Coordination of Body Functions

**Hormones Respond to Stimuli**

**Integration & Cognition**

**Afferent Signal**

**Efficient Signal**

**Sensory Nerves**

**Motor Nerves**

**Central Nervous System**

**Effector response**

**Endocrine Gland**

**Effector response**

**Effector = specific muscle or gland**

**Cellular Communication**

(a) Communicating cell junctions.

(b) Cell-cell recognition.

![Figure 11.3](image-url)
**Cellular Communication via chemical messengers**

1. Release: initiator cell secretes (exocytosis) a chemical messenger (signal molecules).
2. Reception: messenger molecules bind to receptors (binding proteins) on target cells.
3. Transduction: binding of signal molecule to receptor causes a change in the structure and activity of the receptor protein.
4. Response: the altered receptor protein initiates a change in the enzymatic and/or transcriptional activity of the target cell.

**Figure 11.5**

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**Major Classes of Biochemical Signal Molecules**

I. Amino acid origin
   - Amino acids
   - Modified amino acids — bioamines
   - Oligopeptides
   - Proteins

II. Fatty acid origin
   - Derived from cholesterol — steroids
   - Derived from arachidonic acid — prostaglandins

III. Dissolved gases
   - Nitric oxide (NO)
   - Carbon monoxide (CO)
   - Ethylene (H₂C=CH₂)

**Mechanisms of Hydrophilic Signal Molecule Action**

- Hydrophilic signal molecules — most amino acid class
  - Water soluble.
  - Short half-life: minutes
  - Do not enter target cells. Act as ligand by binding to protein receptor on cell surface.

- Lipophilic signal molecules — steroids & thyroid hormones
  - Water insoluble. Must be transported in plasma by carrier proteins.
  - Carrier proteins also protect hormone from degradation. Half-life longer: 1–2 hours.
  - Released from carrier protein to diffuse across cell membrane into target cells. Act by binding to intracellular protein receptors.

**Mechanisms of Messenger Action**

- One cell releases a molecule (messenger) that initiates a change in another cell by binding to a protein receptor on that target cell.

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**Signal transduction pathways via second messengers**

Act as cofactors/coenzymes to modulate intracellular enzyme activity.
Coordination of Body Functions

**Intracellular Receptors for Lipophilic Signal Molecules**

1. Steroid diffuses across membrane into cell
2. Intracellular receptor/steroid complex binds to DNA
3. Transcription factor — turns genes on/off
4. Change nature of the cell (Longer-lasting effect)

**Mechanisms of Messenger Action**

- **Hydrophilic signal molecules** — most amino acid class
  - Primary effect: turn enzymes on/off & activity of cell.
  - Secondary effect: enzymes may produce or activate transcription factors & turn genes on/off.
- **Lipophilic signal molecules** — steroids & thyroid hormones
  - Bind to intracellular receptors in cytoplasm or nucleoplasm
  - Primary effect: turn genes on/off & nature of cell.
  - Secondary effect: gene expression may produce or activate enzymes & turn metabolic pathways on/off.

**Modulation of signal effect**

- **Priming (upregulation)**
  - Signal binds → more receptors synthesized → more hormone can bind cell
- **Desensitization (downregulation)**
  - Prolonged exposure to high signal molecule levels can reduce receptor expression.
  - Downregulation may be avoided by pulsatile secretion of the messenger.
- **Receptor-mediated endocytosis**
  - Receptor-ligand complex internalized on vesicle to enhance duration of effect.

**Compound messenger effects**

- **Antagonistic:**
  - Insulin stimulates lipogenesis; glucagon stimulates lipolysis.
- **Synergistic:**
  - Both glucagon and epinephrine receptors cause the production of cAMP second messenger in the same cell.
- **Complementary:**
  - FSH and testosterone stimulate different parts of spermatogenesis.
- **Permissive:**
  - Glucocorticoids stimulate the synthesis of enzymes that are regulated by epinephrine.

**Electrochemical communication**

Neurons —
1. Membrane potential
2. Excitability
3. Conduction
4. Transmission

**Neurons conduct electrochemical impulses and transmit messages to other cells**
Neuron: A Nerve Cell

- Dendrites: increase surface area of cell body to receive signals.
- Cell body: location of nucleus and most organelles.
- Axon: conducts electrochemical impulses.
- Termini: transmit message to target cell.

Membranes of neurons are electrically charged

- Chemical gradients of ions produce electrical gradients
- Inside of the cell is negative relative to the outside of the cell.
- Electrical gradient produces a membrane potential (voltage)

Axons are Polarized: Resting Potential

- Na is Not allowed in; K is Contained.

