Expert consensus guidelines: Anomalous aortic origin of a coronary artery

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Anomalous aortic origin of the right coronary artery.

Central Message
We sought to establish evidence-based guidelines for the management anomalous aortic origin of a coronary artery.

Perspective
Anomalous aortic origin of a coronary artery is associated with sudden cardiac death. Although the risk for any single affected individual is small, the loss of an otherwise healthy person is particularly devastating. Surgical and interventional therapies have been developed that appear to be protective but these therapies carry risks. The challenge is identifying those individuals at such risk.

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From a perspective of the tenets of the AATS, the expert panel sought to establish evidence-based guidelines for the management of anomalous aortic origin of coronary arteries. A comprehensive review of the existing literature and input from relevant experts in the field was used to establish recommendations for diagnosis, treatment, and follow-up. This document is intended to provide a resource for cardiothoracic surgeons and related health-care professionals for the care of patients with anomalous aortic origin of coronary arteries. The expert panel acknowledges that the field is rapidly evolving and therefore they encourage practitioners to keep up to date with the latest literature and to include individual patient preferences and values in the decision-making process.

See also the AATS Coding and Reimbursement manual for a detailed discussion of payment and cost-implications related to the treatments described in this document.
RATIONALE AND OBJECTIVES

The objective of this project was to establish consensus 2016 American Association for Thoracic Surgery (AATS) evidence-based guidelines for the management of anomalous aortic origin of a coronary artery. In many types of coronary anomalies, the risk of sudden cardiac death (SCD) is largely unknown, as the anomalies are quite rare. However, observational studies have identified the coronary anomalies that appear to be most prevalent and in which the SCD risk appears to be the greatest: when both coronary arteries arise from the same aortic sinus with either a single ostium or 2 separate ostia (Table 1). The aberrant vessel may arise above the inappropriate sinus or above the commissure and not truly from the sinus itself. For this article, we refer to this as anomalous aortic origin of a coronary artery (AAOCA) from the inappropriate coronary sinus. The course the anomalous coronary artery takes appears to have an impact on its risk of SCD. The anomalous aortic origin of the left main coronary artery (LMCA) or right coronary artery (RCA) can course in front of the pulmonary artery (pre-pulmonic) or posterior to the aorta (posterior/retroaortic). The AAOLCA or left anterior descending coronary artery or left circumflex coronary artery may originate from the right sinus alone. The LMCA or left anterior descending coronary artery alone can course through the conal septum (intraseptal or intraconal or intramyocardial). These previous subtypes are generally not believed to be clinically significant. However, the course becomes important if either the aberrant left main coronary artery or right coronary artery travels between the 2 great vessels. This review and recommendations are directed at AAOCA from the opposite sinus of Valsalva with an interarterial course (Figure 1).

METHODS OF REVIEW

The AATS Guidelines Committee identified the management of AAOCA as a key topic in cardiothoracic surgery suitable for the establishment of clinical guidelines. The Guidelines Committee selected James S. Tweddell, MD, as chair of the AAOCA Working Group and asked him to appoint an AAOCA Guidelines writing committee to create evidence-based guidelines for the AATS Guidelines Committee. The chair assembled a multidisciplinary group of experts, the coauthors of this article, who include congenital cardiac surgeons and adult and pediatric cardiologists. Members were tasked with performing comprehensive literature searches, and making recommendations based on a review of the literature. Members also graded the quality of the evidence supporting the recommendations and with assessing the risk-benefit profile for each recommendation. The level of evidence was graded by the work force panel according to standards published by the Institute of Medicine (Figure 2). For the development of the guidelines, we followed the recommendations of the Institute of Medicine’s 2011 Clinical Practice Guidelines We Can Trust: Standards for Developing Trustworthy Clinical Practice Guidelines (http://www.nationalacademies.org/hmd/Reports/2011/Clinical-Practice-Guidelines-We-Can-Trust.aspx). Scheduled teleconferences were used to organize the topics to be covered by the guidelines, review the literature review summaries, and propose recommendations. For all meetings, agendas were circulated beforehand. Summaries of the conference calls were circulated to the writing committee members. The final recommendations were voted on by the writing committee to present to the Councilors of the AATS and review the final manuscript. The writing committee unanimously agreed on all recommendations. Therefore, the process followed the recommendations of the Institute of Medicine, but an extensive consultation with all other stakeholders, including patients, was not performed. Instead, the AATS guidelines attempt to provide a rapid response to the rapidly changing medical literature and provide clinicians with the recommendations of senior content experts based on the best available information. The expert consensus provides important guidance to clinicians, particularly when the quality of the evidence is limited or contradictory. These consensus guidelines provide the best opinion of a group of content experts. The following recommendations are based on expert consensus opinion as well as on the best available evidence. Despite important knowledge gaps, we feel it is important and timely to review the available evidence and present expert opinion based on best practices. The guidelines were prepared for publication in The Journal of Thoracic and Cardiovascular Surgery.

