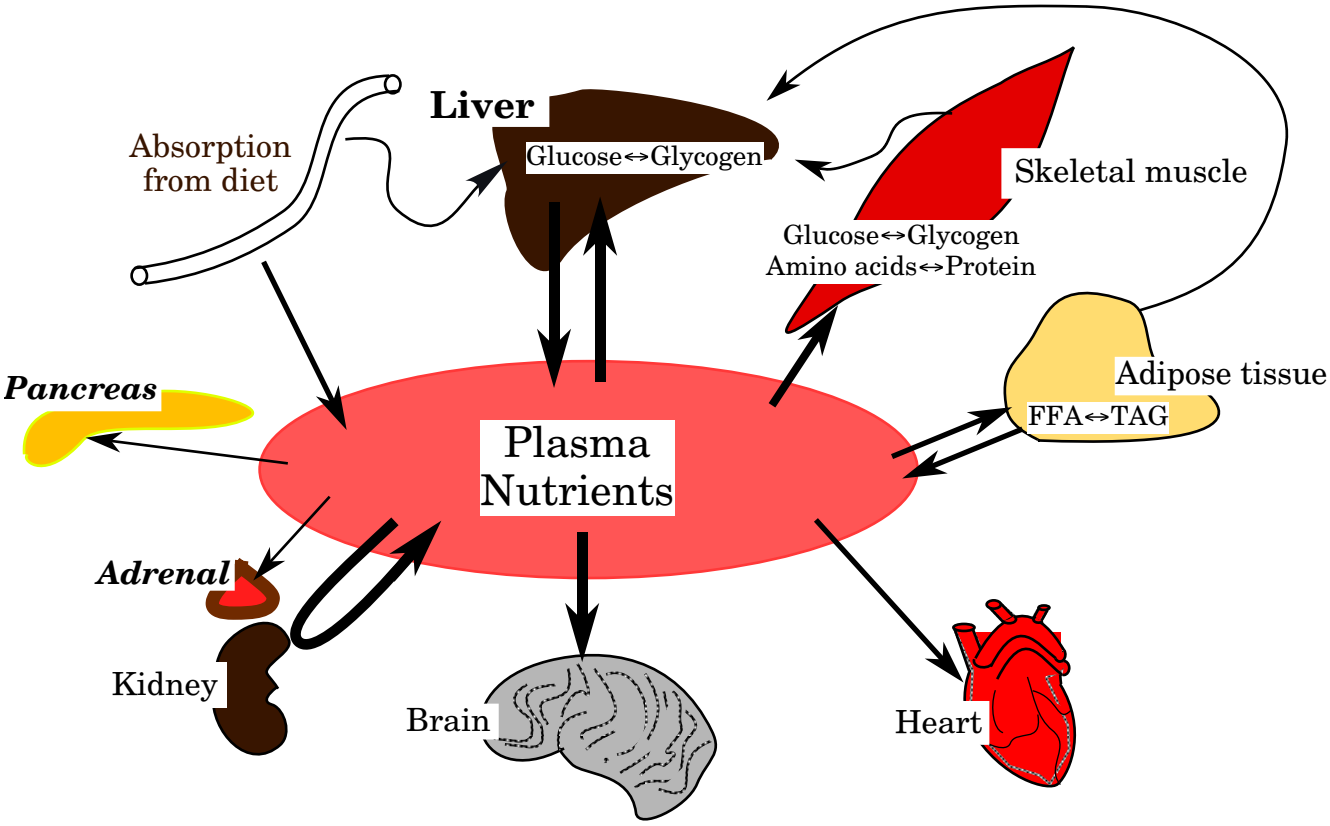
Major Metabolic Control Hormones

Hormone	Receptor	Second messenger	Mechanism	Target tissues
Insulin (51 amino acid heterodimeric peptide)	Tyrosine kinase	Phosphorylated proteins decreased cAMP	Δ Enzyme activity Gene transcription	Liver, muscle, adipose, pancreas, many others
Glucagon (29 amino acid peptide)	G-protein coupled	cAMP	Δ Enzyme activity Sometimes gene transcription	Liver, pancreas
Cortisol (steroid)	Transcription factor	Altered level of specific mRNA	Gene transcription	Nearly all
Epinephrine (tyrosine derivative)	G-protein coupled (at least four types)	cAMP decreased cAMP PI hydrolysis	Δ Enzyme activity	Liver, muscle, adipose, brain, pancreas, cardiovascular
Growth hormone (191 amino acid protein)	Cytokine family cell surface	Tyrosine kinase PI hydrolysis	Δ Enzyme activity Sometimes gene transcription	Liver, muscle, adipose; others mediated by IGF-I