Resting Membrane Potential

- At equilibrium, inside of the cell membrane would have a higher [negative charges] than the outside.
- Potential difference:
  - Magnitude of difference in charge on the 2 sides of the membrane...
- Depends upon 2 factors:
  - Ratio of the concentrations of each ion on the 2 sides of the plasma membrane.
  - Specific permeability of membrane to each different ion.
- Resting membrane potential of most cells ranges from -65 to -85 mV.

Cell Excitability (= Irritability)

- The ability to undergo rapid changes in membrane potential in response to stimuli.
  - Oocytes: rapid block to polyspermy.
  - Neurons: conduct nerve impulses
  - Muscle cells: initiate contraction

Conduction of electrochemical signals in neurons

- Nerves are NOT wires!
- Nerve impulses are NOT electricity!
- Nerve impulse are a series of action potentials propagated in sequence down the neuron.
- Only the axons of neurons conduct the nerve impulse.
  - Initiated at the hillock,
  - Propagate toward the axon terminus
How can conduction rate be increased?

1. Increase diameter of the axon.
   - Increase diffusion rate of cations down through the axon.
   - “Giant axons” of cephalopod molluscs and crustacean arthropods may be 1mm in diameter and have a conduction speed of 100m/sec.

2. Myelinated axons — vertebrates only!
   - Saltatory conduction: 25µm myelinated vertebrate neuron may have conduction rate of 120 m/sec.

Transmission: Synapses & Local Signaling

- **Synaptic terminals** release a neurotransmitter.
  - e.g. acetylcholine
  - NT binds to receptors on postsynaptic cell.

Transmission of the signals: the Synapse

- Synapse: functional connection between a neuron and another neuron or an effector cell (muscle or gland).
- Synaptic cleft: a slight gap between the pre-synaptic cell (axon terminus) and the post-synaptic cell.
- Series of action potentials conducted to axon terminus cause exocytosis of vesicles containing a chemical messenger (neurotransmitter) into the synaptic cleft.
- Neurotransmitter binds to a receptor protein on the surface of the effector cell turns on the receptor.
- The intracellular portion of the activated receptor causes a response in the post-synaptic cell.

Glands: organs specialized for secretion

- **Exocrine glands**: secrete via ducts “out” of body
- **Endocrine glands**: secrete into bloodstream

Endocrine Glands and Hormones

- Endocrine glands may be of epithelial or neural origin.
- Secrete biologically active molecules into the blood.
  - Lack ducts.
- Bloodstream carries hormones to target cells that contain specific receptor proteins for that hormone.
- Target cells can respond in a specific fashion.
Some glands are both exocrine and endocrine.

Pancreas
- Acinar cells produce digestive enzymes.
  - Secreted via bile duct into small intestines
- Islet cells produce hormones
  - $\alpha$-cells † glucagon
  - $\beta$-cells † insulin
  - $\delta$-cells † somatostatin
  - Secreted via capillaries into bloodstream

Gonads
- Ovaries & testes
  - Gametes secreted via sexual accessory ducts.
    - Fallopian tubes/uterus/vagina
    - Epididymus/vas deferens/urethra
  - Sex steroids secreted into bloodstream.

Some endocrine glands have both neural and epithelial components.

Adrenal gland
- Ad-re-nal: “over the kidney”
  - Fishes have in-ter-re-nal gland
  - Inner region: medulla
    - neural
  - Outer region: cortex
    - epithelial
  - Outermost covering: capsule
    - tough connective tissue

{Pituitary gland also has both neural and epithelial components.}

Adrenal Gland
- Adrenal medulla
  - Modified sympathetic postsynaptic neurons
  - Secrete epinephrine (adrenaline) & norepinephrine (noradrenaline) as hormones instead of as neurotransmitters.
  - Extend “fight-or-flight response to whole body.

Adrenal cortex
- Secrete steroid hormones: corticosteroids/corticoids
  - Three sub-regions:
    - outer layer † mineralocorticoids
      - humans: aldosterone
      - regulate salt balance
    - middle layer † glucocorticoids
      - humans: cortisol
      - regulate sugar balance and chronic stress response
    - inner layer † sex steroids androstenedione & DHEA
      - weak androgens
Note: not all hormones are secreted by specialized glands

Regulation of Blood Glucose by Antagonistic Negative Feedback Loops

- **Pancreas** regulates blood sugar levels
- Glucose is taken up or released by:
  - liver as glycogen stores
- **Glucagon** from *alpha cells* ups blood glucose
- **Insulin** from *beta cells* drops it

Insects and Others Also Use Antagonistic Hormones

- **Ecdysone**
  - induces epidermis to secrete new cuticle underneath old one
- **Juvenile Hormone**
  - inhibits metamorphosis

Pituitary Gland — the “Master Gland”

- Pituitary gland is located below the forebrain.
- Structurally and functionally divided into:
  - Posterior lobe — an extension of the hypothalamic neural tissue.
  - Anterior lobe — epithelial gland derived from the roof of the mouth.
Coordination of Body Functions

Posterior Pituitary: Neurohypophysis

- **Antidiuretic Hormone** (vasopressin): kidney reabsorp of water, blood Osm / blood volume / blood pressure.
- **Oxytocin**: contractility of smooth muscle of repro. tract & mammary glands, orgasm / birth / milk ejection reflexes.

