Management of young competitive athletes with cardiovascular conditions

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**Learning Objectives**

To recognize contraindications to exercise/sporting competition and the recommendations for professional sports participation.

To recognize the risk factors and mechanisms of sudden cardiac death during and after strenuous exercise.

To appreciate the benefits of exercise training and safety issues in exercise and sport.

**Introduction**

Physical activity has numerous substantial health benefits, including reduction in cardiovascular disease1, lower incidence of certain cancers2 3, improved healthy ageing4 and all cause mortality1. In this regard, young competitive athletes epitomize the healthiest segment of society. These individuals regularly push their limits for club and country and are a source of inspiration and aspiration to our youth. Paradoxically, occasionally a young athlete may die suddenly during intensive exercise from a diverse spectrum of relatively rare inherited or congenital diseases5-7 ordinarily associated with a low adverse event rate. Indeed, athletes harboring cardiovascular disease have an increased risk of clinical deterioration and sudden cardiac death (SCD) in comparison to sedentary individuals with the same disease8.

Although sudden death is rare (approximately 1:50,0009) most victims lose several decades of life from cardiac diseases which are detectable during life and for which several lifestyle and therapeutic interventions can minimize the risk of SCD. It is on this premise that both the American Heart Association (AHA) and European Society of Cardiology (ESC) recommend screening athletes for disease.

In an effort to prevent exercise-related SCD in affected athletes, expert consensus documents were developed to provide guidance on sports activities that could be performed safely10 11. However, absolute risks of exercise are difficult to quantify where the evidence base is limited. Therefore, in most circumstances the consensus recommendations are conservative in nature, aiming to encompass all preventable deaths. A more individualized approach, tailoring exercise advice and counselling regarding event risk is warranted but currently lacks adequate scientific evidence and remains largely pragmatic. Informed decision-making should take place between a cardiologist with expertise in sports cardiology, the athlete, the club doctor and ideally involve the next of kin.

This review will focus on young competitive athletes, defined as individuals under the age of 35 years, who engage in exercise training on a regular basis and participate in official sports competition with an emphasis on excellence and achievement, either at an amateur or professional level. Older athletes participating in recreational sports are an important and expanding population, where underlying cardiovascular diseases such as ischaemic heart disease and hypertension are particularly relevant and management decisions may be challenging. However, this article will not address those areas.

Competitive sports can be approximately divided into categories of dynamic or static work and of low to high intensity, according to the Mitchell classification12 (see Figure 1). This provides a basic schema on which to anticipate approximate cardiovascular strain during prolonged exercise and a foundation on which to advise which types of sport would likely expose risk to an athlete with cardiovascular disease and which may be practiced safely.

***Cardiomyopathies***

**Hypertrophic Cardiomyopathy**

Hypertrophic cardiomyopathy (HCM) is characterized by unexplained left ventricular hypertrophy (LVH) and a predilection to ventricular arrhythmias but is highly heterogeneous with respect to phenotypic penetrance, clinical presentation, structural morphology and natural history. Whilst, the index presentation of HCM may be SCD, during or immediately after exercise, most affected individuals have a near normal life span. In a large USA registry, HCM was the most common cause of SCD in young people, including competitive athletes13.

Most individuals with HCM fail to augment stroke volumes for prolonged periods, thus inhibiting ability to compete in sports at an elite level. Whereas some with mild localized LVH and normal diastolic function are truly asymptomatic and can perform with excellence in disciplines with an explosive start-stop component such as basketball, football and rugby14.

Management of athletes with HCM follows the same principles as all patients with HCM: treatment of symptoms; risk stratification for SCD, and family screening. Specifically, risk factors for SCD include prior cardiac arrest, ventricular tachycardia, a family history of SCD, syncope, left ventricular wall thickness > 30mm and an abnormal blood pressure response to exercise15. USA and European guidelines recommend restriction of HCM patients to class IA sports only, which have a low dynamic and static component.

