Journal of the American College of Cardiology
© 2014 by the American College of Cardiology Foundation
Published by Elsevier Inc.
Vol. 63, No. 15, 2014
ISSN 0735-1097/$36.00
http://dx.doi.org/10.1016/j.jacc.2013.12.033

STATE-OF-THE-ART PAPERS

Sports and Exercise Cardiology in the United States

Cardiovascular Specialists as Members of the Athlete Healthcare Team

Christine E. Lawless, MD,*† Brian Olshansky, MD,‡ Reginald L. Washington, MD,§ Aaron L. Baggish, MD,|| Curt J. Daniels, MD,¶ Silvana M. Lawrence, MD, PhD,# Renee M. Sullivan, MD,** Richard J. Kovacs, MD,†† Alfred A. Bove, MD, PhD‡‡

Chicago, Illinois; Lincoln, Nebraska; Iowa City, Iowa; Denver, Colorado; Boston, Massachusetts; Columbus, Ohio; Houston, Texas; Columbia, Missouri; Indianapolis, Indiana; and Philadelphia, Pennsylvania

In recent years, athletic participation has more than doubled in all major demographic groups, while simultaneously, children and adults with established heart disease desire participation in sports and exercise. Despite conferring favorable long-term effects on well-being and survival, exercise can be associated with risk of adverse events in the short term. Complex individual cardiovascular (CV) demands and adaptations imposed by exercise present distinct challenges to the cardiologist asked to evaluate athletes. Here, we describe the evolution of sports and exercise cardiology as a unique discipline within the continuum of CV specialties, provide the rationale for tailoring of CV care to athletes and exercising individuals, define the role of the CV specialist within the athlete care team, and lay the foundation for the development of Sports and Exercise Cardiology in the United States. In 2011, the American College of Cardiology launched the Section of Sports and Exercise Cardiology. Membership has grown from 150 to over 4,000 members in just 2 short years, indicating marked interest from the CV community to advance the integration of sports and exercise cardiology into mainstream CV care. Although the current athlete CV care model has distinct limitations, here, we have outlined a new paradigm of care for the American athlete and exercising individual. By practicing and promoting this new paradigm, we believe we will enhance the CV care of athletes of all ages, and serve the greater athletic community and our nation as a whole, by allowing safest participation in sports and physical activity for all individuals who seek this lifestyle. (J Am Coll Cardiol 2014;63:1461–72) © 2014 by the American College of Cardiology Foundation

Confirmation of the benefits of exercise (1–4), increased participation in organized athletics, and efforts to combat the obesity epidemic have led to marked increases in the numbers of Americans participating in sports and exercise in all major demographic groups over the last decade (5–9). Among athletes ≤35 years of age, 44 million youth (≤18 years of age) participate annually in organized sports, with 7.7 million and 463,202 engaged at the high school and collegiate levels, respectively (6,7). Older, or master, athletes (≥35 years of age), are particularly drawn to endurance sports. Marathon finishers have increased from 353,000 in 2000 to over 500,000 in 2011 (8); U.S. triathlon memberships have increased from 21,341 to more than 146,000 during the same period (9). Simultaneously, as children and adults with established heart disease are living longer with improved quality of life, many have contemplated participation in sports and exercise (10).

Paradoxically, despite its favorable effects on well-being and survival, exercise can acutely increase the risk of myocardial infarction (11,12), aortic dissection (13,14), arrhythmias (15–19), and sudden cardiac arrest (SCA) (Online Appendix) and/or death (SCD) (20,21). Chronically,

From the *University of Chicago and Sports Cardiology Consultants LLC, Chicago, Illinois; †Bryan Heart–University of Nebraska, Lincoln, Nebraska; ‡University of Iowa Hospitals, Iowa City, Iowa; §Rocky Mountain Hospital for Children, Denver, Colorado; ||Harvard University and Massachusetts General Hospital, Boston, Massachusetts; ¶The Ohio State University and Nationwide Children's Hospital, Columbus, Ohio; #Baylor College of Medicine and Texas Children's Hospital, Houston, Texas; **University of Missouri, Columbia, Missouri; ††Indiana University School of Medicine, Indianapolis, Indiana; and the ‡‡Temple University Hospital, Philadelphia, Pennsylvania. Dr. Olshansky has served on the data and safety monitoring boards of Boston Scientific, Amarin, and Sanofi-Aventis; has served as a consultant to Boston Scientific, BioControl, Boehringer Ingelheim, Daiichi Sankyo, and Denali Medical; has served as a speaker for Medtronic; and has received honoraria from Boston Scientific, Medtronic, Daiichi Sankyo, Boehringer Ingelheim, BioControl, Amarin, and Sanofi-Aventis. Dr. Daniels receives financial support for research from Actelion, United Therapeutics, Gilead, Bayer, Amplatzer, and the National Institutes of Health. Dr. Sullivan receives financial support from Biotronik for the EPIC Alliance. Dr. Bove has served as a consultant to Insight Telehealth Systems, LLC, and World Health Networks, Inc.; and has stock ownership in Insight Telehealth Systems, LLC. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Manuscript received November 12, 2013; revised manuscript received December 17, 2013, accepted December 24, 2013.

Abbreviations and Acronyms

ACA = anomalous coronary artery

ARVC = arrhythmogenic right ventricular cardiomyopathy

CT = computerized tomography

CV = cardiovascular

echo = echocardiography

EP = electrophysiology

HCM = hypertrophic cardiomyopathy

PPE = pre-participation evaluation

RTP = return-to-play

SCA = sudden cardiac arrest

SCD = sudden cardiac death

complex cardiovascular (CV) demands and adaptations imposed by exercise pose distinct challenges to the cardiologist asked to evaluate athletes (22,23) and/or prescribe a level of participation (24). From cardiac screening to resuscitation, we propose that effective CV care of athletes and active individuals requires: 1) commitment to patient-centered care; 2) an athlete-centered CV knowledge base; 3) clinical tools grounded in the fundamentals of sports and exercise cardiology; 4) relevant cardiology practice; 5) familiarity with the "athlete healthcare delivery system"; 6) willingness to promote research efforts; and 7) desire to advocate for the athlete and exercising individual. Here, we provide the rationale for tailoring of CV care to athletes and exercising individuals, define the role of the CV specialist within the athlete healthcare team, and lay the foundation for the development of sports and exercise cardiology in the United States.

Athletes and Exercising Individuals as Unique Cardiac Patients

Evolution of sports cardiology and the athlete as a patient. Athletes are held in high esteem in society, owing to their extraordinary abilities and the excessive adulation bestowed upon them (i.e., "hero-worship") (25). Importantly, clinicians caring for athletes have identified a distinct set of athlete-related medical issues involving virtually every organ system, while recognizing the potential for interaction between medical conditions and sports performance, and the need to make immediate and long-term "return-to-play" (RTP) decisions (26). Such observations and practices led to the creation of a general sports medicine specialty (27), subspecialty interest groups such as sports podiatry (28) and sports neurology (29), and certifications and fellowships based upon a particular sport or activity, such as the Undersea and Hyperbaric Medicine Certification (30) and Wilderness Medicine Fellowship (31).

Given the CV demands of exercise (32), training-related CV adaptations (33), and the interaction of the heart with internal and external athletic environments (34,35), sports and exercise cardiology is a natural and obvious step in the evolution of the sports medicine subspecialties. One of the major components of any effective healthcare system is "patient-centered care," defined as care "respectful of and responsive to individual patient preferences, needs, and values" (36). In 2012, the American College of Cardiology Foundation (ACCF) Clinical Quality Committee proposed the development of "patient-centered CV care" (37); as the epitome of such care, "athlete-centered CV care" (sports and exercise cardiology) is strongly aligned with the ACCF proposal. Moreover, fundamental to the practice of sports and exercise cardiology is the notion that athletes are "different" from the general population from a physiologic and/or medical perspective; there is also distinct heterogeneity among athletic populations.

Epidemiology of SCD in athletes. Contrary to expectation, when considering exercise as a trigger to SCD, the contemporary incidence of SCD is actually *similar or lower* in young athletes compared with nonathletes (20). Among American populations (age 11 to 19 years), the overall incidence of SCD appears to be *markedly lower* in young athletes compared with nonathletes: 0.44 per 100,000 person-years (38) or less (39) versus 6.37 per 100,000 person-years, respectively (40). However, SCD may be higher, 2.28 per 100,000 athlete-years, in the overall American National Collegiate Athletic Association (NCAA) population, or even higher in subgroups such as African Americans or male Division I basketball players (41), suggesting that there is variable risk according to age, sex, ethnicity, level of play, and sport.

Prevalence of SCA among older athletes, examined largely as a function of sport type, is reported to be 0.54 per 100,000 person-years among marathon and half-marathon participants (N = 10.9 million) (42), with a 29% resuscitation rate and resultant SCD prevalence of 0.39 per 100,000 person-years (42). Among triathletes, SCD risk may be slightly higher due to risks associated with open water swimming (43). Such information can be used to answer important questions related to the sport-specific risk of participation, event preparation, allocation of resources, and clinical trial design (42,44).

