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Hormones and Biochemical Regulation

Biochemistry

Chemical nature and functions of hormones, mechanism of hormone action, second messengers, endocrine regulation and biochemical importance of hormones.

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CHAPTER 12

Hormones and Biochemical Regulation

Chemical classes, receptors, second messengers and endocrine regulation

1. Definition

Hormones are chemical signalling molecules produced by endocrine or other cells that act on target cells possessing appropriate receptors. Endocrine signals travel through blood; paracrine signals act locally and autocrine signals act on the producing cell. Hormone action depends on receptor expression, concentration and downstream signalling.

2. Chemical nature of hormones

Class	Examples	Typical mechanism
Peptide / protein	Insulin, glucagon, ADH, GH, PTH	Cell-surface receptor; intracellular signalling
Steroid	Cortisol, aldosterone, oestrogen, testosterone	Intracellular receptor regulating gene expression
Amino acid-derived	Adrenaline, thyroid hormones, melatonin	Catecholamines: surface receptors; thyroid hormones: nuclear receptors
Lipid-derived local mediators	Prostaglandins, leukotrienes	Local signalling, often membrane receptors

Peptide hormones are generally water-soluble and stored in vesicles. Steroid hormones are cholesterol-derived and usually synthesized as needed; steroid and thyroid hormones circulate substantially protein-bound. Free hormone is often most directly available to receptors.

3. Mechanism of action and second messengers

Pathway	Examples / action
Gs -> adenylyl cyclase -> cAMP -> PKA	Glucagon, ACTH and beta-adrenergic signalling
Gi -> reduced adenylyl cyclase	Selected inhibitory receptor pathways
Gq -> PLC -> IP3 + DAG	IP3 releases intracellular Ca2+; DAG activates PKC (e.g., alpha1 receptors)
Receptor tyrosine kinase	Insulin receptor -> phosphorylation cascades including PI3K/Akt

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JAK-STAT	Growth hormone and prolactin pathways
cGMP	Natriuretic peptide signalling; nitric oxide activates soluble guanylyl cyclase

Steroid/thyroid receptors alter transcription via DNA regulatory elements; responses often develop more slowly than rapid membrane pathways. Signalling amplification permits a small hormone signal to produce substantial cellular effects.

4. Major endocrine hormones

Gland / hormone	Biochemical function
Anterior pituitary: TSH, ACTH, GH, FSH, LH, prolactin	Regulates thyroid, adrenal, growth, reproduction and lactation

Gland / hormone	Biochemical function
Posterior pituitary: ADH, oxytocin	Water reabsorption; uterine contraction and milk ejection (synthesized in hypothalamus)
Thyroid: T3/T4	Metabolic regulation, growth and development
Parathyroid: PTH	Calcium and phosphate regulation
Adrenal cortex: cortisol, aldosterone	Stress and glucose regulation; sodium retention and potassium excretion
Adrenal medulla: adrenaline, noradrenaline	Acute stress response
Pancreatic islets: insulin, glucagon	Glucose and fuel homeostasis
Gonads: sex steroids	Reproductive development and function

5. Regulation and feedback

Negative feedback stabilizes endocrine systems: hypothalamic TRH -> pituitary TSH -> thyroid T4/T3; rising thyroid hormone suppresses TRH/TSH. In the HPA axis, CRH -> ACTH -> cortisol; cortisol normally feeds back. Positive feedback occurs in selected processes, such as oxytocin-associated labour contractions and the LH surge. Circadian rhythms affect cortisol and melatonin. Hormone resistance can occur despite normal or high hormone concentrations.

6. Hormone synthesis, transport and receptor action

Peptide hormones are synthesized as precursors on ribosomes and processed through the secretory pathway. Many are stored in vesicles and released by regulated exocytosis. Steroid hormones are synthesized from cholesterol; thyroid hormones are formed by iodination and coupling of tyrosine residues in thyroglobulin. Binding proteins affect circulation and measured total hormone concentration.

