Instructor's Answer Key

Chapter 14: Cardiac Output, Blood Flow, and Blood Pressure

Answers to Test Your Understanding of Concepts and Principles

1. The preload is the pressure load imposed on the ventricular muscle when the end-diastolic volume of blood stretches the myocardium prior to systole. The contractility is the strength of myocardial contraction at a given preload. The afterload is the workload imposed on the myocardium once contraction has begun and represents the pressure on the semilunar valves that must be overcome in order to eject blood out of the ventricles and into the arteries. Cardiac output is directly proportional to the preload and to the contractility (raises stroke volume); and is inversely proportional to the afterload (reduces stroke volume). [Note: This question is also answered in the Student Study Guide.]

2. (a) During bradycardia the cardiac rate is slower than normal and therefore a longer time is available for the ventricles to fill with blood. Thus during each cardiac cycle, the end-diastolic volume (and preload) is greater than normal, the myocardium is more greatly stretched causing an increase in the contraction strength. As a result, the stroke volume is increased during bradycardia. (b) If the heart "misses a beat," the amount of blood that would have otherwise been ejected remains in and around the ventricles. The incoming blood arriving in preparation for the next beat supplements this volume. The end-diastolic volume is thus greater than normal, the myocardium is more greatly stretched, and more blood (stroke volume) is ejected at the next systole.

3. Most (nearly 60%) of the blood in the circulatory system is contained within the veins. The smaller muscular arteries (arterioles) provide the greatest resistance to blood flow. The capillaries have the greatest cross-sectional area when considered as a group, because—though each capillary is narrower than any other type of vessel—there is a tremendously large number of capillaries in the body.

4. The kidneys are involved in the regulation of blood volume since urine is made in the nephron tubules from filtered blood plasma. The more blood plasma removed to make nephron filtrate and the more urine that is excreted from the body, the less filtered fluid is reabsorbed and thus the lower the blood volume a person will have. While the volume of filtrate produced is very large (~180 L/day), most of this filtered volume is returned to the circulatory system by reabsorption so that only about 1 liter of urine is excreted each day. The amount of the filtrate reabsorbed is adjusted mainly by means of hormones such as ADH, aldosterone, and atrial natriuretic factor that act on the kidneys and by the nervous system regulation of blood flow. In this way the kidneys can adjust the blood volume according to the needs of the body.

5. Dehydration raises the blood plasma osmolality and thereby stimulates osmoreceptors in the hypothalamus that makes a person thirsty to drink more fluids. In addition, these osmoreceptors stimulate other neurons in the hypothalamus that causes the posterior pituitary to secrete ADH. ADH stimulates the kidneys to reabsorb water from the filtrate, so that a lower volume of more highly concentrated urine is excreted.

6. Blood flow is inversely proportional to the vascular resistance. The vascular resistance, in turn, is inversely proportional to the fourth power of the radius of the vessel. Blood flow is thus directly proportional to the fourth power of the radius of the vessel. The fourth power function means that small changes in a vessel's radius can have a disproportionately large effect on blood flow. If the resistance to flow is greatly increased by vasoconstriction within one organ while it is decreased by vasodilation in a second organ, the rate of blood flow will be increased in the second organ at the expense of blood flow to the first organ.

7. During exercise, cardiac output increases primarily because of an increase in cardiac rate, which occurs as a result of decreased parasympathetic activity and increased sympathetic nerve activity and perhaps also by an increase in stroke volume. The stroke volume either remains unchanged or, in well-trained athletes, may increase to some degree. Both heart rate and stroke volume effects are due to the increase in sympathetic stimulation that increases cardiac contractility so that a higher proportion of the end-diastolic volume is ejected per stroke. The end-diastolic volume however remains about the same as it is at rest, as a result primarily of increased activity of the skeletal muscle pumps that effectively return venous blood to the heart. The rate of blood flow to the heart and skeletal muscles is increased as a result of two effects: (1) increased cardiac output causes the blood to circulate many times faster than at rest, and (2) vasodilation in the arterioles of skeletal muscles and heart, produced by intrinsic metabolic mechanisms, acts to divert blood to the organs that have greatly increased metabolic rate during exercise.

8. An anxious person has a highly active sympathetic nervous system. Alpha-adrenergic activity causes cutaneous vasoconstriction while sympathetic cholinergic activity stimulates secretion of the sweat glands. Hence, cold, clammy skin is produced. On a hot, humid day the body core temperature rises, thermoregulation dilates arterioles and cutaneous blood flow is increased while cutaneous arteriovenous anastomoses are constricted. As a result, the skin has a higher rate of blood flow, which is directed to surface capillaries. This makes the skin hot and flushed.

9. Angiotensin converting enzyme (ACE) inhibitors block the enzyme that leads to the formation of angiotensin II, thus reducing its vasoconstrictor effect and its release of aldosterone from the adrenal cortex. The ACE inhibitors also increase the activity of bradykinin, a polypeptide that promotes vasodilation. The reduced formation of angiotensin II and increased action of bradykinin results in vasodilation, which decreases the total peripheral resistance. Less aldosterone means less sodium and water reabsorption from the kidney nephron, and more urine volume. All these effects work to lower blood pressure. Diuretic drugs work to lower blood pressure by increasing urine volume while decreasing blood volume. $Beta_1$-adrenergic blocking drugs lower blood pressure by causing arteriolar vasodilation that lowers peripheral resistance and blood pressure.

