



Cardiac Imaging: Part 2, Normal, Variant, and Anomalous Configurations of the Coronary Vasculature

Phillip M. Young¹
 Thomas C. Gerber²
 Eric E. Williamson¹
 Paul R. Julsrud¹
 Robert J. Herfkens³

OBJECTIVE. Noninvasive imaging of the heart and coronary vasculature using CT and MRI is a new and exciting opportunity for radiologists. The purpose of this pictorial essay is to review normal and variant anatomy of the coronary arteries and of several coronary anomalies that may be clinically significant. The coronary veins and artifacts simulating disease will also be briefly covered. This article will help radiologists learn and review normal coronary anatomy, normal variants, and coronary anomalies and recognize pitfalls, such as coronary veins and artifacts, that may be confusing when first encountered.

CONCLUSION. The coronary arteries generally are predictable in their origin, course, and perfusion territories. Standardized reporting systems exist for describing the location of specific lesions, and radiologists who interpret CT and MR coronary images should be aware of and should attempt to integrate these reporting schemes into clinical practice.

Advances in temporal and spatial resolution in MDCT and MRI have led to new clinical applications in imaging the coronary vasculature. The expanding role of these modalities in noninvasively detecting or excluding coronary stenosis represents a new opportunity for radiologists, and use of the technology has greatly increased in recent years. However, many radiologists have had little training in coronary imaging and may not be familiar with coronary anatomy. Additionally, the increasing use of CT and MRI for noninvasive cardiac imaging also will expose radiologists more frequently to relatively rare anomalous and variant configurations of the coronary vasculature, some of which are associated with an increased risk of sudden cardiac death. This article will review normal, variant, and anomalous coronary artery vascular segmental anatomy.

Basics of Coronary Embryology

Although describing the coronary anatomy of most patients is straightforward, it is important to note that the coronary arteries are named for the structures that they supply rather than for their origin. This nomenclature is based on fundamental embryologic principles; the coronary stems arise within the developing myocardium and only later

attach to their blood supply from the aorta [1] (Fig. 1). The various perturbations in the connections of the coronaries to each other and to their aortic supply occur subsequent to the formation of the coronary stems in the myocardium. The distinction between a variant coronary pattern and a potentially dangerous anomaly is therefore typically based on the potential clinical implications rather than on the embryologic cause.

Normal Coronary Anatomy

The coronary tree and, in particular, the major branches of the coronary arteries are named according to their appearance on angiograms rather than on axial images. The nomenclature of the coronary branches makes sense when keeping in mind the appearance of the heart on a left anterior oblique (LAO) view (Fig. 1).

The reporting scheme for coronary segments presented here is based on that presented in an American Heart Association (AHA) ad hoc committee report [2] and adapted for cross-sectional imaging in a Society of Cardiovascular Computed Tomography report [3] because of its relative simplicity and straightforward translation to cross-sectional imaging (Fig. 2). Other commonly used angiographic schemes are similar, also having been adapted from the original AHA report [4, 5]. Adherence to established schemes is

Keywords: coronary anomalies, coronary arteries, coronary fistulas, coronary veins, myocardial bridging

DOI:10.2214/AJR.10.7249

Received March 8, 2010; accepted after revision May 30, 2010.

¹Division of Cardiovascular Diseases, Mayo Clinic, 200 First St SW, Rochester, MN 55902. Address correspondence to P. M. Young (young.phillip@mayo.edu).

²Departments of Cardiology and Diagnostic Radiology, Mayo Clinic, Jacksonville, FL.

³Department of Diagnostic Radiology, Stanford University Medical Center, Stanford, CA.

CME/SAM

This article is available for CME/SAM credit. See www.arrs.org for more information.

AJR 2011; 197:816–826

0361–803X/11/1974–816

© American Roentgen Ray Society

Coronary Vasculature Configurations

essential both to ensure standardization and reproducibility of results and to gain the confidence of referring physicians.

The coronary veins have historically received less attention than the coronary arteries. They often course alongside the coronary arteries, and it is important not to confuse one for the other. Defining the coronary venous anatomy may also be important in cases of coronary fistula or arteriovenous malformation (AVM) or may be useful before certain electrophysiologic procedures.

Right Coronary Artery of the Heart

Definition—The right coronary artery (RCA) is defined as the artery that supplies the morphologic right ventricle. It typically arises from the right sinus of Valsalva (Fig. 3) and travels in the right atrioventricular groove (Fig. 4) toward the “acute margin” of the heart. The RCA is best seen on an LAO view of the heart, as would be obtained during cardiac catheterization, in which the lateral margin of the right ventricle appears to form an acute angle. The tip of the angle is called the acute margin. When the RCA reaches the acute margin, it turns to continue between the right atrium and right ventricle at the base until it reaches the junction with the atrial and ventricular septa.

The RCA is divided into proximal, middle, and distal segments. The proximal segment is from the origin halfway to the acute margin. The middle segment is from this halfway point to the acute margin itself. The distal segment is from the acute margin to the base of the heart at the junction of the atrial and ventricular septa (Fig. 5).

Right coronary artery branches—In 50–60% of individuals, a conus branch arises as the first branch of the RCA to supply the right ventricular outflow tract. The conus branch can serve as an important source of collateral supply to the left anterior descending (LAD) artery through the so-called “circle of Vieussens” in select cases of severe left main coronary artery (LMCA) or proximal LAD coronary disease.

The right ventricular free wall is supplied through acute marginal branches of the RCA. Typically, the halfway point between the RCA ostium and the acute margin of the right heart border—the dividing point between the proximal and middle RCA segments—is marked by the origin of a large acute marginal branch. This branch can serve as a useful marker for dividing the proximal segment from the middle segment on axial images (Fig. 5).

Other branches that may be present include the sinoatrial nodal branch, arising from the proximal RCA in 60% of people [6], and the atrioventricular nodal branches, arising from a U-shaped crux cordis at the base of the heart in 90% of people.

