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Comprehensive Review

Stent Angioplasty in Coronary Artery Anomalies With Intramural Course: When, Why, How, With What Results?

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ABSTRACT

Although coronary artery anomalies include multiple disorders, few are likely to require intervention, given that the risk for critical sequelae (ie, sudden cardiac arrest and sudden cardiac death) is generally low. This article addresses which coronary artery anomaly carriers may need intervention and which interventions may be required. The recent introduction of stent angioplasty is discussed in particular, along with general reviews of nomenclature, various anatomical and functional presentations, quantitative diagnosis methods, and indications for surgical versus percutaneous intervention. Novel criteria for defining severe stenosis also are proposed. Optimal risk quantification depends on precise imaging that only intravascular ultrasonography or optical coherence tomography can reliably obtain. Accordingly, the technique of intravascular ultrasonography-monitored stent angioplasty is described in detail. Initial results from our group's study of 100 patients with right or left anomalous origin of a coronary artery from an opposite sinus of Valsalva with intramural course are reported. Future efforts should prospectively evaluate stent angioplasty in multicenter studies based on precise, consistent techniques and follow-up protocols, such as those initiated by our group. Comparisons with surgical results should be part of the program, with the understanding that detailed and complete results from those techniques will require long-term (5- to 10-year) studies.

Introduction

Recent small to middle-sized clinical trials at specialized centers for coronary artery anomalies have investigated the value and feasibility of resolving the stenosis associated with anomalous origin of a coronary artery from an opposite sinus of Valsalva (ACAOS). Using stents as an alternative to open-chest surgery is routine in coronary artery atherosclerotic disease; however, in congenital ACAOS, the benefits of stent angioplasty versus open-chest surgery remain largely unproven. This article summarizes current concepts, technical adaptations to established stent angioplasty methods, and our and others' evolving results from the testing of these methods in ACAOS.[1-5] Anatomy, pathophysiology, and interventional indications and techniques in ACAOS with intramural course (ACAOS-IM) are discussed in detail.

Indications for intervention

Many years ago, surgical indications for treating congenital coronary ectopic origin were established de facto without recognizing or measuring associated coronary stenosis (the only indication for intervention). Epidemiological experience specifically hinted to pathologists that ectopic origin with intramural aortic course might be associated with increased mortality. Historically, the initial name given to this condition was "interarterial" or "between the aorta and pulmonary artery," and this terminology is still frequently used—even though intravascular ultrasonography (IVUS) and histology (examples of which are shown in Figures 1 and 2) clearly indicate that the initial course of the culprit ectopic arteries is intramural, inside the aortic wall media layer. This condition is generally associated with stenotic lateral compression; ectopic origin is not the cause of stenotic effect.

A sizable study published by Lee et al[6] in 2012 proposed that ACAOS should be dichotomized according to high origin (more severe) or low origin (less severe) of the ectopic artery, as indicated by computerized tomographic angiography (CTA) imaging.[1,7] Today, this interesting theory has essentially been abandoned, as it does not address the essential mechanisms of coronary dysfunction. A retrospective review of pertinent imaging from the Lee et al study suggested that the low-origin cases were mostly the left coronary artery arising from the right aortic sinus with intraseptal course (L-ACAOS-IS), whereas the high-origin cases most often had an intramural

Abbreviations: ACAOS, anomalous origin of a coronary artery from an opposite sinus of Valsalva; CSA, cross-sectional area; IM, intramural course; IS, intraseptal course; IVUS, intravascular ultrasonography; L-ACAOS, left coronary artery arising from the right aortic sinus; OCT, optical coherence tomography; R-ACAOS, right coronary artery arising from the left aortic sinus; RCA, right coronary artery; SAD, saline-atropine-dobutamine.

Keywords: congenital heart defects; coronary stenosis; coronary vessel anomalies; stent angioplasty.

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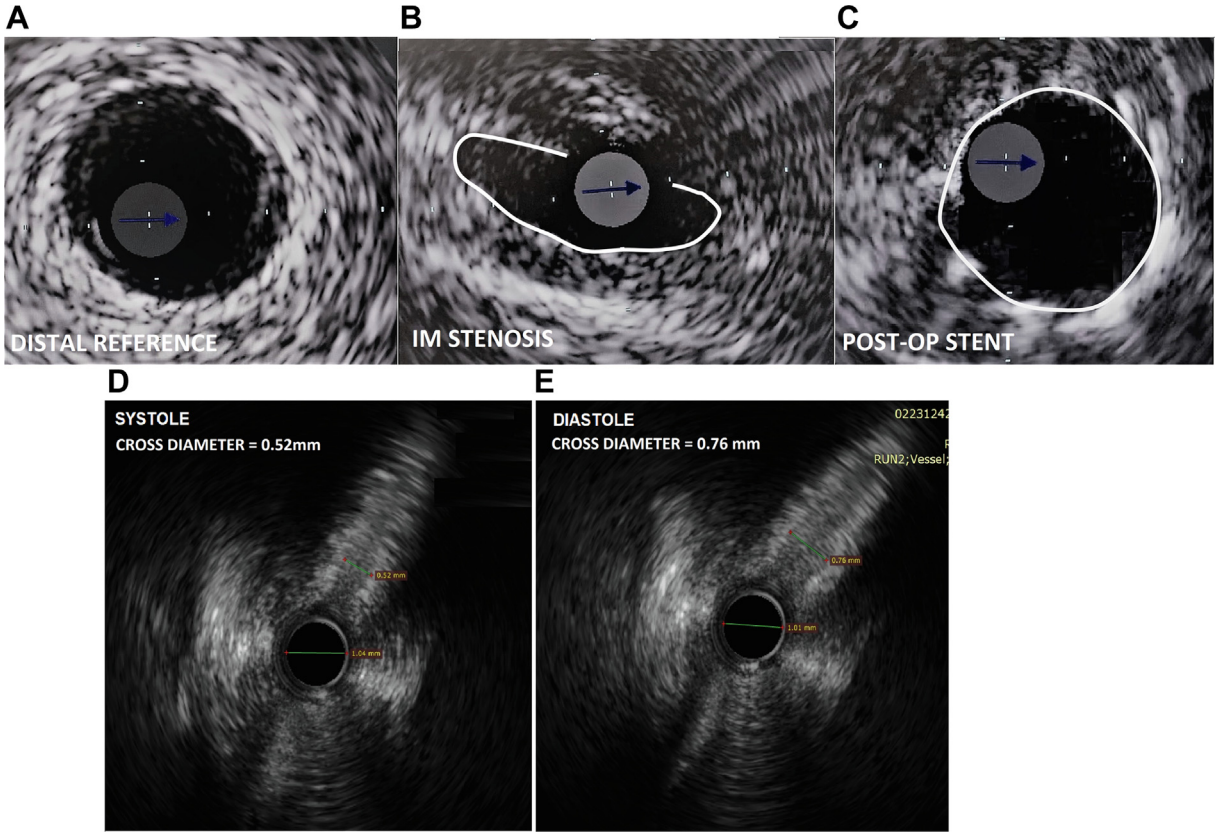


