ACSM's Introduction to Exercise Science, Third Edition

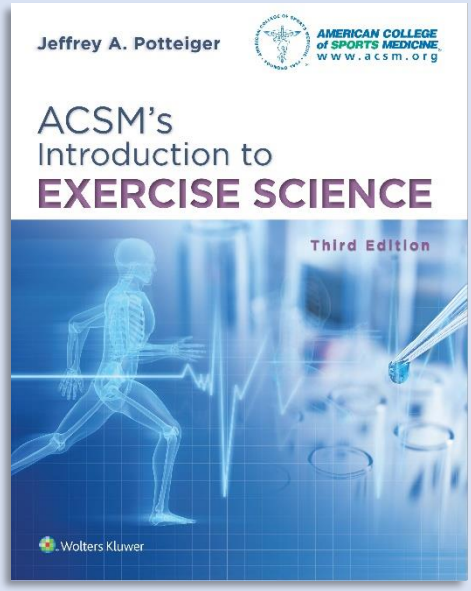

Table 3.9 Functions of the Digestive System and their Relationship to Physical Activity, Exercise, Sport, and Athletic Performance

FUNCTION	RELATION TO PHYSICAL ACTIVITY AND EXERCISE AND SPORT AND ATHLETIC PERFORMANCE
Delivery of macronutrients to the body	Carbohydrates, fats, and proteins are essential for the optimal function of the body during and after movement
Delivery of micronutrients to the body	Vitamins and minerals are essential for the optimal function of the body during and after movement

gastric emptying and intestinal absorption (50). An examination of how the gastrointestinal, cardiovascular, and muscular systems interact can help demonstrate these limitations. Gastric emptying rates and the intestinal absorption of glucose from a 6% glucose electrolyte solution have been measured at 1.2 and 1.3 g/minute under resting conditions and 1 g/minute during exercise (32). As the concentration of glucose in the beverage rises, the rate at which ingested glucose is supplied to the blood is lower than the rate of carbohydrate used in the muscle. This suggests either a gastrointestinal limitation to using the ingested carbohydrate as a fuel or a failure of the cardiovascular system to deliver glucose from the gastrointestinal tract into the main blood supply (87). The simultaneous consumption of both glucose and fructose, which are absorbed from the gastrointestinal tract by different mechanisms, results in the greater use of the carbohydrates for energy by muscle than the ingestion of similar amounts of glucose or fructose consumed alone (3). Furthermore, if glucose is infused into the blood, rather than consumed orally, the glucose can be used to supply energy at a faster rate (27). Collectively, this information suggests that the delivery of ingested carbohydrate from the gastrointestinal tract to the cardiovascular system might be a limiting factor in the use of ingested carbohydrate as an energy source for contracting muscle during exercise (51). Table 3.9 provides a summary of the functions of the digestive system and examples of how those functions relate to physical activity, exercise, sport, and athletic performance.

Thinking Critically

In what ways could consumption of a carbohydrate beverage improve performance during a competitive marathon or triathlon?

ENDOCRINE SYSTEM

The endocrine system is the another primary control system (along with the nervous system) of the body. It helps to regulate physiologic function and influence the function of other systems of the body. One advantage of the endocrine system for controlling functions is that the hormones can circulate and influence tissues throughout the entire body without requiring a hard connection (as in the nervous system). Furthermore, endocrine changes can influence function for a duration lasting from a few seconds to several hours. The endocrine system accomplishes these functions through the use of hormones secreted by the various endocrine glands of the body. Even though the endocrine glands are not connected anatomically, they

Homeostasis The maintenance of relatively stable internal physiologic conditions.

function as a system in a practical sense. Many of these hormones are important for influencing both the acute responses and the chronic adaptations of the systems of the body to physical activity and exercise (49, 118).

The primary components of the endocrine system are the glands of the body and the hormones that each gland secretes. Some endocrine glands only specialize in hormonal secretion (e.g., anterior pituitary and thyroid), whereas other components of the endocrine system consist of organs that perform other functions in addition to secreting hormones (e.g., testes secrete testosterone and also produce sperm). The endocrine system, by means of the blood-borne hormones it secretes, generally regulates activities and functions at a much slower pace than the other primary control mechanism of the body, the nervous system. Most of the activities under the control of hormones are directed toward maintaining **homeostasis** (normal conditions of functioning) of the body (49, 118). Table 3.10 illustrates

Table 3.10 Endocrine Glands and Selected Secreted Hormones (118)

