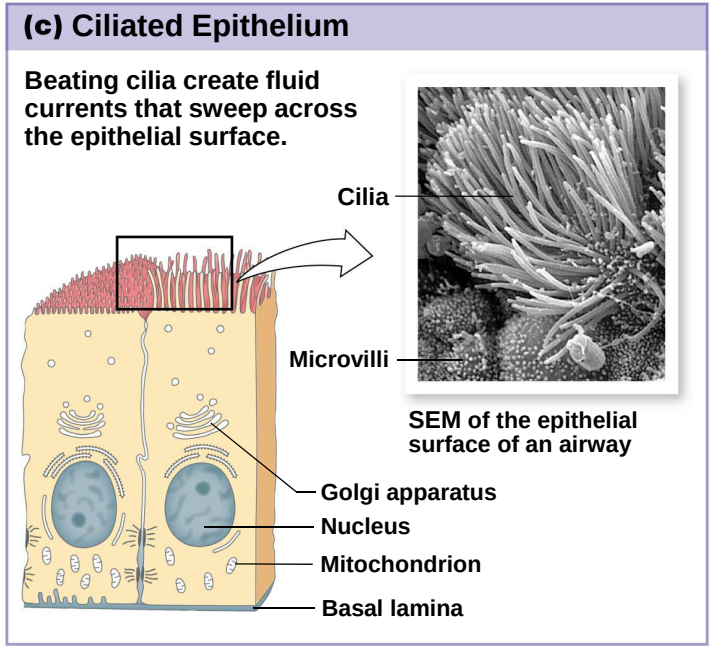


Figure 3.10b ESSENTIALS – Types of Epithelia

63

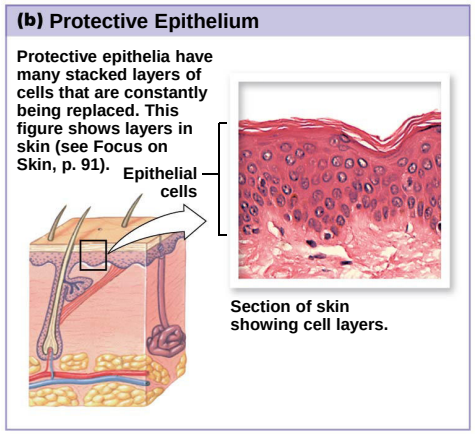
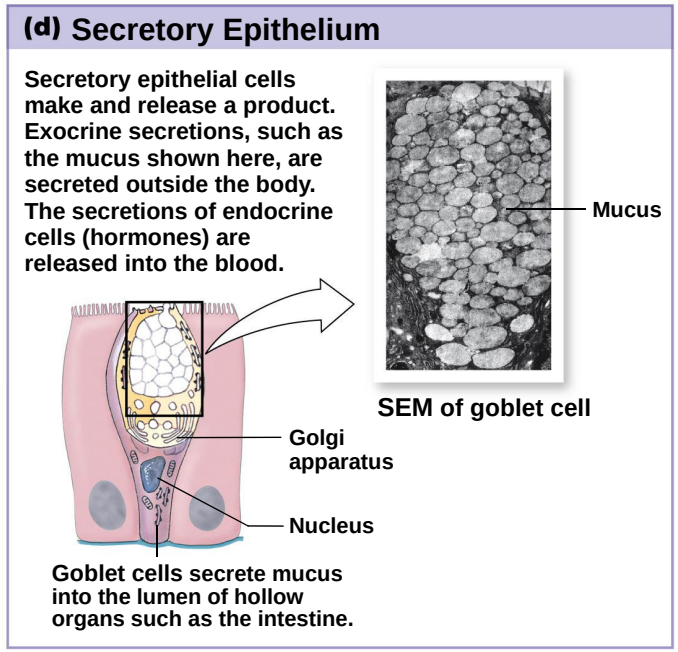