Left Main Coronary Artery

The LMCA typically arises from the left sinus of Valsalva. The LMCA typically does not have significant branches of its own but quickly bifurcates into the LAD and circumflex coronary arteries (Fig. 6).

Left Anterior Descending Artery

The LAD artery arises from the bifurcation of the left coronary artery (LCA) and travels in the epicardial fat along the anterior interventricular groove between the right and left ventricles. On the LAO view of the heart, the LAD artery can be seen appearing to “descend” nearly vertically, giving off diagonal branches to the anterior left ventricular wall. In addition to supplying the anterior wall, the LAD artery also gives off septal perforator branches that supply the anterior two thirds of the basal interventricular septum and the entire septum at the mid and apical levels.

Like the RCA, the LAD artery is divided into three segments (Fig. 7). The proximal segment runs from the LAD origin to the origin of the first septal perforator. The middle segment runs from the first septal perforator origin halfway to the left ventricular apex. The distal segment runs from this halfway point to the apex itself.

Circumflex Artery

The left circumflex (LCX) artery arises from the LCA bifurcation and travels in the left atrioventricular groove, supplying the lateral wall of the left ventricle and variable portions of the inferior wall through the obtuse marginal and posterolateral branches, respectively.

Unlike the RCA and LAD artery, the LCX artery has only two segments (Fig. 8). The proximal segment runs from the LCX origin to the origin of the first obtuse marginal branch. The distal segment includes everything distal to this origin. In some patients, a posterolateral branch arises from the LCX artery or an obtuse marginal branch to supply a portion of the inferior wall. The LCX artery may also supply branches to the atrioventricular node.

Posterior Descending Artery

The posterior descending artery (PDA) runs in the posterior interventricular groove

between the right and left ventricles and supplies the inferior wall and inferior one third of the interventricular septum. The PDA can arise from the distal RCA (70%) or distal LCX artery (10%) or can receive elements from both (20%).

Coronary Dominance

Because of the variability in arterial supply to the inferior wall, the concept of coronary dominance is important to understand. In fact, most cardiac catheterization and coronary CT reports should begin with a statement of coronary dominance. Various definitions of coronary dominance have been proposed, but understanding the supply to the inferior wall and atrioventricular node is the most important concept. The most accurate definition of dominance would refer to the arterial supply to the atrioventricular node. However, the node itself is not directly visualized on CT, and the artery that supplies the atrioventricular nodal branches in the crux cordis typically supplies the inferior wall through the PDA as well.

For our purposes, a right-dominant system will be considered one in which the PDA and a posterolateral branch arise from the distal RCA. A left-dominant system is one in which the PDA and posterolateral branch arise from the distal circumflex artery. A codominant system is one in which the PDA arises from the distal RCA and a posterolateral branch arises from the distal circumflex to supply some of the inferior wall or one in which there are two PDA branches, one from the RCA and one from the LCX artery (Figs. 9 and 10). Approximately 70% of individuals have a right-dominant system, whereas 20% have a codominant system and 10%, a left-dominant system.

Coronary Veins

The coronary veins run in the interventricular and atrioventricular grooves with the coronary arteries and are well seen on CT [7–9]. They may also be important to delineate before surgery or intervention for a coronary artery fistula or AVM, and some investigators have advocated using CT to visualize the coronary veins before electrophysiology procedures [10].

The anterior interventricular vein runs along with the LAD artery in the anterior interventricular groove from the apex of the heart toward the base (Fig. 11). Once the anterior interventricular vein reaches the LAD bifurcation, it turns to descend in the left

atrioventricular groove with the circumflex coronary artery as the great cardiac vein (Fig. 12). As the great cardiac vein descends the atrioventricular groove, the great cardiac vein receives small tributaries (typically including a left marginal vein from the lateral wall or a left posterior vein draining the inferolateral wall) before joining the coronary sinus at the base of the heart (Fig. 13). A small vein draining the left atrium—that is, the vein of Marshall, an embryologic remnant of the left superior vena cava—can often be found draining into the coronary sinus as well, and the point at which it enters the coronary sinus is anatomically the dividing line between the great cardiac vein and the coronary sinus. The coronary sinus also receives the middle cardiac vein, which runs in the posterior interventricular groove with the PDA (Fig. 13). The appropriately named small cardiac vein usually drains directly into the right atrium, as anterior cardiac veins draining the right ventricle, next to the proximal RCA in the right atrioventricular groove.

Normal Variants

Inferior Wall Supply

As we noted earlier, the origin of the PDA is variable. In fact, the vascular supply to the inferior wall may be thought of as a spectrum of variants. Some individuals have a very small PDA and instead have multiple branches from the distal RCA, LCX, and obtuse marginal branches supplying the inferior wall (Fig. 14). Other patients have early takeoff of the PDA, which then courses toward the apex along the diaphragmatic surface of the right ventricle. In another variant, the LAD wraps around the apex to supply some of the apical inferior wall; this variant is known as the “wraparound LAD.” In addition to being a normal anatomic variant, the wraparound LAD can lead to a “mirror image” artifact on centerline vessel trace algorithms (Fig. 15).

Atrioventricular Nodal Supply

Typically, the dominant artery that supplies the PDA and inferior wall gives rise to a U-shaped crux at the base of the heart that, in turn, gives off small branches that supply the atrioventricular node. The atrioventricular node is a small bundle of tissue located at the center of the Koch triangle—a triangle enclosed by the septal leaflet of the tricuspid valve, the coronary sinus, and the membranous part of the interatrial septum. This tissue is important to the electrophys-

iological activity of the heart because it delays conduction of the electric impulse from the atria to the ventricles, allowing time for the additional ventricular preload caused by atrial contraction. Because right dominance is more common, these branches typically arise from the distal RCA.

