Appendix A: Endocrine Glands and Hormones

The major endocrine glands of the body and the hormones produced by these glands are summarized in Tables A.1 through A.12. Each table summarizes the stimulus, source and actions (including cellular mechanism of action) of each hormone produced by a particular gland. These tables are for reference.

Table A.1. Posterior Pituitary and Actions of Posterior Pituitary hormones

Stimulus	*Source*	*Hormone*	*Action*
physical stress (dehydration, hyperosmolarity, blood loss)	Hypothalamic axons in Posterior Pituitary	Vasopressin (water soluble)	V1a receptors act through G-protein coupled activation of phospholipase C and release of Ca^{2+} from the endoplasmic reticulum constricts blood vessels V1b receptors act through G-protein coupled activation of phospholipase C and subsequent release of Ca^{2+} from the endoplasmic reticulum stimulates corticotropin secretion from the anterior pituitary V2 receptors act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP causes the insertion of aquaporin-2 channels into the luminal membrane of the cells lining the collecting duct of the kidney and thus increases reabsorption of water by kidney
childbirth, suckling, sexual activity	Hypothalamic axons in Posterior Pituitary	Oxytocin (water soluble	act through G-protein coupled activation of phospholipase C and release of Ca^{2+} from the endoplasmic reticulum facilitates milk ejection from mammary glands stimulates uterine contraction alters sodium excretion by the kidney facilitates bonding and trust

Table A.2. Hypothalamus and Actions of Hypothalamic Regulatory hormones

Stimulus	*Source*	*Hormone*	*Action of Hypothalamic Regulatory Hormone*
Stress and low metabolism	Hypothalamic Neurons	Thyrotropin Releasing Hormone (TRH) (water soluble)	act through G-protein coupled activation of phospholipase C and release of Ca from the endoplasmic reticulum, and activation of protein kinase C stimulates Thyroid Stimulating Hormone (TSH) by Anterior Pituitary Thyrotrophs
Stress and low metabolism	Hypothalamic Neurons	Corticotropin Releasing Hormone (CRH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP leading to the opening of voltage gated Ca channels stimulates Adrenocorticotropic Hormone (ACTH) by Anterior Pituitary Corticotrophs
Stress and low metabolism	Hypothalamic Neurons	Somatotropin Releasing Hormone (GHRH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP, and activation of the transcription factor CREB by protein kinase A stimulates Growth Hormone (GH) by Anterior Pituitary Somatotrophs
Elevated metabolism	Hypothalamic Neurons	Somatostatin (Somatotropin Inhibiting Hormone) (GHIH) (water soluble)	act through G-protein coupled *inhibition* of adenylyl cyclase and cyclic-AMP and reduction of calcium inhhibits Growth Hormone (GH) by Anterior Pituitary Somatotrophs

Intrinsic pacemaker	Hypothalamic Neurons	Gonadotropin Releasing Hormone (GnRH) (water soluble)	act through G-protein coupled activation of phospholipase C and release of Ca from the endoplasmic reticulum, and activation of protein kinase C stimulates Follicle Stimulating Hormone (FSH) by Anterior Pituitary Gonadotrophs stimulates Luteinizing Hormone (LH) by Anterior Pituitary Gonadotrophs
Pregnancy and Suckling	Hypothalamic Neurons	Prolactin Releasing Hormone (PRH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP? stimulates prolactin (prolactin is also stimulated by TRH and Serotonin)
Intrinsic pacemaker	Hypothalamic Neurons	Dopamine (Prolactin Inhibiting Hormone) (PIH) (water soluble)	act through G-protein coupled *inhibition* of adenylyl cyclase and cyclic-AMP and reduction of calcium inhibits prolactin

Table A.3. Anterior Pituitary and Actions of Anterior Pituitary hormones

Stimulus	*Source*	*Hormone*	*Action of Anterior Pituitary Hormone*
Thyrotropin Releasing Hormone (TRH)	Anterior Pituitary Thyrotrophs	Thyrotropin (Thyroid Stimulating Hormone) (TSH (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP stimulates T3 and T4 production by thyroid follicles
Corticotropin Releasing Hormone (CRH)	Anterior Pituitary Corticotrophs	Corticotropin (Adrenocorticotropic Hormone) (ACTH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP stimulates cortisol production by adrenal cortex
Somatotropin Releasing Hormone (GHRH) and Inhibiting Hormone (GHIH) (Somatostatin)	Anterior Pituitary Somatotrophs	Somatotropin (Growth Hormone) (GH) (water soluble)	act through receptor coupled activation of tyrosine kinase stimulates breakdown of fats to fatty acids (Lipolysis) in Adipose tissue stimulates Insulin Like Growth Factor (IGF-1) production by liver acts directly on cells to stimulate protein synthesis in muscle enhance lipolysis depress the action of insulin on glucose uptake stimulate gluconeogenesis
Gonadotropin Releasing Hormone (GnRH)	Anterior Pituitary Gonadotrophs	Follicle Stimulating Hormone (FSH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP stimulates follicle development and estrogen production by ovary in female; stimulates spermatogenesis by testes in male