Figure 3.10d ESSENTIALS – Types of Epithelia

64



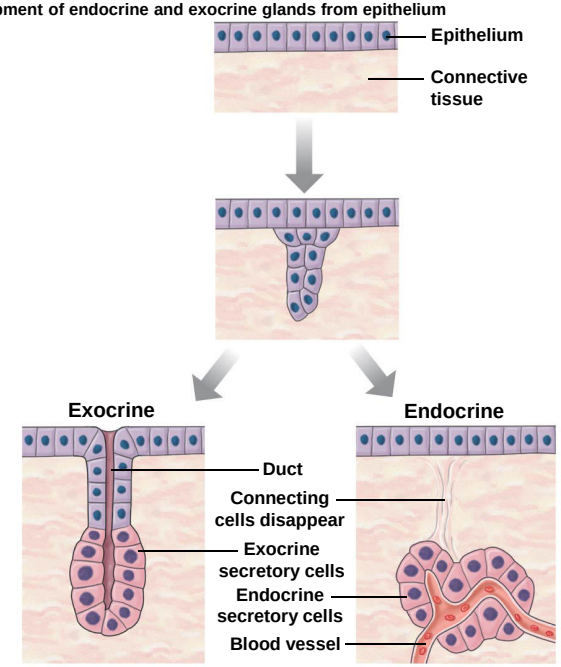
Secretory Epithelium

65

- Scattered
- Grouped into glands
  - Exocrine: release products to external environment (most through ducts)
    - Serous secretions
      - Often watery and can contain enzymes
    - Mucous secretions/mucus: produced by goblet cells
      - Often sticky and contains glycoproteins and proteoglycans
  - Endocrine: release hormones into extracellular compartments or directly into blood
    - No ducts

Figure 3.11 Development of endocrine and exocrine glands from epithelium

66



Connective Tissues: Structure

67

- Ground substance (matrix)
  - Non-fibrous components of ECM containing water, proteoglycans
  - Highly variable (blood to bone)
- Cells are embeded in the extracellular matrix
  - Fixed
    - Blasts (secrete matrix), clasts (breakdown matrix), and cytes (neither secrete nor breakdown matrix)
  - Mobile
- Matrix fibers
  - Collagen, elastin, fibrillin, fibronectin

