

INVITED REVIEWS

Clinical Role of Coronary Magnetic Resonance Angiography in the Diagnosis of Anomalous Coronary Arteries

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ABSTRACT

Though rare, anomalous coronary artery disease is a well-known cause of myocardial ischemia and sudden death among children and young adults. The projectional nature of conventional x-ray angiography often leads to difficulty in the definition of anomalous vessels. Studies have now documented the high accuracy of coronary magnetic resonance angiography (MRA) for the noninvasive detection and definition of anomalous coronary arteries among patients with suspected anomalous coronary arteries of congenital conditions associated with anomalous coronary arteries. With increasing clinical experience, coronary MRA will likely emerge as the gold standard for the diagnosis of this condition.

CLINICAL BACKGROUND

Epidemiology

Congenital coronary anomalies are an unusual but well-recognized cause of myocardial ischemia and sudden cardiac death, especially among children and young adults (1). The prevalence of anomalous coronary arteries is primarily derived from coronary angiography data among adults referred for diagnostic coronary angiography because of chest pain. Engel et al. (2) reviewed the data from 4250 adults without known congenital heart disease who underwent x-ray coronary angiography.

They found 51 patients (1.2%) with at least one anomalous origin of a coronary artery. In a larger series of 7000 patients referred for coronary angiography, Kimbiris et al. (3) reported 45 cases (0.6%) of coronary artery anomalies. Similarly, Chaitman et al. (4) reported 31 cases (0.8%) from 3750 patients undergoing x-ray angiography. Thus, the overall prevalence is approximately 0.85% among adults referred for x-ray angiography. As might be anticipated, the prevalence of anomalous coronary arteries is increased among those with congenital heart disease (5), especially those with certain anomalies (e.g., tetralogy of Fallot, complete transposition of the great arteries, congenitally corrected transposition). Among

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patients with congenitally bicuspid aortic valve, the right and left coronary arteries may be oriented 180 degrees apart, as compared with the more normal 120–150 degrees of orientation. If these patients require surgery, information regarding coronary orientation is relevant for the choice of aortic valve prosthesis.

Coronary Artery Embryology

Coronary artery buds arise from the aorta during the seventh embryonic week, shortly after the aorta is formed by division of the truncus arteriosus. Transient abortive “coronary buds” may also arise from the pulmonary trunk (6). Once established, the coronary arteries rapidly mature with large branches extending over the surface of the heart. The right coronary artery (RCA) travels in the right atrioventricular groove, whereas the left main coronary artery usually bifurcates within 1 cm of its origin to form the left anterior descending (LAD) coronary artery (running in the interventricular groove) and the left circumflex (LCx) coronary artery (coursing in the left atrioventricular groove).

Specific Coronary Anomalies

With normal coronary anatomy (Fig. 1), the coronary arteries originate from the aortic sinus closest to their eventual path. The RCA, which travels in the right atrioventricular groove, originates from the right coronary sinus, whereas the left main coronary artery originates from the left coronary sinus. In contrast, anomalous coronaries typically originate on the contralateral side to their destination (or less commonly from the noncoronary sinus or pulmonary artery) and must “cross” to the other side of the aorta. The anomalous vessels are therefore longer and often without “branching” vessels within the anomalous segment.

The most common adult manifestation of anomalous coronary artery condition is anomalous origin of the LCx from the *right* sinus of Valsalva or RCA. This anomaly accounts for over 50% of all anomalous coronary conditions seen in the adult (2,3,7,8). The anomalous LCx may arise from a common ostium with the RCA, from a proximal branch of the RCA, or from a separate ostium (8). Usually, the anomalous LCx follows a retroaortic course (Fig. 2) and enters the left atrioventricular groove near the site as if it had originated normally as a proximal branch of the left main coronary artery. The second most common anomaly, occurring in 20–25% of ectopic ori-

