The Cardiovascular Physiology of Sports and Exercise

Mildred A. Opondo, MD[a,b,c], Satyam Sarma, MD[a,b,c], Benjamin D. Levine, MD[a,b,c,*]

KEYWORDS

• Exercise • Physiology • Athlete • $\dot{V}O_2$

KEY POINTS

- Exercise and sports performance are influenced by the ability of the cardiovascular system to meet the increased metabolic demand for oxygen by the working muscles.
- The 'athlete's' heart phenomenon involving physiologic hypertrophy and resting sinus bradycardia is among the mechanisms that facilitate a high stroke volume and cardiac output during exercise.
- Graded exercise tests are used to assess peak $\dot{V}O_2$. Other aspects of exercise testing may also be relevant for evaluating sports performance.
- When testing of athletes, it is critical to use a test that closely matches the demands of the sport, including training and competition.
- The level of supervision needed during an exercise test should be determined by the clinician before test and depends on the underlying cardiovascular risk of the individual being tested.

INTRODUCTION

Elite athletes are paragons of physical fitness in our society, and an entire "sports–industrial complex" has developed from playing, watching, and marketing sports.[1] A better understanding of the physiologic factors underlying the human body's ability to perform and sustain high workloads has helped to push sports science into a prominent role in athletic training.

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[a] Institute for Exercise and Environmental Medicine, 7232 Greenville Avenue, Suite 435, Dallas, TX 75231, USA; [b] Texas Health Presbyterian Hospital Dallas, 8200 Walnut Hill Lane, Dallas, TX 75231, USA; [c] Department of Internal Medicine, University of Texas Southwestern Medical Center, 5323 Harry Hines Boulevard, Dallas, TX 75390, USA
* Corresponding author. Institute of Exercise and Environmental Medicine, 7232 Greenville Avenue, Suite 435, Dallas, TX 75321.
E-mail address: BenjaminLevine@Texashealth.org

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Exercise and sports performance depend greatly on the ability of the cardiovascular system to respond to a wide range of metabolic demands and physical exertion. Certain sports, in particular endurance activities, place high demands on the heart and blood vessels to adequately deliver oxygen, remove carbon dioxide, and dissipate heat from exercising muscle. Analogous to a race car engine, the heart forms the core of the response, supplying circulatory power to generate hydraulic pressure. The greater the circulatory power, the more work that can be expended by the body. The regulation of cardiac output in turn is under the control of a complex system of feedback and feedforward signals originating from skeletal muscle metaboreceptors and mechanoreceptors, as well as coming directly from higher order centers in the brain, largely occurring under autonomic control. The integration of these neural reflexes with the cardiovascular system is controlled tightly, yet allows for flexibility such that the body can respond rapidly to changes in exercise intensity.

With habitual endurance exercise training, the cardiovascular system remodels and can undergo a number of changes, leading to improvements in internal cardiac efficiency (lower heart rate for a given cardiac output) and overall exercise capacity or fitness. The remarkable ability of the human body to increase aerobic fitness highlights the plasticity and trainability of the system. This article reviews the basic principles of exercise physiology, cardiovascular adaptations unique to the "athlete's heart," and utility of exercise testing in athletes.

PRINCIPLES OF EXERCISE PHYSIOLOGY

At the most basic level, the primary purpose of the cardiovascular system during physical exertion is to deliver oxygen to exercising muscle to support the metabolic demands of respiring mitochondria. Different sports or activities have different degrees of aerobic and strength requirements and forms the basis for categorization of recreational and competitive sports by the 36th Bethesda conference, which has been updated recently (**Fig. 1**).[2]

Physical activities can be characterized by their degree of dynamic (aerobic) or static (strength) requirements. Indeed, the cardiovascular and skeletal muscle adaptations of an endurance trained athlete are quite different compared with a sprinter and highlight the unique metabolic machinery necessary for each activity. Endurance activities typically place more demand on aerobic respiration and require large increases in cardiac output and a higher density of "slow twitch" skeletal muscle fibers. In contrast, short bursts of explosive activity place significant demands on substrate level phosphorylation to rapidly supply adenosine triphosphate for maximal power generation and rely less on bulk delivery of oxygen to the exercising muscle.

THE OXYGEN CASCADE AND QUANTIFYING AEROBIC FITNESS

The ability to absorb, deliver, and metabolize oxygen determines aerobic fitness. Oxygen uptake ($\dot{V}O_2$) is a direct measure of aerobic capacity and a fundamental concept in sports science. The V denotes "volume" and the dot over the V reflects "rate" and is expressed as liters per minute, but is often scaled by adjusting to body weight as milliliters per minute per kilogram to account for differences in body size. Measuring an individual's maximum $\dot{V}O_2$ provides a useful assessment of cardiorespiratory fitness by integrating the various organ systems (lung, heart, and muscle) involved in generating aerobic power into what is effectively a single variable. The determinants of oxygen uptake can be understood by following the "oxygen cascade," the steps in the respiratory chain that start with oxygen absorption within the lungs to oxidation within the mitochondria.