Figure 1.
Intravascular ultrasonography (IVUS) imaging of a moderate-severity case of right coronary artery arising from the left aortic sinus with intramural course (R-ACAOS-IM), showing (**A**) the distal reference luminal cross-sectional anatomy, (**B**) the site of worse stenosis before stenting, and (**C**) the site of worse stenosis after stenting. In a severe case of R-ACAOS-IM, IVUS imaging shows phasic area changes in systole (**D**) versus diastole (**E**). Note that in severe cases, the IVUS probe's diameter can be larger than the minimal luminal cross-diameter, a mild artifact caused by the foreign body.

course (L-ACAOS-IM) with stenosis.[8] This could explain why L-ACAOS-IS generates fewer significant clinical repercussions than L-ACAOS-IM. It is widely believed that only in L-ACAOS-IM would intervention be needed when significant stenosis is present; conversely, L-ACAOS-IS generally does not require intervention, as fixed stenosis is usually absent.

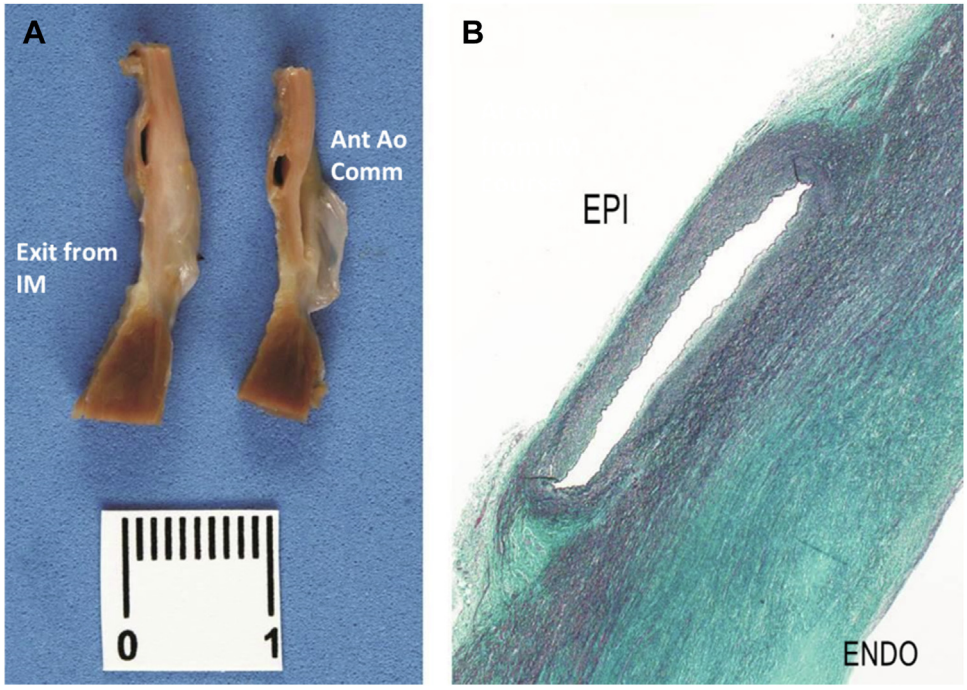


Figure 2.
Gross (**A**) and histological (**B**) anatomy in the case of an adolescent female who died suddenly while jogging. The gross anatomy shows a cross-section at the site of the anterior commissure of the aortic valve (mild stenosis by lateral compression) and the distal exit from the aortic wall (worse stenosis, about 1 mm in short diameter of the severely compressed extramural left coronary artery, shortly after exiting the IM course). See Figure 6 for a clinical case of the same form of left coronary artery arising from the right aortic sinus with IM course (with rare distal stenosis). Ant Ao Comm, anterior aortic commissure; ENDO, endocardial; EPI, epicardial; IM, intramural. Reprinted with permission from Angelini P.[25]