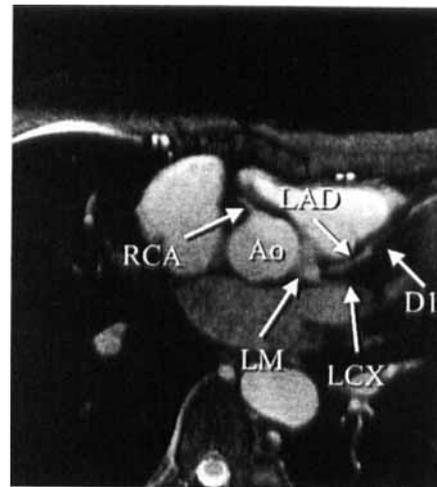


Figure 1. Normal coronary artery orientation. Transverse reconstruction from free-breathing, navigator gated, and real-time correction three-dimensional T2-prep gradient echo data set (44,45) depicting the normal orientation of the ascending aorta (Ao), proximal RCA and left main (LM) coronary artery, LAD with first diagonal (D1), and LCx.

gins, is one in which the RCA originates from the *left* sinus of Valsalva (Fig. 3). The anomalous RCA classically follows an anterior course running between the aorta and pulmonary artery. Anomalous origin of the left main or LAD from the right sinus of Valsalva is among the rarest of anomalies. The anomalous vessel may follow one of four proximal pathways: interarterial (i.e., between the aorta and pulmonary trunk; Fig. 4), posterior or retroaortic, anterior to the pulmonary artery, or intra-septal in which the proximal vessel is intramyocardial. Sometimes noted, though often not reported as an anomaly in all series, is the benign absence of the left main with direct origin of the LAD and LCx from the left sinus of Valsalva (9).

Finally, other very rare coronary anomalies are associated with hemodynamic manifestations. As previously mentioned, the entire left coronary system can arise from the pulmonary artery (10,11). Because of the significant hemodynamic and oxygen delivery impact of this lesion, this anomaly typically presents in infancy or early childhood with myocardial infarction or congestive heart failure and has substantial morbidity. Coronary fistulas, with connections to the coronary sinus (12) pulmonary artery or the right ventricle, may also be hemodynamically important, especially if there is substantial left-to-right shunting (12–14).

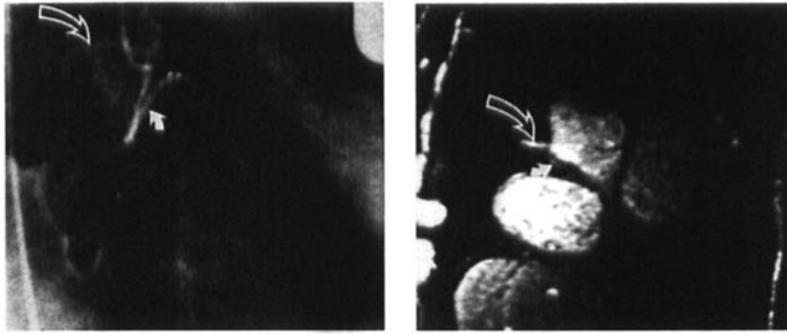


Figure 2. (A) Conventional x-ray angiogram with Judkins catheter (black arrow) in the right coronary ostium and (B) single-oblique coronary MRA using the two-dimensional breathhold technique (34). Note the normal RCA (open white arrow) with the anomalous LCx (solid white arrows) from the proximal RCA traversing in a “benign” retroaortic manner. (From ref. 34, reprinted with permission of the American Heart Association).

Clinical and Hemodynamic Significance

Although the incidence of coronary anomalies is very low, the impact on premature cardiac morbidity and mortality, especially among young adults, is not trivial. A recent prospective study (15) following young athletes (as part of a screening program for hypertrophic cardiomyopathy) identified an anomalous coronary artery as the cause of death in over 12% of athletes dying suddenly.

