PHYSIOLOGIC RESPONSES AND LONG-TERM ADAPTATIONS TO EXERCISE

The body's physiologic responses exercise occurs in the following systems

Musculoskeletal

Cardiovascular

Respiratory

Endocrine

immune systems.

Cardiovascular and Respiratory Systems

The primary functions of the cardiovascular and respiratory systems are to provide the body with oxygen (O_2) and nutrients, to rid the body of carbon dioxide (CO_2) and metabolic waste products, to maintain body temperature and acid-base balance, and to transport hormones from the endocrine glands to their target organs (Wilmore and Costill 1994). To be effective and efficient, the cardiovascular system should be able to respond to increased skeletal muscle activity. As the rate of muscular work increases, these two systems will eventually reach their maximum capacities and will no longer be able to meet the body's demands.

Cardiovascular Responses to Exercise

The cardiovascular system, composed of the heart, blood vessels, and blood, responds predictably to the increased demands of exercise. With few exceptions, the cardiovascular response to exercise is directly proportional to the skeletal muscle oxygen demands for any given rate of work, and oxygen uptake increases linearly with increasing rates of work. Cardiac Output Cardiac output (Q) is the total volume of blood ˙ pumped by the left ventricle of the heart per minute. It is the product of heart rate (HR, number of beats per minute) and stroke volume (SV, volume of blood pumped per beat). The arterial-mixed venous oxygen (A-- vO_2) difference is the difference between the oxygen content of

Adapted from Wilmore JH, Costill DL. Physiology of sport and exercise. Champaign, IL: Human Kinetics, 1994,
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the arterial and mixed venous blood. A person's maximum oxygen uptake (VO˙ 2 max) is a function of cardiac output (Q) multiplied by the ˙ A-- vO2 difference. Cardiac output thus plays an important role in meeting the oxygen demands for work. As the rate of work increases, the cardiac output increases in a nearly linear manner to meet the increasing oxygen demand, but only up to the point where it reaches its maximal capacity (Q max).

Blood Flow

The pattern of blood flow changes dramatically when a person goes from resting to exercising. At rest, the skin and skeletal muscles receive about 20 percent of the cardiac output. During exercise, more blood is sent to the active skeletal muscles, and, as body temperature increases, more blood is sent to the skin. This process is accomplished both by the increase in cardiac output and by the redistribution of blood flow away from areas of low demand, such as the splanchnic organs. This process allows about 80 percent of the cardiac output to go to active skeletal muscles and skin at maximal rates of work (Rowell 1986). With exercise of longer duration, particularly in a hot and humid environment, progressively more of the cardiac output will be redistributed to the skin to counter the increasing body temperature, thus limiting both the amount going to skeletal muscle and the exercise endurance (Rowell 1986).

Blood Pressure

Mean arterial blood pressure increases in response to dynamic exercise, largely owing to an increase in systolic blood pressure, because diastolic blood pressure remains at near-resting levels. Systolic blood pressure increases linearly with increasing rates of work, reaching peak values of between 200 and 240 millimetres of mercury in normotensive persons. Because mean arterial pressure is equal to cardiac output times total peripheral resistance, the observed increase in mean arterial pressure results from an increase in cardiac output that outweighs a concomitant decrease in total peripheral resistance. This increase in mean arterial pressure is a normal and desirable response, the result of a resetting of the arterial baroreflex to a higher pressure. Without such a resetting, the body would experience severe arterial hypotension during intense activity (Rowell 1993). Hypertensive patients typically reach much higher systolic blood pressures for a given rate of work, and they can also experience increases in diastolic blood pressure. Thus, mean arterial pressure is generally much higher in these patients, likely owing to a lesser reduction in total peripheral resistance. For the first 2 to 3 hours following exercise, blood pressure drops below preexercise resting levels, a phenomenon referred to as post exercise hypotension (Isea et al. 1994). The specific mechanisms underlying this response have not been established. The acute changes in blood pressure after an episode of exercise may be an important aspect of the role of physical activity in helping control blood pressure in hypertensive patients.

Oxygen Extraction

The A-- vO2 difference increases with increasing rates of work (Figure 3-2) and results from increased oxygen extraction from arterial blood as it passes through exercising muscle. At rest, the A-- vO2 difference is approximately 4 to 5 ml of O2 for every 100 ml of blood (ml/100 ml); as the rate of work approaches maximal levels, the A-- vO2 difference reaches 15 to 16 ml/100 ml of blood.

Coronary Circulation

The coronary arteries supply the myocardium with blood and nutrients. The right and left coronary arteries curve around the external surface of the heart, then branch and penetrate the myocardial muscle bed, dividing and subdividing like branches of a tree to form a dense vascular and capillary network to supply each myocardial muscle fiber. Generally one capillary supplies each myocardial fiber in adult humans and animals; however, evidence suggests that the capillary density of the ventricular myocardium can be increased by endurance exercise training. At rest and during exercise, myocardial oxygen demand and coronary blood flow are closely linked. This coupling is necessary because the myocardium depends almost completely on aerobic metabolism and therefore requires a constant oxygen supply. Even at rest, the myocardium's oxygen use is high relative to the blood flow. About 70 to 80 percent of the oxygen is extracted from each unit of blood crossing the myocardial capillaries; by comparison, only about 25 percent is extracted from each unit crossing skeletal muscle at rest. In the healthy heart, a linear relationship exists between myocardial oxygen demands, consumption, and coronary blood flow, and adjustments are made on a beat-to-beat basis. The three major determinants of myocardial oxygen consumption are heart rate, myocardial contractility, and wall stress (Marcus 1983; Jorgensen et al. 1977). Acute increases in arterial pressure increase left ventricular pressure and wall stress. As a result, the rate of myocardial metabolism increases, necessitating an increased coronary blood flow. A very high correlation exists between both myocardial oxygen consumption and coronary blood flow and the product of heart rate and systolic blood pressure (SBP) (Jorgensen et al. 1977). This socalled double product (HR x SBP) is generally used to estimate myocardial oxygen and coronary blood flow requirements. During vigorous exercise, all three major determinants of myocardial oxygen requirements increase above their resting levels. The increase in coronary blood flow during exercise results from an increase in perfusion pressure of the coronary artery and from coronary vasodilation. Most important, an increase in sympathetic nervous system stimulation leads to an increase in circulating catecholamines. This response triggers metabolic processes that increase both perfusion pressure of the coronary artery and coronary vasodilation to meet the increased need for blood flow required by the increase in myocardial oxygen use

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