Figure 3.12a-1 ESSENTIALS – Connective Tissue

68

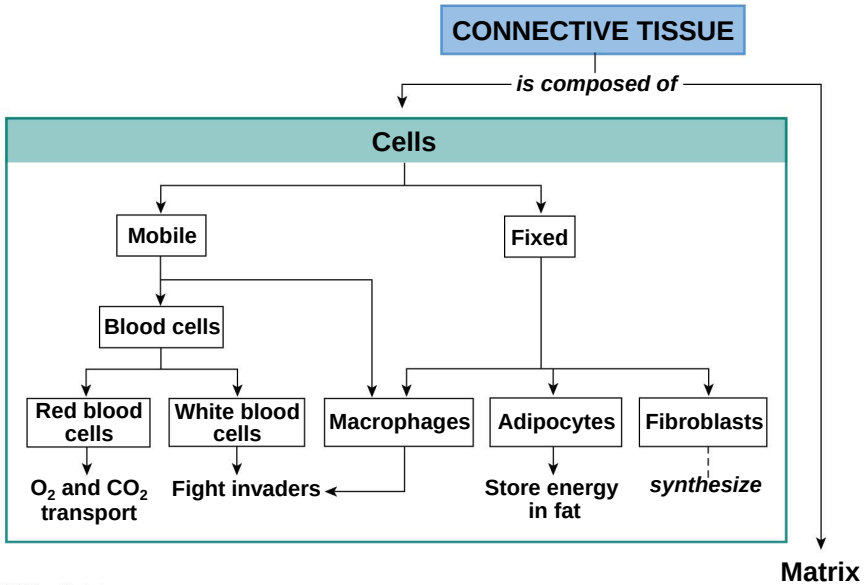


Figure 3.12a-2 ESSENTIALS – Connective Tissue

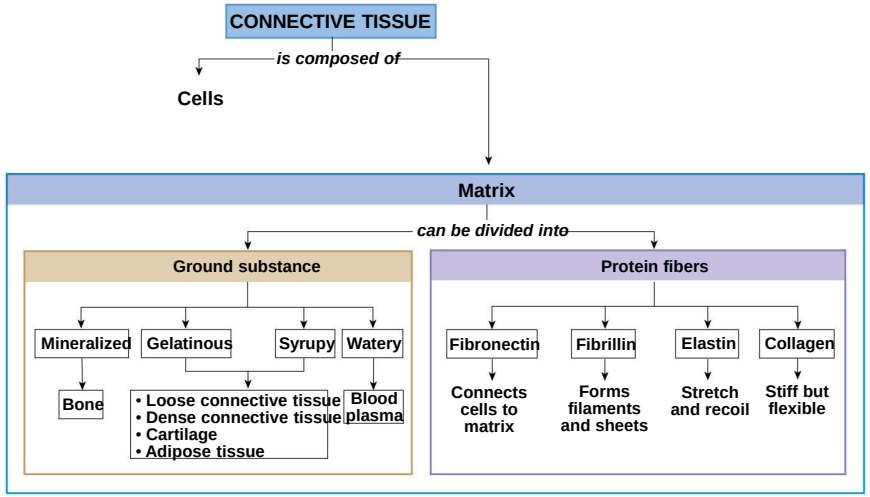


Figure 3.12b ESSENTIALS – Connective Tissue

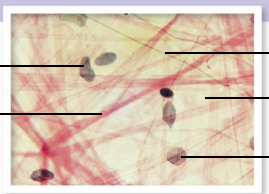
(b) Types of Connective Tissue

Tissue Name	Ground Substance	Fiber Type and Arrangement	Main Cell Types	Where Found
Loose connective tissue	Gel; more ground substance than fibers or cells	Collagen, elastic, reticular; random	Fibroblasts	Skin, around blood vessels and organs, under epithelia
Dense, irregular connective tissue	More fibers than ground substance	Mostly collagen; random	Fibroblasts	Muscle and nerve sheaths
Dense, regular connective tissue	More fibers than ground substance	Collagen; parallel	Fibroblasts	Tendons and ligaments
Adipose tissue	Very little ground substance	None	Brown fat and white fat	Depends on age and sex
Blood	Aqueous	None	Blood cells	In blood and lymph vessels
Cartilage	Firm but flexible; hyaluronic acid	Collagen	Chondroblasts	Joint surfaces, spine, ear, nose, larynx
Bone	Rigid due to calcium salts	Collagen	Osteoblasts and osteocytes	Bones

Figure 3.13a ESSENTIALS – Types of Connective Tissue

(a) Loose Connective Tissue

Loose connective tissue is very flexible, with multiple cell types and fibers.

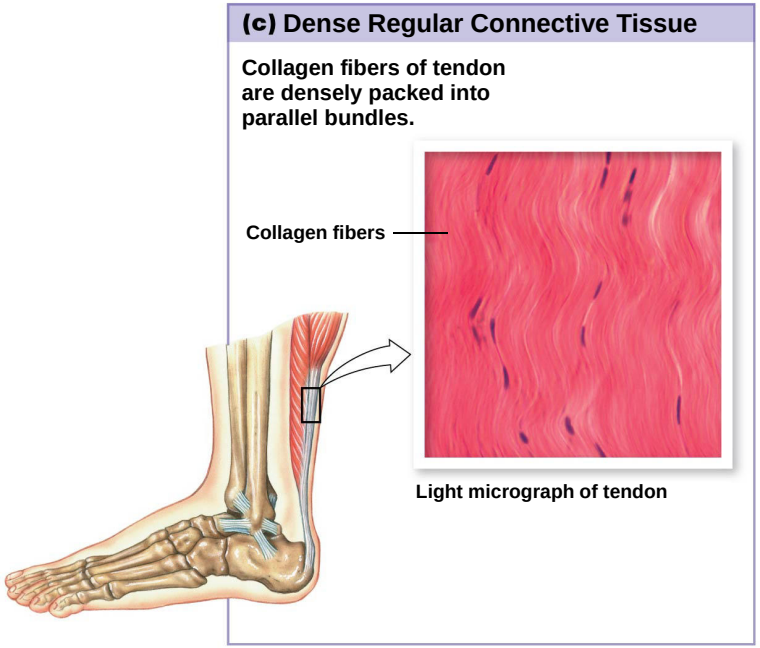


Light micrograph of loose connective tissue

Dense Connective Tissues

- Tendons
  - Skeletal muscles to bone
  - Do not stretch
- Ligaments
  - Bones to bones
  - Can stretch some