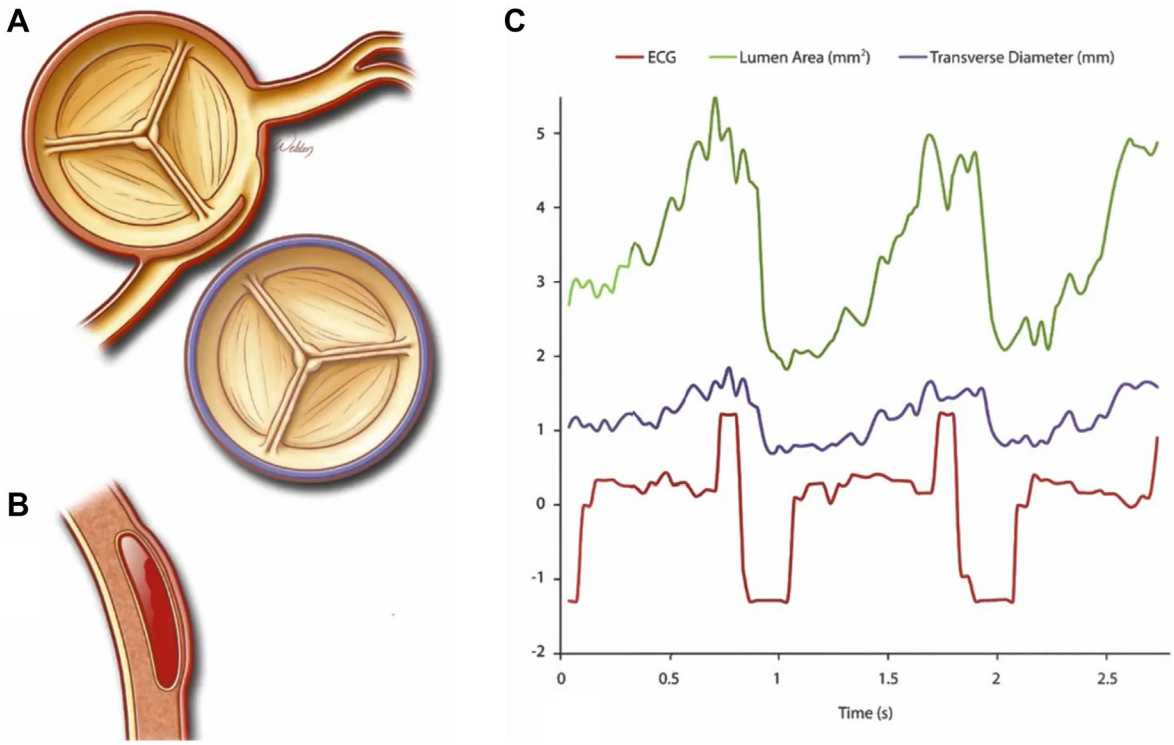


Figure 3.
General dynamic changes at the site of worst stenosis in a patient with right coronary artery arising from the left aortic sinus with intramural course (R-ACAOS-IM). (**A**) Diagrammatic image of the transverse cross-section of the aortic root in systole, suggesting the effect of aortic expansion on the right coronary artery (RCA)'s intramural lumen. (**B**) Vertical aortic root transection at the level of the R-ACAOS-IM course. (**C**) Multiparametric cartoon illustrating the main functional features of R-ACAOS-IM. The dynamic anatomical and hemodynamic variations produced by stenosis within the intramural course are expressed in instantaneous measurements of the cross-sectional area (purple line) and the short transverse diameter (green line); the red line is the electrocardiogram (ECG) signal. All data are reported synchronously across time (30 intravascular ultrasonography datapoints per second; see Video 1). Reprinted with permission from Angelini P.[25]

The following sections summarize current concepts on determining the severity of obstruction in congenital coronary anomalies and explore justifications for conducting large multicenter studies to investigate stent angioplasty as an alternative to surgery. These concepts originated primarily at our referral center and are based on IVUS imaging.

Preoperative symptoms and stress testing

Preoperative symptoms and stress test results can indicate the clinical severity of ACAOS.[8,9] Chest pain and dyspnea can be reliably related to exertion in adolescents and adults, although they are not universally present—in particular, they are absent in cases of nondominant right coronary artery (RCA) arising from the left aortic sinus with intramural course (R-ACAOS-IM).[8] Incidentally, the patients successfully resuscitated after sudden cardiac arrest (SCA) generally are those who start with ischemia-related low cardiac output and asystole, rather than with initial ventricular fibrillation[3] and/or coronary thrombosis. For this reason, aggressive early external resuscitation massage is frequently successful, even without artificial respiratory support. In our experience of R-ACAOS-IM, electrocardiography-monitored treadmill stress testing is not usually positive, even in important cases of IVUS-identified stenosis.[4]

Even though sudden cardiac death (SCD) is much more frequent in young athletes (and in L-ACAOS-IM), older adults also can become symptomatic, albeit typically only after onset of obesity, aortic dilatation, or hypertension. In adults, the possibility of coronary artery disease (CAD)-related pathology must be always ruled out as a cause of new-onset symptoms, typically by using CTA or catheter angiography. Additionally, coronary spasm has been reported in every kind of ACAOS and also should be considered, especially in patients with chest pain at rest that responds to sublingual nitroglycerin (Japanese ethnicity is a risk factor in this regard).[4] Acetylcholine testing has shown that spasm is most frequently diffuse across the entire coronary tree. In ACAOS-IM segments, the media is aortic and not intrinsically coronary; because no circularly oriented smooth muscle fibers are present at that site, potential spasticity is avoided. Nonetheless, intimal injury related to the use of nondedicated guiding catheters has been described.[5]

One question merits consideration: Is the mechanism underlying SCD or SCA related to primary arrhythmia? Although SCD can be related to both bradyarrhythmia and tachyarrhythmia, the initial dysfunction is generally coronary ischemia or myocardial depression rather than primary ventricular tachycardia or fibrillation, with bradyarrhythmia more typical of the early postarrest state.[10] It is only after prolonged arrest that reperfusion arrhythmia can occur, especially if catecholamines were administered during resuscitation. The frequent occurrence of L-ACAOS-IM with exercise-related SCA or SCD, in which patients often recover after chest compression only (without defibrillation), supports this theory.[10-12] Prospective studies are needed to test the hypothesis that intramural ischemic patches are the main reason for ventricular tachycardia or fibrillation.[13] Acute myocardial infarction is rarely reported in ACAOS-IM.

Basic anatomical and functional characteristics

Myocardial territory. The size of the dependent myocardial territory in any case of ACAOS determines the potential clinical severity of

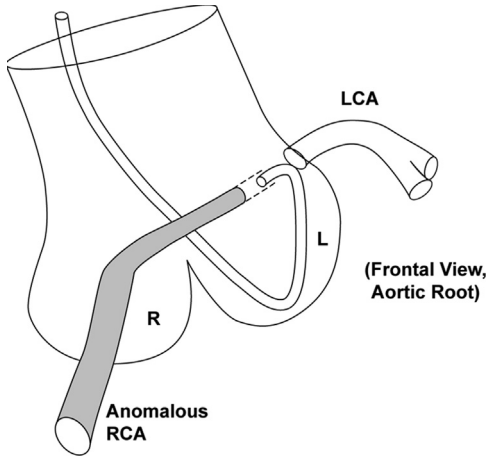


Figure 4.
Diagram illustrating the concept of a novel, custom-made guiding catheter (currently produced by Medtronic Inc) used for angiography, intravascular ultrasonography, and stent delivery in patients with the right coronary artery (RCA) arising from the left sinus of Valsalva (L) with intramural course. Not only is the vessel ectopic from the left sinus of Valsalva, but it also has a tangential initial course (it always has a tangential initial course, which would imply 90 degrees relative to the normal exit from the aorta). LCA, left coronary artery; R, right sinus of Valsalva. Reprinted with permission from Angelini and Uribe.[5]