Regulation of Liver Metabolism

Pathway	Regulatory enzyme	Stimulators	Inhibitors	Hormones affecting enzyme activity	Hormones affecting enzyme levels
Glycolysis	*Glucokinase*	(High plasma glucose)			Insulin ↑ Cortisol ↓
	Phosphofructokinase	Fructose 2,6-bisphosphate, AMP	Citrate, ketone bodies, ATP, phosphoenolpyruvate	Insulin ↑ Glucagon ↓ Epinephrine ↓ (all via altered [F2,6bP])	Insulin ↑ Cortisol ↓
	Pyruvate kinase	AMP, Fructose-1,6-bisphosphate	ATP, alanine	Insulin ↑ Glucagon ↓ Epinephrine ↓	Insulin ↑ Cortisol ↓
Gluco-neogenesis	*Phosphoenolpyruvate carboxykinase*			Glucagon ↑	Insulin ↓ Cortisol ↑ Glucagon ↑
	Fructose 1,6-bisphosphatase		Fructose 2,6-bisphosphate, AMP	Insulin ↓ Glucagon ↑ Epinephrine ↑	Insulin ↓ Cortisol ↑
	Glucose-6-phosphatase				Insulin ↓ Cortisol ↑
TCA Cycle	*Pyruvate dehydrogenase*	CoA, NAD, ADP, pyruvate, Ca^{2+}	Acetyl-CoA, NADH, ATP	Insulin ↑	
	Pyruvate carboxylase	Acetyl-CoA	ADP		Insulin ↓ Cortisol ↑ Glucagon ↑
	Citrate synthase	NAD, (TCA cycle intermediates)	Citrate, Long chain acyl-CoA, ATP, NADH, succinyl-CoA		
	Isocitrate dehydrogenase	ADP, Ca^{2+}	ATP, NADH		
	α-ketoglutarate dehydrogenase	Ca^{2+}	ATP, NADH, succinyl-CoA, GTP		
Glycogen synthesis	*Glycogen synthase*	Glucose-6-phosphate	Glycogen	Insulin ↑ Glucagon ↓ Epinephrine ↓	Insulin ↑ Cortisol ↑
Glycogen breakdown	*Glycogen phosphorylase*	AMP	Glucose-6-phosphate, ATP	Insulin ↓ Glucagon ↑ Epinephrine ↑	
Hexose mono-phosphate	*Glucose-6-phosphate dehydrogenase*	NADP	NADPH		Insulin ↑
Urea cycle	*Glutamate dehydrogenase*	ADP	ATP, GTP, NADH		
	Carbamoyl phosphate synthetase I	N-acetyl-glutamate (substrate)			
Fatty acid synthesis	*Acetyl-CoA carboxylase*	Citrate	Long-chain acyl-CoA	Insulin ↑ Glucagon ↓	Insulin ↑
Ketone body synthesis	*HMG-CoA synthase*	Acetyl-CoA			Glucagon ↑
Cholesterol synthesis	*HMG-CoA reductase*		Cholesterol, bile acids	Insulin ↑ Glucagon ↓	
Purine synthesis	*Ribose-phosphate pyrophosphokinase*		Adenine, Guanine and Thymine nucleotides		
	PRPP glutamyl amidotransferase	PRPP	Adenine and Guanine nucleotides		
Pyrimidine synthesis	*Carbamoyl phosphate synthetase II*	ATP, PRPP	Uridine nucleotides, GTP		
	Aspartate transcarbamoylase		CTP		

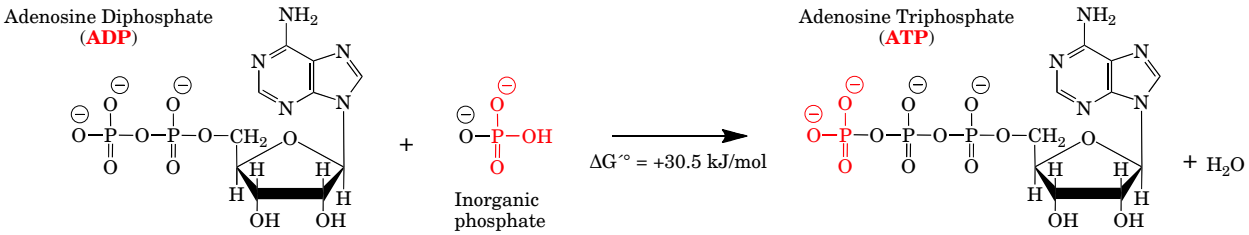
Regulation of Skeletal Muscle Metabolism