The clinical significance of the common coronary artery anomalies primarily relates to their association with

myocardial ischemia or infarction and syncope and sudden cardiac death (4,16–20). This premature cardiac morbidity and mortality in young adults is most common in the setting of vigorous physical exercise. Clinical and pathologic data suggest that the proximal course of the anomalous vessel is the primary determinant of hemodynamic significance. In particular, anomalous coronary arteries that course between the aorta and pulmonary trunk (Figs. 3 and 4) have been shown to be associated with exercise-induced ischemia, myocardial infarction, and sudden cardiac death in young patients without evidence of coronary atherosclerosis (18). There are several postu-

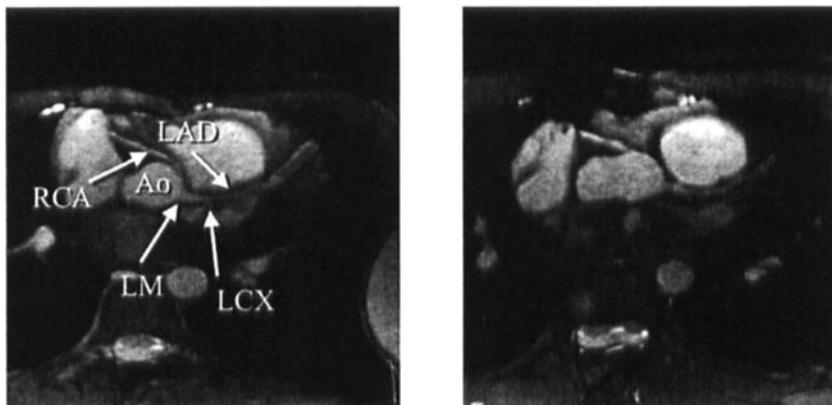


Figure 3. Free-breathing three-dimensional T2-prep (44,45) coronary MRA from a 14 year-old boy who presented with atypical exertional chest pain. (Left) An anomalous RCA is seen originating from the left coronary sinus immediately adjacent to the origin of the left main. The anomalous vessel then travels in a “malignant fashion” between the aorta (Ao) and pulmonary artery. (Right) After surgical repositioning of the anomalous RCA (black arrow).

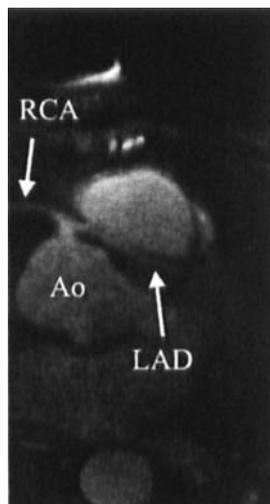


Figure 4. Free-breathing three-dimensional T2-prep coronary MRA obtained in a 57-year-old man with exertional angina. Note the single right coronary ostia with the anomalous LAD originating from the proximal RCA and coursing in a “malignant fashion” between the aorta (Ao) and pulmonary artery.

lated mechanisms. The most widely accepted hypothesis is that the aorta and pulmonary artery impinge on the proximal anomalous vessel, especially during exercise when there is aortic and pulmonary artery dilation in response to increased cardiac output, coincident with increased coronary flow demand (21). Another contributing mechanism to flow limitation may be a sharp turn or bend at the origin of the anomalous vessel from the contralateral sinus of Valsalva. Again, with increased cardiac output, a “kink” may transiently develop in the anomalous segment, thereby limiting blood flow (4,22). Finally, the anomalous origin can be associated with a slitlike ostial stenosis that impairs coronary blood flow. The interarterial course (between the aorta and pulmonary artery) of an anomalous left main coronary artery is considered the highest risk for ischemia and sudden death. Although the three non-interarterial pathways of the left main are considered lower risk (19), they have been associated with documented cases of myocardial infarction and sudden death in the absence of atherosclerosis (20). An anomalous RCA, which is typically, interarterial, has also been documented to be at risk for myocardial ischemia and infarction (18). In the absence of atherosclerosis, there has been no risk ascribed to the retroaortic anomalous circumflex.