10. (a) Hypovolemic shock refers to circulatory shock due to abnormally low blood volume, which causes low blood pressure and decreased cardiac output. (b) Septic shock refers to dangerously low blood pressure that may result from infection (sepsis) in the blood. Often, bacterial lipopolysaccharides called endotoxin is released that stimulates macrophages to secrete nitric oxide, which promotes vasodilation and the fall in blood pressure. In response to low blood pressure, people in shock have an activated sympathetic nervous system caused by the baroreceptor reflex. Shock results in a rapid, but weak pulse due to increased heart rate, but decreased blood volume and decreased venous return; whereas (as in question #8) alpha-adrenergic vasoconstriction combined with cholinergic stimulation of the sweat glands explains the cold, clammy skin. Urine output decreases because less filtrate is formed so that blood volume will increase or stay elevated.

Answers to Test Your Ability to Analyze and Apply Your Knowledge

1. The Frank-Starling intrinsic law of the heart demonstrates that the strength of ventricular contraction varies directly with the end-diastolic volume. The heart has essentially two pumps: the right ventricle drives the pulmonary circulation while the left ventricle supplies the systemic circulation. Since the return of venous blood to the right ventricle varies considerably throughout the day, the Frank-Starling law operates so that the right ventricular contraction strength and thus, the stroke volume will adjust instantly to these preload variations. The net result is the ventricle raises its stroke volume output when venous return is increased and lowers its stroke volume when venous return is lowered. Furthermore, when the left ventricle subsequently receives the newly altered volume of blood, it too will adjust its stroke volume to match that of the right ventricle. In this way the heart can intrinsically compensate for the moment-to-moment fluctuations in the return of blood to the heart. If the stroke volumes were not matched, one ventricle or the other would soon be depleted of blood and the pump would fail.

2. This man is suffering from congestive heart failure (CHF). The digoxin is prescribed to promote the intracellular Ca^{2+} concentrations in the myocardial fibers and thus increase the strength of contraction. However, his failing right ventricle is resulting in increased right atrial pressures. The backup of venous blood raises venous pressures that oppose the venous return and ultimately, the return of interstitial fluid to the capillaries. In this way the veins become engorged and edema forms, especially in the dependent limbs affected by gravity such as the feet. The expanded veins, the purple splotches (from ruptured veins near the skin surface), and the edema therefore all result from failure of the right ventricle as a pump. Partial compensation for CHF is an increase in renin secretion and consequent activation of the renin-angiotensin-aldosterone system causing salt and water retention. This patient's chronically low cardiac output is associated with elevated blood volume that places a work overload on the heart. Lasix is prescribed as a diuretic to encourage the urinary excretion of salt and water that would help lower the blood volume and reduce the workload on the heart and relieve the edema and venous engorgement. In addition, elevating his feet would help relieve the edema by promoting the return of excess tissue fluid both to the capillaries and to the lymphatics.

3. You are thirsty because you are dehydrated and your blood plasma osmolality is elevated. During exercise, the need to maintain a deep-body temperature takes precedence over the need to maintain an adequate systemic blood pressure. In this endurance race, your blood sodium and total blood volume have been lowered by the increased need to sweat while racing for subsequent evaporative heat loss. The resulting low blood pressure is very dangerous. Drinking pure water may not be the answer in this extreme case. This is because blood sodium is lost in sweat, so that a lesser amount of water is required to dilute the blood osmolality back to normal. When the blood osmolality is normal, the urge to drink is extinguished. Therefore, on prolonged endurance races such as this one, you should accept the sports drink offered by race volunteers providing it contains only a weak solution of sodium and carbohydrate concentrations and providing you drink it following predetermined schedule (rather than waiting until thirsty).

4. Salt (NaCl) is an important dietary requirement in the maintenance of blood volume, blood pressure, and in the distribution of body water in general. Since Na^+ and Cl^- are easily filtered in the kidneys, complex mechanisms are in place to regulate the overall salt balance in the body. Hormones play important roles in this regulation of body salt. Aldosterone, for example is a hormone from the adrenal cortex that serves to reabsorb salt from the kidney filtrate and thus conserve body salt and water; whereas atrial natriuretic peptide is a hormone from the heart atrial wall that works to discard salt and thereby rid the body of extra salt and water (regulated also by ADH). In this way salt and water homeostasis can be efficiently regulated. However, about 20% of all adults in the United States have hypertension. High-salt intake along with perhaps an inability of the kidneys to properly eliminate salt and water are commonly associated with hypertension. Thus, recommending sodium (salt) restriction diets would be prudent advice to citizens since reduced salt intake has been shown to be effective in lowering blood pressure.

5. Exercise using isometric muscle contractions would put a greater “strain” on the heart. Isometric contractions occur when great force is applied without appreciable movement of the muscle, such as during very heavy weight lifting. To accomplish heavy lifts, people often employ the Valsalva’s maneuver in which a deep breath is taken with an expiratory effort against a closed glottis. Performance of this maneuver transiently increases the intrathoracic pressure that, in turn, reduces venous return, lowers stroke volume, decreases cardiac output, and lowers arterial blood pressure. Also, during this breath holding interval the drop in blood pressure stimulates the baroreceptor reflex, resulting in tachycardia and decreased total peripheral resistance. When the glottis is finally opened, the intrathoracic pressure and cardiac output return to normal. However, the decrease in peripheral resistance is still in effect causing a transient, explosive, flow of blood to dilated capillaries, possibly causing rupture (hemorrhage) or if in the brain, a stroke. Although the baroreceptor reflex will eventually respond and compensate for the blood pressure changes, the fluctuations that occur during isometric muscular exercise can be dangerous in people predisposed to cardiovascular disease and/or weakened blood vessels. Isotonic exercise is usually not associated with breathholding.