Gonadotropin Releasing Hormone (GnRH)	Anterior Pituitary Gonadotrophs	Luteinizing Hormone (LH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP stimulates ovulation and progesterone production by ovary in female; stimulates testosterone production by testes in male
Prolactin Releasing Hormone (PRH) and Inhibiting Hormone (PIH)(Dopamine)	Anterior Pituitary Prolactotrophs	Prolactin (PRL) (water soluble)	act through receptor coupled activation of tyrosine kinase stimulates milk production by mammary glands; stimulates reabsorption of electrolytes by kidney

Table A.4. Thyroid Gland and Actions of Thyroid Hormones

Stimulus	*Source*	*Hormone*	*Action*
stimulated by Thyrotropin (TSH)	Thyroid follicles	Tetraiodothyronin (Thyroxin or T4) (lipid soluble) Triiodothyronin (T3) (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs increases Na^+/K^+-ATPase, mitochondrial, and respiratory enzymes stimulates oxygen and food consumption, carbohydrate absorption, and substrate use enhances response to epinephrine and norepinephrine (thermogenesis, lipolysis, glycogenolysis and gluconeogenesis) increases cardiac output, heart rate, ??direct or indirect?
stimulated by an increase in Extracellular Ca^{++}	Thyroid Parafollicular ("C") cells	Calcitonin (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP inhibits osteoclasts and inhibits resorption of calcium from bone into plasma

Table A.5. Parathyroid Gland and Actions of Parathyroid Hormones

Stimulus	*Source*	*Hormone*	*Action*
stimulated by a fall in Extracellular Ca^{++}	Parathyroid Chief cells	Parathyroid hormone (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP stimulates osteoclasts and the resorption of calcium and phosphate from bone into plasma stimulates reabsorption of calcium by the kidney into plasma increases excretion of phosphate by the kidney into the urine stimulates production of Calcitriol by kidney, liver, and intestine

Table A.6a. Adrenal Medulla and Actions of Adrenal Medullary Hormones

Stimulus	*Source /*	*Hormone*	*Action of Adrenal Medullary Hormones*
Physical activity, physical stress, emotional stress	Chromaffin Cells (ganglionic neurons)	Epinephrine (water soluble) Norepinephrine (water soluble)	Varies depending on adrenergic receptors - **α_1** , **α_2** , **β_1** , **β_2** , **β_3** (see below)

Table A.6b. Actions of Alpha (α) and Beta (**β**) Adrenergic Receptor Activation

Hormone	*Receptor*	*Action of Adrenal Medullary Hormones*
Norepinephrine Epinephrine	**α_1** receptors or **α_2** postsynaptic receptors	act through G-protein coupled activation of phospholipase C and production of IP3 and DAG; release of Ca from the endoplasmic reticulum; activation of protein lipase C constrict blood vessels in abdominal organs, kidney, skin and genitals increase breakdown of glycogen to glucose (Glycogenolysis) in liver and skeletal muscle via **α_1** stimulate glucagon secretion by pancreas via **α_1**
Norepinephrine Epinephrine	**α_2** presynaptic and some **α_2** non-synaptic receptors	act through G-protein coupled *inhibition* of adenylyl cyclase and cyclic-AMP; reduction of calcium decrease neurotransmitter release via presynaptic **α_2** inhibit insulin secretion by pancreas via non-synaptic **α_2**
Epinephrine Norepinephrine	**β_1** receptors	act through G-protein coupled activation of adenylyl cyclase, cyclic-AMP, and protein kinase A; increase of calcium increase heart rate and force of cardiac contraction stimulate glucagon secretion by pancreas stimulate renin secretion by kidney
Epinephrine Norepinephrine	**β_2** receptors	act through G-protein coupled activation of adenylyl cyclase, cyclic-AMP, and protein kinase A; activate calcium pumps; modulate various enzymes dilate airways and dilate blood vessels in skeletal muscle increase breakdown of glycogen to glucose (Glycogenolysis) in liver and skeletal muscle increase production of glucose from fatty acids and amino acids (Gluconeogenesis) in liver
Epinephrine Norepinephrine	**β_3** receptors	act through G-protein coupled activation of adenylyl cyclase, cyclic-AMP, and protein kinase A; modulate various enzymes increase breakdown of lipids (lipolysis) and release of fatty acids in adipose tissue

Table A.7. Adrenal Cortex and Actions of Adrenal Cortical Hormones

Stimulus	*Source*	*Hormone*	*Action*
stimulated by Angiotensin II, III and by elevated plasma K^+	Zona glomerulosa	Aldosterone (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs for Na^+/K^+-ATPase stimulates the reabsorption of sodium and secretion of potassium from the distal renal tubules of the kidney into the plasma
stimulated by adrenocorticotropin (ACTH)	Zona fasciculata	Cortisol (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs breaks down protein and releases amino acids from Muscle breaks down fat (lipolysis) and releases free fatty acids from Adipose tissue stimulates the conversion of amino acids (and glycerol) to glucose (Gluconeogenesis) in the Liver inhibits cellular uptake of glucose inhibits inflammation and immune responses helps maintain blood volume by decreasing the permeability of the vascular epithelium
stimulated, in part, by adrenocorticotropin (ACTH)	Zona reticularis	Androstenedione (precursor to Testosterone and Estradiol) (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs stimulates muscle growth increases bone density may increase libido provide 50% of androgens in women