DIAGNOSIS OF ANOMALOUS CORONARY ARTERY DISEASE

Echocardiography

In the infant and child, acoustic windows are usually excellent, allowing transthoracic echocardiography with a high-frequency transducer to successfully define the origin and proximal course of the native coronary arteries (23). Anomalous coronary artery definition is often easily defined. In the adolescent and adult, however, progressive rib ossification and thoracic/lung growth often lead to inadequate transthoracic echocardiographic visualization (24). In small series and case reports, transesophageal echocardiography (TEE), with close proximity of the high-frequency transducer to the coronary ostia, has been used to image coronary anomalies. The largest published TEE series included nine coronary anomaly patients (25). TEE was used to confirm the origin and initial course of the anomalous coronary vessel found on angiography. TEE image acquisition and analysis were performed with prior knowledge of the angiographic findings. Thus, the ability of TEE to identify coronary anomalies in a “blinded analysis” remains unknown. Though generally well tolerated, TEE is considered moderately invasive.

X-Ray Angiography

Until recently, the gold standard for the premorbid diagnosis of coronary artery anomalies in the adolescent and adult has been invasive x-ray coronary angiography. As previously discussed, defining the presence and proximal course with respect to the aorta and pulmonary artery is essential, because this is the most important indicator of the risk of the anomalous coronary and determines treatment. A limitation of conventional x-ray coronary angiography is that it requires selectively engaging each vessel. Commonly, the anomalous origin may not be engaged during a standard procedure, sometimes leading to the erroneous assumption that the vessel is occluded. After sheath removal and later review of the left ventriculogram, an anomalous vessel may then be suspected. Misclassification by x-ray angiography of the proximal course of anomalous coronary arteries is a well-described phenomenon (26), although visual aids, including placement of a right heart catheter in the pulmonary artery, have been developed to try to minimize this problem (20). Because of its invasive nature and expense, however, invasive x-ray coronary angiography poses some

risk to the patient and is impractical for screening purposes in young adults presenting with typical or atypical exertional chest pain. More importantly, x-ray angiography only provides a two-dimensional projection of the complex tree-dimensional course of the anomalous vessel.

Magnetic Resonance Angiography

The use of magnetic resonance angiography (MRA) of the coronary arteries (27–30) has several advantages in the diagnosis of coronary anomalies. MRA is noninvasive and does not require ionizing radiation or iodinated contrast agents. Most importantly, it provides a three-dimensional “road map” (i.e., not the two-dimensional projection of invasive x-ray angiography) in which the user can acquire an image at any orientation. Coronary MRA is also particularly suited to imaging the larger proximal coronary vessels (27–30).

Early reports of MR imaging to visualize anomalous coronary arteries included case reports without blinded analysis (31–33). There are currently two published series of patients who underwent blinded comparison of coronary MRA results with x-ray angiography. We reported on 16 patients with anomalous coronaries studied using the two-dimensional electrocardiogram-gated, segmented k-space, gradient echo technique with fat suppression and breathholding (34). Investigators interpreting the coronary MRA were blinded to the coronary anomaly and all other clinical data. Coronary MRA correctly identified the anomalous vessel in 93% of cases (using conventional x-ray coronary angiography as the gold standard). The proximal course of the anomalous vessel was not well seen in one case with a small non-dominant anomalous RCA and in another case with a small anomalous retroaortic LCx. In the same issue of *Circulation*, Post et al. (35) reported a 38-subject study, including 19 patients with anomalous coronaries and 19 “control” patients without coronary anomalies. A similar two-dimensional MRA sequence was used with overlapping slices obtained at the level of the aortic root and along the atrioventricular groove. Coronary MRA identified all subjects with anomalous vessels and the course of the proximal segment of the anomalous vessel. Importantly, three cases showed a disagreement between x-ray angiography and coronary MRA regarding the proximal course of the vessel. Side-by-side review of these cases led to the consensus conclusion that coronary MRA was correct in all three instances. These investigators con-

cluded that coronary MRA should be considered the new gold standard for this condition.

