Cell Function – 2404

What does the cell do = **cell physiology**:

1. **Cell Cycle & Cell Division**
2. **Membrane Transport**
3. **Secretion**
4. **Membrane Potential**
5. **Metabolism**
6. **Cellular Interactions**
7. **Cellular Control: Genes & Chromosomes**

The Cell Cycle & Cell Division

Cell Cycle

the cell cycle is the life cycle of a cell:
from its formation until it divides or dies

→ each day ~50 Billion body cells die and are replaced

cell cycle typically involves a period of **interphase**

alternating with a period of **cell division**

Intephase

during most of a cell's "life" (cycle) it performs its specialized functions and activities

we've defined what some of those "normal" activities are
= **"normal" metabolism**

Cell Division

at one or more points during its life it must **reproduce** to make copies of itself

→ for growth (># of cells)

all life begins as a single cell

in complex organisms that single cell grows and divides repeatedly to form a complex multicellular organism

eg. humans: ~100 trillion

→ repair or replace damaged cells

each new cell must receive:

→a complete set of instructions (chromosomes, genes, DNA)

→and a basic assortment of cellular structures to continue this metabolism

two basic types of cell division: **Mitosis & Meiosis**

Mitosis

makes identical copies of cells

→ parent cell is genetically identical to the two daughter cells produced (clone)

almost every cell in your body is essentially a clone of the original **fertilize egg**

only difference is which genes are "switched on"

→ determines what it has specialized into

Meiosis

the formation of egg and sperm require a different kind of cell division in which the

daughter cells contain only a single set (23) of chromosomes

only sex cells (eggs and sperm) are formed by Meiosis

Mitosis

Interphase

the nondividing stage of a cells life cycle = **interphase**

normal metabolism characteristic of the cell occurs here

as the cell approaches time to divide:

it begins to duplicate all the organelles and materials the new cells will need to get started

it also must duplicate the genetic instructions (chromosomes) that will be needed

the chromosomes are replicated during interphase

→ this process in not visible to us

Stages of Mitosis

after DNA is replicated, the cell begins the division process that becomes visible (under a microscope and special stains) as a series of distinct stages or phases called **Mitosis**

mitosis in most human cells typically takes ~ 1-2 hours

1. Prophase

nuclear membrane disappears
nucleoli disappear
chromosomes begin to appear
centrioles split and begins to form **spindle**

2. Metaphase

spindle is fully formed
replicated chromosomes (2 **chromatids**) line up along the center of cell (equatorial plane)

3. Anaphase

centromere splits and **chromatids** (each half of the replicated chromosome) separate and begins to migrate toward the opposite side of the cell (now each chromatid = chromosome)

4. Telophase

the chromosomes reach opposite sides of cell
begin to disappear (no longer visible)
the nucleus reforms
the spindle disappears
telophase is end of nuclear division; overlaps with…

cytokinesis → division of the cytoplasm = the cell splits (pinches) into two separate cells

cytokinesis doesn't always occur during mitosis

eg coenocytic striated muscle cells, no cytokinesis)

The end result of mitosis:

1 **parent cell** produces two **daughter cells**

each new daughter cell has the

same # and

same kinds of chromosomes as the original parent cell

Variations in the Cell Cycle

Variations in the Cell Cycle

the length of a the cell cycle varies greatly from one tissue to another

a. during development, most cell cycles are relatively short

many cells are dividing about every 30 minutes

b. in adults cell cycles vary considerably between different organs and tissues:

How old is your body?

our bodies are in a constant state of breakdown and renewal

most of our body cells are much younger than our chronological age

the body is made up of 100 T individual human cells

most of these cells are replaced as they die or wear out

lifespan of some human cells:

inner gut epithelium	→ 5 days
skin	→ 2 weeks
red blood cells	→ 120 days
bone	→ 10 yrs
intercostals muscle cells	→ 15.1 yrs
gut cells (not lining)	→ 15.9 yrs
cerebellum	→ slightly younger than you are
cerebral cortex	→ as old as you are
visual cortex	→ as old as you are

may be important question in terms of regenerative medicine and neuroscience

may also be used to help treat certain diseases and to manage the effects of aging on the human body

c. some cells **divide only irregularly** or as needed in adult life

eg. liver & kidney cells only divide if repair is needed

d. some cells **stop dividing** shortly after birth → divide little all our adult lives

eg. muscle cells, nerve cells

Cancer cells

an inability to stop cycling at a rapid rate is a characteristic of **cancer cells**

Cell Death (Apoptosis)