Sinoatrial Nodal Supply

The sinoatrial node, another electrically active bundle of tissue, sits near the junction of the upper right atrium and the superior vena cava. It acts as the primary pacemaker in normal sinus rhythm and is supplied by a single sinoatrial nodal branch from the proximal RCA in 60% of people [6]; however, the sinoatrial nodal branch can also arise from the proximal LCX artery or even the distal RCA or LCX artery in unusual circumstances.

Ramus Intermedius

In some patients, rather than bifurcating into an LAD artery and LCX artery, the LCA trifurcates into an LAD artery, an LCX artery, and a ramus intermedius (Fig. 16). The ramus intermedius typically acts to supply the lateral and inferior walls in the manner of diagonal or obtuse marginal branches. The arteries that typically would supply that territory are diminutive or nonexistent presumably because the vessels supplying that portion of the myocardium have coalesced into the ramus intermedius rather than into their typical pattern.

Right Superior Septal Perforator

The right superior septal perforator is a variant occurring in approximately 3% of patients who undergo coronary angiography [11]. Like the septal perforators arising from the proximal LAD artery, the right superior septal perforator supplies the anterior septum but arises from the proximal RCA or the right sinus of Valsalva. Like the conus branch, the right superior septal perforator may serve as a potential source of collateral supply to the LAD artery with LCA or proximal LAD disease.

Supernumerary Coronary Ostia

In addition to the typical RCA and LCA origins from the aorta, some patients have smaller branches that arise directly from the aorta rather than arising as branches from the coronary arteries. Among the more common variants are separate origins of the LAD and LCX arteries from the left coronary sinus with no common LMCA and a

separate origin of the conus branch directly from the aorta rather than from the proximal RCA (Fig. 17). Although these anomalies could potentially have clinical consequences if unrecognized during surgery or coronary catheterization, they are not clinically significant in most people.

Myocardial Bridging

Normally, the coronary arteries travel in the epicardial fat along the surface of the heart as they cross their perfusion territories. In some individuals, however, the coronary artery “dives” from the epicardial fat into the myocardium for variable lengths (Fig. 18). This configuration leaves a segment of bridging myocardium superficial to the coronary artery and typically occurs in the middle segment of the LAD artery but can occur in other segments as well. Although angiography may show up to 50% systolic narrowing of the affected artery, these findings are very rarely clinically significant at least in part because most coronary blood flow occurs in diastole (when the myocardium is relaxed and requires less pressure for perfusion). Interestingly, the bridged coronary segment is frequently spared of atherosclerotic disease [12]. The typically benign prognosis of these variants is underscored by the results of an 11-year follow-up study [13] of 61 patients with bridged coronary segments incidentally discovered during coronary angiography; in that study population, no patients developed myocardial ischemia and outcomes did not correlate with the degree of systolic compression seen during angiography [13]. Angiography may, in fact, significantly underestimate the prevalence of myocardial bridging: Recent articles have shown bridging on CT in nearly a third of patients at low risk of ischemic heart disease [14, 15]. The term “tunneling” rather than “bridging” may be used to signify the likely benign prognosis of most cases.

As with any finding, however, the clinical significance should be interpreted only in conjunction with the remaining scanning results and the clinical situation. Myocardial bridging may rarely cause limitation of flow, particularly if the segment is long or deep, is associated with coexistent stenoses, or is supplying a collateralized territory. Atypical angina may be the presenting symptom in such patients [16].

Coronary Anomalies

Coronary artery anomalies are fairly common, occurring in 0.3–1.3% of patients at an-

Coronary Vasculature Configurations

giography and 0.3–0.5% at autopsy [17–19]. Some of the variability in the reported incidence likely reflects referral bias and even variability in definitions of “anomalous” and “normal” variant.

Ectopic Coronary Origin From the Contralateral Coronary Sinus

Ectopic coronary origin is the most frequently encountered coronary anomaly and is particularly important to recognize because some forms can be associated with angina and an increased risk of sudden cardiac death. The most common of these coronary anomalies is ectopic origin of a coronary artery from the coronary sinus opposite its normal perfusion territory. As many as 26% involve some sort of aortic root abnormality, such as bicuspid aortic valves. In general, the origin of the ectopic coronary artery is not problematic, but the course that the abnormal coronary artery takes to its perfusion territory can have important consequences.

Conceptually, a coronary artery that arises from the contralateral sinus of Valsalva has four potential paths it may take to its perfusion territory: prepulmonic (anterior to the right ventricular outflow tract), retroaortic (posterior to the aortic root), septal (through the proximal interventricular septum, analogous to a right superior septal perforator), or interarterial (between the aorta and pulmonary artery) (Figs. 19–22). The former two scenarios (i.e., prepulmonic and retroaortic) are considered benign coronary anomalies, putting the patient at little risk of an adverse event. An interarterial course of an anomalous coronary artery, however, is associated with an increased risk of sudden cardiac death for reasons that are still not entirely clear. The risk of sudden death may be as high as 30% [20], and anomalous coronary arteries have been implicated as the cause of 5–35% of sudden deaths in young athletes [21]. Most deaths attributed to coronary anomalies occur in young individuals during vigorous exercise. The risk of sudden death in a middle-aged or elderly individual with an incidentally discovered anomaly is unclear but is probably lower than the risk of sudden death in a younger patient.

The most frequently cited hypothesis for the cause of sudden death is that angulation of the anomalous vessel can cause a valve-like ostial ridge. In addition, some interarterial coronaries actually take an intramural course through the wall of the aorta, which may cause them to be compressed during aor-

tic pulsation (Fig. 21). Either of these mechanisms may limit inflow. A series of 32 necropsies of patients with interarterial coronaries originating from the contralateral coronary sinus did not establish a statistically significant outcome difference in patients with a slitlike ostial morphology but did note an association between negative outcomes and dominance of the anomalous coronary artery [22].