Some caveats are worthy of special mention. Firstly, that the distinction between physiological adaptation to exercise and HCM can be diagnostically challenging, particularly in black athletes of African or Afro-Caribbean origin and involvement of a specialist with experience in sports cardiology and inherited heart disease is advisable16 (see Figure 2). Secondly, the HCM risk-SCD model17 is derived from sedentary individuals assessed in laboratory conditions and cannot be extrapolated to the haemodynamic and metabolic stresses associated with athletic competition. A recently emerging notion is that following ICD implantation, an athlete with HCM may safely undertake physical activity18. However, irrespective of the ICD, the substrate and triggers for fatal arrhythmia remain and high catecholamine concentration, electrolyte shifts and acidosis may compromise the efficacy of shock therapy19 20. Therefore, exercise recommendations for athletes with cardiac conditions must be based on the underlying disease process and not influenced by the presence of an ICD.

In the investigation of relatives of patients with HCM, one may identify an athlete who is genotype-positive for one of the known causative HCM genes but does not exhibit any of the overt features of disease after extensive investigation. At present this is a challenging dilemma, as the natural history of genotype-positive/phenotype-negative (G+/P-) individuals is not completely understood. Recent studies suggest that these individuals generally have a benign clinical course with low penetrance of phenotypic disease and an absence of clinical events21 22. Based on these considerations if no phenotype of HCM is demonstrated after extensive investigation and there is no family history of SCD, AHA recommendations permit competition in all sports23.

**Arrhythmogenic Right Ventricular Cardiomyopathy**

The risk of SCD during exertion is particularly high with arrhythmogenic right ventricular cardiomyopathy (ARVC) and is thought to be secondary to arrhythmias provoked by repeated bouts of myocyte detachment and subsequent inflammation exacerbated by the haemodynamic burden of exercise on the ventricles. Athletes with ARVC should cease competitive sport, with the exception of class IA sports. As with HCM, the differentiation between physiological RV enlargement and ARVC may be difficult, particularly in endurance athletes who show both RV enlargement and anterior T wave inversion (see Figure 2).

A wealth of recent human and animal studies demonstrate that those with an ARVC genotype are susceptible to developing the phenotype with intensive exercise24-29. Based on this evidence, it is recommended that G+/P- athletes cease competitive sports, with the exception of class IA sports 23.

Whilst the risk of disease progression with continued high intensity physical activity is a genuine concern, advising ARVC patients to live a sedentary lifestyle may be associated with greater morbidity in the long term. Therefore, young patients should be counseled about the importance of maintaining regular low to moderate intensity aerobic and static exercises. Practical exercise advice for all patients with cardiovascular conditions is outlined at the end of this article.

**Dilated Cardiomyopathy and Left Ventricular Non-Compaction Cardiomyopathy**

Dilated cardiomyopathy (DCM) includes various aetiologically diverse disorders that may be genetic or secondary to infection, inflammation, metabolic disorders, exposure to toxic substances or idiopathic. Left ventricular non-compaction (LVNC) is a novel and yet unclassified cardiomyopathy, characterized by prominent left ventricular trabeculation separated by deep recesses30.

Both conditions share similarities in that they are rare causes of SCD in athletes, those at risk of SCD tend to be symptomatic and unable to perform intensive physical activity and they share the same clinical management. As with the other cardiomyopathies some athletes reveal structural changes overlapping with mild phenotypes of both DCM and LVNC (see Figure 2).

Athletes with DCM or LVNC should not participate in competitive sports, with the exception of class IA sports23. Other principles of management include evidence-based therapy for left ventricular systolic impairment and device therapy when indicated for primary and secondary prevention of SCD31.

It remains a matter of current debate, whether physiological remodeling of the athlete’s heart in some individuals can include prominent left ventricular hypertrabeculation. In the knowledge that current imaging criteria for the diagnosis of LVNC suffer substantial false-positive rates when applied to low risk populations32-34, there exists potential to erroneously label an athlete with LVNC. Therefore, athletes who are incidentally found to have excessive trabeculation consistent with LVNC but have no family history of cardiomyopathy, LV impairment or ventricular arrhythmia should be allowed to participate in all sports and followed up annually.