SECTION I: BACKGROUND

Prevalence

The true prevalence of congenital coronary anomalies that are potentially pathologic in the general population is difficult to ascertain. Several studies have attempted to quantify this value, with estimates ranging between 0.1% and 1.0% in both the adult and pediatric populations. The wide difference in prevalence rates is likely due to...
choice of imaging modality, patient population chosen to study, and/or the how coronary anomalies were defined.°

When looking specifically at the estimated prevalence of interarterial AAOCA, this has ranged between 0.1% and 0.7%.5,6 Yamanaka and Hobbs5 found the incidence to be approximately 0.3% of more than 100,000 adults evaluated with coronary angiography. In a large population-based prospective study in asymptomatic children using transthoracic echocardiography, the incidence of AAOCA was found to be 0.17%.5 Because this study evaluated only asymptomatic patients, the true prevalence was likely underestimated, as they did not include those children with symptomatic AAOCA. Recently, Angelini7 reported on a magnetic resonance imaging screening program designed to identify high-risk cardiac lesions, and found 0.7% of the population screened had interarterial AAOCA, with 0.5% interarterial AAORCA. If we extrapolate this to the population of young people (ages 12-35) in the United States, this could mean more than 600,000 children and young adults have interarterial AAOCA. In most studies, interarterial AAORCA is from 3 to 6 times more common than AAOLCA.1,7

Genetics

Little is known about the genetics of coronary anomalies, especially those that have the potential for sudden death, including interarterial AAOCA. The development of the coronary arteries is complex, with many different sites at which a mutation leads to a potentially lethal coronary anomaly. There are minimal data regarding the genetic patterns of AAOCA. Bloor et al9 reported on the coronary artery anatomy in albino rats and found that the genetic variation in newborn rats and their parents was likely determined from multiple genes and not of classical Mendelian inheritance. There are no published data about the genetic inheritance in humans. However, there have been reports of families with at least 2 first-degree relatives affected by AAOCA.10-12 Genetic testing in association with focused imaging of the relatives of the AAOCA patient may help elucidate any potential genetic factors. In a more general, nonspecific sense, there are multiple population studies demonstrating familial clustering of sudden cardiac arrest (SCA) as a first clinical manifestation of ischemia.13-16 This suggests a yet-undefined genetic basis for an arrhythmic response to ischemia, distinct from, but in addition to, any genetic basis for the primary structural defect itself.

SCD and the Mechanism of Ischemia

Since the exact mechanism of SCD associated with coronary anomalies is not known, several hypotheses have been put forth based on anatomic and physiologic properties of the anomalous coronary. Certain factors appear to predispose to myocardial ischemia and/or lethal ventricular arrhythmias, likely due to limitation of coronary reserve. These include 1 or more of the following: ostial stenosis in association with an oblique take-off from the aorta, ostial ridge, vessel spasm, intussusception, noncompliant pericommisural area, and compression of the anomalous coronary artery intramurally and/or between the great arteries.17-19 It remains unknown whether these mechanisms act alone or in combination to provide the substrate for SCD.

Risk of SCD. The most common anomaly that appears to carry some increased risk of SCD is AAORCA. However,
interarterial AAOLCA is proportionally far more prevalent among individuals who have died suddenly with no other explanation.\textsuperscript{17-21} Despite not knowing the exact mechanism of ischemia in those with AAoca, identifying and treating those anomalies that place the patient at risk of SCD is of utmost importance, and management should ideally be based on the risk assessment. Although the true risk is unknown, an estimation based on some assumptions can be calculated. The mortality rates frequently cited and used for risk assessment are from autopsy series data and include 0\% to 57\% for AAORCA and 27\% to 100\% for AAOLCA.\textsuperscript{17-21} What is necessary to understand is that these rates reflect the prevalence of AAoca in those who have already died and not the risk of SCD in those living with AAoca. Recently, 2 studies reported on the incidence of SCD or SCA in people 35 years and younger.\textsuperscript{22,23} In the combined cohorts, there were 4 cases of AAoca associated with SCD or SCA in a combined 34 million patient-years; in 1 study, the 2 cases of SCD (ages <19 years) were both interarterial AAOLCA and known to be associated with vigorous physical activity.\textsuperscript{23} These studies demonstrate that the risk of SCD or SCA in the young, in the absence of participation in competitive sports, is exceedingly low.\textsuperscript{24}

**Exercise and SCD risk.** Vigorous physical activity increases the risk of SCD in those with interarterial AAOLCA.\textsuperscript{6,23,25} Maron et al\textsuperscript{25} published a comprehensive analysis of sudden deaths among competitive athletes in the United States over a 27-year period. Of the 690 SCD episodes ascribed to a cardiovascular cause, 119 of these were due to AAoca. Based on their data, the incidence of SCD would be approximately 0.1 per 100,000 person-years from AAoca. A similar incidence of SCD was found among Minnesota high school athletes over a 26-year period, with 2 SCD events occurring due to AAoca, both of which were AAOLCA.\textsuperscript{26} Using the data of Maron et al,\textsuperscript{25} Brothers et al\textsuperscript{27} calculated the cumulative risk of death over a 20-year period in children and young adults with AAoca (ages 15-35 years) participating in competitive sports was 6.3\% for AAOLCA and 0.2\% for AAORCA. Even though these analyses are prone to ascertainment bias as well as underreporting, it does seem that the risk of SCD ascribed to AAoca is far less than reported in autopsy series.