Subsequently, Vliegen et al. (35) reported on 12 patients with coronary anomalies, including 5 patients referred for MRA because the x-ray angiogram was inconclusive with regards to the anatomic course of the anomalous vessel. A breathhold two-dimensional approach was also used. MRA provided the diagnosis in all five subjects for whom the x-ray angiogram had been inconclusive. Of seven patients in which the diagnosis had been established by x-ray, the x-ray diagnosis was changed in one patient as a result of the MRA data. The x-ray in this one subject had suggested the anomalous RCA coursed anterior to the pulmonary artery, whereas the MRA conclusively documented its retroaortic course (which was confirmed at surgery).

In a recent report, Taylor et al. (37) extended the value of coronary MRA for identification of anomalous vessels by performing a study in 25 patients with congenital cardiac anomalies often associated with anomalous coronary arteries. Respiratory gated coronary MRA was used and compared in a blinded manner with conventional x-ray coronary angiography, with consensus diagnosis. Respiratory gated coronary MRA had an 88% sensitivity and 100% specificity for detecting coronary anomalies. These investigators also found that coronary MRA was superior to x-ray angiography for defining the proximal course of the vessels.

MRA Limitations and Pitfalls

Although MR imaging is noninvasive and without significant short- or long-term risk, some studies are still suboptimal. Patients may have contraindications, such as pacemakers, intracranial clips, or certain other metal implants or they may be claustrophobic. To obtain a good-quality coronary MRA study typically requires a regular heart rhythm and consistent breathholding or regular respiratory rhythm. New techniques for respiratory gating or rapid acquisition of the entire cardiac volume remove the need for repetitive breathholding (37–41). Real-time cardiac MR imaging can be performed regardless of cardiac rhythm or breathing (42,43).

Several pitfalls must be considered when interpreting coronary MRA for anomalous vessels. The anomalous vessel may be quite small and thereby challenge the spatial resolution of coronary MRA, as in the two cases in which we could not identify the proximal vessel course. Higher resolution and contrast-enhanced coronary MRA techniques may overcome this limitation (43–45). The

retroaortic pericardium may be mistaken for an anomalous circumflex. The one case from our study (34) in which the anomalous vessel was incorrectly identified was initially interpreted as a retroaortic anomalous circumflex. On later review, it was noted that this linear retroaortic structure was present over multiple transverse slices (i.e., too large for a vessel) and was pericardial tissue that on a single slice mimicked an anomalous circumflex.

CLINICAL IMPLICATIONS

The ability of coronary MRA to noninvasively identify coronary artery anomalies has several potential clinical applications. First, coronary MRA may be used to evaluate the three-dimensional path of anomalous coronary vessels identified by x-ray angiography, particularly when there is uncertainty as to whether an anomalous vessel follows a hemodynamically significant course between the aorta and pulmonary artery. Second, coronary MRA could distinguish an occluded vessel from an anomalous one in cases in which a vessel cannot be engaged by conventional angiography. Third, it should be considered among patients with congenital coronary anomalies associated with coronary anomalies (especially before cardiac interventions). Finally, though currently unproven, coronary MRA may be helpful in selected cases of young patients with unexplained syncope or chest discomfort in whom a coronary anomaly is part of the differential diagnosis. Although cost would be a factor in considering this technique as a screening test for competitive athletes (15), it would have the advantage over echocardiography in more comprehensively detecting coronary and myocardial abnormalities.

SUMMARY

In conclusion, coronary artery anomalies are a rare but important cause of cardiac morbidity and mortality, especially in adolescents and young adults. Coronary MRA is well suited to noninvasively detect anomalous coronaries and to define their proximal course and thereby guide therapy. With increasing clinical experience and continued technologic improvements, coronary MRA will likely emerge as the gold standard for the diagnosis of this condition.

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