Although the precise mechanism of death is unclear, patients with interarterial coronaries (particularly young, active patients) are at risk of sudden death. Patients who are incidentally discovered to have these anomalies often empirically undergo coronary bypass surgery. However, given the rarity of coronary anomalies, optimal management of these patients has not yet been established. For example, no outcomes data support the notion that coronary bypass grafting decreases the risk of sudden cardiac death in this population. There is some evidence that anomalous RCAs with an interarterial course are associated with a more benign prognosis than interarterial LCAs. In our practice, some patients with interarterial RCAs undergo some form of stress testing before determination of an operative course.

Some anomalous interarterial coronary arteries are known to take an intramural course—that is, tunneling through the wall of the aorta. Whether this course places the patient at additional risk of sudden cardiac death is unclear but it does offer a surgical option for the correction of this anomaly of unroofing rather than bypass [23]. Our experience has been that when using the most up-to-date CT scanners (in our institutions, dual-source CT scanners), CT can predict with good accuracy which arteries have an intramural course (Fig. 21).

Radiologic reporting of these cases should clearly include the origin of each coronary artery, the path of the abnormal coronary artery to its perfusion territory, and the overall coronary dominance pattern. Additional tortuosity, marked angulation, and coexistent atherosclerosis should be noted as well as any objective evidence of downstream myocardial ischemia or infarction, such as myocardial thinning or hypoattenuation of the subendocardial myocardium.

We should also note that nongated chest CT studies may have pulsation artifacts that can mimic interarterial coronary arteries. Between 6% and 20% of patients thought to have interarterial course on ungated chest CT have been shown to have normal coronary origins on gated cardiac CT, MRI, or

selective angiography. Some of the variation in the positive predictive values of ungated CT probably relates to the detector number and temporal resolution of the scanner in use [24, 25] (Fig. 23).

Bland-White-Garland Syndrome

An anomalous LCA arising from the pulmonary artery, known by the eponym of Bland-White-Garland syndrome, usually presents in infants or children. In very young patients, the presenting symptoms of Bland-White-Garland syndrome are usually those of myocardial ischemia due to coronary steal phenomenon. In older patients whose bodies presumably have compensated for the steal with collateralized vessels, progressive left-to-right shunting may develop. The physiology of left-to-right shunting is similar to that of coronary fistulas and AVMs (discussed later) and patients with left-to-right shunting can present with pulmonary hypertension. Imaging findings in these patients can be striking, with markedly dilated collateral arteries and coronary veins [26].

Coronary Aneurysms

Coronary aneurysms may result from many causes, including inflammatory disorders such as Kawasaki disease, connective tissue disorders, or iatrogenic complications of surgery or catheterization; however, the most common cause is atherosclerosis [27] (Fig. 24). Coronary aneurysms are uncommon, occurring in roughly 1.5% of autopsies [28]. The prognosis associated with coronary aneurysms is often uncertain both because relatively few cases have been followed and because the prognosis likely varies according to the underlying cause. Complications are similar to those of aneurysms in other areas of the body, including rupture, thrombosis, and distal embolization. Coronary aneurysms are most often incidentally discovered, and management is controversial.

Coronary Fistulas and Arteriovenous Malformations

Unfortunately, there is not a clear distinction between discrete coronary fistulas, which are comparatively common, and complex coronary AVMs in the medical literature. Collectively, they have been described in as many as 0.5% of coronary angiograms [29]. Historically, coronary fistulas and AVMs are the most common indications for surgical repair of a coronary artery anomaly.

Coronary fistulas and AVMs usually have a benign clinical course, but patients can

present with symptoms resulting from left-to-right shunting, such as pulmonary hypertension. Coronary steal phenomenon may also occur, leading to ischemia and, only very rarely, to infarction. In one study of 51 patients with coronary steal phenomenon (mean age, 60 years) [30], the 5-year mortality was only 4%. Thirteen patients had angina pectoris without significant coronary atherosclerosis, and seven had objective evidence of coronary insufficiency [30]. In some cases, severe symptoms and striking imaging findings may be present, and imaging can be key in helping to outline the anatomy and plan treatment (Fig. 25). If suspected or incidentally found, coronary AVMs should be imaged up to the aortic arch because they may have significant bronchial contributions, which could be important to know if surgical intervention is planned.

Conclusion

The coronary arteries generally are predictable in their origin, course, and perfusion territories. Standardized reporting systems exist for describing the location of specific lesions, and radiologists who interpret CT and MR coronary images should be aware of and should attempt to integrate these reporting schemes into their clinical practices. Coronary variants and anomalies are commonly encountered and sometimes can be clinically relevant. Familiarity of radiologists with the more commonly encountered anomalies, such as origin of a coronary artery from the contralateral coronary sinus, will become increasingly important as cardiac imaging volumes with CT and MR continue to increase.