It is important to understand that most risk estimates are based on the presumed incidence of SCD in those who are participating in competitive athletics, which is only approximately 10\% to 15\% of children and adolescents. They do not assess risk among those who have SCA during high-intensity recreational sports, or in the general population not participating in higher-level sports. Competitive athletes are defined as individuals of middle school age and older (generally \(\geq\)11 years of age) who are engaged in exercise training on a regular basis and participate in official sports competition organized by a recognized athletic association. Competitive athletes place a high premium on athletic excellence and these individuals typically exercise more than 10 hours per week. In contrast, recreational athletes are defined as individuals engaged in recreational or leisure-time sports activities, on either a regular basis or intermittently. Usually, they exercise less than 10 hours...
per week. Recreational sports do not necessarily require systematic training or the pursuit of excellence. Although there are rare case reports of SCD from AAOCA at rest or while participating in recreational activity, these reports are just that: individual cases that occur rarely, and not derived from any formal databases. Notably, a recent study from France demonstrated that many more SCDs occur during recreational sports than during competitive activities, albeit at an older age. This increasing number of older individuals (eg, ages late 20s to 40s) with reports of SCD or SCA from AAOCA may be due to the growth of sanctioned sporting events for adults, such as triathlons and running and bicycle races. In fact, these older athletes may now be exerting themselves at a higher level than they did when they were young. Taking a conservative prevalence rate of AAOCA in the population of approximately 0.2%, which may be underestimating the prevalence based on recent studies, there are at least 600,000 young people in the United States with AAOCA. Besides the competitive athlete, in whom there are only a small number of SCD events reported every year, the risk of SCD for the asymptomatic young person with interarterial AAOCA, even AAOLCA, who is not participating in competitive sports does not appear to be significantly greater than the SCD risk for those without AAOCA who are participating only in recreational athletics.

SECTION II: PRESENTATION AND DIAGNOSIS

Presentation

There is not a typical way that patients present with AAOCA. For some, the initial presentation is aborted SCD or true SCD. However, most patients with AAOCA are diagnosed when the anomaly is found incidentally on a transthoracic or transesophageal echocardiogram or computed tomography (CT) angiogram that is performed for another reason, such as a heart murmur or abnormal electrocardiogram (ECG). The patient may also have an echocardiogram performed for symptoms related to exertion, such as chest pain, palpitations, dizziness, presyncope, or syncope. Although many of these symptoms are often seen in those without coronary anomalies, these complaints prompt the referral to a cardiologist and an echocardiogram is performed. Chest pain should be considered ischemic if it is accompanied by evidence of myocardial injury, noted by ST segment depression at rest or with exercise, ventricular arrhythmias that increase with exercise, lack of increase or a decrease in blood pressure with exercise, evidence of wall motion abnormality on echocardiography, perfusion defect on nuclear scan in the correct distribution of the anomalous coronary artery, and/or evidence of past fibrosis/scar or perfusion abnormality seen by cardiac magnetic resonance imaging (MRI). Recent large-scale screening programs have increased the frequency of incidentally diagnosed AAOCA.

Diagnostic Studies

A screening ECG is not reliable for suspecting or recognizing AAOCA. The presence of a q-wave consistent with a previous myocardial infarction scar is rarely, if ever, seen in AAOCA. Exertional chest pain or dyspnea in a relatively young individual not otherwise suspected to be at risk for coronary atherosclerosis may be helpful; however, 2 reports suggest that 50% of SCD associated with coronary artery anomalies were first events without previous symptoms. As well, stress tests are not uniformly positive among individuals with these anomalies.

In the past, cardiac catheterization with coronary angiography was routinely used for diagnosis of AAOCA; however, due to the invasive nature of the test and its inherent exposure to ionizing radiation, it is rarely used in the pediatric population. Cardiac catheterization is indicated if the anatomy cannot be defined with noninvasive imaging and in adults with suspected or echocardiographically defined anomalous vessels, for both complete definition of the anatomy and concomitant evaluation for coronary atherosclerotic disease. Obviously, it is not used for routine screening in the absence of ischemic symptoms or clues from other imaging studies. The best method for initially identifying AAOCA is a carefully performed transthoracic echocardiogram with Doppler color flow mapping. This is generally the initial diagnostic modality due to availability, cost-effectiveness, ease of performance, and absence of radiation exposure. Imaging should clarify origin of left or right, as well as the presence or absence of an intramural course. Additional imaging is indicated when the anatomy cannot be accurately defined.

Coronary CT angiography or cardiac MRI is commonly used to obtain better visualization of the coronary artery anatomy to confirm the diagnosis. Once the anatomy has been established, a maximal exercise stress test should be used to help assess the potential ischemic burden of the anatomic variant, especially in competitive athletes or high-intensity recreational athletes. We also recommend that the exercise test be combined with a nuclear perfusion scan or stress echocardiogram to optimize the sensitivity of identifying ischemia; however, it must be emphasized that a normal stress test, nuclear perfusion scan, or stress echocardiogram is, at best, incompletely reassuring. These studies have a low negative predictive value, and are most helpful only if they are positive.

