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Cardiovascular adaptation in athletes

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ABSTRACT

Millions of athletes train for and participate in competitive athletics each year. Many of these athletes will present to a cardiovascular specialist with signs or symptoms that might indicate heart disease and these athletes/patients will ask for advice on their ability to continue to train and compete safely. By virtue of their training, athletes' hearts may undergo significant structural and electrical change, presenting a special challenge for the cardiovascular specialist. It is important to understand normal adaptive changes in order to separate normal physiology from pathology.

Keywords: Athlete's heart, Sports cardiology, Exercise, Athlete, Cardiomyopathy, Hypertrophy.

Magnitude and complexity of the athlete population

A recent state-of-the-art paper [1] summarized the role of cardiovascular specialty in respect to an explosion in the number of athletes training for and participating in organized and recreational sports. More than 44 million boys and girls participate in youth sports each year, nearly 10 million at the high school level and nearly half a million at the collegiate level. About 541,000 runners finished a marathon in 2013 in the U.S. Professional sports teams employ thousands of athletes. The number of older athletes (>35 years) is increasing but difficult to estimate. Many of these athletes have pre-existing heart disease including the adult survivors of congenital heart disease whose numbers now exceed the number of children with congenital heart disease.

The variety of sports has also dramatically increased, with athletes participating in traditional sports such as football, basketball, and track but also emerging and extreme sports that push the limits of human endurance. A total number of 28 sports will be contested at the 2016 Summer Olympics, and many of those sports are subdivided into disciplines that each has unique demands on the cardiovascular system.

The ethnic diversity of the athlete population is increasing but also may be increasingly sport specific. African-Americans comprised 76% of all NBA players but only 8% of major league baseball players. Statistics on youth and recreational sports are more difficult to come by but can be expected to reflect the increasing diversity in the population in general.

These factors are all important to consider in framing the discussion of cardiovascular adaptation in the athlete, as adaptation will be dependent on both the characteristics of the sport and the participant. One size will not fit all, and the lessons learned in one sport may not translate to the athletes in another sport. The field has developed to the point where experts have called for new paradigms in the care of this unique population by the cardiovascular care team [1].

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Evolving tools to characterize cardiovascular adaptation in athletes

Cardiovascular adaptation in the athlete was limited to the description of physical findings until the advent of modern imaging techniques. Morganroth et al. [2] described the assessment of cardiac adaptation through the use of modern imaging techniques such as echocardiography for the assessment of chamber size and wall thickness [2]. In 2014, multimodality imaging is readily available to assess cardiac structure and function in the athlete, with cardiac CT, cardiac MR, and advanced echo techniques such as strain imaging or 3-D available to define cardiac anatomy.

Cardiac electrophysiology was limited in the past to evaluation by resting electrocardiogram or hard-wired stress tests. Ambulatory monitoring with standard Holter recorders or event monitors remains difficult in any person during exercise and nearly impossible during competition. In 2014, a variety of wearable sensors, miniaturized event recorders, and even implantable devices allow for easier assessment of electrophysiological changes in athletes.

Classification of sports into categories with expected adaptive changes has also evolved. These categories have been incorporated in guidelines for athletic participation [3]. Sports-specific databases are being developed, with the National Football League and the National Basketball Association performing screening imaging exams, and recording data to allow for the establishment of normative values in professional sports. Collegiate programs have been developed to evaluate incoming student athletes and have demonstrated the rapid pace of cardiac adaptation that occurs upon beginning collegiate training programs.

The need to differentiate normal adaptation from disease

Increasing numbers of competitive and highly trained athletes are presenting to both primary care providers and specialists for initial clearance to play as well as for return to play decisions after potential cardiac symptoms or a suspicious event. These decisions have important ramifications for the athlete, their family, team, league, and community. Athletes want to return to play, whether for the personal reasons of an amateur or the financial incentives of a professional. Accurate and timely decisions need to be made to avoid interruptions in training or competition. Several states have enacted laws that regulate return to play in student athletes. All parties want safety for the athlete. The medical provider faces the special issues of medical liability.

The overlap between physiology and pathology is important in clinical medicine but is even more crucial in the athlete population, where several important causes of athletic sudden cardiac death can be difficult to differentiate from adaptation. We refer specifically (but not exclusively) to the left ventricular hypertrophy of training, as opposed to the pathologic hypertrophy of a hypertrophic cardiomyopathy; right ventricular chamber enlargement, as opposed to arrhythmogenic right ventricular cardiomyopathy; or prolonged ventricular repolarization due to a training-related bradycardia, as opposed to a congenital long-QT syndrome.

The cardiovascular specialist as well as the primary care provider involved in screening athletes or determining return to play needs to understand cardiac adaptation to athletic training. In addition, the practitioner should also be aware of the particular demands of the sport, understand what is expected for the age and level of training of the individual athlete they are faced with, and be aware of confounding factors, such as performance enhancing drugs, that might interfere with the ability to differentiate adaptation from disease.

Physiologic demands of sports

Basics of exercise physiology

The physiology underlying competitive athletics and vigorous exercise is complex. Physical activity requires the coordinated and purposeful contraction of specific groups of skeletal muscle that are recruited by the central nervous system to perform specific tasks. The actions that are inherent in sporting activity, referred to in aggregate as “external work,” include, but are not limited to, actions such as running, pedaling, and jumping. These actions can be quantified precisely using sport-specific metrics, including running speed or cycling wattage. For any given athletes, there is a direct correlation between the magnitude of external work and the amount of internal work required to complete any specific task. Internal work, the total metabolic cost of physical activity, is a broad term that encompasses substrate utilization, substrate transport, and metabolic by-product removal and is most commonly quantified by measurement of oxygen consumption (VO_2). The cardiovascular system plays a key role in dynamic process of internal work. Specifically, the primary goal of the cardiovascular system is to simultaneously provide the activated skeletal muscle with energy-rich substrate (i.e., glucose, fatty acids, and oxygen) and to return the by-products of metabolism to the organs responsible for their disposal. This process is accomplished by increases in cardiac output, the magnitude of which is tightly coupled to the needs of the activated skeletal muscle groups. Fundamental mechanisms responsible for increased cardiac output in the context of exercise include increases in heart rate, ventricular stroke volume, and peripheral arterial vasodilation.

The physiology of cardiac remodeling

Exercise-induced cardiac remodeling (EICR) is stimulated by the pressure and volume stressors that accompany increases in both external and internal work (Fig.) [4]. The specific stimuli inherent in the exercise response can be dichotomous into isometric and isotonic physiology. Isotonic stress refers to the movement of large quantities of blood through the cardiovascular system. Endurance sporting disciplines including long-distance running, Nordic skiing, rowing, and cycling are characterized by a predominance of isotonic