References

- Angelini P. Normal and anomalous coronary arteries: definitions and classification. *Am Heart J* 1989; 117:418–434
- Austen WG, Edwards JE, Frye RL, et al. A reporting system on patients evaluated for coronary artery disease: report of the Ad Hoc Committee for Grading of Coronary Artery Disease, Council on Cardiovascular Surgery, American Heart Association. *Circulation* 1975; 51(suppl 4):5–40
- Raff GL, Abidov A, Achenbach S, et al.; Society of Cardiovascular Computed Tomography. SCCT guidelines for the interpretation and reporting of coronary computed tomography. *J Cardiovasc Comput Tomogr* 2009; 3:122–136
- Alderman EL, Stadius M. The angiographic definitions of the Bypass Angioplasty Revascularization Investigation study (BARI). *Coron Artery Dis* 1992; 3:1189–1207
- Kennedy JW, Kaiser GC, Fisher LD, et al. Clinical and angiographic predictors of operative mortality from the collaborative study in coronary artery surgery (CASS). *Circulation* 1981; 63:793–802
- Kennel AJ, Titus JL. The vasculature of the human sinus node. *Mayo Clin Proc* 1972; 47:556–561
- Gerber TC, Sheedy PF, Bell MR, et al. Evaluation of the coronary venous system using electron beam computed tomography. *Int J Cardiovasc Imaging* 2001; 17:65–67
- Jongbloed MR, Lamb HJ, Bax JJ, et al. Noninvasive visualization of the cardiac venous system using multislice computed tomography. *J Am Coll Cardiol* 2005; 45:749–753
- Abbara S, Cury RC, Nieman K, et al. Noninvasive evaluation of the cardiac veins with 16-MDCT angiography. *AJR* 2005; 185:1001–1006
- Mlynarski R, Sosnowski M, Wlodyka A. A user-friendly method of cardiac venous system visualization in 64-slice computed tomography. *Pacing Clin Electrophysiol* 2009; 32:323–329
- Bream PR, Souza AS, Elliott LP, Soto B, Curry GC. Right superior septal perforator artery: its angiographic description and clinical significance. *AJR* 1979; 133:67–73
- Möhlenkamp S, Hort W, Ge J, Erbel R. Update on myocardial bridging. *Circulation* 2002; 106:2616–2622
- Juilliere Y, Berder V, Suty-Selton C, Buffet P, Danchin N, Cherrier F. Isolated myocardial bridges with angiographic milking of the left anterior descending coronary artery: a long-term follow-up study. *Am Heart J* 1995; 129:663–665
- Konen E, Goitein O, Sternik L, Eshet Y, Shemesh J, Di Segni E. The prevalence and anatomical patterns of intramuscular coronary arteries: a coronary computed tomography angiographic study. *J Am Coll Cardiol* 2007; 49:587–593
- De Rosa R, Sacco M, Tedeschi R, et al. Prevalence of coronary artery intramyocardial course in a large population of clinical patients detected by multislice computed tomography coronary angiography. *Acta Radiol* 2008; 49:895–901
- Joshi SN, Blackshear JL. 66-year-old man with long-standing intermittent chest pain. *Mayo Clin Proc* 2003; 78:1405–1408
- Click RL, Holmes DR Jr, Vlietstra RE, Kosinski AS, Kronmal RA. Anomalous coronary arteries: location, degree of atherosclerosis and effect on survival—a report from the Coronary Artery Surgery Study. *J Am Coll Cardiol* 1989; 13:531–537
- Yamanaka O, Hobbs RE. Coronary artery anomalies in 126,595 patients undergoing coronary arteriography. *Cathet Cardiovasc Diagn* 1990; 21:28–40
- Alexander RW, Griffith GC. Anomalies of the coronary arteries and their clinical significance. *Circulation* 1956; 14:800–805
- Lipsett J, Kohle SD, Berry PJ, Russell G, Byard RW. Anomalous coronary arteries: a multicenter pediatric autopsy study. *Pediatr Pathol* 1994; 14:287–300
- Angelini P. Coronary artery anomalies: current clinical issues. *Tex Heart Inst J* 2002; 29:271–278
- Corrado D, Thiene G, Cocco P, et al. Nonatherosclerotic coronary artery disease and sudden death in the young. *Br Heart J* 1992; 68:601–607
- Davies JE, Burkhart HM, Dearani JA, et al. Surgical management of anomalous aortic origin of a coronary artery. *Ann Thorac Surg* 2009; 88:844–847
- Kragel AH, Roberts WC. Anomalous origin of either the right or left main coronary artery from the aorta with subsequent coursing between aorta and pulmonary trunk: analysis of 32 necropsy cases. *Am J Cardiol* 1988; 62:771–777
- Katoh M, Wildberger JE, Guenther RW, Buecker A. Malignant right coronary artery anomaly simulated by motion artifacts on MDCT. *AJR* 2005; 185:1007–1010
- Pena E, Nguyen ET, Merchant N, Dennie G. ALCAPA syndrome: not just a pediatric disease. *RadioGraphics* 2009; 29:553–565
- Barriaes-Villa R, Moris C. Usefulness of helical computed tomography in the identification of the initial course of coronary anomalies. *Am J Cardiol* 2001; 88:719
- Daoud AS, Pankin D, Tulgan H, Florentin RA. Aneurysms of the coronary artery: report of ten cases and review of the literature. *Am J Cardiol* 1963; 11:228–237
- Reul RM, Cooley DA, Hallman GL, Reul GJ. Surgical treatment of coronary artery anomalies: report on a 37.5-year experience at the Texas Heart Institute. *Tex Heart Inst J* 2002; 29:299–307
- Said SA, van der Werf T. Dutch survey of coronary artery fistulas in adults: congenital solitary fistulas. *Int J Cardiol* 2006; 106:323–332

Coronary Vasculature Configurations

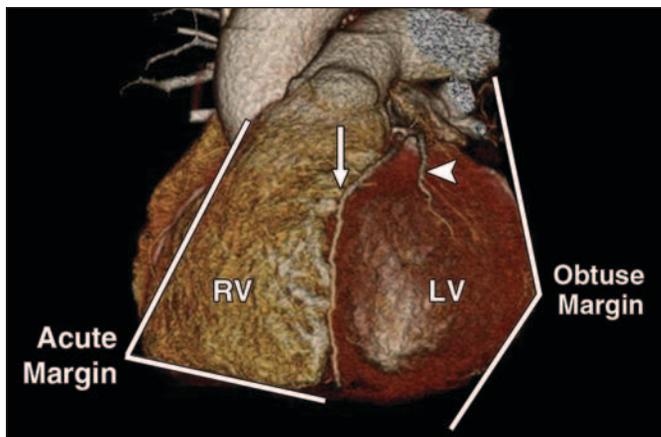


Fig. 1—Volume-rendered CT image of heart in left anterior oblique projection shows acute angle formed by right ventricular (RV) free wall (acute margin) and obtuse angle formed by left ventricular (LV) lateral wall (obtuse margin). Also note that left anterior descending (LAD) coronary artery really does appear to descend in anterior interventricular groove (*arrow*) and gives off diagonal branch (*arrowhead*). In some languages, LAD artery is referred to as “ramus interventricularis anterior.”