Recommendations on Diagnostic Imaging

1. Individuals with suspected AAOCA should undergo transthoracic echocardiography to identify the origin and course of the proximal coronary arteries. (Class I, Level of Evidence B—supporting references)

2. Additional imaging studies, such as coronary CT angiography or cardiac MRI are reasonable to better visualize...
the coronary artery anatomy and to confirm the diagnosis. (Class IIa, Level of Evidence B—supporting references 40,46,52,59,63,67,69-87,89-95,100)

3. In those individuals without a history of ischemic chest pain or aborted SCD, exercise stress testing combined with nuclear perfusion scan or echocardiographic imaging should be used to help assess the potential ischemic burden of the anatomic variant. (Class I, Level of Evidence B—supporting references 27,32,40,98,99)

4. Cardiac catheterization should be performed in those individuals with anomalous origin of a coronary artery if the anatomy cannot be defined with noninvasive imaging, and in adults with risk factors for coexistent atherosclerotic coronary artery disease. (Class I, Level of Evidence B—supporting references 132-55)

SECTION III: TREATMENT

Overview
Most would agree that activity restriction and surgical intervention is indicated in any patient with AAOCA who presents with signs and/or symptoms of myocardial ischemia, or has inducible ischemic changes with exercise testing. The treatment dilemma occurs when this diagnosis is made in the asymptomatic patient, especially the patient with AAORCA, as provocative testing is often negative. Treatment options for AAOCA include surgical and nonsurgical interventions and/or medical management.

Surgical Intervention
The clinical indication for intervention, even in those who are asymptomatic, is based on the calculated risk of SCD. Although an intervention is not warranted in most cases of coronary anomalies, there are some instances in which intervention may be warranted, including syncope associated with documented or reasonably suspected ventricular arrhythmia (nonvagally mediated), high-risk ambient ventricular arrhythmias, chest pain consistent with angina, aborted sudden death/cardiac arrest, and evidence of ischemia on provocative testing.101,102 In those with interarterial AAOLCA, most children ages 10 and older are referred for surgical intervention, even if asymptomatic, due to the significantly increased risk of SCD with this anomaly, especially with exercise.103 In contrast, there is far less agreement about whether patients with AAORCA without symptoms should undergo operation. Until recently, American College of Cardiology (ACC) and American Heart Association (AHA) guidelines have suggested avoidance of athletic activity for all patients with AAOCA and so for asymptomatic young patients with AAORCA, surgery has sometimes been performed to permit them to participate in competitive athletics.104,105

The recent AHA/ACC Scientific Statement now differentiates between the much higher-risk interarterial AAOLCA and the lower-risk interarterial AAORCA, with the potential for those with AAORCA who are asymptomatic to return to competitive sports after a complete evaluation.105 AAOLCA with intraseptal, prepulmonic, or retroaortic courses are generally considered benign with only rare case reports of ischemia.106-108 These patients are generally not referred for surgery and are not exercise-restricted, but should have a stress test as part of preparticipation clearance for competitive athletics.

Once the decision to perform surgery has been made, surgical procedures are available. These various approaches have not been compared in any rigorous fashion, and so the superiority of any one remains speculative. Each type of operation is performed to address 1 or more of the proposed mechanisms of myocardial ischemia in patients with AAORCA, as discussed previously.

Specific surgical procedures.
Unroofing. Among the various surgical options, perhaps the most technically and conceptually simple is the so-called “unroofing” procedure. It is the procedure of choice for interarterial, intramural AAOC in the young patient.109,110 The operation is accomplished via an anterior aortotomy and consists of incising the common wall between the aorta and intramural segment of the anomalous coronary artery (Figure 3). This incision has several salutary consequences in that it relocates the functional orifice to the appropriate sinus, enlarges the orifice significantly, eliminates the intramural component of the artery, and eliminates the portion of the vessel that lies between the great arteries.

There are 3 particular pitfalls to be avoided in the performance of the operation. The intramural course typically runs behind the intracoronary commissure, which might be damaged or distorted by the unroofing incision, potentially causing aortic insufficiency. Strategies for approaching this anatomic variant include resuspension of the commissure if it has been injured or creating a neo-ostium of the anomalous vessel by unroofing only that portion which is not behind the commissure (Figure 4). Another potential difficulty with the unroofing procedure is the exposure of the layers of the aortic wall to systemic pressure at the site of the neo-ostium, creating the possibility for a localized dissection, which might occlude the coronary artery. This can be prevented by the placement of fine “tacking” sutures to approximate the layers of the aortic wall at the neo-ostium. An additional hazard of unroofing is seen with overly aggressive unroofing, whereby the incision is inadvertently carried through the aortic or coronary wall in an area in which the coronary is not actually intramural. This is particularly easy if the intramural component of the vessel is very short. If not recognized, this can result in troublesome bleeding, which requires very precisely placed sutures for repair, possibly necessitating an
additional period of cardioplegic arrest. Clearly the best approach to this complication is prevention.

Pulmonary artery translocation. This operation is based on the concept that the anomalous vessel is compressed or pinched between the great arteries in AAOCA, and therefore the goal of the operation is to reposition the main pulmonary artery (Figure 5).\(^{112,113}\) This technique is mainly used when the anomalous coronary is not intramural but the ostia are in close approximation or if there is a single coronary artery in the presence of ischemia. This procedure consists of an initial meticulous dissection to permit full mobilization of the proximal pulmonary root. In one version of the operation, the main pulmonary artery is transected, the pulmonary confluence is patched, and the main pulmonary artery is anastomosed to a “neo-confluence” location created by making an incision well out onto the left pulmonary artery. In effect, this moves the course of the main pulmonary artery leftward, preventing it from compressing the anomalous coronary.

An alternative version of the operation is accomplished by dividing the proximal right pulmonary artery at its origin and then transposing it anterior to the aorta, where it is re-anastomosed to its original site. This is usually accomplished by a tissue-to-tissue posterior wall suture line, with a generous augmentation patch placed anteriorly to prevent stenosis in the stretched right pulmonary artery. This version of the operation has the effect of moving the main pulmonary artery anteriorly and away from the anomalous coronary artery.