***Arrhythmogenic Conditions***

**Wolff-Parkinson-White (WPW) Syndrome**

One of the chief concerns regarding WPW syndrome is that approximately one third of patients may develop atrial fibrillation10. If the properties of the accessory pathway are such that rapid activation of the ventricles is possible, then atrial fibrillation can degenerate into ventricular fibrillation. The risk of SCD in patients with WPW may approach 4% over a lifetime35. Management follows that those with symptoms or documented atrial fibrillation should undergo electrophysiological study and catheter ablation as this procedure is potentially curative, enjoys a high success rate and a low risk of complications.

Asymptomatic athletes with WPW are a contentious issue. It is appreciated that malignant arrhythmias in WPW correlate more strongly with electrophysiological properties of the accessory pathway rather than symptom status36. Therefore, whilst there is general agreement that risk stratification of affected athletes is necessary, the consensus statements differ on the proposed methods. The aim of risk stratification is to identify those athletes possessing accessory pathways with short refractory periods that allow rapid ventricular conduction during AF and offer curative catheter ablation. USA guidelines recommend initial non-invasive exercise testing, specifically to determine if there is an ***abrupt and complete*** loss of pre-excitation during exercise. This would indicate the presence of a low risk accessory pathway with a long refractory period37. However, the specificity of this test is only 17%38 and in clinical practice there is significant interobserver variability. Therefore, the ESC guidelines recommend that all athletes undergo an electrophysiological study as the most accurate means of assessing the risk of potentially malignant arrhythmia. Measurement of accessory pathway refractoriness and induction of atrial fibrillation to assess the shortest pre-excited RR interval are validated SCD risk factors39. Athletes with any high risk features should be offered catheter ablation and may return to competition as early as 3 weeks40.

**Long QT Syndrome**

Making the correct diagnosis of long QT syndrome in the athlete can be fraught with difficulty. Firstly, acquired long QT interval requires exclusion of an electrolyte disturbance (e.g. hypokalaemia) or drugs capable of prolonging repolarization. Sports where a weight restriction must be met, such as boxing and horse racing, may be associated with diuretic abuse and hypokalaemia-induced long QT interval. Athletes frequently reveal sinus arrhythmia and prominent U waves or atypical T waves, resulting in inaccurate measurement of the corrected QT interval. Hence automated values must be checked manually using the tangent method41. Finally, athletes have a longer QT interval compared to the sedentary population. Therefore the 99th percentile defines a long QT interval in athletes. Measuring in lead II or V5, a QT interval of >470 ms in males and >480 ms in females using Bazett’s formula, raises suspicion of long QT syndrome. The Priori-Schwarz probability score should then be employed to confirm congenital long QT syndrome42. If doubt persists, genetic testing should be performed and has a diagnostic yield of up to 75%40.

Athletes with confirmed long QT syndrome should receive treatment with propanolol or nadolol, a non-selective beta-blocker. Treatment with beta-blockers may result in disqualification from particular sports such as archery, gymnastics, shooting and golf43. Whilst there appears to be a low event rate in athletes with long QT syndrome18 44-46 the authors suggest counselling athletes regarding the uncertainty of SCD risk during exercise and the importance of good medication compliance. Those athletes who are eager to continue competing in their sport should be encouraged to take precautionary measures and attend annual follow up, which should include maximal ECG exercise testing. Precautionary measures include: avoidance of QT prolonging drugs (http://www.crediblemeds.org); avoidance of dehydration; electrolyte/hydration replenishment; avoidance of hyperthermia, heat exhaustion or heat stroke, and an emergency action plan where sport or training is undertaken, to include the presence of an automatic external defibrillator47. Close periodic surveillance is important and special consideration should be given to those with LQTS type 1, as there is a strong association with SCD during swimming/diving. Cardiopulmonary resuscitation is challenging in this environment, therefore restriction should be advised48.

Survivors of sudden cardiac arrest, ventricular tachycardia or fibrillation and those experiencing arrhythmogenic syncope despite beta-blockers should be considered for ICD and be restricted to competitive sports in category IA49.

USA consensus recommendations acknowledge that asymptomatic athletes with long QT syndrome have a low risk of SCD when compliant with beta-blockers and can return to competitive sports after 3 months of therapy. G+/P- individuals are permitted to participate in all sports provided the aforementioned precautionary measures are taken.