Apoptosis = programmed cell death

normal death of cells that have completed their function

programmed cell death plays a crucial role in growth and development

may also play a role in maintaining normal cell lines by killing off unneeded cells

billions of cells die every hour by apoptosis

→ don't trigger inflammation since cell contents never escape; cell is engulfed by macrophages

eg. embryo produces ~ twice as many neurons as we need those that make connections survive, those that don't die

eg. embryo has webbing between digits this normally goes away as cells between digits die

eg. causes "free earlobes" in those with trait

eg. causes shrinkage of uterus after pregnancy ends

eg. immune cells can trigger cancer cells to commit suicide by apoptosis

Membrane Transport

cell life must be maintained within a narrow range of conditions (requirements for life)

the "external" environment changes much more drastically than internal environment

→a cell's survival depends on its ability to maintain this difference

1st line of defense in protecting the cell is **cell membrane**

interface between living and nonliving

ALL living organisms possess a cell membrane

The cell membrane is **semipermeable** (=selectively permeable)

→ some small molecules cross by passive diffusion

→ some substances require expenditure of energy

→ some require extra "helpers" to get across

Two general kinds of movement

passive - works with a gradient
occurs spontaneously
does not require extra ATP

active - works against gradient
requires ATP
doesn't usually occur outside living cells

PASSIVE MOVEMENTS

1. Simple Diffusion

movement of a substance down a concentration gradient

main way small things cross membranes and move within cells and fluid compartments

based on intrinsic motion of molecules [Brownian Motion]

occurs for solids, liquids and gasses in a solvent

materials can diffuse through air, liquids, and solids

eg. O_2, CO_2, small molecules, lipid soluble molecules
nonpolar, lipid soluble
some small polar molecules

movement down a concentration gradient until ***dynamic equilibrium*** is reached

cell does not have to expend any energy

define: **solute** and **solvent**

speed of diffusion depends on
a. steepness of the gradient
b. permeability (may or not be membrane)
c. molecular weight of solute
d. surface area (eg. microvilli)
e. (temperature)

2. Facilitated Diffusion

movement of a solute across a membrane down a concentration gradient using a carrier protein

resembles ordinary diffusion

move lipid insoluble things across membrane
– they need help to cross
- specific for certain solutes

accelerates diffusion through membrane

uses specific **carrier molecule** (=**carrier protein**)

may be through channels or pores created by these proteins

does not require ATP (energy)

eg. absorb glucose & amino acids in intestine and kidneys

can be **leakage** or **gated** channels
→ important in muscle and nerve impulse conduction

eg. some ion leakage channels in muscle and nerve cells

eg. chemical and voltage gated channels in muscle and nerve cells

3. Osmosis

diffusion of water*, across a membrane, down a* water *concentration gradient*

osmotic pressure increases as water moves in and volume increases pushing out on membrane

(osmotic pressure develops in the solution that originally contained the highest concentration of solute)

two solutions with same osmotic pressure =isosmotic; no osmotic pressure actually develops

isosmotic ~ isotonic

hypertonic = sol has more solutes than another
(eg. human cell is hypertonic to distilled water)

hypotonic = sol has fewer solutes than another

isotonic = solutions have equal concentrations

of solutes

4. Filtration

movement of water and solutes through a membrane down a pressure *gradient*

hydrostatic pressure = blood pressure

unidirectional (no equilibrium is reached)

eg. kidney filtration to form urine

eg. materials leaving blood in capillary beds

ACTIVE MOVEMENT

1. Solute Pumping

movement of a solute across a membrane up *a concentration gradient using ATP and a protein carrier*

requires energy (ATP) and protein carriers

moves specific solutes against (up) concentration gradient

helps maintain concentration gradients

able to move things in or out quickly

counteracts diffusion

eg. Na/K pump (pumps sodium out, potassium into cell)
→ plays role in
controlling cell volume
generating body heat
excitability of muscle and nerve cells

~ half of calories you "burn" every day are used just to operate your Na/K pumps

2. Bulk Transport

movement of large particles, macromolecules, and cells across membrane inside bubble-like vesicles

requires ATP

several kinds of vesicular transport:

a. **Exocytosis**
moves substances out of cell
secretory cells, gland cells

eg. how golgi bodies secrete things

b. **Endocytosis**
moves substances into cell
cell membrane forms vesicle around material and pinches off to form vacuole

kinds of endocytosis

1. **phagocytosis**
"cell eating"
esp macrophages

2. **pinocytosis**
"cell drinking"

Secretion

a specific "application" of membrane transport

many body cells function in secretion

→correlated with number of **golgi bodies**

either as individual **gland cells** or as components of multicellular **glands**

glandular secretions can be through a tube or passageway **= exocrine glands**

or directly into blood capillaries **= endocrine glands**

examples of materials secreted:

1. **sweat**
   → temperature homeostasis
2. **oils and fats**
   → scents, lubrication, protection, waterproofing
3. **mucus**
   → protection, trap pathogens
4. **collagen and various fibers**
   → important components of connective tissues
5. **digestive enzymes**
6. **hormones**

Membrane Potential

"application" of membrane transport

all cells are **polarized**
→ separation of charge
more "**+**" charges on **outside**
more "**-**" charges on **inside**

determined mainly by
differing concentrations of Na^+, K^+, Cl^-, & proteins$^-$
and differing membrane permeabilities to these ions

this separation of charge creates a voltage difference (=**potential**) across the membrane

eg. as in a battery

varies between -20mv to –200mv

exists across all cell membranes

this difference on nerve and muscle cells = **resting potential**

→ because they can alter it

Cell Metabolism

the sum of all chemical reactions taking place within a cell = **metabolism**

metabolism involves chemical changes (reactions)

the two major kinds of metabolic reactions are:

synthesis = anabolic reactions (anabolism)

decomposition = catabolic reactions (catabolism)

1. Anabolic Reactions (Anabolism)

refer to all the **synthesis** reactions occurring in the cell

→synthesis reactions make bonds

→synthesis reactions **require** (or **store**) **energy**

synthesis of organic polymers occurs by **dehydration synthesis**

2. Catabolic Reactions (Catabolism)

refer to all the **decomposition** reactions occurring in the cell

→decomposition reactions generally break bonds

→decomposition reactions generally **release energy**

decomposition of organic polymers occurs through **Hydrolysis**

Metabolism = Synthesis + Decompositon
(Anabolism) + (Catabolism)

<u>Enzymes</u>

enzymes are **catalysts** that facilitate a reaction

essentially all reactions that occur in cells require **enzymes** in order to occur

in any reaction,

the material(s) you begin with = **substrate(s)**

the material(s) you end up with = **product(s)**

the enzyme latches onto the substrate(s) and causes them to react to produce product(s)

Substrate(s)+Enzyme → Product(s) + Enzyme

Characteristics of Enzymes:

1. all enzymes are **proteins**

2. each reaction uses a **specific** enzyme

   usually each enzyme catalyzes only a single reaction

   each has a characteristic shape

3. Usually only a small part of the enzyme protein is involved in a particular reaction
   = **active site**

   Lock and Key model

   enzymes act by holding onto one or more substrates to bring them together for a reaction.

4. enzymes are **not used up** in reactions
   they can be used over and over again

   E + Substrate → ES Complex → E + Product

5. enzymes are very **efficient**:

   eg. a single enzyme molecule can cause
   300-400 reactions/ second

   eg. 1 molecule of catalase can metabolize
   5 – 6 million substrate molecules/ minute

6. because they are used over and over and are very

efficient, enzymes are needed in only **very low amounts**

7. some enzymes require

   coenzymes or **cofactors** to shape the active site properly
   eg. coenzymes: NAD, FAD, NADP, etc
   eg. cofactors: Ca^{++}, Fe, Zn, Mg, etc

8. enzymes (and all proteins) are **very sensitive to environmental conditions**

   since the shape of the enzyme is due mainly to weak hydrogen bonds

   each enzyme operates under a narrow range of conditions

   optimum range of
   temperature
   pH
   salt/water concentration
   pressure
   etc

Metabolic Pathways

Metabolism in most cells is a collection of **groups of enzymes** working together

many of the reactions occurring in cells occur in a sequential, stepwise fashion

= **metabolic pathways**

Compartmentalization of cells helps to organize enzyme activities and makes them more efficient

eg. aerobic respiration → mitochondria
eg. digestion → lysosomes
eg. protein synthesis → ribosomes
eg. lipid synthesis → endoplasmic reticulum

ATP & Energy Use

ATP is the immediate source of energy for cells

ATP can easily absorb energy from the breakdown of organic molecules and release energy for various cellular processes

the energy released by catabolism of glucose is absorbed by ATP

ATP then transfers this energy to various cell processes that require it

1. Solute Pumping and Bulk Transport

moving things in and out of cell against concentration gradients

2. Movement

contraction of muscle cells requires large amounts of ATP

also beating of cilia and flagella and the amoeboid movement of WBC's

3. Nerve Impulses

4. Synthesis Reactions

the formation of new organic molecules requires ATP since new bonds are made

Cellular Interactions

the 100 trillion cells in the body must be able to communicate and interact with each other to coordinate their activities