Table A.8. Pancreas and Actions of Pancreatic Hormones

Stimulus	*Source*	*Hormone*	*Action of Pancreatic Hormone*
stimulated by low blood glucose and by epinephrine; inhibited by high blood glucose and Beta cell activity	pancreatic Alpha cells	Glucagon (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP increase breakdown of glycogen to glucose (Glycogenolysis) in Liver increase production of glucose (Gluconeogenesis) from amino acids in Liver increase production of ketones (ketogenesis) from fatty acids in Liver
stimulated by high blood glucose; inhibited by epinephrine	pancreatic Beta cells	Insulin (water soluble)	act through a membrane tyrosine kinase receptor that phosphorylates several proteins that act as insulin receptor substrates stimulates transport of glucose into cells in Muscle and Adipose tissue and in Liver stimulates glycogen formation from glucose (Glycogenesis) in Muscle and Liver facilitates fat storage by stimulating transport of fatty acid into and inhibiting transport of fatty acids out of Adipose cells facilitates protein storage by stimulating transport of amino acid into and inhibiting transport of amino acids out of Muscle cells

Table A.9. Kidney and Actions of Renal Hormones

Stimulus	*Cells / Source*	*Hormone*	*Action*
stimulated by norepinephrine (NE) via β-1	JG cells	renin (water soluble)	enzymatically converts converts angiotensinogen to angiotensin I
stimulated by a fall in erythrocytes	kidney	Erythropoietin (water soluble)	act through coupled "non-receptor protein tyrosine kinases." accelerates the differentiation of stem cells of the bone marrow into erythrocytes
stimulated by Parathyroid hormone (stimulated by a fall in extracellular Ca^{2+} or P_i)	kidney	Calcitriol (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and transcription of mRNAs stimulates calcium and phosphate absorption from the intestinal tract stimulates resorption of calcium and phosphate from bone into plasma may decrease excretion of calcium and phosphate by the kidney into the urine

Table A.10. Renin – Angiotensin – Aldosterone

Stimulus	*Cells / Source*	*Enzyme / Hormone*	*Action*
stimulated by norepinephrine (NE) via β-1	JG cells	renin (water soluble)	enzymatically converts angiotensinogen to angiotensin I
	blood	Converting enzyme (water soluble)	enzymatically converts angiotensin I to angiotensin II
	blood	Angiotensin II (water soluble)	AT1 receptors act through G-protein coupled activation of phospholipase C and subsequent release of Ca^{2+} from the endoplasmic reticulum constricts blood vessels stimulates Aldosterone production by the adrenal cortex and vasopressin secretion by the posterior pituitary stimulates thirst AT2 receptors act through G-protein coupled activation of Mitogen Activated Protein kinase. ?? inhibit cell growth modulate apoptosis and cellular differentiation dilate blood vessels

Table A.11. Ovary and Actions of Ovarian Hormones

Stimulus	*Cells / Source*	*Hormone*	*Action*
stimulated by follicle stimulating hormone (FSH)	Granulosa cells surrounding the oocyte	Estradiol (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs increases the endometrial thickness (3 to 5 fold) triggers the ovulatory surge of LH and FSH inhibits the GnRH neurons of the hypothalamus and stimulates the LH gonadotrophs of the pituitary increase receptors for Estradiol, LH and FSH
stimulated by luteinizing hormone (LH)	Theca cells of developing follicle	Androstenedione and Testosterone (lipid soluble)	serve as precursors for synthesis of Estradiol
stimulated by LH and FSH	Luteal cells of the corpus luteum	Progesterone and Estradiol (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression Progesterone inhibits the rapid endometrial growth and stimulates growth of glands and elongation of arteries Progesterone inhibits the GnRH neurons in the hypothalamus
stimulated by LH and FSH	Luteal cells of the corpus luteum	Relaxin (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP (at least in part) relaxes the cervix and softens cartilage and fibrous connective tissue stimulates VEGF in endometrium

Table A.12. Testes and Actions of Testicular Hormones

Stimulus	*Cells / Source*	*Hormone*	*Action*
stimulated by follicle stimulating hormone (FSH)	Sertoli cells within the Seminiferous tubules	Estradiol (lipid soluble)	FSH stimulates production of androgen binding globulin
stimulated by follicle stimulating hormone (FSH)	Sertoli cells	Inhibin (water soluble)	Inhibits FSH gonadotrophs in pituitary
stimulated by luteinizing hormone (LH)	Leydig cells between the Seminiferous tubules	Testosterone (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs Essential in high local concentration for spermatogenesis Inhibits GnRH secretion by hypothalamic neurons required for pubertal masculinization to occur increases muscle mass and body growth close Epiphyseal growth plate