**Brugada Syndrome**

Brugada syndrome is associated with SCD due to malignant ventricular arrhythmias, usually ocurring at rest and often during sleep. Hyperpyrexia has also been associated with arrhythmia storms. Athletes with Brugada syndrome may be predisposed to arrhythmia through high resting vagal tone and potential vulnerability in the post exercise period. The augmentation of ST-segment elevation and unmasking of the type 1 Brugada ECG during the recovery phase of exercise testing may support this hypothesis50-52.

Asymptomatic athletes with Brugada syndrome should be subjected to an exercise test to volitional exhaustion. Athletes with no evidence of significant ST-segment elevation or arrhythmias 1 to 4 minutes into recovery should not be restricted from competitive sports but should be advised to avoid: dehydration; long endurance events which are associated with hyperthermia during exercise (e.g. marathons) and exacerbating drugs (http://www.brugadadrugs.org). G+/P- individuals can participate in all sports.

Survivors of sudden cardiac arrest, ventricular arrhythmias and those experiencing syncope should be restricted from competitive sports, with the exception of class IA sports and require consideration of ICD implantation.

**Catecholaminergic Polymorphic Ventricular Tachycardia**

Catecholaminergic polymorphic ventricular tachycardia (CPVT) is characterized by exercise-induced polymorphic ventricular tachycardia (most often with “bi-directional pattern”), which can degenerate in ventricular fibrillation. CPVT can only be detected on exercise testing or pharmacological provocation testing.

Given the strong association of malignant arrhythmias with exercise, CPVT is a contraindication for all competitive sports. Patients with CPVT require treatment with beta-blockers and consideration of an ICD.

ICD implantation in CPVT is worthy of special mention, given differences in outcomes and programming issues. Multiple case reports have highlighted that ICD shocks can trigger endogenous catecholamine release in CPVT patients, setting in motion a vicious cycle of induced polymorphic VT and further multiple shocks, potentially culminating in a fatal electrical storm53 54. Published case series have consistently reported that whilst ventricular fibrillation is successfully terminated by ICD discharges in this population, polymorphic and bidirectional VT are relatively resistant to successful primary termination and are frequently exacerbated by shocks55-57.

Athletes with cardiovascular conditions and ICDs, who continue to engage in high intensity physical activity, experience more arrhythmias and more inappropriate shocks during exercise18. Careful specialist ICD programming is required to prevent inappropriate or potentially harmful ICD therapies.

***Arrhythmia***

**Atrial fibrillation and atrial flutter**

AF in adolescent athletes is uncommon but causes include accessory pathways, ion channelopathies, myocarditis, excess alcohol intake with caffeinated drinks and thyrotoxicosis. More commonly, AF affects the older athlete, often following decades of endurance exercise58-60. where evaluation for hypertension and underlying coronary artery disease is recommended.

After addressing any associated conditions, it is reasonable to discuss a period of detraining, on suspicion that ongoing exercise may reduce the likelihood of maintaining sinus rhythm.

First is to assess the need for anticoagulation using the CHA2DS2-VASc score61. If indicated, this will result in exclusion from sports with a risk of bodily collision. Rapid AV conduction during physical activity may lead to symptoms of haemodynamic impairment such as dizziness, syncope or sudden extreme fatigue. As such, recommendations for competitive sports participation largely depend on the ventricular rate during AF episodes during exercise. If heart rate during atrial fibrillation is acceptable at maximum physical performance for a given athlete without signs of haemodynamic impairment, the athlete may participate in all sports. Those with symptoms of haemodynamic compromise or unacceptable rises in heart rate, intervention will be required to permit ongoing sports participation. Rate control is often not an ideal initial choice for athletes with paroxysmal AF as achieving adequate rate control may negatively impact on performance. Therefore, most choose a rhythm control strategy, specifically catheter ablation, as long-term anti-arrhythmic drug therapy can have variable efficacy, concerning side effects and potential proarrhythmic risk. By comparison, catheter ablation enjoys a high procedural success rate and sustained benefit62 63.

For atrial flutter, catheter ablation can be more easily justified as the established treatment of choice, particularly for typical flutter, given its proven superior efficacy over drug treatment, high procedural success and low complication rate64 65.