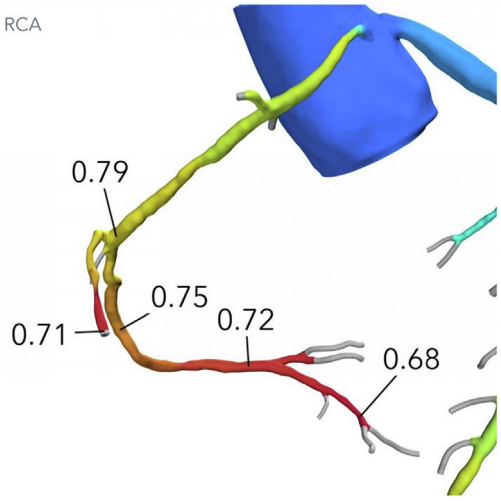


Figure 5.
Computerized axial tomography angiography (CTA) and fractional flow reserve imaging of a case of right coronary artery arising from the left aortic sinus with intramural course (R-ACAOS-IM). Angiographically, this patient had no coronary artery disease of any severity. The proximal obstruction was severe, as calculated according to coronary artery disease evaluation parameters, and the site of stenosis was not indicated as ostial. An index of 0.79 would indicate severe R-ACAOS-IM (but with minimal clinical symptoms and negative nuclear stress testing in this patient). The cross-sectional severity of ostial stenosis measured by intravascular ultrasonography was 3.1 × 1.5 mm, consistent with significant stenosis. Note that in this left anterior oblique CTA rendition, the original angiographic appearance featured an increased proximal right coronary artery (RCA) diameter caused by lateral compression, but this 3-dimensional imaging reconstruction erroneously shows severe and round stenosis (caused by suboptimal interpretation of artificial-intelligence fractal analysis). This asymptomatic patient and the treating physicians, in absence of objective evidence of functional ischemia, have decided not to pursue intervention at this time.

coronary insufficiency (angina, myocardial infarction, SCD). In general, the RCA provides 10% to 30% of total coronary flow to the ventricular myocardial territory, with the remaining coronary flow provided by the left coronary artery. This explains why the clinical manifestations in R-ACAOS-IM are most commonly chest pain and dyspnea but only rarely the SCA or SCD typical of L-ACAOS-IM in young athletes.[14]

Physical exertion. The amount of physical exertion and its duration, frequency, and nature (competitive vs amateur) are data that can be documented in a symptomatic individual's clinical history. The best and simplest quantification is hours of running-time equivalents/week.[9] Pursuing maximal personal performance and participating in competitions are the main risk factors for SCD, especially for young athletes (the peak age associated with SCD in ACAOS-IM is 19 years).[14] In a study of 6.3 million military recruits, Eckart et al[14] found that SCD correlated with potentially critical stenosis-related ischemia identified at autopsy. Of 126 instances of nontraumatic SCD, 86% occurred during exercise (rate: 13/100,000 per year), with only L-ACAOS-IM related to SCD being reported in this population.[14] Patient history and physical examination were the only baseline screening approaches used during these years (1977-2001). More recently, our own group at The Texas Heart Institute conducted a study that used magnetic resonance imaging to screen for ACAOS-IM in general-population adolescents.[15] Over the 7-year study period, autopsy results identified ACAOS-IM in 23 of 5169 adolescents (0.44%); 17 had R-ACAOS-IM and 6 had L-ACAOS-IM.[16] If these results were extrapolated to the 6.3 million military recruits studied by Eckart et al,[14] approximately 28,000 would have had ACAOS-IM (20,700 R-ACAOS-IM cases and 7,300 L-ACAOS-IM cases).[14] These are rare anomalies, and SCA also is rare, even in patients observed during strenuous exertion.

Stenosis severity. The essential features correlated with potential coronary insufficiency in ACAOS-IM are detailed below. These features are readily obtainable by using IVUS, but not echocardiography or CTA, which can identify only ectopic origin.

1. Stenosis specifically related to IM course, with proximal coronary artery compression inside the aortic media. The degree of compression varies during aortic pulsatile expansion but is not related to progressive obliterative thickening of the vascular wall, as in CAD.
2. Stenosis (Figures 3 and 4; Supplemental Video 1) with dynamic narrowing caused by lateral IM compression. The compression varies at different times in the cardiac cycle (worse in systole) and with different activities, and it is modulated by factors like heart rate (tachycardia increases the time of worst stenosis/minute during systole), stroke volume, and aortic wall elasticity. These dynamic parameters also vary from one patient to another. The effect of β-blockers on dynamic stenosis has not been carefully evaluated.
3. Increased cardiac work and output. These factors enhance the imbalance between demand and supply (ie, worsening stenosis at the time of increased oxygen demand) and can cause critical ischemia during maximal exertion. This applies especially to elite athletes and military recruits.