Athletic adaptations and cardiac testing. Briefly, endurance training (e.g., long-distance running) causes sustained volume load to the heart (45), resulting in 4-chamber enlargement and increased stroke volume at rest and exercise (46). By contrast, strength training (e.g., weight lifting) causes a pressure load to the heart (45) accompanied by normal left ventricular (LV) wall thickness (<1.2 cm), but a disproportionate increase in relation to cavity size (47–49). Some sports, such as basketball, present a combination of the 2 types of loads. For further study, readers are referred to several excellent reviews of CV exercise physiology, training adaptations, and interaction of the heart with the athletic environment (22,33–35,46,47,50,51).

Training-related electrophysiological (EP) adaptations, which appear on the electrocardiogram (ECG) in the form of bradycardias, atrioventricular and interventricular blocks, extrasystoles, interval prolongations, increased voltage, and repolarization abnormalities (52), are more common in athletes compared with nonathletes (53,54), and vary according to sex, ethnicity, body size, and type of training or sport (55,56). What is known about cardiac structural athletic adaptations is shown in Table 1 (22,46–49,57–71).

Table 1 Cardiac Structural Athletic Adaptations: 35 Years of Research

1. Increases in LV and RV dimension and volume are common and more apt to occur in endurance sports such as cycling, rowing, and cross country skiing (46–48).
2. Increases in LV wall thickness more than 1.3 cm are unusual, but can occur in up to 1.7% of elite athletes (46,47) and 0.4% of junior elite athletes (63).
3. Degree of adaptation varies according to sex, age, body size and mass, type of sport, and ethnicity, especially for athletes of African descent (47,57–68).
4. A small number of healthy athletes can show 1.3- to 1.5-cm LV wall thickness (66).
5. African athletes can demonstrate LV wall thickness up to 1.6 cm (64,67).
6. Patterns of hypertrophy vary, with endurance and strength training more likely to cause eccentric and concentric hypertrophy, respectively (23).
7. Strength sports (weightlifting or wrestling) are associated with usually normal thickness (<1.2 cm, but disproportionate increase in relation to cavity size) (46–49).
8. Although uncommon among athletes in general (46), up to 11% of healthy long-distance cyclists may have mildly reduced LVEF (68).
9. Newer techniques such as tissue Doppler and speckle tracking radial strain echocardiography assist in differentiating physiological from pathological remodeling (69–71).

LV = left ventricular; LVEF = left ventricular ejection fraction; RV = right ventricular.

Similar to ECG, these differ significantly from nonathletes (63,65) and vary considerably among athlete subgroups (57–71). Most of this work has been generated in European or endurance athletes, with relatively little data generated in American athletes at relevant levels of sport (high school, collegiate, professional, masters, and recreational).

Athlete "gray zone" and differentiation from inherited diseases. EP and structural adaptations become clinically significant when cardiac testing requires differentiation from cardiac pathologies. A high prevalence of training-related changes that mimic features of inherited diseases, accompanied by what is likely low disease prevalence in athletes, can place athletes into a unique category known as the "gray zone" (47). Classically applied to LV cavity and wall thickness (24,47), the gray zone may also apply to the RV, corrected QT interval, and ST-segment. Although specialized tools, including cardiopulmonary exercise testing, advanced echocardiography (echo), cardiac magnetic resonance imaging, supervised detraining, pharmacological infusion, and genetic testing may be useful to differentiate between normal adaptations and true cardiac pathology (22,24,47), to successfully navigate gray zone nuances, CV specialists must have a clear understanding of both the "normal" limits to cardiac athletic adaptations and the cardinal features of the inherited diseases that cause athlete SCD (21).

Unlikely to be the only manifestation of hypertrophic cardiomyopathy (HCM) (72), isolated LV hypertrophy can be seen in up to 40% of athlete ECGs (55) and is considered a normal variant (52,73). If LV hypertrophy is accompanied by ST-segment depression, Q waves, or left axis deviation, HCM is far more likely, as such features are rare in athlete ECGs (52,73,74). Given the upper limit of LV wall thicknesses in healthy Caucasian athletes (1.3 to 1.5 cm) (Table 1) and those of African descent (1.6 cm) (Table 1) and the overlap with HCM wall thickness, advanced echo (tissue Doppler and speckle tracking radial strain) may be particularly helpful to differentiate adaptation from HCM (69–71).

Anterior T-wave inversion (leads V_1 to V_4) is more common in black athletes (14.3% of ECGs), compared with either white athletes or control subjects of either race (65), and must be distinguished from the T waves of ARVC. Both black and white athletes have greater RV cavity dimensions compared with control subjects of the same ethnicity; however, wall motion abnormalities in combination with RV dilation is rare, which may aid in distinguishing normal adaptation from ARVC (65).

Although increased RV and LV volumes are very common in athletes (58), reduced left ventricular ejection fraction (LVEF) is rare (46,47). However, 11% of healthy endurance athletes (cyclists) demonstrate mildly reduced LVEF (68), which must be distinguished from dilated cardiomyopathy. Improved LVEF with exercise may not be a helpful clinical tool, because the heart with dilated cardiomyopathy is capable of some degree of contractile reserve (75).

The corrected QT interval, longer in athletes compared with nonathletes (53), requires differentiation from long QT syndromes, and early repolarization patterns prevalent in athletic populations should not be confused with Brugada patterns (76,77) or other potentially lethal conditions (78).

Other cardiac testing. Athletes frequently require ambulatory monitoring; difficulty with lead adherence during physical activity or contact with an opponent can impede monitoring. In such instances, special water-resistant external devices (79), implantable loop recorders (80), commercial heart rate monitors (81), or smart shirts (82) may be helpful. Bruce protocol stress testing, intended to diagnose coronary artery disease, may be insufficient to reproduce athlete symptoms. Clinicians are advised to either monitor during the sporting activity (Fig. 1), or to recreate exercise load and conditions in the exercise laboratory (83). Upright tilt table testing is considered unreliable in athletes, perhaps because of the interaction of high vagal tone with neurocardiogenic responses (84).

Management of CV conditions. Specific antihypertensives (i.e., diuretics or beta-blockers) may be on the World Anti-Doping Agency prohibited list (85) and are thus not suitable for certain athletes. Beta-blockade may not be the best choice due to negative effects on cardiac performance (86). CV medications, tested in general populations, may not be able to control cardiac symptoms, or rhythms during athletics, and the tendency of exercise to trigger arrhythmias may prompt clinicians to ablate re-entrant rhythms or accessory pathways earlier or without a trial of drug therapy (87,88) in athletic individuals. The fact that anticoagulants are contraindicated in contact-sport athletes (24) may influence choice of valve replacement versus repair in those wishing to resume contact sports after surgery. Implanted pacemakers may negatively impact sports performance due