Reimplantation (ostial translocation). Reimplantation is perhaps most useful when there is little or no intramural component of the anomalous coronary and there are 2 separate ostia.\(^ {65,114-117}\) In this operation, the anomalous vessel is mobilized over its proximal course. Ideally, a few millimeters of aortic wall containing the ostium of the anomalous coronary is excised from its abnormal location, and then reimplanted in the correct sinus of Valsalva (Figure 6). Sometimes a patch of autologous pericardium is used to enlarge the connection. It is somewhat technically challenging in that it requires full mobilization of the anomalous vessel to avoid kinking as well as very precise patching and reimplantation.

Ostioplasty. In the ostial approach, a neo-ostium is created for the anomalous vessel in the sinus from which it would normally have exited. An incision is created in the aortic sinus with a matching incision in the coronary artery away from the aortic wall. By joining these incisions and augmenting the opened areas with a patch, typically of autologous pericardium, a neo-ostium is fashioned (Figure 7), and the course of the artery is no longer either intramural or between the great vessels.\(^ {118-120}\) The operation is facilitated by transection of the main pulmonary artery to optimize exposure, and requires meticulous reconstruction of the coronary artery itself. Of all of the surgical options, this is therefore probably the most technically challenging.

Bypass grafting. An indirect approach for AAOCA is to use standard coronary artery bypass techniques, with either a mammary artery or saphenous vein conduit.\(^ {121}\) This approach has generally been unsatisfactory because flow in the anomalous vessel is typically only compromised during periods of stress or exercise, so that there is substantial competitive flow the vast majority of the time.\(^ {122}\) The patency of a bypass graft in such a setting is likely to be disappointing. Ligation of the native vessel at its origin has been advocated by some as a solution to the issue of competitive flow, but concern has also been raised that a native mammary artery may have inadequate flow early on to replace all of the flow produced by a nonstenotic native coronary artery. Therefore, bypass grafting has a very limited role for AAOCA, and should probably be limited to settings in which the anomaly is accompanied by significant atherosclerotic narrowing or in which an alternative approach has been technically unsatisfactory.
Summary of surgical approaches to AA0CA. In summary, surgical address of AA0CA may take 1 of several forms. For patients with significant intramural length of the anomalous vessel, unroofing is generally the preferred procedure. For patients with a very short or minimal intramural course, reimplantation or ostial reconstruction would be more appropriate. If the AA0CA is accompanied by atherosclerotic narrowing or if an alternative reconstruction technique has failed, coronary bypass grafting is reasonable. Pulmonary artery translocation techniques may be used to supplement any primary reconstruction, and are relatively low risk and technically simple adjuncts to other procedures.

The risk of surgery for AA0CA in published series is extremely low, with excellent intermediate-term survival. Nevertheless, despite a patent coronary ostium, 1 study found that subclinical changes suggestive of ischemia occur on stress testing in more than one-third of postoperative patients. Furthermore, although the surgical procedures may remove the hypothesized mechanism of ischemia leading to SCD, the long-term impact of surgery on the coronary arteries is unknown. Specifically, we do not know if these procedures place the patient at long-term risk of coronary stenosis due to scarring or accelerated atherosclerosis.

FIGURE 4. Unroofing procedure in which a neo-ostium was created without taking down the intercoronary commissure. A, The left coronary artery arises from the right sinus of Valsalva with an intramural course. The site for creation of a neo-ostium is identified by passing an instrument into the coronary (B). The anomalous coronary is unroofed into the appropriate sinus (C). Because the commissure between the left and right sinuses is not disrupted, this may decrease the risk of aortic valve regurgitation. A neo-ostium is created in that sinus at the point at which the artery leaves the aortic wall. Reprinted with permission.111
Ongoing assessment of patients who have undergone surgery for AAORCA is essential to define the risks both short- and long-term.

**Percutaneous Coronary Intervention**

Before the development of the field of percutaneous coronary interventions (PCI), management of symptomatic or high-risk coronary arteries with anomalous origins, with or without superimposed atherosclerotic lesions, was limited to surgery and medical therapy directed at superimposed coronary vasospasm. The development of PCI technology has added the strategy of stenting the anomalous vessels, based on their anatomic take-off anatomy and coexisting lesions, with or without vasospasm. It has been suggested that intravascular ultrasound technology aids in the PCI approach to identifying and intervening for an ischemic burden associated with AAORCA, especially in those with a partial intramural course and proximal intramural stenosis. There are no large-scale studies or registries comparing outcomes of surgery versus PCI, leaving evaluation limited to objective ischemic burden testing before and after interventions. Furthermore, long-term follow-up data are limited regarding this procedure in adults. Due to safety issues with stenting anomalous coronary arteries in growing children, this procedure is not advisable in the pediatric population, but may be considered in select cases in the adult population.

**Medical Therapy**

**Beta-blockers.** There are a small number of case reports using beta-blockers in adults to treat AAORCA. The single largest series in the literature described 56 adult patients (average age 55.9 years) with beta-blockade and reported no episodes of SCD over a 5-year period. In this study, however, there were no patients with AAORCA and no patients younger than 30, both variables known to increase the risk of sudden death in patients with AAORCA. There are no reports of the use of beta-blockers in patients with AAORCA younger than 30 years. Presently, there does not appear to be adequate data to justify medical therapy for AAORCA.