Comparison of membrane and intracellular receptors

Feature	Membrane receptor	Intracellular receptor
Common ligands	Peptides and catecholamines	Steroids and thyroid hormones
Location	Plasma membrane	Cytoplasm or nucleus
Mechanism	Signal transduction and enzyme activation	Regulation of gene transcription
Response	Often rapid	Often slower, with sustained effects

There are exceptions. Receptor pathways can interact and timing varies with the particular hormone and tissue.

7. Biochemical effects of insulin and glucagon

Insulin stimulates glucose uptake in skeletal muscle and adipose tissue through GLUT4 translocation. It promotes glycogen synthesis and suppresses hepatic glucose production, adipose lipolysis and ketogenesis. Glucagon primarily acts on the liver, promoting glycogenolysis and gluconeogenesis during fasting. Cortisol, growth hormone and catecholamines also influence glucose availability and fuel metabolism.

8. Endocrine investigations and feedback

A low free T4 with raised TSH commonly suggests primary hypothyroidism, whereas low free T4 with a low or inappropriately normal TSH may suggest central disease. Discordant results require clinical review, including medication effects, acute illness and assay interference. A single hormone result may be misleading when secretion is pulsatile or follows a daily rhythm.

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9. Clinical relevance and nursing applications

Diabetes reflects impaired insulin availability/action. Hypothyroidism may cause fatigue and slow metabolism; hyperthyroidism may cause heat intolerance and tachycardia. Adrenal insufficiency can lead to hypotension and electrolyte abnormalities. Monitoring requires correct specimen timing, clinical context, knowledge of drugs and recognition of acute endocrine emergencies. Educate patients about prescribed therapy and follow-up without changing hormone doses independently.

10. Important Examination Questions

Long Answer Questions

1. 1. Classify hormones and explain their mechanisms of action.
2. 2. Explain second messenger systems and intracellular receptor mechanisms.
3. 3. Describe hormonal feedback and the biochemical effects of insulin and glucagon.

Short Answer Questions

1. 1. Write a short note on cAMP.
2. 2. Write a short note on negative feedback.
3. 3. Write a short note on insulin receptor.

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4. 4. Write a short note on thyroid axis.

Very Short Answer Questions

1. 1. What is a second messenger? - An intracellular signal transmitting receptor activation.
2. 2. Which gland produces glucagon? - Pancreatic alpha cells.
3. 3. Which hormones are synthesized in the hypothalamus and released by posterior pituitary? - ADH and oxytocin.
4. 4. Which hormone increases renal water reabsorption through aquaporin-2? - ADH (vasopressin).

Additional objective question

The insulin receptor is which type? - Receptor tyrosine kinase.

11. Quick Revision

- Hormones act on target cells with appropriate receptors.
- cAMP, IP3, DAG and calcium are important intracellular messengers.
- Insulin uses a receptor tyrosine kinase; many steroids act through intracellular receptors.
- Negative feedback maintains endocrine homeostasis.

Conclusion

Hormones coordinate biochemical pathways and maintain homeostasis through receptor-mediated signalling and feedback regulation.

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Practice questions

Choose one best answer. The answer key and explanations follow the questions.

1. Which term describes a signal acting on the same cell that produced it?

A. Endocrine
B. Paracrine
C. Exocrine
D. Autocrine

2. What type of receptor is the insulin receptor?

A. Nuclear steroid receptor
B. Receptor tyrosine kinase
C. Ligand-gated chloride channel
D. G-protein-coupled beta receptor

3. Which hormone class is synthesized from cholesterol?

A. Steroid hormones
B. Peptide hormones
C. Catecholamines

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D. Thyroid hormones

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Answer key and explanations

1. D - Autocrine

Autocrine signals act on their producing cell.

2. B - Receptor tyrosine kinase

Insulin uses a receptor tyrosine kinase and downstream phosphorylation cascades.

3. A - Steroid hormones

Steroid hormones derive from cholesterol.

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