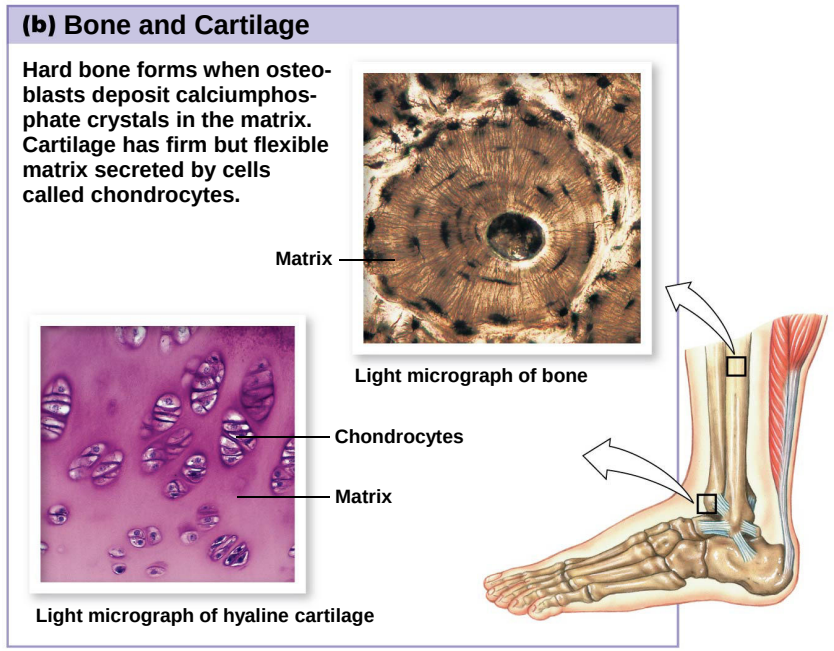
Figure 3.13c ESSENTIALS – Types of Connective Tissue



Supporting Connective Tissues

- Cartilage
  - Solid and flexible
  - Lacks blood supply
  - Nose, ears, knee, windpipe/trachea
- Bone
  - Calcified (Calcium Phosphate)
  - Strong and rigid

Figure 3.13b ESSENTIALS – Types of Connective Tissue



Additional Connective Tissues

- Adipose connective tissue
  - White
    - Single lipid droplet
  - Brown
    - Multiple lipid droplets
    - Thermogenesis
- Blood
  - Ground substance is plasma
  - Free blood cells

Figure 3.13e ESSENTIALS – Types of Connective Tissue

(e) Adipose Tissue

In white fat, the cell cytoplasm is almost entirely filled with lipid droplets.

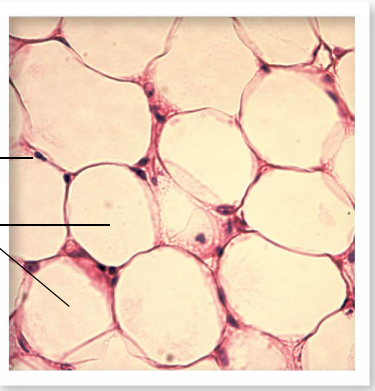
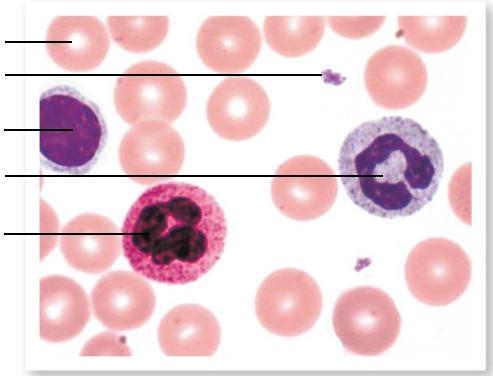


Figure 3.13d ESSENTIALS – Types of Connective Tissue

(d) Blood

Blood consists of liquid matrix (*plasma*) plus red and white blood cells and the cell fragments called platelets.