**Exercise restriction from competitive athletics.** In the young patient, exercise restriction from competitive athletics is the most common nonsurgical strategy. The
recommendation to avoid competitive athletics in patients with AAOCA is based on 2 observations: (1) the mortality risk associated with AAOCA is high, and (2) sudden death in patients with AAOCA occurs most frequently during or after peak exercise.\textsuperscript{6,18,21-23,29} However, because children should remain active and discouraging exercise may lead to other issues with long-term cardiovascular health, asymptomatic children are encouraged to participate in physical education class and other recreational activities. In contrast to previous recommendations, the current recommendations by the AHA/ACC permit individuals with unrepaired AAORCA who are without symptoms or a positive exercise stress test to participate in competitive sports.\textsuperscript{105,128} It is important to note, however, that as of this report, there are no short- or long-term follow-up studies on unoperated patients with AAOCA who have been observed and restricted from competitive sports. The guidelines are generally based on Level of Evidence C, expert consensus opinions, in the absence of reliable objective clinical or epidemiological data. The one exception is surgery for interarterial AAOLCA, for which intervention is based on Level of Evidence B. To better address this issue, the Congenital Heart Surgeons’ Society has established a Registry of Anomalous Aortic Origin of the Coronary Artery.\textsuperscript{129} The overall purpose of the registry is to determine the outcome of surgical intervention versus observation in children and young adults with AAOCA, and to describe the natural and “unnatural” history of these patients over the course of their lifetime.

**Observation without exercise restriction.** If the cumulative risk for interarterial AAORCA is estimated at 0.2\%, is it safer to observe than to recommend surgery? We must also take into account the risks of surgical intervention, the lack of long-term follow-up for these patients, and the few scattered reports of postoperative sudden death, ischemia, and other complications from surgery.\textsuperscript{58,96,111,130}

We agree with the current AHA/ACC guidelines\textsuperscript{51} in that participation in competitive sports may be a reasonable option for the asymptomatic patient with AAORCA without evidence of inducible ischemia, as this appears to be a more benign lesion than previously recognized. It is essential that we have a clear definition of “symptoms.” Palpitations, chest pain, and even presyncope are common in the pediatric population and rarely have a cardiac etiology, whereas frank syncope and true anginalike chest pain with exercise are much less common and could be considered related to the coronary anomaly. Thus, even in the symptomatic patient, if all provocative testing for ischemia is negative, especially in the case in which the symptoms are replicated during the test and the test is normal, there is little reason to limit these individuals. In the absence of inducible ischemia on testing, there should be convincing historical evidence that the symptoms are likely due to ischemia or

**FIGURE 6.** Direct reimplantation of an anomalous right coronary artery arising from the left sinus of Valsalva. A button of aortic sinus containing the anomalous coronary is excised and mobilized (A). The anomalous coronary is then reimplanted into the right sinus of Valsalva (B). RCA, Right coronary artery; L, left; R, right. Reprinted with permission.\textsuperscript{116}
arrhythmias before restricting the individual from competitive athletics.

RECOMMENDATIONS ON TREATMENT

5. Individuals with AAOCA and symptoms of ischemic chest pain or syncope suspected to be due to ventricular arrhythmias, or a history of aborted SCD, should be activity restricted and offered surgery. (Class I; Level of Evidence B—supporting references 6,18,21-23,29,32,40,58,72,82,105,113,123,124)

6. Individuals with AAOCA and symptoms of ischemic chest pain or syncope suspected to be due to ventricular arrhythmias, or a history of aborted SCD, should be activity restricted and if deemed prohibitively high risk for surgery, catheter-based intervention may be considered. (Class IIb; Level of Evidence C)

7. Individuals with or without symptoms with an unrepaired anomalous origin of a left coronary artery from the right sinus of Valsalva, with an interarterial course, should be restricted from participation in all competitive sports. (Class I; Level of Evidence B—supporting references 6,18,21-23,29,105)

8. Individuals without symptoms with anomalous origin of a left coronary artery from the right sinus of Valsalva with an interarterial course should be offered surgery. (Class I; Level of Evidence B—supporting references 17-24)

9. Individuals with an anomalous origin of a right coronary artery from the left sinus of Valsalva should be evaluated for inducible ischemia, using an exercise stress test with additional imaging, including stress echocardiography or nuclear perfusion imaging. For those without symptoms concerning for ischemia or a positive exercise stress test, and after counseling concerning the risk of SCD, participation in competitive athletics is permissible. (Class IIa; Level of Evidence C)

10. Surgery for repair of AAOCA from the opposite sinus of Valsalva should include elimination of the intramural course and any associated ostial narrowing by unroofing, ostioplasty, or reimplantation. (Class I; Level of Evidence B—supporting references 56,59,65,82,117,123)

11. Repositioning of the pulmonary artery confluence away from the anomalous artery (laterally or anteriorly) may be considered as an adjunctive procedure. (Class IIIb; Level of Evidence C)
TABLE 2. Recommended follow-up for AAOCA, surgical repair