→need to be able to "talk" to each other

Membrane Receptors & Chemical Signaling

membrane receptors are the main way cells talk to each other

virtually every cell in the body receives chemical signals this way

specific chemicals bind to receptors on or in cell to cause change in cell function

cell only responds to a chemical if it has the correct receptor protein
→ **target cell**

different cells respond in different ways to same chemical

eg. ACh → stim skeletal muscle cells

→ inhibits heart muscle cells

Many different kinds of chemicals can be used for signaling:

eg. neurotransmitters

secreted by neurons in response to electrical stimulus

very short range → cell to cell across synapse

eg. hormones

long range

secreted into blood by endocrine gland

eg. tissue hormones

local effects only on neighboring cells

eg. histamine

Cellular Control: Genes & Chromosomes

the cell is a bag of controlled chemical reactions

these reactions are controlled by the DNA of the chromosomes in the nucleus of the cell

on these chromosomes are the genetic instructions that control everything the cell does

each instruction = **gene**

(human cells contain ~22,000 different genes)

each **gene** is a "unit of inheritance"

each **chromosome** contains many genes

(~500-600 genes/chromosome)

in humans, each cell has a double set of chromosomes 46 or 23 pairs

→ 1 of each pair from mom; 1 from dad

also,

most cells periodically divide into two daughter cells

the cell must be able to transmit genetic "instructions" to new cells as it divides

"daughter cells" must get copies of all genes
ie. exact copies of the DNA in "parent" cell

therefore DNA must be able to perform 2 major functions:

1. control metabolism
2. pass the genetic code to next generation

Protein Synthesis

all life involves a complex series of interacting chemical reactions → metabolism

anabolic → photosynthesis
protein synthesis
dehydration synthesis

catabolic → hydrolysis
respiration

these reactions do not take place randomly

they must be controlled:

the cell maintains a balance of materials

can accelerate and decelerate the production of various products

almost all reactions occurring in a cell require a specific **enzyme** to occur

all enzymes are **proteins**

therefore, if you control protein synthesis you can regulate all metabolism

codes for individual proteins ~ **genes**

each gene is a consecutive sequence of several 1000 nucleotides

a typical cell is continually producing 100's of different

kinds of proteins, many of them are enzymes

as an enzyme is needed the gene(s) is (are) activated and the required protein (enzyme) is made

---

somehow, the nucleotide sequence on the DNA molecule must direct the assembly of amino acids to make proteins

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Two problems with protein synthesis:

1. DNA is in chromosome in nucleus and proteins are made at ribosome

   → how does info move from nucleus to ribosomes?

2. proteins consist of a series of 20 different kinds of amino acids
   nucleic acids are a series of only 4 kinds of nucleotides

   → how do 4 different nucleotides code for 20 different amino acids

protein synthesis is a 2 step process:

transcription
translation

involves a second kind of nucleic acid = **RNA**

<u>Transcription</u>

RNA copies the code on the DNA molecule

unwinds DNA at area of specific gene and unzips it

RNA molecule separates completely from DNA

DNA strands reform double helix

mRNA now contains the complementary bases (U for T) that were on the DNA molecule

= the code for a specific protein

<u>Translation</u>

translation is the process by which the genetic code on the RNA is converted to a specific sequence of amino acids at the ribosome

RNA moves out to ribosomes and directs the construction of a specific protein

each strand of mRNA may be used to make several copies of the same protein

what is the "code" contained on the RNA molecule

<u>Triplet Code</u>

4 nucleotides must code for 20 different amino acids:

if 1 nucleotide codes for 1 amino acid
→ could only get 4 different AA's

if 2 nucleotides codes for 1 amino acid
→ could get no more than 16 different AA's

if 3 nucleotides code for 1 amino acids

→ can get 64 different combinations
more than enough for the 20 AA's
plus some extra for punctuation

Amino Acid	DNA codons
Isoleucine	ATT, ATC, ATA
Leucine	CTT, CTC, CTA, CTG, TTA, TTG
Valine	GTT, GTC, GTA, GTG
Phenylalanine	TTT, TTC
Methionine	ATG
Cysteine	TGT, TGC
Alanine	GCT, GCC, GCA, GCG
Glycine	GGT, GGC, GGA, GGG
Proline	CCT, CCC, CCA, CCG
Threonine	ACT, ACC, ACA, ACG
Serine	TCT, TCC, TCA, TCG, AGT, AGC
Tyrosine	TAT, TAC
Tryptophan	TGG
Glutamine	CAA, CAG
Asparagine	AAT, AAC
Histidine	CAT, CAC
Glutamic acid	GAA, GAG
Aspartic acid	GAT, GAC
Lysine	AAA, AAG
Arginine	CGT, CGC, CGA, CGG, AGA, AGG
Stop codons	TAA, TAG, TGA

DNA is the molecule of inheritance for all organisms

the code is nearly universal (bacteria to humans)

→ all life is interrelated