JACC Vol. 63, No. 15, 2014
April 22, 2014:1461–72

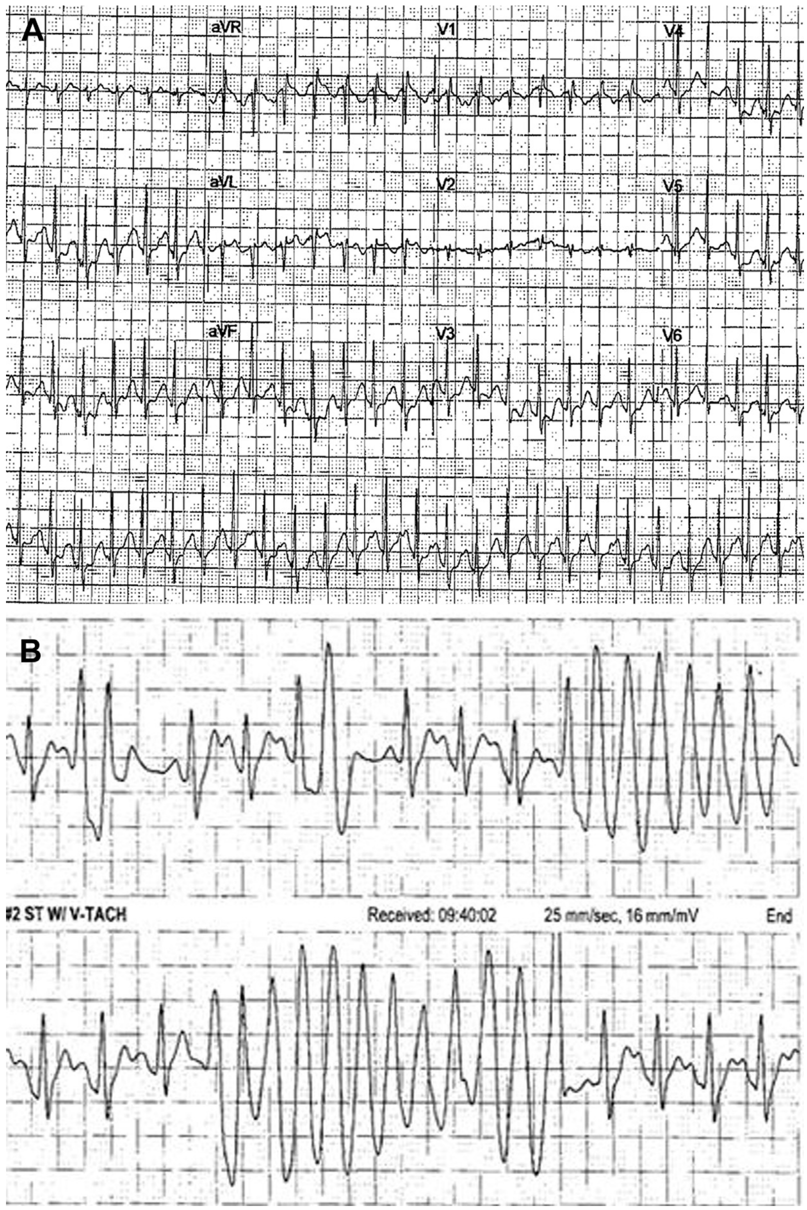

Figure 1 **Importance of Proper Choice of Monitoring in Athletes**

A 44-year-old man complained of palpitations and dizziness while playing competitive racquetball. A Bruce protocol stress test to 11:50 min was normal at a heart rate of 177 beats/min **(A)**, and failed to reveal the cause of the symptoms. But ambulatory monitoring while playing racquetball revealed ventricular tachycardia at a heart rate of 144 beats/min **(B)**.

to the upper rate limit behaviors of standard pacemaker models (89), prompting the use of custom-made pacemakers with the ability to achieve and sustain higher heart rates (90). Implantable cardioverter-defibrillators (ICDs) may not reliably defibrillate under athletic conditions (91,92), in which defibrillation thresholds theoretically might be higher or the ICD may suffer damage to leads or to the device itself. This hypothesis prompted a recent multinational prospective registry of the safety of ICDs in sports (93).

Thus, significant evidence supports that athletes are "different" from nonathletes from the epidemiological, physiological, evaluation, and management perspectives, with significant heterogeneity among athlete subgroups. Combined with the need to consider the effects of CV conditions and treatments on sports performance and to incorporate RTP into medical decision making, these differences render the athlete a unique CV patient who is deserving of tailored CV care.

Cardiovascular Specialists as Members of the Athlete CV Care Team

Athlete CV care team and role of the CV specialist. Specialized CV care teams have been designed and implemented to manage heart failure (94) and acute coronary syndromes (95) more effectively, but athlete CV care teams are not as well-defined. Traditionally, team medical staff and primary care physicians (PCPs) perform initial evaluations of athletes and place CV referrals as necessary (96). But contemporary models of athlete CV care increasingly require CV specialist participation to occur earlier and more directly. At the National Basketball Association, National Football League, and Major League Soccer player recruitment combines, local cardiologists partner with league medical staff to design and oversee athlete CV testing (personal communication, E. Dabby [December 2012], J. Provo [September 2013], A. Tucker [June 2012]). From 30% to 47% of Division 1 NCAA schools perform ECG or echo during pre-participation evaluation (PPE) (97,98), often requiring CV specialist interpretation. American high school athletes are only required to undergo basic PPE (96), but elective CV screening programs may enlist CV specialist collaboration (99–101).

Dedicated sports cardiology clinics exist in the United States (102–107); however, CV specialists in closest proximity to the athlete, athletic facilities, and teams generally provide immediate athlete CV care, which allows for efficient evaluation and thereby avoids prolonged absences from practice or competition and the deleterious effects of detraining (108). Further care may be provided by a local CV subspecialist (e.g., EP), an expert in one of the inherited or acquired diseases (e.g., HCM), or a sports cardiologist with expertise in a given sport (e.g., American football). This overall referral pattern supports that all types of CV specialists acquire at least basic knowledge in sports and exercise cardiology.

Beyond screening, CV specialists serve athletes for a variety of other reasons (Table 2). In this capacity, they have a tremendous opportunity and responsibility to balance the risk of both underinterpretation and overinterpretation of findings and application of technology (109). Underinterpretation, or lack of proper treatment, results in exposing the athlete to unnecessary risk. Similarly, overinterpretation of normal findings runs the risk of stigmatizing a young athlete with a diagnosis of heart disease when no disease actually exists, potentially resulting in a lifetime of perceived disability; problems with employment, military service, health insurance, and overall perceptions of health; and resignation to a lifetime of inactivity.

ACC Sports and Exercise Cardiology Section and annual summit. In 2011, the American College of Cardiology (ACC) launched the Section of Sports and Exercise Cardiology. Membership has grown from 150 to over 4,000 members in just 2 short years, indicating marked interest from the CV community to advance the integration of sports and exercise cardiology into mainstream CV care. The European Society of Cardiology has had a similar section since 2005 (110). A survey conducted in July 2013 indicated that the ACC section member cardiologists' specialties are: general (77%), imaging (33%), heart failure/cardiomyopathy (17%), interventional (15%), EP (11%), and pediatrics (9%). More than 68% of respondents evaluate >10 athletes annually (Fig. 2A), most often at the high school, collegiate, and recreational levels (Fig. 2B). When asked why they joined the

Table 2 Reasons CV Specialists See Athletic Patients

1. Help create and implement cardiac policy.
2. Perform and interpret CV screening tests.
3. Make immediate participation and return-to-play decisions.
4. Determine whether there is a CV cause of symptoms.
5. Evaluate finding(s) suggestive of underlying CV pathology during non-CV medical encounters or dedicated pre-participation CV screening.
6. Provide work-up and treatment after nonfatal sudden cardiac arrest.
7. Participation recommendation and exercise prescription with known or corrected CV disease.
8. Assist in transition from cardiac rehabilitation to higher level of exercise.

CV = cardiovascular.

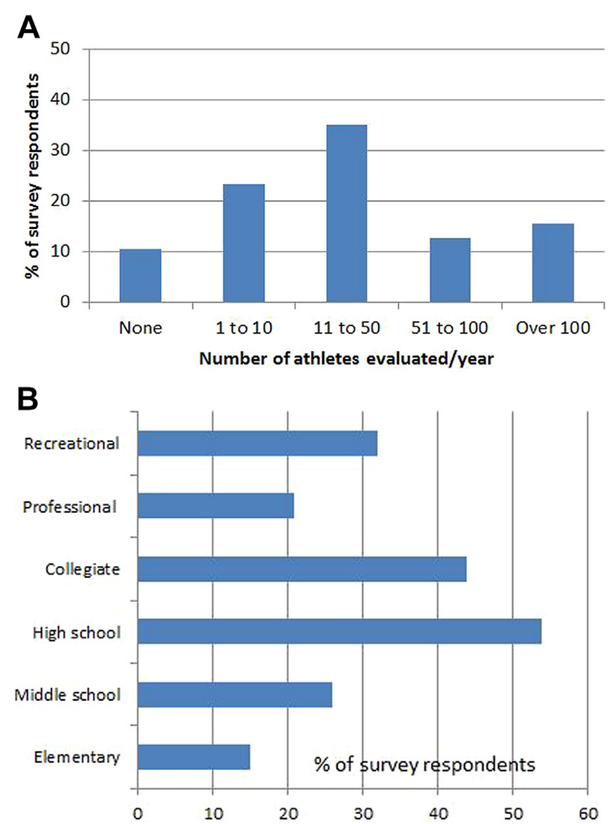

Figure 2 Survey of Members of ACC Sports and Exercise Cardiology Section (n = 250)

A survey conducted in July 2013 among American College of Cardiology (ACC) Sports and Exercise Cardiology Section member cardiologists indicated that more than 68% of respondents evaluate >10 athletes annually **(A)**, most often at the high school, collegiate, and recreational levels **(B)**.

JACC Vol. 63, No. 15, 2014
April 22, 2014:1461–72

section, 86% of respondents indicated to "gain knowledge in sports and exercise cardiology," 55% said to "network with other cardiology providers with an interest in this subject," 42% to "assist in athlete ECG or echo screening," and 41% to "provide evaluation, participation decisions, and exercise prescriptions for athletes." Based on these responses, the ACC Sports and Exercise Cardiology Summit was created. Held annually, this event features sports cardiology education, networking opportunities with medical directors of sports governing bodies, roundtable discussions, and work group meetings. The section is open to any ACC member with interest in sports and exercise cardiology (111).

Limitations of the Current Diagnostic and Therapeutic Model

Deficiencies in training and consensus documents. Although athletes clearly require tailored CV care, and CV specialists serving athletes consider it a priority to be educated in sports and exercise cardiology, current U.S. CV training programs fail to provide any organized or required training in athlete CV care (112,113), and current CV learning pathways neither define nor contain core competencies in this subject matter (114). CV specialists rely on a few expert consensus documents and conference proceedings (24,87,88,115–118), primarily based on studies conducted in nonathletic general populations with known diseases, knowing that vigorous exercise is a trigger of cardiac events in these conditions (119,120). In general, documents are not based on outcome studies in athletic populations with known diseases. Adherence to these recommendations is less than optimal (121), perhaps related to the lack of solid evidence base in athletic populations and/or clinician opinion that they are too restrictive (122,123).