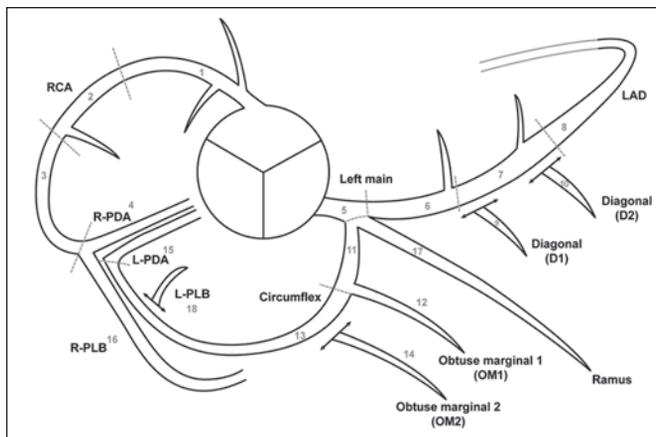


Fig. 2—Diagram shows coronary segments proposed in [3] and used by Society of Cardiovascular Computed Tomography. RCA = right coronary artery, LAD = left anterior descending artery, R-PDA = right posterior descending artery, L-PDA = left posterior descending artery, L-PLB = left posterolateral branch, R-PLB = right posterolateral branch. (Reprinted with permission from [3])

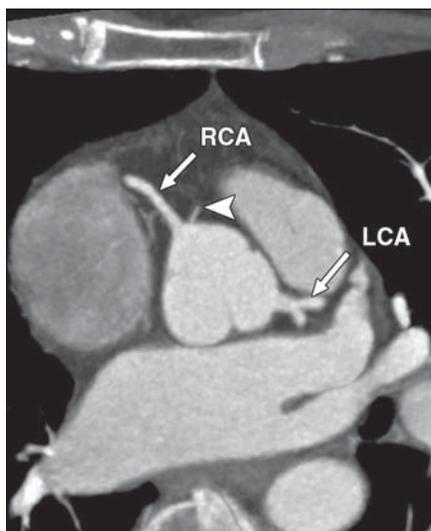


Fig. 3—Conventional origin of coronary arteries. Thin-slab maximum-intensity-projection CT image shows origins of right coronary artery (RCA) from right sinus of Valsalva and left coronary artery (LCA) from left sinus of Valsalva. Small conus branch (*arrowhead*) is also seen arising from right coronary sinus.

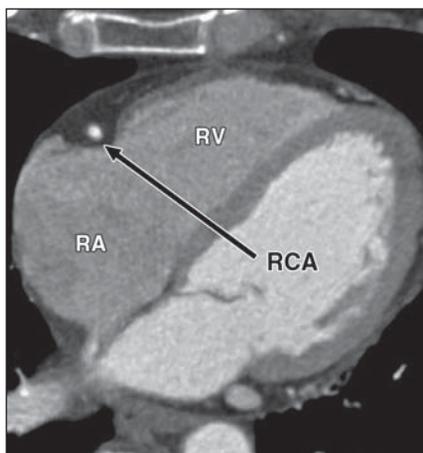


Fig. 4—Normal right coronary artery (RCA) in right atrioventricular groove. Maximum-intensity-projection CT image shows RCA in right atrioventricular groove between right atrium (RA) and right ventricle (RV).

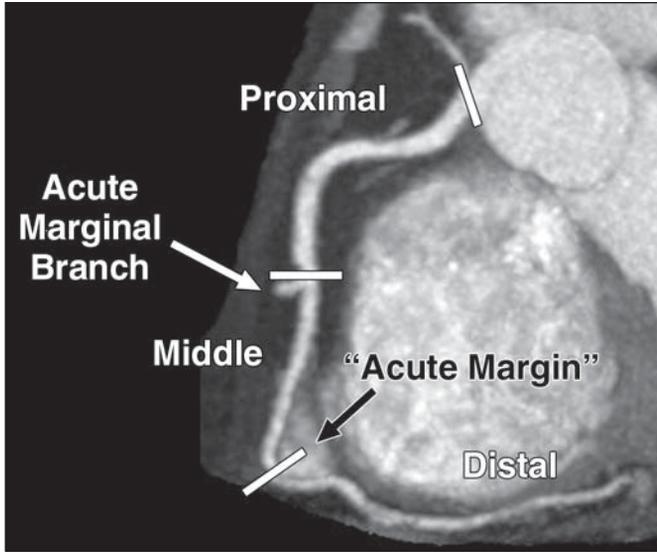


Fig. 5—Segmentation of right coronary artery (RCA). White lines divide three segments of RCA. Proximal segment runs from ostium halfway to “acute margin” of heart. Note that this point is often marked by origin of large acute marginal branch. Middle segment runs from this point to acute margin itself. Distal segment runs from acute margin until RCA terminates or gives rise to posterior descending artery.

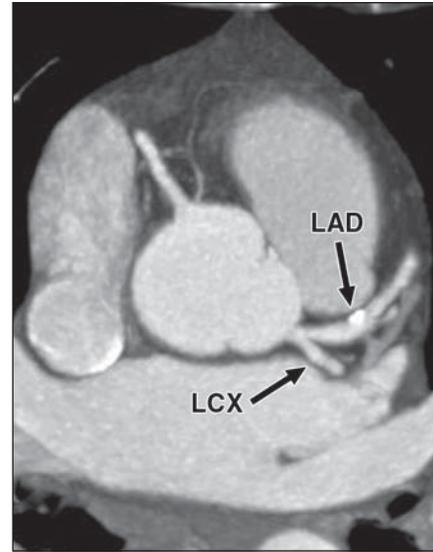


Fig. 6—Axial thin maximum-intensity-projection CT image shows bifurcation of left coronary artery into left anterior descending (LAD) artery and left circumflex (LCX) coronary arteries shortly after its origin from left sinus of Valsalva.