**Ventricular ectopy**

Premature ventricular complexes (PVC), or ventricular ectopic beats, are most commonly benign. However, ventricular ectopy can be a manifestation of important electrical or structural diseases (see Figure 3). Therefore, in order to assuage concern relating to these conditions, some investigation is appropriate including 12-Lead ECG, exercise stress testing, echocardiography and 24h Holter monitoring.

If PVCs are suppressed during exercise, this supports a likely benign nature. A PVC burden of >20,000 per 24 hours places an individual at greater risk of PVC-induced cardiomyopathy66. It is therefore reasonable to treat these individuals with beta-blockers even if asymptomatic. In cases where ventricular ectopy is monomorphic, electrophysiological study and catheter ablation can be an effective therapy for those symptomatic despite beta-blockade or intolerant to beta-blockade. A low PVC burden in an asymptomatic individual requires no treatment.

Echocardiography is helpful to exclude underlying structural heart disease, particularly cardiomyopathies and assesses ventricular function for those at risk of PVC-induced cardiomyopathy. Contrast-enhanced cardiac MRI can provide additional anatomical information if transthoracic echocardiography views are not optimal and tissue characterization in myocardial diseases. A schema for the investigation of the athlete with PVCs is given in Figure 3.

***Valvular heart disease***

In general regurgitant valvular lesions are better tolerated than stenotic lesions during exercise. Figure 467 details the exercise recommendations for left-sided valvular lesions, though similar principles apply to corresponding right-sided lesions.

**Bicuspid aortic valve**

Bicuspid aortic valves (BAV) are associated with connective tissue abnormalities that affect the aortic valve and aorta. Any degree of aortic stenosis or regurgitaion should be evaluated on a periodic basis, given the risk of progression. Independent to the valvular lesion, aortic dilatation and aneurysm formation requires simultaneous assessment in athletes with BAV. Aortic dimensions, particularly at the Sinus of Valsalva, should be expressed as Z scores based on age, gender and body surface area, as well as absolute measurements. A Z score of >3.5 restricts an athlete to low dynamic/low static sports (Class IA) only. Intense physical exertion is associated with haemodynamic changes that increase aortic wall tension and may increase aortic dimensions.

All investigations and management recommendations for young athletes with cardiovascular conditions are summarized in Figure 5.

**General practical considerations of exercise in athletes with cardiovascular conditions**

Eligibility recommendations for competitive sports participation for athletes with cardiovascular abnormalities conservatively aim to protect against devastating SCD and serious arrhythmias. However, it is a commonly held misconception that these individuals are safer being sedentary. Athletes with cardiovascular abnormalities should be encouraged to maintain the recommended minimum physical activity level68 and not deprived the numerous benefits of moderate recreational exercise.

It is our practice to perform cardiopulmonary exercise testing to assess functional capacity and determine the ventilatory anaerobic threshold, which provides an indication of physiological reserve and at what workload metabolic acidosis and skeletal muscle hypoxia ensue. For an athlete it is important to try to achieve maximum performance with an appropriate testing protocol, rather than 80-100% of the target heart rate. A standard Bruce protocol, for example, would not suit this purpose. Ideally, treadmill or cycle ergometry use should match the sporting discipline where the athlete achieves greatest performance.

Daily exercise for 20 minutes at a heart rate correlating with the ventilatory anaerobic threshold would appear to be safe in those with underlying cardiovascular abnormalities. Where the ventilatory anaerobic threshold is not known, a reasonable surrogate is 80% of the maximum predicted heart rate (220 - age) or 60-70% for those treated with beta-blockers69. Static muscle strengthening also improves mitochondrial function and prevents sarcopenia70, therefore should be encouraged, using pulley systems for heavier weights (see Figure 6).

**Conclusion**

Young athletes with underlying cardiovascular conditions face a small but important increased risk of clinical deterioration and SCD. Consensus recommendations for athletes are designed to address all potentially avoidable deaths attributable to exercise. These are conservative in nature and based mostly on expert opinion due to the scarcity of research pertaining to athletes. Until more evidence is available, physicians have a duty of shared decision-making with athletes when discussing the risks and uncertainties of intense exercise in those with underlying cardiovascular conditions. It should be emphasized that a sedentary lifestyle for a young individual with a cardiovascular abnormality is not safe and may be more harmful than the underlying condition. Tailored practical advice and continued periodic follow up in specialist clinics provides the best model of care.