Lack of "athlete-specific" knowledge base. Practical guidelines on how to evaluate clinical symptoms and interpret cardiac testing in athletes are nonexistent, perhaps due to major knowledge gaps (23), lack of normative data in large numbers of U.S. athletes at all levels of play (124), or lack of awareness of athlete CV care as an emerging discipline (76). What is known about cardiac symptoms in general populations, such as chest pain (125), may not apply to the athlete. If not studied prospectively in athletes, the true predictive value of this symptom cannot be known. Thus, CV specialists evaluate athletes with little evidence-based guidance or expert consensus.

Gaps in research, science, and quality. To date, there has not been a single large-scale, prospective, randomized, controlled CV trial in athletes. Without quality data, the ability to create true guidelines (supported by a high level of data) is very limited. Such deficiencies result in multiple controversies in sports and exercise cardiology (Table 3). As an example, many gaps remain in the CV screening controversy. Older retrospective studies suggest a poor sensitivity, 2.5% to 3% (126), of the PPE alone (history and physical). This figure may now be as high as 35% to 40% (127), which perhaps questions the need for ECG. PPE practices in the United States are highly variable and can suffer from a variety of flaws in design and execution (128,129). To allow any meaningful comparisons between PPE with and without CV screening tests, improved PPE practices are necessary. As to whether there is truly any "value added" by ECG and/or echo regarding outcomes, scholarly findings are mixed (20,44). Several ECG interpretation schemes have been proposed (52,73,77), but no scheme has been prospectively validated or correlated with CV outcomes, using data derived from knowledge of underlying structure, in large populations of U.S. athletes of varying ages, sexes, race/ethnicities, and sports. Anomalous coronary artery, the second most common cause of athlete SCD, is not likely to be detected by ECG (130). Precise sensitivity of echo in detecting origins of the coronary artery in athletes is not known (131–133), and may vary according to demographics (e.g., large U.S. football linemen) or type of anomaly (133). The "ECG versus no-ECG" debate (134,135) is bound to continue until uniform acceptable outcome metrics have been established and a well-designed prospective clinical trial has been conducted to answer the question as to which strategy is superior.

Table 3 Controversies in Sports and Exercise Cardiology

1. True epidemiology of SCD events In athletes compared with nonathletes Among athlete subpopulations
2. CV disease prevalence in athletes compared with nonathletes
3. Best practices in screening for CV disease in athletic populations: none, PPE, ECG, echo?
4. Best practices to distinguish Long QT syndrome vs. athlete's heart? Brugada syndrome vs. athlete's heart? Physiological vs. pathological atrioventricular conduction disturbances? Physiological vs. pathological early repolarization? HCM vs. athlete's heart? ARVC vs. athlete's heart? DCM vs. athlete's heart?
5. Utility, efficacy, and proper use of cardiac testing and treatments in athletes ECG, echo, CMRI, CT Stress testing Tilt table Ambulatory monitoring ICDs and pacemakers EP ablations in athletic populations Antihypertensives, antiarrhythmics, lipid-lowering drugs
6. Is there such a thing as "too much exercise?"
7. Can the differences in ACCF/AHA and ESC recommendations be bridged? Screening recommendations Sports participation with known CV disease
8. Can data generated in non-U.S. populations be extrapolated to American athletes?
9. In the absence of prospective outcome data, can participation guidelines be less restrictive in those with known CV disease?
10. Can issues of efficacy, cost, and disparities in ECG screening be resolved?

ACCF/AHA = American College of Cardiology/American Heart Association; ARVC = arrhythmogenic right ventricular cardiomyopathy; CMRI = cardiac magnetic resonance imaging; CT = computed tomography; CV = cardiovascular; DCM = dilated cardiomyopathy; ECG = electrocardiogram; echo = echocardiography; ESC = European Society of Cardiology; EP = electrophysiology; HCM = hypertrophic cardiomyopathy; ICD = implantable cardioverter-defibrillator; PPE = pre-participation evaluation; SCD = sudden cardiac death.

Proportionately, more research has been generated in European and endurance athletes, whereas far less is known about the U.S. athlete, especially those age ≤18 years. Some will possess undiagnosed CV disease and are at risk during sports participation. More commonly, children and adolescents will carry a known diagnosis of congenital heart disease (the most common birth defect, 8 of 1,000 live births) (136). Little to no information has been generated from registries or research to guide sports participation decisions in this population (122).

Up to 10% of elite senior athletes report having existing heart disease or hypertension (137). In this group, sports participation recommendations may be highly variable, and outcome data are scarce to nonexistent. Pathological processes that promote atherosclerotic vascular disease *may* receive comparatively less emphasis in older athletes than they do among sedentary aging adults, and medications may be poorly tolerated (138). Effective management of CV disease with simultaneous preservation of sport performance may be difficult to balance in the aging athlete and merits further study.

Traditional funding sources, such as federal agencies or private foundations, have no mechanism(s) in place that prioritize athlete work, so investigators may compete with grants that are designed to study more traditional diseases in sicker populations, which invariably lead to a better priority score. In the future, this may change, considering the recent $30 million donation by the National Football League to the National Institutes of Health, earmarked for sports medicine research (139).

Liability, advocacy, and communications. Legal and socioeconomic considerations, such as physician liability concerns, access to care, legislation, governing body rules and regulations, insurance, scholarships, player union policies, collective bargaining, and workman's compensation, may influence the CV specialist's ability to deliver appropriate athlete CV care (140). Effective interfaces at the national level are suboptimal. Professional societies present sports cardiology subject matter at their respective meetings and meet "as needed" to publish consensus documents, but organized, periodic, interactive formats in this topical area among the CV community do not exist.

Improving Cardiovascular Care for Athletes and Exercising Individuals

Care model. To address the aforementioned concerns, we propose a new paradigm of care for the U.S. athlete and exercising individual, based upon the fundamentals of athlete-centered care and a commitment to sports and exercise cardiology (Table 4).

Education. Essential to the development of a curriculum in sports and exercise cardiology is the need to define core competencies. The 2012 European Society of Cardiology document provides an exemplary model (76), which can be adjusted to the way CV specialists train, certify, and practice in the United States. We suggest that current ACC CV learning pathways be adapted to incorporate sports and exercise cardiology competencies within each of the existing pathways, while creating unique competencies that are distinct to sports and exercise cardiology. This would result in an "overlap" between general sports and exercise cardiology and each subspecialty in cardiology (Fig. 3). Importantly, consideration must be given to incorporating pediatric sports and exercise cardiology into the competency model.

Widespread dissemination of and enhanced adherence to existing clinical tools, such as the 4th PPE monograph (96), 12 AHA elements (141), 36th Bethesda Conference Proceedings (24), and automated external defibrillators/emergency preparedness protocols (142), should be promoted and can be achieved through partnering with medical professional societies, sports governing bodies, and state legislative policy makers. Current imbalances between the need

Table 4 New Paradigm: Cardiovascular Care of Athletes

1. Athlete-centered, individualized approach
   - Athlete heterogeneity
   - Effects of supplements, recreational drugs, and performance-enhancing agents
   - Diagnostic testing: accuracy, interpretation, risk-to-benefit ratio
   - Therapies: efficacy, risk-to-benefit ratio, effect on performance
   - Return to play: athlete patient preferences vs. risk of sport
   - Rules/regulations and rights of: athlete and pertinent governing bodies
   - Prescribing proper level of exercise in all
2. Athlete-specific knowledge base
   - Cultivate individual CV specialist core competencies
   - Adhere to existing clinical tools
   - Consensus documents: awareness of limitations, and consequences
   - Gain experience with athletes and athletic culture
   - Be aware of legal precedents
3. Clinical tools grounded in sports and exercise cardiology
   - Use athlete-specific protocols for stress tests, ambulatory monitoring
   - Develop interpretation schemes to read athlete ECG, echo, CMRI, CT
   - Create best practices in sports and exercise cardiology
   - Strive toward evidence-based participation guidelines
4. Maintain relevant general or subspecialty cardiology practice
5. Familiarity and collaboration with the overall "athlete healthcare delivery system"
   - Collaborate with athlete care team and their professional organizations and societies*
   - Maintain HIPAA and FERPA compliance (if applicable)
   - Communicate clearly and efficiently to the athlete care team
   - Strive for consensus and consistent messaging
   - Assist with transition from any cardiovascular event and/or treatment to return to play
6. Research, quality, and science
   - Promote and perform research
   - Develop new registries
   - Publish new guidelines, position papers, consensus documents
7. Advocacy
   - Promote best practices in sports and exercise cardiology to entire athlete CV care team
   - Encourage creation of athlete CV care teams and centers
   - Collaborate with all stakeholders in athlete CV care*
   - Assist in responsible legislation that does not discriminate against the athlete

*Athletic trainers; school nurses; primary care physicians; team physicians; cardiology subspecialty, sports medicine and primary care professional societies; governing body officials; coaches; other cardiovascular (CV) specialists; and parents.