Positive feedback: amplifying the oxytocin response

Anterior Pituitary Trophic Hormones

- Trophic: “feeding”
  - Stimulate activity of other glands, “Master Gland”
  - Stimulate growth of target tissues
    - High blood [hormone] causes target organ to hypertrophy.
    - Low blood [hormone] causes target organ to atrophy.

Regulating the Master Gland

1. Releasing (stimulating) and inhibitory hormones from the hypothalamus.
2. Negative feedback by hormones secreted by the target glands.

Control of Pituitary Releasing Hormones

Feedback Control of the Anterior Pituitary

E.g., sex hormones:
1. Hypothalamus secretes releasing hormone (GnRH) to stimulate Ant. Pituitary.
2. Ant. Pituitary secretes gonadotropins (LH & FSH) to stimulate gonads to:
   1. Grow & mature
   2. Secrete sex steroids
3. Sex steroids from gonads feedback to inhibit pituitary from secreting more gonadotropin.

Negative feedback hormones (estrogens and androgens)
Coordination of Body Functions

Feedback Control of the Anterior Pituitary

So, …
1. If a body builder takes anabolic steroids (synthetic androgens) …
2. The steroids act like other androgens and inhibit the pituitary from secreting gonadotropins. …
3. With suppressed gonadotropin secretion, the gonads fail to grow.

*Their grapes turn to raisins.*

Feedback Control of the Anterior Pituitary

Another example: thyroid function:
1. Hypothalamus secretes releasing hormone (TRH) to stimulate anterior pituitary.
2. Anterior pituitary secretes thyrotropin (TSH) to stimulate thyroid to:
   1. Grow
   2. Secret thyroid hormone (thyroxine)
3. Thyroxine from thyroid feedback to inhibit pituitary from secreting more TSH.

Feedback Control of the Anterior Pituitary

But, iodine is needed to synthesize thyroxine.
1. If the diet is deficient in iodine, thyroid cannot make thyroxine.
2. If no thyroxine, no negative feedback on anterior pituitary.
3. Anterior pituitary continues to secrete TSH.
4. TSH continues to stimulate thyroid to overgrow.
5. Overgrown thyroid forms a goiter.

Pars Intermedia

In most vertebrates, a portion of the pituitary anterior lobe adjacent to the posterior lobe develops into an intermediate lobe.
- Principle activity is secreting melanocyte-stimulating hormone (MSH)
- MSH promotes hyperpigmentation from increased melanin production in melanocytes in skin and hair.
  - Cryptic coloration
  - Sexual/territorial advertising

Pars Intermedia

Alternate processing of the same pro-hormone polypeptide:

Pro-opiomelanocortin (POMC)

[pro-opiod-melanotropin-corticotropin]

- In anterior pituitary, POMC cleaved to form endorphins (opioids) + adrenocorticotropic hormone (ACTH)
- In intermediate lobe, ACTH fragment is further cleaved to form α-MSH
- In humans, intermediate lobe is greatly reduced, but present.
  - Syndromes that cause an overproduction of ACTH (pregnancy, adrenal insufficiency [Addisons disease]) also result in elevated MSH and hyperpigmentation.
- Red-headed, poorly tanning people often have normal MSH levels, but decreased MSH-receptors.

Endocrine Pathologies

I. Abnormal hormone title —
   - Primary pathology: caused the endocrine gland secreting that hormone
     - Secondary pathology: caused by a factor (e.g., trophic hormone) regulating that gland
       - Hyposecretion of hormone
       - Idiopathic: gland “turned on” for no obvious reason
       - Tumor hyperplasia of secretory cells
       - Secondary: hypersecretion of trophic hormone
       - Hyposecretion of hormone
       - Enzyme defect in biosynthesis of the hormone
       - Autoimmune destruction of of secretory cells
       - Receptor defect/insufficiency responding to trophic hormone
     - Secondary: hyposecretion of trophic hormone
   - Abnormal hormone response —
     - Number of receptors in target organ: desensitization
     - Mutant defective receptors in target organ
   - Defective transduction pathway step
II. Exogenous hormones