<table>
<thead>
<tr>
<th>Postoperative short-term follow-up (timeline respective to surgical date)</th>
<th>Postoperative long-term medical follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 7-10 d: Cardiology appointment with ECG and echocardiogram</td>
<td>• Cardiology follow-up annually</td>
</tr>
<tr>
<td>• 4-6 wk: Cardiology appointment with ECG and echocardiogram</td>
<td>• Echocardiogram annually</td>
</tr>
<tr>
<td>• 3 mo: Cardiology appointment with exercise stress test with imaging</td>
<td>• Exercise stress test every 1-3 y, depending on activity level</td>
</tr>
<tr>
<td>• 6 mo: Cardiology appointment with ECG and cardiac MRI, if available</td>
<td>• If participating in high-level recreational or competitive sports, exercise stress test annually</td>
</tr>
<tr>
<td>• Remain on 1 baby aspirin daily indefinitely</td>
<td>• With nuclear perfusion only if new symptoms</td>
</tr>
</tbody>
</table>

Physical activity

• No competitive athletics until at least 3 mo after surgery and after a complete evaluation has been performed by the pediatric cardiologist
• No competitive athletics for at least 12 mo after surgery and after a complete evaluation has been performed by the pediatric cardiologist in those whose presentation was sudden cardiac arrest/aborted sudden death
• Patients should be counseled that they are to cease exercise until further evaluation by the cardiologist if any symptoms develop, such as chest pain, palpitations, or fainting, during or just after exercise
• Patient should be allowed to rest if he or she gets tired
• Patient should stay well-hydrated with water, aiming for at least 60 ounces of water daily, or more, based on his or her activity level

SECTION IV: FOLLOW-UP

Ongoing Risk

The follow-up for patients with AAOCA will depend somewhat on the management chosen; however, all patients should be followed by a cardiologist for their lifetime. This should include a transition from a pediatric to an adult cardiologist, if necessary. Lifelong follow-up is especially important for those who undergo surgical repair, as long-term outcomes from surgical repair are largely unknown. Short- and mid-term complications have been noted, including mild aortic valve insufficiency, severe aortic valve insufficiency requiring aortic valve replacement, pericardial effusions, and ischemic changes on postoperative provocative testing. Postoperative death has been reported rarely in the literature in both the pediatric and adult age groups. The authors are aware of a handful of other pediatric deaths postoperatively that have not been published. It is interesting to note that, at least in the young, if a patient presents with SCD or SCA and survives the surgery, he or she may still be at increased risk for an SCD event once the patient returns to sport.

TABLE 3. Long-term follow-up and physical activity recommendations, unrestricted

<table>
<thead>
<tr>
<th>Medical follow-up</th>
<th>Physical activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cardiology follow-up annually</td>
<td>• Full participation in competitive athletics</td>
</tr>
<tr>
<td>• Electrocardiogram annually</td>
<td>• Recommend automated external defibrillator at all team practices and sporting events</td>
</tr>
<tr>
<td>• Echocardiogram every 1-2 y</td>
<td>• Patients should be counseled that they are to cease exercise until further evaluation by a cardiologist if any symptoms develop, such as chest pain, palpitations, or fainting, during or just after exercise</td>
</tr>
<tr>
<td>• Exercise stress test every 1-3 y, depending on activity level</td>
<td>• Patient should be allowed to rest if he or she gets tired</td>
</tr>
<tr>
<td>• If participating in high-level recreational or competitive sports, exercise stress test annually</td>
<td>• Patient should stay well-hydrated with water, aiming for at least 60 ounces of water daily, or more, based on his or her activity level</td>
</tr>
<tr>
<td>• With nuclear perfusion only if new symptoms</td>
<td>• Holter monitor as needed, if symptoms</td>
</tr>
</tbody>
</table>

Those who have undergone surgery will need close follow-up in the initial postoperative period, but will be able to lengthen the interval between visits after the first postoperative year. According to the recent AHA/ACC guidelines, these patients may return to competitive sports at least 3 months postoperatively and if an exercise stress test reveals no evidence of myocardial ischemia or ventricular arrhythmias. However, those who present with true aborted SCD appear to remain at increased risk, even after surgical repair. We would recommend those

TABLE 4. Follow-up and activity recommendations for AAOCA, restricted from competitive athletics

<table>
<thead>
<tr>
<th>Medical follow-up</th>
<th>Physical activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cardiology follow-up annually</td>
<td>• No competitive sport at the middle school level or higher that requires moderate to vigorous activity levels (&lt;40% maximum oxygen uptake and &lt;20% maximal voluntary contraction)</td>
</tr>
<tr>
<td>• Electrocardiogram annually</td>
<td>• Examples include running, soccer, tennis, swimming, basketball, baseball, football</td>
</tr>
<tr>
<td>• Echocardiogram every 1-2 y</td>
<td>• Participation at the middle school level or higher is allowed in those sports that require low activity levels</td>
</tr>
<tr>
<td>• Exercise stress test every 1-3 y, depending on activity level</td>
<td>• Examples include golf, bowling, cricket, archery, equestrian, karate</td>
</tr>
<tr>
<td>• With nuclear perfusion only if new symptoms</td>
<td>• Participation is allowed in recreational athletics, including gym class</td>
</tr>
<tr>
<td>• Holter monitor as needed, if symptoms</td>
<td>• Patient should be allowed to rest if he or she gets tired</td>
</tr>
<tr>
<td></td>
<td>• Patient should stay well-hydrated with water, aiming for at least 60 ounces of water daily, or more, based on his or her activity level</td>
</tr>
</tbody>
</table>

AAOCA, Anomalous aortic origin of a coronary artery; ECG, electrocardiogram; MRI, magnetic resonance imaging.
patients with true SCA or aborted SCD should not return to competitive athletics for at least 1 year postoperatively and then only return to competitive athletics if they are free of symptoms and have a negative exercise stress test. Those managed conservatively with exercise restriction will need follow-up annually. Those patients who are not exercise-restricted should be seen annually, especially if they are participating in competitive athletics. Finally, when there is a family history of clustering of SCD as a first manifestation of any ischemic event, more specific counseling of risk-versus-benefit should be undertaken with both the athlete and family so they can make an informed decision about participation. Further for further details, please refer to Tables 2-4, which are suggested protocols that we have created for follow-up of patients with AAORCA, based on their management.