FERPA = Family Educational Rights and Privacy Act; HIPAA = Health Insurance Portability and Accountability Act; other abbreviations as in Table 3.

JACC Vol. 63, No. 15, 2014
April 22, 2014:1461–72

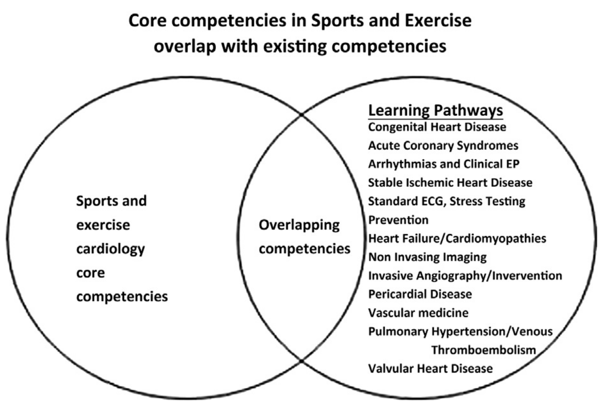

Figure 3 **Sports and Exercise Cardiology Core Competencies**

We suggest that current American College of Cardiology (ACC) cardiovascular (CV) learning pathways be adapted to incorporate sports and exercise cardiology competencies within each of the existing pathways, while creating unique competencies that are distinct to sports and exercise cardiology. This results in an "overlap" between general sports and exercise cardiology and each subspecialty in cardiology. Importantly, pediatric and adolescent sports and exercise cardiology must be incorporated into the competency model.

for sports and exercise cardiology education and training deficiencies can be corrected by providing low-cost knowledge transfer (online training), adding basic sports and exercise cardiology education to CV specialist training, and enhancing programming at annual meetings.

In the short term, the ACC Sports and Exercise Section plans to pursue the creation of certificates of competency indicating that CV specialists have met basic requirements to interpret athlete CV tests and clear athletes for sports participation, while at the same time, encouraging and working with other professional societies to do the same for PCPs and allied health professionals. For the long term, we will strive toward an American Board of Internal Medicine–approved Sports and Exercise Fellowship, with board certification.

Coupled with basic education in sports and exercise cardiology is the need for CV specialists to obtain practical experience with athletes and become immersed in the athletic culture. This can be accomplished through mentoring opportunities, dedicated sports cardiology clinics, and encouraging cardiologists to serve on multidisciplinary athlete CV care teams.

Publications, research, science, and quality. Even if they are based on expert consensus and have not yet been prospectively validated, there exists a great opportunity to create practical clinical practice statements to assist CV specialists and PCPs in delivering uniform athlete CV care. As ongoing research occurs, statements can be periodically updated and gradually elevated to the level of true guidelines.

When designing and planning studies, it is crucial that clinical datasets be tailored to the athlete, and include age; sex; ethnicity; use of supplements, alcohol, and/or recreational drugs and performance-enhancing agents; symptoms; family history; and type and amount of sport, exercise, and training. Because mortality occurs infrequently and cardiac disease prevalence may be low, it may be necessary to define new outcome measures, perhaps going beyond the traditional endpoint of mortality, and to be inclusive of nontraditional outcomes such as days away from sports and practice, presence of high-risk conditions, disqualification versus RTP, need to see a CV specialist, cardiac events, cardiac procedures, cardiac structure and function, biomarkers, quality of life, iatrogenesis, and the impact of a potential cardiac issue on the athlete's mental health, and performance. Given the growth of the athletic demographic, their unique needs, and the marginal evidence base, these challenges should and must be resolved.

Opportunities for research in sports and exercise cardiology are, at this time, limitless. Based on the areas of known controversy (Table 3), important future research imperatives are listed in Table 5. The most effective research approaches will be those that emphasize athlete health and safety, while simultaneously minimizing unnecessary sport restriction and inappropriate overtreatment. Clinical algorithms based on rigorously obtained data need to be developed to address the symptomatic athlete and positive AHA elements (141), ambiguities surrounding diagnosis, proper interpretation of cardiac testing and treatments, and the ECG screening issue.

Table 5 **Potential Research Directions: Sports and Exercise Cardiology**

1. Epidemiology of cardiac events in athletes
    - Detect true prevalence and the clinical relevance of heart diseases in athletes
    - Identify individuals at highest risk
    - Develop standardized outcomes metrics for fatal and nonfatal events
    - Determine true rate of SCD and SCA in well-defined athletic populations
2. Evaluation
    - Determine predictive value of symptoms
    - Define normative data and reference values for ECG, echocardiography, and CMRI in multiethnic American athletes at different levels (high school through masters)
    - Characterize chamber remodeling in all ages and levels of athletes
    - Correlate symptoms and surface ECG with underlying structure
    - Elucidate why some athletes remodel and others do not, even among homogeneous athletic populations
    - Prospectively validate cardiac testing in athletes
    - Define which cardiac tests (ambulatory monitoring, stress protocols) lead to greatest diagnostic yield
    - Conduct randomized trials of PPE vs. PPE plus ECG in varying demographic groups
3. Management
    - Determination of efficacy of defibrillation (AEDs and ICDs)
    - Create data-driven approach to differentiate pathology from adaptation
        i. Cardiomyopathies
        ii. Aortic dimension, pulmonary pressure, valvular regurgitation
        iii. Long QT, Brugada, early repolarization
    - Specify best treatments for asymptomatic WPW and atrial fibrillation
    - Identify best way to diagnose and treat anomalous coronary artery
    - Correlate changes seen in endurance athletes with long-term outcomes
    - Determine risk and/or safe level of exercise in individuals with heart disease to allow for revision of participation guidelines

AED = automated external defibrillator; SCA = sudden cardiac arrest; WPW = Wolff-Parkinson-White; other abbreviations as in Table 3.

The ACC has been a leader in the development of national registries in the form of the National Cardiovascular Data Registry (143). Its powerful clinical datasets may provide an opportunity to assess large numbers of athletes who could not be studied by any other means. Such analyses are costly, requiring extensive computer capability and a certain amount of groundwork before studies can be initiated. But there is no longer an impediment to pooling the data from ECG and echo to determine "normal" in any particular type of individual. Digital data streams can be used to establish publicly available normative data.

Liability concerns. Legal precedent has established that high school or college team medical staff may withhold student athletes with unacceptable medical risk from competitive sports and that those clinicians providing CV care (including CV screening) to athletes must adhere to published standards of care (140). However, some feel that, rather than clinicians disqualifying individual athletes, perhaps it is time for shared decision making between the athlete patient, family, and the CV specialist, such that an "individualized approach" be applied to the complex issue of participation (123). This approach may be more likely to be adopted in settings where educational institutions, governing bodies, and professional franchises are not involved, and the athlete is more autonomous (140).

Advocacy and communications. In view of the crucial need for research and improved clinical tools, it is increasingly important to forge collaborative relationships among the key federal institutes (National Institutes of Health, Centers for Disease Control, and the Agency for Healthcare Research and Quality) and lawmakers, as well as sports organizations and alliances (National Athletic Trainers' Association, NCAA, U.S. Olympic Committee, National Federation of State High School Associations, Youth Sports Safety Alliance and Joint Commission on Sports Safety) to create knowledge that will better inform clinical decision making, public policy, and reimbursement. Linked to these broad objectives is a need to disseminate principles of sports and exercise cardiology to CV caregivers, coaches, administrators, legislators, and athlete patients (and parents).

Conclusions

The growing athletic population demonstrates a unique need for highly tailored CV care, known as sports and exercise cardiology. Dedicated to this new paradigm of athlete CV care, the ACC Sports and Exercise Cardiology Council and Section will devote its collective energy and effort toward achieving the goals outlined here. By doing so, we believe we have the ability to serve the greater athletic community and our nation by allowing the safest participation in sports and physical activity for all individuals who seek this lifestyle.

Acknowledgments

The authors thank the members of the ACC Sports and Exercise Section who completed the member survey, and Drs. Pamela Douglas, Mark Estes, William O. Roberts, and Robert Vogel for their thoughtful review of this paper.

Reprint requests and correspondence: Dr. Christine E. Lawless, Sports Cardiology Consultants, LLC, 360 West Illinois Street, #7D, Chicago, Illinois 60654. E-mail: drlawless1221@gmail.com.