The pathophysiology of ACAOS-IM differs from that of other coronary courses (intraseptal, prepulmonic, retroaortic, and retrocardiac).[8,9] The basic mechanism of coronary insufficiency is the variable IM-related proximal stenosis.[9,17-19]

Geometric anatomical quantification

Imaging methods like transthoracic echocardiography or CTA can be used to diagnose ectopic origin (ACAOS), but they cannot accurately define the severity of stenosis in individuals with ACAOS.[2,7] Only IVUS and optical coherence tomography (OCT) imaging have the precision required for accurate spatial and temporal measurement of dynamic stenosis. Such precision is needed to establish cutoff values for indicating critically severe stenosis and the need for intervention (surgical or not[1]). Of note, IVUS is not used extensively in pediatric cardiology departments.[11,20-22]

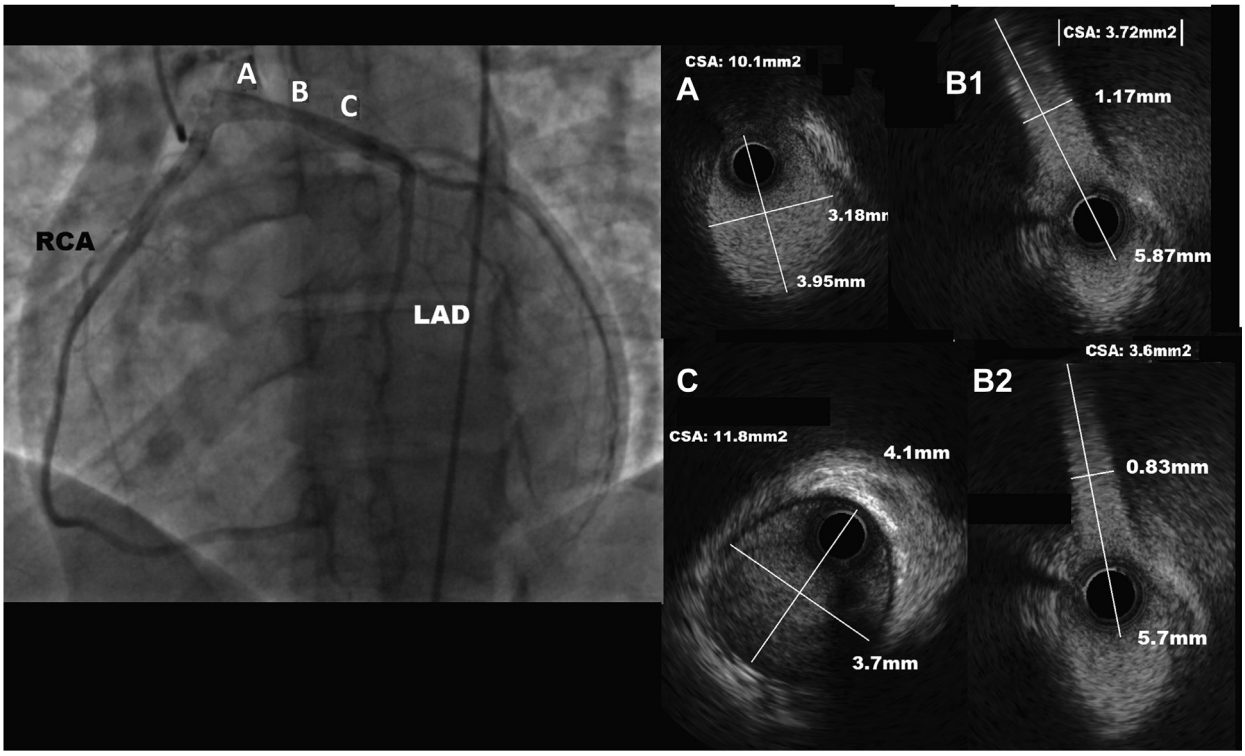


Figure 6.

Angiogram (left panel) and IVUS imaging (right panel) of a 25-year-old man with the left coronary artery arising from the right aortic sinus, with intramural course (L-ACAOS-IM), similar to the case illustrated at autopsy in Figure 5. Left: The 2 ostia for the right coronary artery (RCA) and the left anterior descending coronary artery (A-B-C/LAD) are adjacent and originating from the right sinus of Valsalva. The L-ACAOS-IM appeared normal (round), but it had mild hypoplasia, compared with the distal reference left main artery (C). Right: Diastolic (B1) and systolic (B2) imaging shows significant baseline and phasic narrowing (worse in systole: mean short diameter values = 0.83 vs 1.17 mm). Placing a stent angioplasty in a case such as this would be quite delicate. This patient had successful bypass grafting to the LAD. CSA, cross-sectional area. Reprinted with permission from Angelini and Uribe.[5]

Stenosis at rest and in diastole is typically mild, but it is likely to worsen with exertion. Exertion may not need to be assessed in every ACAOS-IM patient but only in potential candidates for intervention who have borderline resting stenosis or symptoms. Multicenter, long-term experience appears necessary to validate precise conclusions regarding which patients to study and at what level of severity to intervene.

Figure 5 shows the CTA/fractional flow reserve imaging evaluation of a case of R-ACAOS-IM: the reading of 0.79 to 0.80 implies severe or significant stenosis (in CAD cases only). Validation of similar data is still pending for ACAOS-IM.[2,3,5,23]

Recent investigations have attempted to ascertain whether intracoronary hemodynamic pressure gradients could be valid alternatives to IVUS images.[2,23] The basic issue is that stenosis-related pressure drop in ACAOS-IM is generally absent or mild at rest in patients without severe symptoms. Mean pressure gradients could decrease or be kept trivial using vasodilators, which induce microvascular dilation that increases the flow rate only moderately (generally 2.0-2.5 times baseline). In contrast, maximal muscular exertion increases the severity of obstruction and the level of cardiac work and oxygen demand. A simulated exercise method for measuring maximal stenosis (the saline-atropine-dobutamine[9] [SAD] test; see below) may be superior to simple baseline imaging and is being preliminarily investigated.[8,9]

Stenosis quantification by IVUS imaging

The fundamental reasons for using IVUS to measure stenosis are to capture the spectrum of stenotic narrowing (both at rest and in diastole) in any given case, to correlate stenosis severity and symptoms or