Pathway	Regulatory enzyme	Stimulators	Inhibitors	Hormones affecting enzyme activity	Hormones affecting enzyme levels
Glycolysis	*Glucose transporter (GLUT 4)*	(Muscle contraction)		Insulin ↑ Cortisol ↓ (change amount in plasma membrane)	Insulin ↓ Cortisol ↑
	Hexokinase		Glucose-6-phosphate		
	Phosphofructo-kinase	Fructose 2,6-bisphosphate, AMP, (Muscle contraction)	Citrate, ketone bodies, ATP		Cortisol ↓
Glycogen synthesis	*Glycogen synthase*	Glucose-6-phosphate, low Glycogen levels	Ca^{2+}, AMP	Insulin ↑ Epinephrine ↓	Insulin ↑
Glycogen breakdown	*Glycogen Phosphorylase*	Ca^{2+}, AMP	Glucose-6-phosphate, ATP	Insulin ↓ Epinephrine ↑	
Protein synthesis	*Transcription and translation initiation*				Insulin ↑ Growth hormone ↑ Androgens ↑ Cortisol ↓
Protein breakdown	*Protease activation*				Insulin ↓ Cortisol ↑

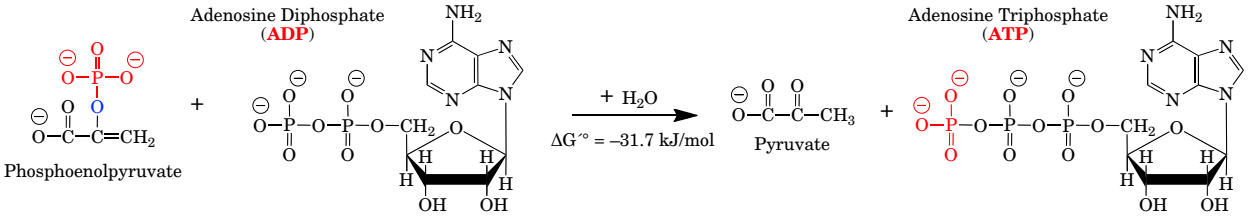
Regulation of Adipose Tissue Metabolism

Pathway	Regulatory enzyme	Stimulators	Inhibitors	Hormones affecting enzyme activity	Hormones affecting enzyme levels
Glycolysis	*Glucose transporter (GLUT 4)*			Insulin ↑ Cortisol ↓ (change amount in plasma membrane)	Insulin ↓ Cortisol ↑
	Hexokinase		Glucose-6-phosphate		
	Phosphofructo-kinase	Fructose 2,6-bisphosphate, AMP, (Muscle contraction)	Citrate, ketone bodies, ATP		Cortisol ↓
Triacyl-glycerol synthesis	*Lipoprotein lipase*	(high VLDL, chylomicrons)			Insulin ↑
	Glycerol phosphate acyltransferase		(low glycerol phosphate levels)		
Triacyl-glycerol breakdown	*Hormone-sensitive lipase*			Insulin ↓ Epinephrine ↑	Insulin ↓ Cortisol ↑

Oxidative Phosphorylation and Photo-phosphorylation (*ATP synthase*)