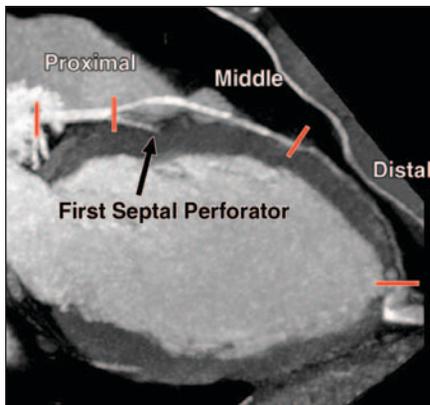


Fig. 7—Segmentation, shown by lines, of left anterior descending (LAD) artery. Oblique long-axis reformat CT image shows lines dividing LAD artery into three segments. Proximal segment runs from origin of LAD to origin of first septal perforator. Middle segment runs from first septal perforator halfway to apex. Distal segment runs from this point to apex itself.

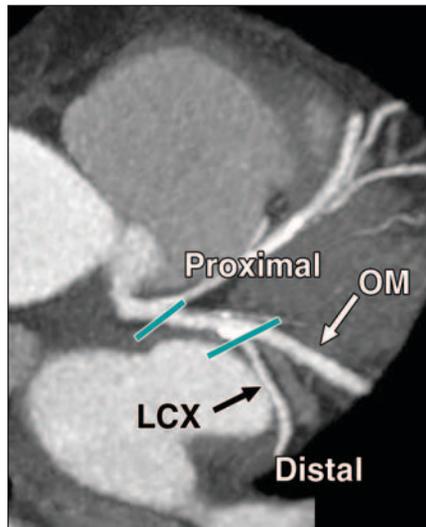


Fig. 8—Segmentation of circumflex artery. Oblique maximum-intensity-projection CT image shows lines demarcating proximal segment (from origin of left circumflex artery [LCX] to origin of first obtuse marginal branch [OM]) and distal segment (distal to first obtuse marginal branch).

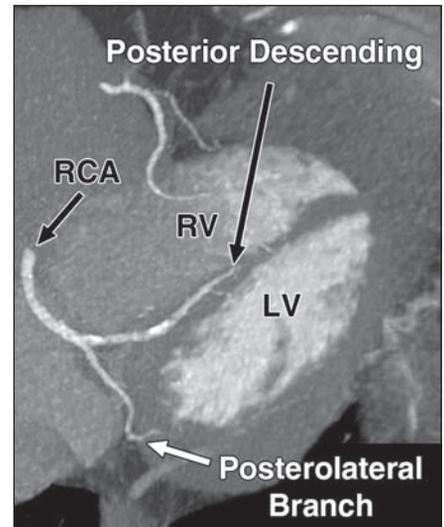


Fig. 9—“Right dominant” coronary pattern. Oblique axial maximum-intensity-projection CT image shows distal right coronary artery supplying posterior descending artery in posterior interventricular groove, between right ventricle (RV) and left ventricle (LV), and also supplying posterolateral branch, which is partially visualized in distal left atrioventricular groove. RCA = right coronary artery.

Coronary Vasculature Configurations

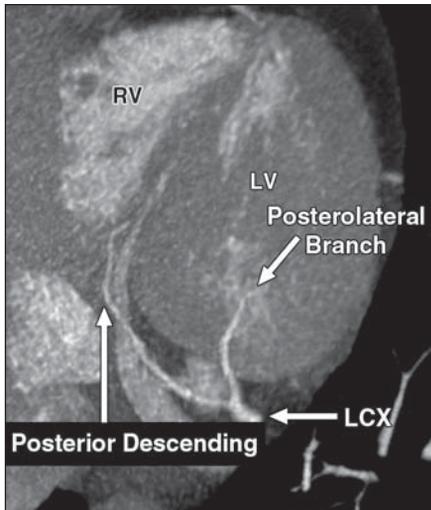


Fig. 10—“Left dominant” coronary pattern. Oblique axial maximum-intensity-projection CT image shows distal left circumflex (LCX) artery supplying posterior descending artery in posterior interventricular groove, between right ventricle (RV) and left ventricle (LV), as well as posterolateral branch.

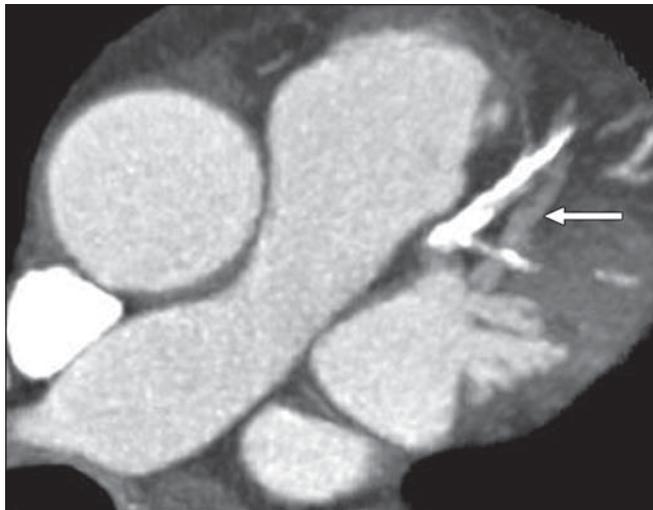


Fig. 11—Anterior interventricular vein. Oblique axial CT image shows anterior interventricular vein (*arrow*), which travels in anterior interventricular groove with left anterior descending (LAD) artery; in this case, LAD artery shows extensive calcification.