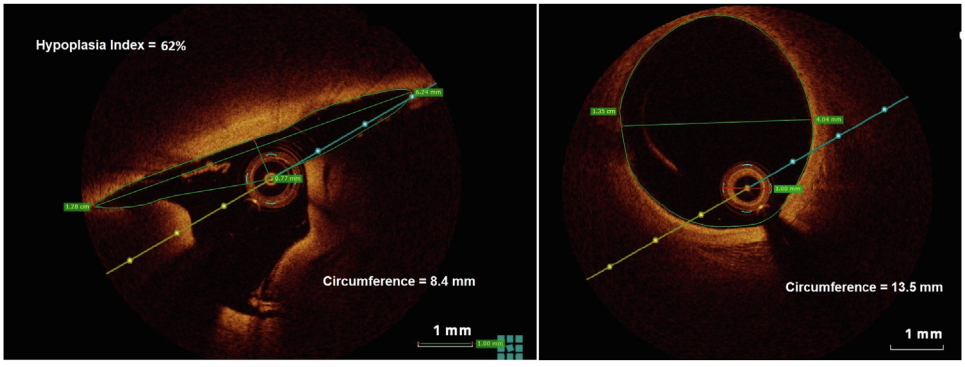
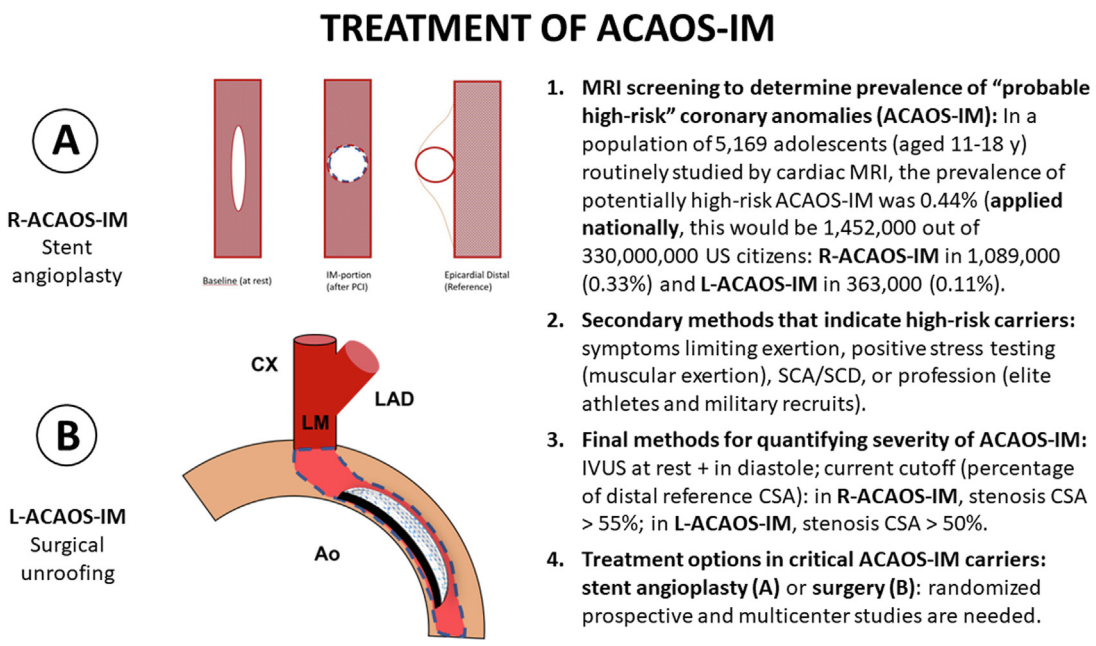


Figure 7.

Optical coherence tomography in a patient with right coronary artery arising from the left aortic sinus, with intramural course. Left: At the ostium (where the imaging probe exits the artery), both severe compression (short diameter = 1.7 mm, in green) and hypoplasia are indicated by the ratio of circumferences: proximal (left) with respect to the distal reference vessel; hypoplasia= 62% (or 8.4:13.5, in white). Right: The longitudinal proximal diameter of the distal reference vessel is much larger than that of the mean reference vessel (4.2 mm, in green). Reprinted with permission from Angelini and Uribe.[5]



Central Illustration.

Left panels: (**A**) Conceptual drawing of R-ACAOS-IM treated by stent angioplasty (*left*, the intramural section at maximal stenosis, inside the aortic wall; *center*, results of stent deployment inside the obstructed segment; *right*, the cross-sectional area of the distal reference vessel. (**B**) An illustration of L-ACAOS-IM repaired surgically by unroofing. Right panel: Project outline, in 4 phases (needs and modes of intervention): (1) *assess the prevalence* of ACAOS-IM in a general-population study (by MRI screening); (2) *identify individual carriers* at risk (by symptom assessment); (3) *quantify the severity of stenosis* (by IVUS); and (4) *determine intervention alternatives* (eg, stent angioplasty (**A**) or surgical repair (**B**), as shown in left panels). ACAOS-IM, anomalous origin of a coronary artery from an opposite sinus of Valsalva with intramural course; Ao, aorta; CSA, cross-sectional area; CX, circumflex coronary artery; IVUS, intravascular ultrasonography; L-, left; LAD, left anterior descending coronary artery; LM, left main coronary artery; MRI, magnetic resonance imaging; PCI, percutaneous coronary intervention; R-, right; SCA/SCD, sudden cardiac arrest/death. See text.

prognosis, and to validate operational recommendations and technical planning (such as the location and dimensions of the required stent).[7] Stenosis also varies with aortic root distensibility. This is an incomplete but promising work (also important for surgical considerations) that requires validation in coordinated multicenter studies.

As a general rule, IVUS image acquisition should be done in 2 stages: (1) using *automatic pullback* to measure the length of the IM course and to identify the site of worst stenosis, and (2) using *manual pullback* to locate the exact site and severity of worst stenosis at the inner lumen and, in borderline cases, to reveal dynamic maximal stenosis during SAD testing.[3,4,8] Anatomical parameters to be obtained by IVUS include:

1. The cross-sectional area (CSA) of the IM stenosis and the CSA of a distal reference vessel. These 2 values can then be compared (% stenosis formula: distal CSA minus maximal-stenosis CSA, divided by the distal CSA).
2. The length of the IM course. By itself, this is not a significant parameter of stenosis severity but is vital for ensuring accurate stent placement. Avoiding overlapping stents is important for preventing restenosis.
3. The diastolic CSA of the IM stenosis. This is practically the only IVUS parameter required to establish severity, as it can indicate important worsening (by 20%-30%) during exertion.