REFERENCES

1. Swift DL, Lavie CJ, Johannsen NM, et al. Physical activity, cardiorespiratory fitness, and exercise training for the in primary and secondary coronary prevention. Circ J 2013;77:281–92.
2. Fletcher GF, Balady G, Blair SN, et al., for the Committee on Exercise and Cardiac Rehabilitation of the Council on Clinical Cardiology, American Heart Association. Statement on exercise: benefits and recommendations for physical activity programs for all Americans. Circulation 1996;94:857–62.
3. Thompson PD, Franklin BA, Balady GJ, et al. Exercise and acute cardiovascular events placing the risks into perspective: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism and the Council on Clinical Cardiology. Circulation 2007;115:2358–68.
4. Pate R, Davis M, Robinson T, et al. AHA scientific statement: promoting physical activity in children and youth: a leadership role for schools: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism (Physical Activity Committee) in Collaboration With the Councils on Cardiovascular Disease in the Young and Cardiovascular Nursing. Circulation 2006;114:1214–24.
5. Sports and Fitness Industry Association. Available at: http://www.sfia.org/reports/302_2013-STATE-OF-THE-INDUSTRY-REPORT——PRE-ORDER%21. Accessed December 8, 2013.
6. National Federation of State High School Associations. Available at: http://www.nfhs.org/content.aspx?id=3282. Accessed December 8, 2013.
7. National Collegiate Athletic Association. Latest news: participation rates continue to rise. Available at: http://www.ncaapublications.com/productdownloads/PR2014.pdf. Accessed March 2, 2014.
8. Running USA. 2013 annual marathon report. Available at: http://www.runningusa.org/index.cfm?fuseaction=news.details&ArticleId=332&returnTo=annual-reports. Accessed June 3, 2013.
9. USA Triathlon. Triathlon participation, growth trends and demographics. Available at: http://www.usatriathlon.org/about-multisport/demographics.aspx. Accessed June 3, 2013.
10. Dua JS, Cooper AR, Fox KR, Graham Stuart A. Physical activity levels in adults with congenital heart disease. Eur J Cardiovasc Prev Rehabil 2007;14:287–93.
11. Thompson P, Funk E, Carleton R, Sturner W. Incidence of death during jogging in Rhode Island from 1975 through 1980. JAMA 1982;247:2535–8.
12. Albano A, Thompson P, Kapur N. Acute coronary thrombosis in Boston Marathon runners. N Engl J Med 2012;366:184–5.
13. Elefteriades JA, Hatzaras I, Tranquilli M, et al. Weight lifting and rupture of silent aortic aneurysms. JAMA 2003;290:2803.
14. Hatzaras I, Tranquilli M, Coady M, Barrett P, Bible J, Elefteriades J. Weight lifting and aortic dissection: more evidence for a connection. Cardiol 2006;107:103–6.
15. Mozaffarian D, Furberg CD, Psaty BM, Siscovick D. Physical activity and incidence of atrial fibrillation in older adults: the Cardiovascular Health Study. Circulation 2008;118:800–7.
16. Ofman P, Khawaja O, Rahilly-Tierney CR, et al. Regular physical activity and risk of atrial fibrillation: a systematic review and meta-analysis. Circ Arrhythm Electrophysiol 2013;6:252–6.
17. Aizer A, Gaziano JM, Cook NR, et al. Relation of vigorous exercise to risk of atrial fibrillation. Am J Cardiol 2009;103:1572–7.
18. Abdulla J, Nielsen JR. Is the risk of atrial fibrillation higher in athletes than in the general population? A systematic review and meta-analysis. Europace 2009;11:1156–9.
19. Rosengren A, Hauptman PJ, Lappas G, et al. Big men and atrial fibrillation: effects of body size and weight gain on risk of atrial fibrillation in men. Eur Heart J 2009;30:1113–20.

20. Link MS, Estes NA 3rd. Sudden cardiac death in the athlete: bridging the gaps between evidence, policy, and practice. Circulation 2012;125:2511–6.
21. Maron BJ, Doerer JJ, Haas TS, et al. Sudden deaths in young competitive athletes: analysis of 1866 deaths in the United States, 1980-2006. Circulation 2009;119:1085–92.
22. Baggish AL, Wood MJ. Athlete's heart and cardiovascular care of the athlete: scientific and clinical update. Circulation 2011;123: 2723–35.
23. La Gerche A, Baggish A, Knuuti J, et al. Cardiac imaging and stress testing asymptomatic athletes to identify those at risk of sudden cardiac death. J Am Coll Cardiol Img 2013;6:993–1007.
24. Maron BJ, Zipes DP. 36th Bethesda Conference: eligibility recommendations for competitive athletes with cardiovascular abnormalities. J Am Coll Cardiol 2005;45:1313–75.
25. Wann DL, Melznick MJ, Russell GW, Pease DG. Sport Fans: the Psychology and Social Impact of Spectators. New York, NY: Routledge, 2001.
26. DeLee & Drez's Orthopaedic Sports Medicine. Principles and Practices. 3rd edition. Philadelphia, PA: Saunders, 2010.
27. Puffer J. Sports medicine: the primary care perspective. Southern Med J 2004;97:1–2.
28. American Academy of Podiatric Sports Medicine. About AAPSM. Available at: http://www.aapsm.org/. Accessed February 28, 2014.
29. American Academy of Neurology. Sports neurology section. Available at: http://www.aan.com/go/about/sections/sports. Accessed February 28, 2014.
30. American Board of Preventative Medicine. Undersea & hyperbaric medicine. Available at: http://www.theabpm.org/uhm.cfm. Accessed February 28, 2014.
31. Wilderness Medical Society. Available at: http://wms.org/fawm/default.asp. Accessed February 28, 2014.
32. Mitchell JH, Haskell WL, Raven PB. Classification of sports. J Am Coll Cardiol 1994;24:864–6.
33. Fagard R. Athlete's heart. Heart 2003;89:1455–61.
34. Gooden BA. Mechanism of the human diving response. Integr Physiol Behav Sci 1994;29:6–16.
35. Bärtsch P, Gibbs JS. Effect of altitude on the heart and the lungs. Circulation 2007;116:2191–202.
36. Institute of Medicine. Crossing the Quality Chasm: a New Health System for the Twenty-First Century. Washington, DC: The National Academies Press, 2001.
37. Walsh M, Bove A, Cross R, et al. ACCF 2012 health policy statement on patient-centered care in cardiovascular medicine. J Am Coll Cardiol 2012;59:2125–43.
38. Maron BJ, Haas T, Ahluwalia A, Rutten-Ramos SC. Incidence of cardiovascular sudden deaths in Minnesota high school athletes. Heart Rhythm 2013;10:374–7.
39. Roberts WO, Stovitz SD. Incidence of sudden cardiac death in Minnesota high school athletes 1993-2012 screened with a standardized pre-participation evaluation. J Am Coll Cardiol 2013;62: 1298–301.
40. Atkins DL, Everson-Stewart S, Sears GK, et al. Epidemiology and outcomes from out-of-hospital cardiac arrest in children: the Resuscitation Outcomes Consortium Epistry-Cardiac Arrest. Circulation 2009;119:1484–91.
41. Harmon KG, Asif IM, Klossner D, Drezner JA. Incidence of sudden cardiac death in National Collegiate Athletic Association athletes. Circulation 2011;123:1594–600.
42. Kim JH, Malhotra R, Chiampas G, et al., Race Associated Cardiac Arrest Event Registry (RACER) Study Group. Cardiac arrest during long-distance running races. N Engl J Med 2012;366: 130–40.
43. Harris K, Henry J, Rohman E, et al. Sudden death during the triathlon. JAMA 2010;303:1255–7.
44. Lawless C. Minnesota high school athletes 1993–2012: evidence that American screening strategies and sideline preparedness are associated with very low rates of sudden cardiac deaths. J Am Coll Cardiol 2013; 62:1302–3.
45. Mitchell JH, Haskell W, Snell P, Van Camp SP. Task force 8: classification of sports. J Am Coll Cardiol 2005;45:1364–7.
46. Pluim BM, Zwinderman AH, van der Laarse A, van der Wall EE. The athlete's heart: a meta-analysis of cardiac structure and function. Circulation 2000;101:336–44.
47. Maron BJ, Pelliccia A. The heart of trained athletes: cardiac remodeling and the risks of sports, including sudden death. Circulation 2006;114:1633–44.
48. Longhurst JC, Kelly AR, Gonyea WJ, Mitchell JH. Echocardiographic left ventricular masses in distance runners and weight lifters. J Appl Physiol 1980;48:154–62.
49. Pelliccia A, Spataro A, Caselli G, Maron BJ. Absence of left ventricular wall thickening in athletes participating in intense power training. Am J Cardiol 1993;72:1048–54.
50. Keteyian SJ, Schairer JR. Exercise training and prescription. In: Lawless CE, editor. Sports Cardiology Essentials: Evaluation, Management and Case Studies. 1st edition. New York, NY: Springer Science+Business Media, 2010:63–84.
51. Levine BD. Exercise and Sports Cardiology. New York, NY: McGraw Hill, 2001.
52. Corrado D, Pelliccia A, Heidbuchel H, et al. Recommendations for interpretation of 12-lead electrocardiogram in the athlete. Eur Heart J 2010;31:243–59.
53. Sharma S, Whyte G, Elliott P, et al. Electrocardiographic changes in 1000 highly trained junior elite athletes. Br J Sports Med 1999;33: 319–24.
54. Van Ganse W, Versee L, Eylenbosch W, Vuylsteek K. The electrocardiogram of athletes: comparison with untrained subjects. Br Heart J 1970;32:160–4.
55. Pelliccia A, Maron BJ, Culasso F, et al. Clinical significance of abnormal electrocardiographic patterns in trained athletes. Circulation 2000;102:278–84.
56. Magalski A, Maron BJ, Main ML, et al. Relation of race to electrocardiographic patterns in elite American football players. J Am Coll Cardiol 2008;51:2250–5.
57. Hauser A, Dressendorfer RH, Vos M, et al. Symmetric cardiac enlargement in highly trained endurance athletes: a two-dimensional echocardiographic study. Am Heart J 1985;109:1038–44.
58. Spirito P, Pelliccia A, Proschan MA, et al. Morphology of the "athlete's heart" assessed by echocardiography in 947 elite athletes representing 27 sports. Am J Cardiol 1994;74:802–6.
59. Scharhag J, Schneider G, Urhausen A, et al. Athlete's heart: right and left ventricular mass and function in male endurance athletes and untrained individuals determined by magnetic resonance imaging. J Am Coll Cardiol 2002;40:1856–63.
60. Scharf M, Brem MH, Wilhelm M, et al. Cardiac magnetic resonance assessment of left and right ventricular morphologic and functional adaptations in professional soccer players. Am Heart J 2010;159: 911–8.
61. Perseghin G, De Cobelli F, Esposito A, et al. Effect of the sporting discipline on the right and left ventricular morphology and function of elite male track runners: a magnetic resonance imaging and phosphorus 31 spectroscopy study. Am Heart J 2007;154:937–42.
62. La Gerche A, Burns AT, Mooney DJ, et al. Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes. Eur Heart J 2012;33:998–1006.
63. Sharma S, Maron BJ, Whyte G, et al. Physiologic limits of left ventricular hypertrophy in elite junior athletes: relevance to differential diagnosis of athlete's heart and hypertrophic cardiomyopathy. J Am Coll Cardiol 2002;40:1431–6.
64. Basavarajaiah S, Boraita A, Whyte G, et al. Ethnic differences in left ventricular remodeling in highly trained athletes: relevance to differentiating physiologic left ventricular hypertrophy from hypertrophic cardiomyopathy. J Am Coll Cardiol 2008;51:2256–62.
65. Zaidi A, Ghani S, Sharma R, et al. Physiological right ventricular adaption in elite athletes of African and Afro-Caribbean origin. Circulation 2013;127:1783–92.
66. Pelliccia A, Maron BJ, Spataro A, et al. The upper limit of physiologic cardiac hypertrophy in highly trained elite athletes. N Engl J Med 1991;324:295–301.
67. Di Paolo FM, Schmied C, Zerguini YA, et al. The athlete's heart in adolescent Africans: an electrocardiographic and echocardiographic study. J Am Coll Cardiol 2012;59:1029–36.
68. Abergel E, Chatellier G, Hagege AA, et al. Serial left ventricular adaptations in world-class professional cyclists: implications for disease screening and follow-up. J Am Coll Cardiol 2004;44:144–9.
69. Pela G, Bruschi G, Montagna L, et al. Left and right ventricular adaptation assessed by Doppler tissue echocardiography in athletes. J Am Soc Echocardiogr 2004;17:205–11.