**Key Points**

Athletes with cardiovascular conditions are at increased risk of SCD compared to normal individuals, though it is difficult to estimate the precise risk attributable to exercise.

Consensus recommendations are largely based on expert opinion and are cautious and conservative in an effort to encompass all potentially preventable deaths.

Moderate exercise confers numerous health benefits and individuals with cardiovascular conditions should receive tailored advice on how to continue regular physical activity safely.

Figure legends

Figure 1. Classification of sports. Classification of sports based on peak static and dynamic components achieved during competition. The lowest cardiovascular demands (cardiac output and blood pressure) are shown in the palest colour with increasing dynamic load depicted by increasing blue intensity and increasing static load depicted by increasing red intensity. Considerable overlap is appreciated based on the individual athlete’s player position and style of play.

\*Danger of bodily collision †Increased risk if syncope occurs.

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Figure 2. Differentiating features between physiological cardiac changes and cardiomyopathy in athletes.

ARVC, arrhythmogenic right ventricular cardiomyopathy; CMR, cardiac magnetic resonance; DCM, dilated cardiomyopathy; FH, family history; HCM, hypertrophic cardiomyopathy; LBBB, left bundle branch block; LV left ventricle; LVH, left ventricular hypertrophy; LVNC left ventricular non compaction cardiomyopathy; MRI, magnetic resonance imaging; Peak VO2, peak oxygen consumption; RV, right ventricle; RWMA, regional wall motion abnormalities; VT, ventricular tachycardia.

Reproduced with permission from Sharma et al16.

Figure 3. Investigation of athletes with premature ventricular complexes.

ARVC, arrhythmogenic right ventricular cardiomyopathy; CMR, cardiac magnetic resonance; CPVT, catecholaminergic polymorphic ventricular tachycardia; CT, computed tomography; ECG, electrocardiogram; HCM, hypertrophic cardiomyopathy; NSVT, non-sustained ventricular tachycardia; PVC, premature ventricular complexes; RVOT, right ventricular outflow tract.

Figure 4. Recommendations regarding competitive sports participation in patients with valvular heart disease.

AF, atrial fibrillation; AR, aortic regurgitation; AS, aortic stenosis; AV, aortic valve; EF, ejection fraction; LA, left atrium; LV, left ventricle; MR, mitral regurgitation; MS, mitral stenosis; MV, mitral valve.

¶Satisfactory exercise capacity without symptoms, ST depression, ventricular tachyarrhythmias and normal blood pressure response.

§ left ventricular end-systolic dimension (LVESD) <50 mm in men, <40 mm in women, or <25mm/m2 either sex

\*left ventricular end-diastolic dimension (LVEDD) <60 mm or <35 mm/m2 in men or <40 mm/m2 in women

†left ventricular end-diastolic dimension (LVEDD) ≥65 mm or ≥35.3 mm/m2 in men or ≥40 mm/m2 in women

‡ejection fraction (EF) <60% or left ventricular end-systolic dimension (LVESD) >40 mm

Cardiac 5-chamber view figure reproduced with permission from Bertrand et al67.

Figure 5. Diagnosis and management algorithm for athletes with cardiovascular conditions including which patients benefit from referral to tertiary level specialist centres.

AF, atrial fibrillation; ARVC, arrhythmogenic right ventricular cardiomyopathy; BrS, Brugada syndrome; CAD, coronary artery diseease; CPVT, catecholaminergic polymorphic ventricular tachycardia; DCM, dilated cardiomyopathy; ECG, electrocardiogram; EP, electrophysiological; G+/P-, genotype-positive/phenotype-negative; ICD, implantable cardioverter-defibrillator; LQT, long QT syndrome; LQT1, long QT syndrome type 1; LVNC, left ventricular non-compaction; MRI, magnetic resonance imaging; SCD, sudden cardiac death; WPW, Wolff-Parkinson-White syndrome.

Figure 6. Practical exercise advice for individuals with cardiovascular conditions.

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