Typically, the ostium in R-ACAOS-IM is a peculiarly shaped *a bocca di flauto,* or flute-like mouth (oblique edge cut, flattened lumen; see Figures 1 and 5). Possible mechanisms of stenosis include (1) lateral compression, (2) hypoplasia, and (3) stenosing ostial membrane (Figure 5). During stent angioplasty, the usual operational compromise is to cover an additional 2 mm or so of the coronary artery proximal to the initial IVUS-proven interruption of the inner circular lumen while avoiding prolapse into the aortic lumen. A delicate approach during catheterization is required, especially if subsequent catheter procedures could be needed, so a coaxial guiding catheter is obligatory for optimal stenting.

Interestingly, Farjat-Pasos et al[24] reported R-ACAOS arising from the left anterior descending artery, resulting in a single coronary ostium; a similar RCA course is usually pre-pulmonic. In 20% to 30% of L-ACAOS-IM cases, the critical stenosis is atypically located at the exit from the IM course (Figures 2 and 6).[25]

Mild limitations associated with IVUS measurements are seen with severe stenoses and are related to artifacts that could be created by the presence of a sizable foreign body (the guidewire or the device) at the site of maximal stenosis, especially during SAD testing. The crossing profile of an IVUS catheter device is 1.0 to 1.1 mm, which becomes relevant when the short cross-sectional diameter at the target lesion is less than 1.1 mm at baseline (Figures 1, 2, 3, and 7). As a typical clinical example, a recent case of ours[26] involved a symptomatic adult with what appeared to be a systolic phasic RCA occlusion, as detected on an angiogram before coronary guidewire advancement. However, after the guidewire and IVUS device were introduced, the supposed RCA occlusion was actually only an 80% stenosis.

OCT imaging

Optical coherence tomography provides unprecedented precision imaging (Figure 7) of the intraluminal contour. That said, OCT cannot study the aorto-pulmonary wall thickness and interarterial free space; IVUS is much better at clarifying the IM versus the interarterial concept of the ectopic artery. Also, a manual pullback cannot be easily obtained with OCT, as it is impossible to clear blood with contrast medium, given the requirement for a tightly closed Touhy valve (which may prevent

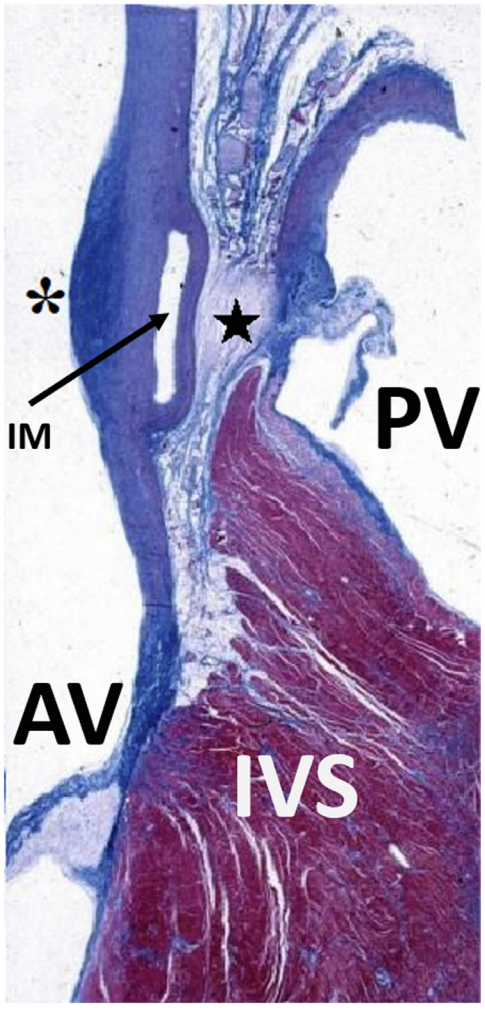


Figure 8.
Histological cross-section of the neighboring aortic and pulmonary artery roots, in a typical case of an older woman who died of apparent critical coronary artery disease in the left coronary artery that coexisted with important right coronary artery arising from the left aortic sinus with intramural (IM) course (R-ACAOS-IM). Note that the inner aortic wall at the level of the R-ACAOS-IM has a fibrotic thickening (4-5 mm thick, at asterisk), and the IM coronary artery is severely stenotic. Also note that the space between the great vessels was obliterated by some fibrotic material outside the arterial media (ie, not atherosclerotic, at star), a condition that is not uncommon at this age but rare in young patients. Such finding has never been reported in cases of R-ACAOS-IM and could potentially explain the clinical worsening of IM stenosis acquired with advanced age. AV, aortic valve; IVS, intraventricular septum; PV, pulmonary valve. Reprinted with permission from Rizzo et al.[19].

pullback). During such procedures, dedicated coaxial guiding catheters are required in both R-ACAOS-IM and L-ACAOS-IM to ease guidewire entry, alignment, and selective ostial positioning. Placement is frequently problematic in view of the tangential, slit-like origin of ACAOS-IM and the small ostial opening (Figures 1 and 7).[17]

Surgical versus percutaneous repair of ACAOS-IM

Well-tested recanalization techniques to treat acquired CAD—including coronary bypass surgery (starting with vein grafting by Favaloro in the late 1960s) and stent angioplasty (starting with Palmaz-Schatz in 1993)—have also become options for treating coronary anomalies. Revascularization in patients who have congenital coronary anomalies with documented, consequential stenosis is well established in surgical departments,[20-22] yet stent angioplasty has only recently begun to be tested in such rare pathology. Whether to use percutaneous stent angioplasty versus open surgery remains debatable, given the lack of reliable, long-term follow-up data on the most important end points for comparing the 2 procedures: mortality, the incidence of acute myocardial infarction, and restenosis beyond the 1-year follow-up (Central Illustration).[3] The age of a young patient at the time of clinical recognition is an additional factor to be studied carefully (especially regarding the long-term restenosis rate).

Generally, both open-chest surgery and stent angioplasty can completely resolve symptoms and objective signs of ischemia or stenosis. However, when performed in well-trained environments, stent angioplasty confers much lower operative risk, less discomfort, and fewer complications than surgery, usually with only a 1-day hospital stay. With acute presentation,[24] the dominant factors against a surgical decision include a high-risk clinical state (eg, diabetes, age, obesity, renal failure, heart failure), post-SCA status (eg, mental impairment, shock, congestive heart failure, renal failure, depressed left ventricular function), and limited local availability of expert surgical operators. Importantly, when patients are evaluated and monitored solely by IVUS, only ~30 cc of contrast agent is typically required for stent angioplasty.