Muscle Tissues

- Excitable
- Contractile
  - Force and movement
- Three types
  - Cardiac
  - Smooth
  - Skeletal

Figure 12.1a The Three Types of Muscle

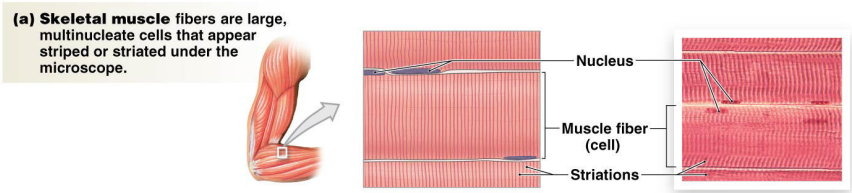


Figure 12.1b The Three Types of Muscle

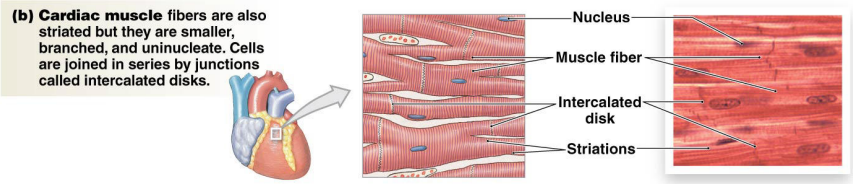
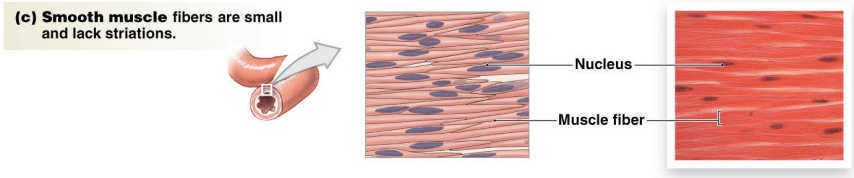


Figure 12.1c The Three Types of Muscle



Nervous Tissues

- Neurons (nerve cells) send signals
  - Excitable
- Glial cells (neuroglia) support