70. Kato TS, Noda A, Izawa H, et al. Discrimination of nonobstructive hypertrophic cardiomyopathy from hypertensive left ventricular hypertrophy on the basis of strain rate imaging by tissue Doppler ultrasonography. Circulation 2004;110:3808–14.
71. Galderisi M, Lomoriello VS, Santoro A, et al. Differences of myocardial systolic deformation and correlates of diastolic function in competitive rowers and young hypertensives: a speckle-tracking echocardiography study. J Am Soc Echocardiogr 2010;23:1190–8.
72. Savage DD, Seides SF, Clark CE, et al. Electrocardiographic findings in patients with obstructive and nonobstructive hypertrophic cardiomyopathy. Circulation 1978;58:402–8.
73. Uberoi A, Stein R, Perez M, et al. Interpretation of the electrocardiogram of young athletes. Circulation 2011;124:746–57.
74. Johnson JN, Horner JM, Ackerman MJ, et al. Assessing electrocardiographic screening in elite high school athletes with comparison to adolescents with hypertrophic cardiomyopathy. Circulation 2011;124: A10616.
75. Ramahi TM, Longo MD, Cadariu AR, et al. Dobutamine-induced augmentation of left ventricular ejection fraction predicts survival of heart failure patients with severe non-ischaemic cardiomyopathy. Eur Heart J 2001;22:849–56.
76. Heidbuchel H, Papadakis M, Panhuyzen-Goedkoop N, et al. Position paper: proposal for a core curriculum for a European Sports Cardiology qualification. Eur J Prev Cardiol 2013;20:889–903.
77. Drezner JA, Ackerman MJ, Anderson J, et al. Electrocardiographic interpretation in athletes: the 'Seattle Criteria'. Br J Sports Med 2013; 47:122–4.
78. Adler A, Rosso R, Viskin D, et al. What do we know about the "malignant form" of early repolarization? J Am Coll Cardiol 2013;62: 863–8.
79. Saxon LA, Tun H, Riva G, et al. Dynamic heart rate behavior of elite athletes during football. Paper presented at: Heart Rhythm 33rd Annual Scientific Sessions; May 10, 2012; Boston, MA.
80. Rossano J, Bloemers B, Sreeram N, et al. Efficacy of implantable loop recorders in establishing symptom-rhythm correlation in young patients with syncope and palpitations. Pediatrics 2003;112: e228–33.
81. Müssigbrodt A, Richter S, Wetzel U, et al. Diagnosis of arrhythmias in athletes using leadless, ambulatory HR monitors. Med Sci Sports Exerc 2013;45:1431–5.
82. Bowie L. Smart shirt moves from research to market; goal is to ease healthcare monitoring. Georgia Institute of Technology. Available at: http://www.gatech.edu/news-room/archive/news_releases/sensatex.html. Accessed February 28, 2014.
83. Drust B, Reilly T, Cable NT. Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise. J Sports Sci 2000;18:885–92.
84. Gopinathannair R, Olshansky B. Electrophysiological approach to syncope and near-syncope in the athlete. In: Lawless CE, editor. Sports Cardiology Essentials: Evaluation, Management and Case Studies. 1st edition. New York, NY: Springer Science+Business Media, 2010:181–212.
85. World Anti-Doping Agency. The 2014 prohibited list. Available at: http://www.wada-ama.org/Documents/World_Anti-Doping_Program/WADP-Prohibited-list/2014/WADA-prohibited-list-2014-EN.pdf. Accessed February 28, 2014.
86. Tesch PA. Exercise performance and beta-blockade. Sports Med 1985;2:389–412.
87. Blomström-Lundqvist C, Scheinman MM, Aliot EM, et al. ACC/AHA/ESC guidelines for the management of patients with supraventricular arrhythmias—executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and the European Society of Cardiology Committee for Practice Guidelines (Writing Committee to Develop Guidelines for the Management of Patients With Supraventricular Arrhythmias). J Am Coll Cardiol 2003;42: 1493–531.
88. Estes NA 3rd, Link MS, Cannom D, et al. Report of the NASPE policy conference on arrhythmias and the athlete. J Cardiovasc Electrophysiol 2001;12:1208–19.
89. Bennekers JH, van Mechelen R, Meijer A. Pacemaker safety and long-distance running. Neth Heart J 2004;12:450–4.
90. Lawless CE, Briner W. Palpitations in athletes. Sports Medicine 2008;38:687–702.
91. Lampert R, Cannom D, Olshansky B. Safety of sports participation in patients with implantable cardioverter defibrillators: a survey of Heart Rhythm Society members. J Cardiovasc Electrophysiol 2006;17:11–5.
92. Lawless CE. Implantable cardioverter defibrillators in athletes: rationale for use and issues surrounding return to play. Curr Sports Med Rep 2008;7:86–92.
93. Lampert R, Olshansky B, Heidbuchel H, et al. Safety of sports for athletes with implantable cardioverter-defibrillators: results of a prospective, multinational registry. Circulation 2013;127:2021–30.
94. Grady KL, Dracup K, Kennedy G, et al. Team management of patients with heart failure. a statement for healthcare professionals from the Cardiovascular Nursing Council of the American Heart Association. Circulation 2000;102:2443–56.
95. O'Connor RE, Brady W, Brooks SC, et al. 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care science. Part 10: acute coronary syndromes. Circulation 2010;122:S787–817.
96. Bernhardt DT, Roberts WO. Preparticipation Physical Examination. 4th edition. Chicago (Downers Grove), IL: American Academy of Pediatrics, 2010.
97. Asplund C, Asif IM. Cardiovascular pre-participation screening practices among college team physicians (abstr). Clin J Sport Med 2013;23:147.
98. Coris EE, Sahebzamani F, Curtis A, et al. Preparticipation cardiovascular screening among National Collegiate Athletic Association Division I institutions. Br J Sports Med 2013;47:182–4.
99. Championship Hearts Foundation. Texas Adolescent Athlete Heart Screening Registry. Available at: http://www.champhearts.org/what-we-do/research/. Accessed February 28, 2014.
100. The John H. Stewart Foundation. Available at: http://johnstewartfoundation.com/. Accessed February 28, 2014.
101. Nick of Time Foundation. Available at: http://nickoftimefoundation.org/. Accessed February 28, 2014.
102. Bryan Health. Athlete care. Available at: http://www.bryanhealth.com/athlete-care. Accessed February 28, 2014.
103. Massachusetts General Hospital. Corrigan Minehan Heart Center: Cardiovascular Performance Program. Available at: http://www.massgeneral.org/heartcenter/services/treatmentprograms.aspx?id=1364. Accessed February 28, 2014.
104. Tufts Medical Center. Available at: http://www.tufts-nemc.org/apps/TuftsFindAPhysician/PhysicianDetail.aspx?OID=1922. Accessed February 28, 2014.
105. Hartford Hospital. Physician detail: about Paul Thompson. Available at: http://www.harthosp.org/findaphysician/default.aspx?view=detail&physicianID=918. Accessed February 28, 2014.
106. Mayo Clinic. Departments and Centers: Cardiovascular Diseases in Minnesota: Sports Cardiology Clinic. Available at: http://www.mayoclinic.org/departments-centers/cardiovascular-diseases/minnesota/overview/specialty-groups/sports-cardiology-clinic. Accessed February 28, 2014.
107. Greenville Health System. GHS Sports Cardiology Program. Available at: http://ghssportscardiology.org/. Accessed February 28, 2014.
108. Madsen K, Pedersen PK, Djurhuus MS, Klitgaard NA. Effects of detraining on endurance capacity and metabolic changes during prolonged exhaustive exercise. J Appl Physiol 1993;75:1444–51.
109. Thompson PD, Levine BD. Protecting athletes from sudden cardiac death. JAMA 2006;296:1648–50.
110. European Society of Cardiology. Sports Cardiology Section. Available at: http://www.escardio.org/communities/EACPR/about/EACPR-main-sections/Pages/EACPR-Sports-Cardiology.aspx?hit=section. Accessed February 28, 2014.
111. American College of Cardiology. Cardiosource. Sports and Exercise Cardiology Section & Leadership Council. Available at: http://www.cardiosource.org/ACC/ACC-Membership/Sections-Segments-Councils/Sports-and-Exercise-Cardiology.aspx. Accessed February 28, 2014.
112. American Board of Internal Medicine. Cardiovascular disease. Available at: http://www.abim.org/specialty/cardiovascular-disease.aspx. Accessed February 28, 2014.
113. Beller GA, Bonow RO, Fuster V, et al. ACCF 2008 Recommendations for Training in Adult Cardiovascular Medicine Core Cardiology Training (COCATS 3) (Revision of the 2002 COCATS Training Statement). J Am Coll Cardiol 2008;51:333–414.
114. American College of Cardiology. Cardiosource. Education by Clinical Topic. Available at: http://www.cardiosource.org/Lifelong-Learning-and-MOC/Learning-Pathways.aspx. Accessed February 28, 2014.