ENDOCRINE GLAND	HORMONES
Hypothalamus	Releasing and inhibiting hormones
Posterior pituitary	Vasopressin
Anterior pituitary	Thyroid-stimulating hormone, adrenocorticotropic hormone, and growth hormone
Thyroid gland	Thyroxin, triiodothyronine, and calcitonin
Adrenal cortex	Aldosterone, cortisol, and androgens
Adrenal medulla	Epinephrine and norepinephrine
Pancreas	Insulin and glucagon
Parathyroid gland	Parathyroid hormone
Ovaries	Estrogen and progesterone
Testes	Testosterone
Kidneys	Renin and erythropoietin
Stomach	Gastrin
Liver	Somatomedins
Skin	Vitamin D
Heart	Atrial natriuretic peptide
Adipose tissue	Leptin and adiponectin

various endocrine glands of the body of interest to exercise science and the primary hormones each secretes.

Endocrine System and Exercise Science

Hormones affect the systematic responses of the body in various ways and often work with other systems of the body to regulate normal functions during physical activity and exercise. For example, epinephrine and norepinephrine (also called adrenaline and noradrenaline, respectively) have been shown to increase heart rate and blood pressure in response to stress, including physical activity and exercise (16). Insulin maintains blood glucose concentrations by increasing glucose uptake and utilization as an energy source in tissues of the body. The interaction of epinephrine, norepinephrine, and insulin has been associated with the development of hypertension in a disease condition called metabolic syndrome (129). Metabolic syndrome describes the clustering of several conditions of the body, including obesity, hyperinsulinemia, elevated triglyceride levels, hypertension, and type 2 diabetes. Figure 3.10 shows the relationship among the clustering of metabolic syndrome risk factors. Central to the understanding of metabolic syndrome is the role insulin resistance plays in the development of some of the associated disease conditions. A diet high in fat and refined sugar (6) contributes significantly to the development of insulin resistance. A decreased ability of cells to absorb glucose at

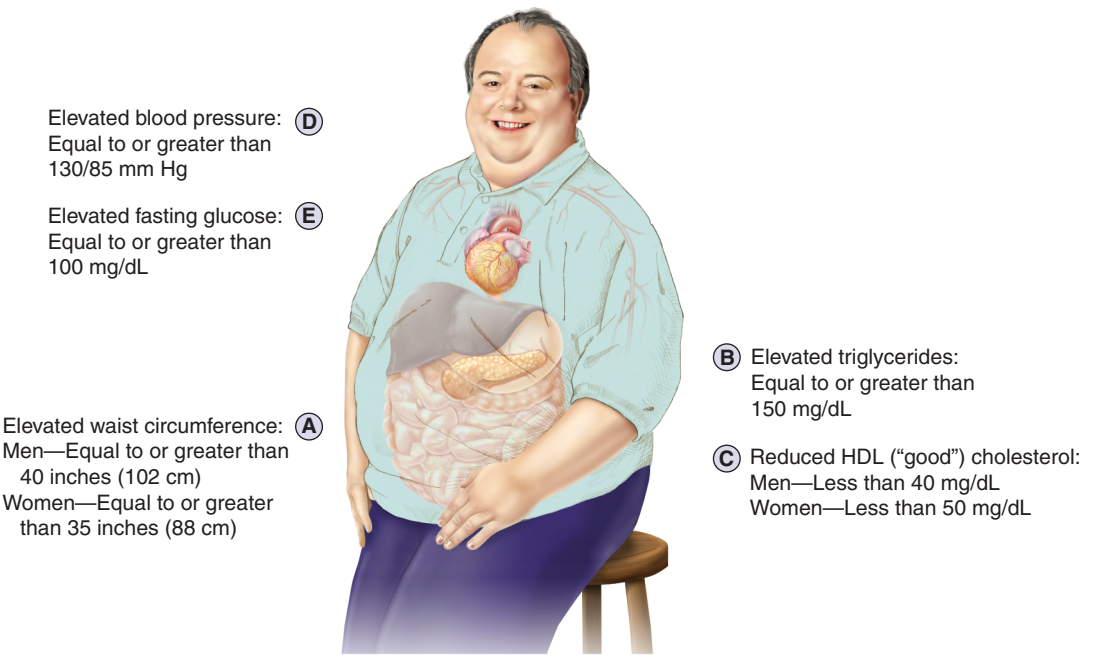

FIGURE 3.10 The relationship among the clustering of metabolic syndrome risk factors. (Asset provided by Anatomical Chart Co.)