Recommendations on Follow-up

12. Following surgical repair of an anomalous coronary artery, individuals without a history of aborted SCD should be offered the opportunity to return to competitive or recreational athletics after waiting at least 3 months after surgery, provided they have remained without symptoms concerning for ischemia or arrhythmia and an exercise stress test does not show evidence of myocardial ischemia or concerning arrhythmia. (Class I; Level of Evidence C)

13. Following surgical repair of an anomalous coronary artery, in an individual who presented with aborted SCD, it is reasonable to permit return to competitive athletics after a longer waiting period of 12 months after surgery provided the patient has remained without symptoms concerning for ischemia or arrhythmia and an exercise stress test does not show evidence of myocardial ischemia or concerning arrhythmia. (Class IIa; Level of Evidence C)

14. After surgical repair of an anomalous coronary artery, in an individual who presented with aborted SCD, it is reasonable to permit return to recreational sports, including physical education class, 3 months after surgery, provided the patient has remained without symptoms concerning for ischemia or arrhythmia and an exercise stress test does not show evidence of myocardial ischemia or concerning arrhythmia. (Class IIa; Level of Evidence C)

15. An automated external defibrillator with trained personnel should be immediately available during competition and training. (Class I; Level of Evidence B—supporting references)

SECTION V: GAPS IN KNOWLEDGE

One major gap in knowledge regarding AAORCA is our ability to adequately risk stratify patients for surgery versus observation, notably in the asymptomatic young person with AAORCA. Although there are suspected anatomic and physiologic reasons for myocardial ischemia and/or potentially lethal arrhythmias, we are still unable to distinguish which person is at high risk for ischemia and should undergo surgery from the individual who will remain asymptomatic and may be allowed to participate in competitive sports. Another gap arises from our lack of long-term follow-up of patients after surgical repair. Short- and medium-term results are encouraging; however, there are reports of issues, such as new aortic valve regurgitation, that will need to be followed over time.

SECTION VI: SUMMARY AND RECOMMENDATIONS

Summary

AAORCA with an intramural course is associated with SCD, due to ischemia and arrhythmias. Although the risk for any single affected individual is small, the loss of an otherwise healthy person is particularly devastating. Surgical and interventional therapies have been developed that appear to be protective, but these therapies carry risks. The challenge is identifying those individuals at such risk that there is net benefit to the therapy. Although we acknowledge there is still much to be learned with this entity, the guidelines put forth in this article are based on best practice and knowledge regarding the risk of SCD that we have to date.

Recommendations

1. Individuals with suspected AAORCA should undergo transthoracic echocardiography to identify the origin and course of the proximal coronary arteries. (Class I, Level of Evidence B—supporting references)

2. Additional imaging studies, such as coronary CT angiography or cardiac MRI are reasonable to better visualize the coronary artery anatomy and to confirm the diagnosis. (Class IIa, Level of Evidence B—supporting references)

3. In those individuals without a history of ischemic chest pain or aborted SCD, exercise stress testing combined with nuclear perfusion scan or echocardiographic imaging should be used to help assess the potential ischemic burden of the anatomic variant. (Class I, Level of Evidence B—supporting references)

4. Cardiac catheterization should be performed in those individuals with anomalous origin of a coronary artery if the anatomy cannot be defined with noninvasive imaging, and in adults with risk factors for coexistent atherosclerotic coronary artery disease. (Class I, Level of Evidence B—supporting references)
5. Individuals with AAOCA and symptoms of ischemic chest pain or syncope suspected to be due to ventricular arrhythmias, or a history of aborted SCD, should be activity restricted and offered surgery. (Class I; Level of Evidence B—supporting references 6,18,21-23,29,32,40,58,72,82,105,113,123,124)

6. Individuals with AAOCA and symptoms of ischemic chest pain or syncope suspected to be due to ventricular arrhythmias, or a history of aborted SCD, should be activity restricted and if deemed prohibitively high risk for surgery, catheter-based intervention may be considered. (Class IIb; Level of Evidence C)

7. Individuals with or without symptoms with an un repaired anomalous origin of a left coronary artery from the right sinus of Valsalva, with an interarterial course, should be restricted from participation in all competitive sports. (Class I; Level of Evidence B—supporting references 6,18,21-23,29,105)

8. Individuals without symptoms with anomalous origin of a left coronary artery from the right sinus of Valsalva with an interarterial course should be offered surgery. (Class I; Level of Evidence B—supporting references 17-24)

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15. An automated external defibrillator with trained personnel should be immediately available during competition and training. (Class I; Level of Evidence B—supporting references 131-143)

Webcast
You can watch a Webcast of this AATS meeting presentation by going to: http://webcast.aats.org/2016/Video/Sunday/05-15-16_Ballroom_III_1520_Brothers-800.mp4.

Conflict of Interest Statement
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References