115. Cohen M, Triedman J, Cannon BC, et al. PACES/HRS expert consensus statement on the management of the asymptomatic young patient with a Wolff-Parkinson-White (WPW, Ventricular Preexcitation) electrocardiographic pattern. Heart Rhythm 2012;9:1006–24.
116. Pelliccia A, Fagard R, Bjornstad HH, et al. Recommendations for competitive sports participation in athletes with cardiovascular disease. Eur Heart J 2005;26:1422–45.
117. Maron BJ, Chaitman BR, Ackerman MJ, et al., on behalf of Working Groups of the American Heart Association Committee on Exercise, Cardiac Rehabilitation, and Prevention; Councils on Clinical Cardiology and Cardiovascular Disease in the Young. Recommendations for physical activity and recreational sports participation for young patients with genetic cardiovascular diseases. Circulation 2004;109:2807–16.
118. Maron BJ, Araujo GS, Thompson PD, et al. Recommendations for preparticipation screening and the assessment of cardiovascular disease in master athletes: an advisory for healthcare professionals from the working groups of the World Heart Federation, the International Federation of Sports Medicine, and the American Heart Association Committee on exercise, cardiac rehabilitation, and prevention. Circulation 2001;103:327–34.
119. Corrado D, Migliore F, Basso C, Thiene G. Exercise and the risk of sudden cardiac death. Herz 2006;31:553–8.
120. Albert CM, Mittleman MA, Chae CU, et al. Triggering of sudden death from cardiac causes by vigorous exertion. N Engl J Med 2000; 343:1355–61.
121. Lawless CE, Winicur ZM, Bellande B. Preparedness of US physician workforce to screen competitive athletes for sports participation. Circulation 2009;120:S672.
122. Longmuir PE, Brothers JA, de Ferranti SD, et al. Promotion of physical activity for children and adults with congenital heart disease. Circulation 2013;127:2147–59.
123. Johnson JN, Ackerman MJ. Competitive sports participation in athletes with congenital long QT syndrome. JAMA 2012;308:764–5.
124. Vetter V, Dugan N, Guo R, et al. A pilot study of the feasibility of heart screening for sudden cardiac arrest in healthy children. Am Heart J 2011;161:1000–6.
125. MacKnight JM, Mistry DJ. Chest pain in the athlete: differential diagnosis, evaluation, and treatment. In: Lawless CE, editor. Sports Cardiology Essentials: Evaluation, Management and Case Studies. 1st edition. New York, NY: Springer Science+Business Media, 2010:115–39.
126. Maron BJ, Shirani J, Poliac LC, et al. Sudden death in young competitive athletes. Clinical, demographic, and pathological profiles. JAMA 1996;276:199–204.
127. Baggish AL, Hutter AM Jr., Wang F, et al. Cardiovascular screening in college athletes with and without electrocardiography: a cross-sectional study. Ann Intern Med 2010;152:269–75.
128. Glover DW, Glover DW, Maron BJ. Evolution in the process of screening United States high school student-athletes for cardiovascular disease. Am J Cardiol 2007;100:1709–12.
129. Madsen NL, Drezner JA, Salerno J. Sudden cardiac death screening in adolescent athletes: an evaluation of compliance with national guidelines. Br J Sports Med 2013;47:172–7.
130. Lawless CE, Best TM. Electrocardiograms in athletes: interpretation and diagnostic accuracy. Med Sci Sport Exerc 2008;40:787–98.
131. Pelliccia A, Spataro A, Maron BJ. Prospective echocardiographic screening for coronary artery anomalies in 1,360 elite competitive athletes. Am J Cardiol 1993;72:978–9.
132. Frommelt PC, Frommelt MA, Tweddell JS, Jaquiss R. Prospective echocardiographic diagnosis and surgical repair of anomalous origin of a coronary artery from the opposite sinus with an interarterial course. J Am Coll Cardiol 2003;42:148–54.
133. Angelini P. Coronary artery anomalies and sports activities. In: Lawless CE, editor. Sports Cardiology Essentials: Evaluation, Management and Case Studies. 1st edition. New York, NY: Springer Science+Business Media, 2010:277–98.
134. Myerburg RJ, Vetter VL. Electrocardiograms should be included in preparticipation screening of athletes. Circulation 2007;116: 2616–26.
135. Chaitman BR. An electrocardiogram should not be included in routine preparticipation screening of young athletes. Circulation 2007; 116:2610–4.
136. Hoffman JI, Kaplan S, Liberthson RR. Prevalence of congenital heart disease. Am Heart J 2004;147:425–39.
137. Wright VJ, Perricelli BC. Age-related rates of decline in performance among elite senior athletes. Am J Sports Med 2008;36:443–50.
138. Sinzinger H, O'Grady J. Professional athletes suffering from familial hypercholesterolaemia rarely tolerate statin treatment because of muscular problems. Br J Clin Pharmacol 2004;57:525–8.
139. National Football League. NFL donates $30 million to National Institutes of Health. Available at: http://www.nfl.com/news/story/0ap1000000058447/article/nfl-donates-30-million-to-national-institutes-of-health. Accessed February 28, 2014.
140. Paterick TE, Paterick TJ, Fletcher GF, Maron BJ. Medical and legal issues in the cardiovascular evaluation of competitive athletes. JAMA 2005;294:3011–8.
141. Maron BJ, Thompson PD, Ackerman M, et al. Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update. Circulation 2007;115:1643–55.
142. Drezner J, Courson R, Roberts W, et al. Inter-association task force recommendations on emergency preparedness and management of sudden cardiac arrest in high school and college athletic programs: a consensus statement. Heart Rhythm 2007;4:549–65.
143. National Cardiovascular Data Registry. Available at: https://www.ncdr.com/webncdr/home. Accessed February 28, 2014.

Key Words: athlete ▪ cardiology ▪ sports ▪ sudden cardiac arrest ▪ sudden cardiac death.

APPENDIX

For an expanded list of abbreviations, please see the online version of this article.