Resumption of sports activities should not be authorized earlier than 6 months after a revascularization intervention, and only after the patient passes a follow-up examination that includes nuclear treadmill stress testing (especially if such test was positive preoperatively). In cases of competitive sport exercise or dubious results at routine testing, IVUS may be needed to reevaluate the delicate ostial anatomy.

Procedural aspects specific to stent angioplasty in ACAOS-IM

The main IVUS-based objective data needed to characterize candidates for stenting of ACAOS-IM are detailed below. Using a dedicated guiding catheter affords a selective, aligned approach to tangential-origin vessels that avoids intimal trauma and ostial obstruction (Figure 4).[17]

1. Intramural course and stenosis severity,[1] to substantiate or contradict indication for intervention.
2. Length of the IM course from the ostium to the distal site of round coronary lumen recovery, as measured using IVUS pullback.
3. The exact site of the obstructive ostium on fluoroscopy, as identified by angiography. This enables accurate delivery of the stent.
4. Final lumen size—especially essential at the most severe stenotic site—as characterized by a circular lumen and optimal apposition of the stent. Of note, the latter is not always achievable, because the cross-sectional IVUS diameter may initially be much wider than the distal reference diameter).
5. Any degree of coronary luminal hypoplasia (eg, decreased proximal circumference) present in the proximal IM segment (Figure 7). This is usually well resolved with stent dilatation. Edge dissection has not been reported.

An atypical, rare anomaly was described in a recent report from the Padua group.[19] A histological cross-section of the site of IM stenosis (Figure 8) from the autopsy of an adult with R-ACAOS-IM revealed definite thickening of the inner media of the aortic wall within the IM course and a similar, but probably fibrotic, thickening of the aorto-pulmonary cul-de-sac. This patient died of associated critical CAD in the left coronary artery. The case raises several questions: Could similar plaques or calluses be related to late-onset clinical events in older patients? How common is this feature? Can it be identified (clinically, only by IVUS)? Incidentally, our group has never seen IVUS-based evidence of atherosclerotic thickening inside the IM segment, probably because no lipid deposits are present inside the aortic media covering the IM coronary intima.

Preliminary investigations at The Texas Heart Institute

At The Texas Heart Institute's Center for Coronary Artery Anomalies, 120 IVUS studies in ACAOS have been completed (80 R-ACAOS-IM, 20 L-ACAOS-IM, 20 non-IM anomalies).[8,9] All participants had a complete history and preliminary CTA, followed by IVUS imaging when indicated. All stent-angioplasty patients had symptoms or were regularly engaged in high-risk activities (typically elite athletes and military recruits), and/or had a positive nuclear stress test, and/or had IM stenosis with a more than 2:1 long-to-short axis ratio by CTA. These criteria can clinically define "probable significant stenosis," although IVUS is required to confirm exact severity.

About half of the R-ACAOS-IM patients studied by IVUS required intervention at our center, whereas the others were considered to have only mild stenosis and were followed clinically. Our experience to date suggests that, to produce ischemia at rest and in diastole in symptomatic patients, the stenotic CSA must be smaller than 50% of the distal reference CSA in L-ACAOS-IM and smaller than 55% of the distal reference CSA in R-ACAOS-IM. Nonetheless, we admit that these values are still tentative and approximate. A larger multicenter, coordinated, prospective study is needed to confirm these results. After IVUS imaging, only 3 patients with drug-eluting stents went on to surgery: 2 by decision of the referring physician, and 1 because of 2 previous restenosis events (see below). None of the patients sent for medical treatment have experienced acute myocardial infarction or SCD (as determined through in-person and/or telephone follow-up).

Most R-ACAOS-IM cases requiring intervention at our center during the last 20 years have been treated with stents, in consultation with the patient, the family, and the referring physician. Conversely, symptomatic L-ACAOS-IM patients with more than 50% CSA stenosis were treated surgically. Three patients with L-ACAOS-IM underwent stent angioplasty because of high surgical risk (early postoperative status after failed surgery or unstable status after SCA, with residual myocardial dysfunction or shock); all 3 stenting procedures were successful, and no hospital deaths were observed. No clinical restenosis was reported in these patients. In our R-ACAOS-IM series of the initial 36 drug-eluting stent cases,[9] the restenosis rate was 2.7%, or 1 in 36 (in contrast, the restenosis rate was 50% in our first 4 bare-stent cases; these stents were subsequently abandoned for this indication). Twice, late restenosis of a drug-eluting stent occurred in a patient with R-ACAOS-IM originating from the left main trunk. Still, it is unclear if such a case of single coronary ostium with R-ACAOS-IM should be considered a general contraindication for stenting in this rare anomaly. The 2 drug-eluting stents used in this patient involved the RCA ostium off the main trunk. Of note, no stent crashing due to lateral compression occurred in our patients; evidently, the pressures exerted by the stent versus the aortic wall do not significantly compress the stent. In our many years of observation, only a few cases of restenosis have occurred, and all were caused by fibrotic buildup. One patient (an athlete) was able to return to marathon running while completely asymptomatic.

Conclusions

In adults, the use of IVUS to quantify coronary proximal stenosis appears to explain definitively how this pathology produces coronary ischemia and provides a clear measure of its clinical severity. Stent angioplasty in ACAOS-IM produces a permanent dilatation of a congenitally compressed ectopic artery within the aortic media's intramural space. Early series results are insufficient for final cutoff recommendations, but they encourage prospective clinical testing through coordinated multicenter studies that use IVUS to determine objectively which interventions are needed, if any (including surgical correction).

Declaration of competing interest

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Ethics statement and patient consent

This work adhered to relevant ethical guidelines.

Supplementary material

To access the supplementary material accompanying this article, visit the online version of the *Journal of the Society for Cardiovascular Angiography & Interventions* at 10.1016/j.jscai.2023.100595.

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