Figure 8.2f Nervous Tissue

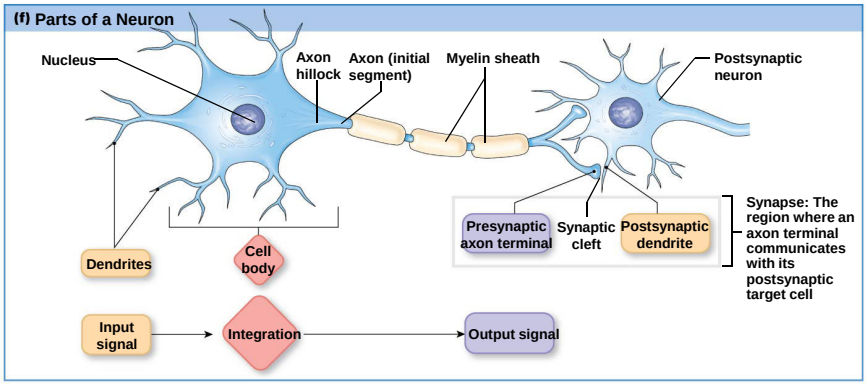


Table 3.4 Characteristics of the Four Tissue Types

Characteristics of the Four Tissue Types — Table 3.4

	Epithelial	Connective	Muscle	Nerve
Matrix amount	Minimal	Extensive	Minimal	Minimal
Matrix type	Basal lamina	Varied—protein fibers in ground substance that ranges from liquid to gelatinous to firm to calcified	External lamina	External lamina
Unique features	No direct blood supply	Cartilage has no blood supply	Able to generate electrical signals, force, and movement	Able to generate electrical signals
Surface features of cells	Microvilli, cilia	N/A	N/A	N/A
Locations	Covers body surface; lines cavities and hollow organs, and tubes; secretory glands	Supports skin and other organs; cartilage, bone, and blood	Makes up skeletal muscles, hollow organs, and tubes	Throughout body; concentrated in brain and spinal cord
Cell arrangement and shapes	Variable number of layers, from one to many; cells flattened, cuboidal, or columnar	Cells not in layers; usually randomly scattered in matrix; cell shape irregular to round	Cells linked in sheets or elongated bundles; cells shaped in elongated, thin cylinders; heart muscle cells may be branched	Cells isolated or networked; cell appendages highly branched and/or elongated

Tissue Remodeling

- Cell death
  - Necrosis
  - Apoptosis (programmed cell death, cell suicide)
- Stem cells
  - Totipotent – can become any cell and can generate a complete organism
  - Pluripotent – can become any cells except placental; lone will not form an embryo
  - Multipotent – undifferentiated stem cells that give rise to tissue specific cells (bone marrow)

Organs

- Groups of tissues with related function
- Skin as an example of an organ

Figure 3.15-1 FOCUS ON … The Skin (1 of 4)

The layers of the skin

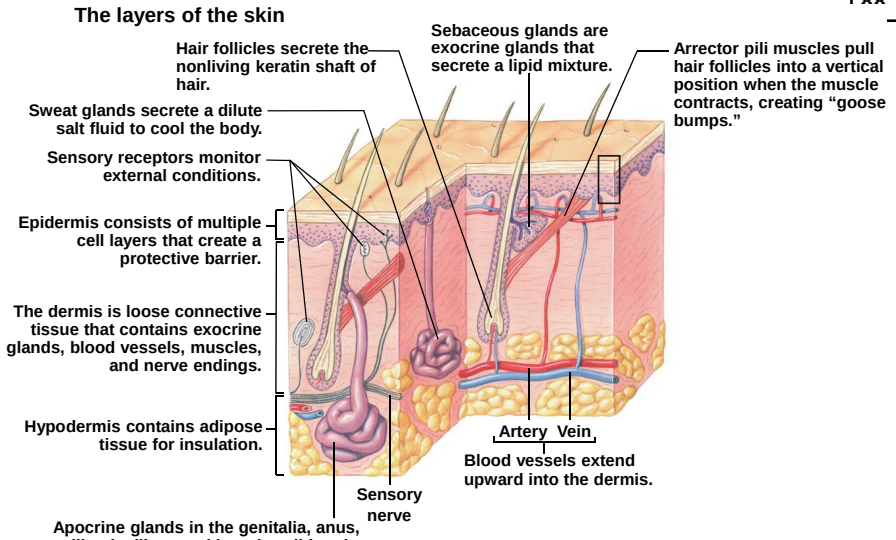


Figure 3.15-2 FOCUS ON … The Skin (2 of 4)

Epidermis

The skin surface is a mat of linked keratin fibers left behind when old epithelial cells die.

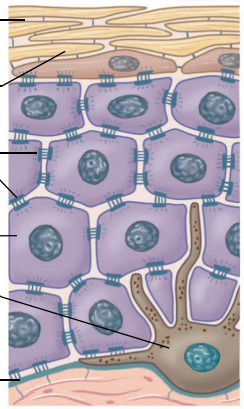
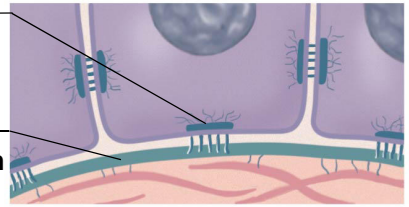


Figure 3.15-3 FOCUS ON … The Skin (3 of 4)

Connection between epidermis and dermis



Summary

- Functional compartments of the body
- Biological membranes
- Intracellular compartments
- Tissues of the body
- Tissue remodeling
- Organs: skin as an example