a given insulin concentration characterizes the condition of insulin resistance. In response to increasing insulin resistance by the tissues of the body, the pancreas secretes more insulin in an effort to promote blood glucose uptake into cells and return the blood glucose concentration to normal. If the pancreas cannot secrete sufficient amounts of insulin, the blood glucose concentration remains elevated and type 2 diabetes results (49). When the pancreas is forced to secrete additional insulin to address the insulin resistance, the plasma insulin level becomes elevated (called hyperinsulinemia). This condition can elevate blood pressure and contribute to the development of hypertension. Sympathetic nervous system activity increases in response to elevated insulin levels. This response can lead to an elevation of the hormones epinephrine and norepinephrine, which can lead to an increase in heart rate, stroke volume, and blood pressure. The elevated levels of epinephrine and norepinephrine can also interfere with insulin release from the pancreas and glucose uptake at the tissue, causing an aggravation of the problem. In this case, insulin resistance contributes significantly to the hypertension. Alternatively, given the complex interaction of the events, hypertension may in fact cause the insulin resistance. Physical activity and regular exercise can benefit individuals with insulin resistance and hypertension by improving the body's sensitivity to the hormones insulin, epinephrine, and norepinephrine (51, 83, 108).

Coaches and athletes have long been interested in the use of **exogenous** hormone supplementation to improve assorted types of sports and athletic performance. For example, the use of anabolic steroids (e.g., synthetic testosterone) and human growth hormone for improving athletic performance is common among certain groups of athletes (17, 33, 58, 94, 127) although recent evidence indicates that androgen use has decreased in adolescents (58). Anabolic steroids have both **androgenic effects** and **anabolic effects** (128). The anabolic actions cause the body to increase protein synthesis in skeletal muscles and various other tissues, which can then lead to increased nitrogen retention. The increased protein synthesis can result in an increased muscle size and strength as well as increased body weight (49). For those sports that rely on body size or the generation of power and force by the muscle, the increase in muscle mass and strength often result in improvements in sport and athletic performance. When used in high dosages, as often the case with athletes, there are potentially serious side effects that may be irreversible and cause serious health problems (58, 128). Although the use of these types of substances and others like them is illegal and considered unethical, there has been considerable interest in understanding how these substances work and how the illegal use of these substances can be detected (58, 128). Identifying the mechanism by which these hormones work is important for determining how these substances can be detected in saliva, blood, and urine (66) for compliance

Exogenous Coming from outside the body.
Androgenic effects The development and maintenance of masculine characteristics.
Anabolic effects The development and maintenance of tissue, particularly skeletal muscle.

with athletic-governing association rules. Issues surrounding effective drug testing include using equipment that is sensitive enough to detect drug metabolites in the blood or urine, identifying the various metabolites that are associated with synthetic anabolic steroids, and ensuring that effective drug testing is a deterrent to anabolic steroid and other anabolic substance use by athletes (66). Table 3.11 provides the primary hormones of the endocrine system and some examples of how those functions relate to physical activity, exercise, sport, and athletic performance.

Table 3.11 Primary Hormones of the Endocrine System and Relationship of Their Functions to Physical Activity, Exercise, Sport, and Athletic Performance

HORMONE	FUNCTION	RELATION TO PHYSICAL ACTIVITY, EXERCISE, SPORT, AND ATHLETIC PERFORMANCE
Adiponectin	Regulates glucose and fatty acid metabolism	Plays a role in the suppression of metabolic abnormalities
Aldosterone	Increases sodium reabsorption and potassium excretion in the kidneys	Helps regulated fluid balance to prevent dehydration
Calcitonin	Decreases plasma calcium concentration	Increases calcium deposition in bone
Cortisol	Increases blood glucose concentration; contributes to stress adaptation	Helps increase blood glucose concentration to avoid hypoglycemia
Epinephrine and norepinephrine	Reinforces sympathetic nervous system activity	Assists the body when responding to the stress of movement
Erythropoietin	Stimulates red blood cell production in bone marrow	Increases oxygen delivery to working tissues
Estrogen	Responsible for development of secondary sexual characteristics	Helps regulate lean mass and skeletal mass in the body
Glucagon	Promotes maintenance of nutrient levels in blood, especially glucose	Helps regulate blood glucose levels during exercise
Growth hormone	Essential for the growth of bones and soft tissue, protein anabolism, fat mobilization	Promotes the growth of lean and skeletal tissue
Insulin	Promotes uptake of absorbed nutrients, especially insulin	Helps regulate blood glucose levels after food consumption
Leptin	Assists the brain in regulating appetite and metabolism	Helps assist the body in the regulation of an appropriate body weight
Testosterone	Responsible for development of secondary sexual characteristics	Helps regulate lean mass in the body
Vitamin D	Increases absorption of ingested calcium and phosphate in the gastrointestinal tract	Helps regulate levels of calcium in the body, especially bone