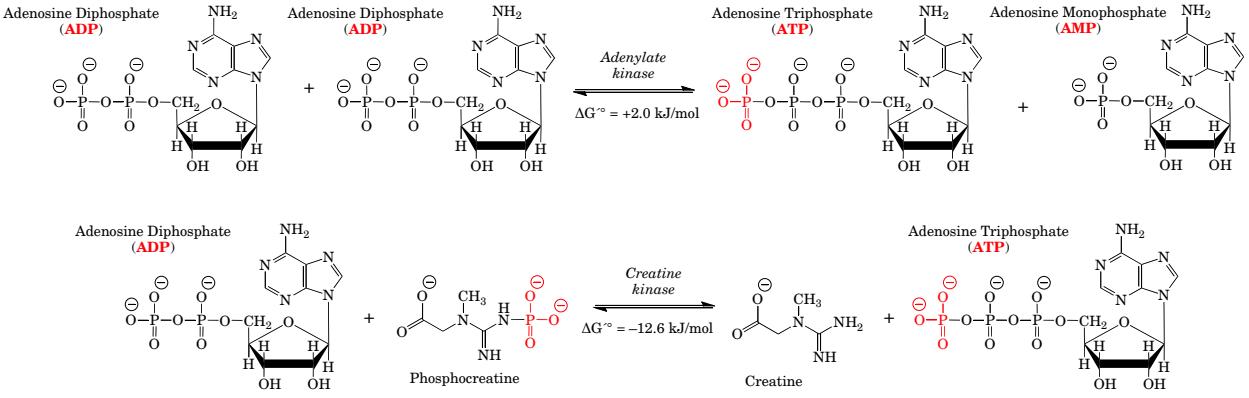


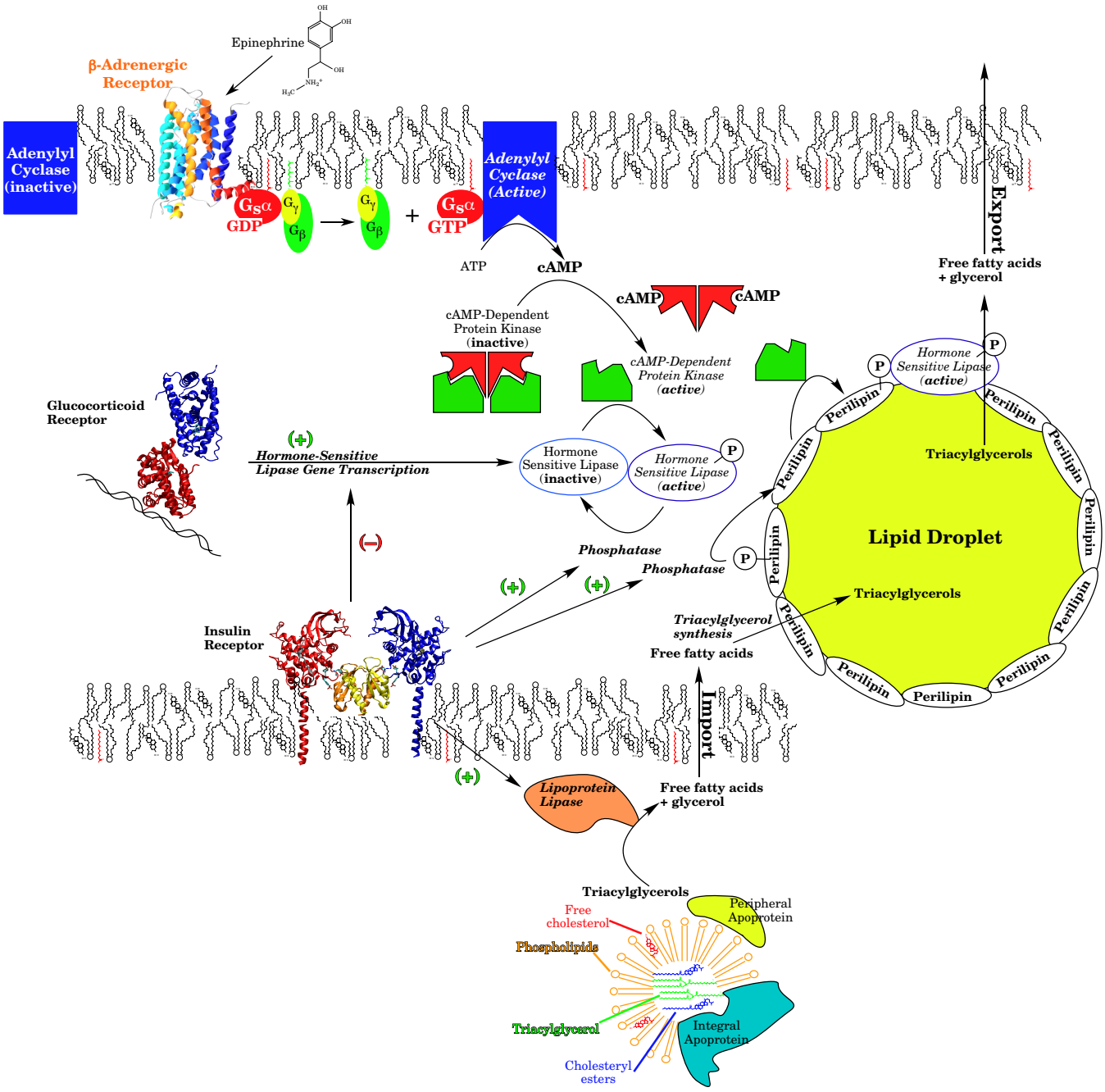
Substrate-Level Phosphorylation (*Pyruvate kinase*)



Phosphoglycerate kinase
Succinyl-CoA synthetase

ATP Buffers




Epinephrine
β-Adrenergic Receptor
Adenylyl Cyclase (inactive)
Adenylyl Cyclase (Active)
GSα
GDP
Gγ
Gβ
GTP
ATP
cAMP
cAMP-Dependent Protein Kinase (inactive)
cAMP-Dependent Protein Kinase (active)
Export
Free fatty acids + glycerol
Glucocorticoid Receptor
(+)
Hormone-Sensitive Lipase Gene Transcription
Hormone Sensitive Lipase (inactive)
Hormone Sensitive Lipase (active)
P
Perilipin
Triacylglycerols
Lipid Droplet
(–)
Phosphatase
Insulin Receptor
Triacylglycerol synthesis
Free fatty acids
Import
Lipoprotein Lipase
Free fatty acids + glycerol
Triacylglycerols
Peripheral Apoprotein
Free cholesterol
Phospholipids
Triacylglycerol
Integral Apoprotein
Cholesteryl esters