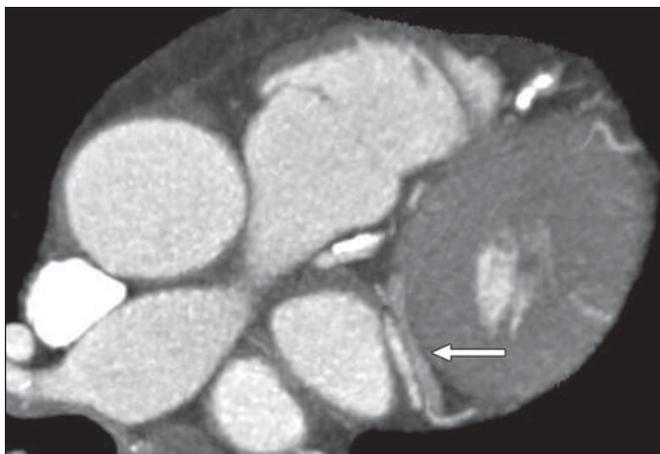


Fig. 12—Great cardiac vein. Oblique axial CT image shows great cardiac vein (*arrow*), which is continuation of anterior interventricular vein. At left coronary bifurcation, anterior interventricular vein turns to descend left atrioventricular groove with left circumflex artery.

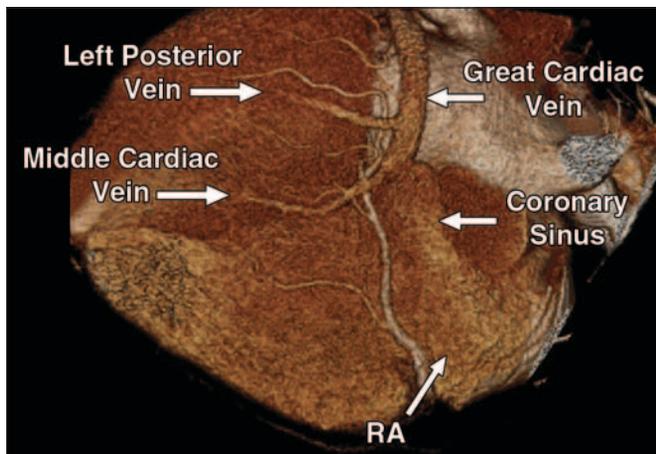


Fig. 13—Major coronary veins draining into coronary sinus. Volume-rendered CT image from inferior projection shows great cardiac vein receiving left posterior vein and joining in confluence with middle cardiac vein to form coronary sinus, which subsequently drains into right atrium (RA).



Fig. 14—Supply of inferior wall through multiple small thready branches rather than by robust posterior descending artery. Image shows that multiple small branches of distal right coronary artery (*arrowheads*) supply inferior wall and largest branch (*arrow*) does not run to atrioventricular groove. Distal circumflex artery also supplies posterolateral wall.



Fig. 15—Wraparound left anterior descending (LAD) artery causing "mirror image" artifact on vessel trace postprocessing software. Note that as LAD artery wraps around apex to travel toward base of heart in posterior interventricular groove, it causes "mirror image" appearance about apex (*dashed line*).

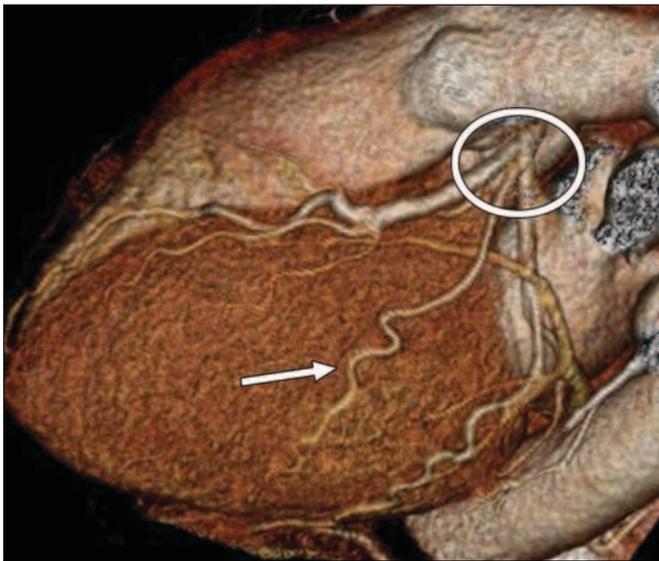


Fig. 16—Normal variant ramus intermedius. Lateral projection volume-rendered CT image of lateral wall of left ventricle shows ramus intermedius (*arrow*) is supplying lateral wall as it arises from trifurcation (*circle*) of left coronary artery into left anterior descending (LAD) artery, left circumflex artery, and ramus.

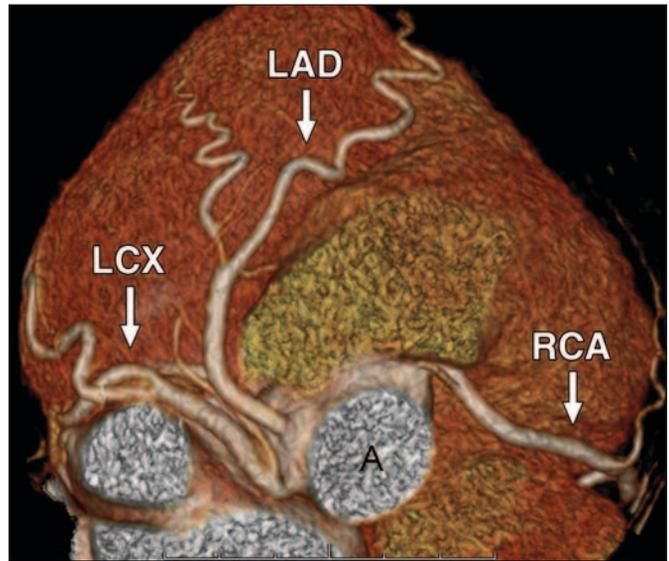


Fig. 17—Separate origins of left anterior descending (LAD) and circumflex coronaries from left sinus of Valsalva. Craniocaudal volume-rendered CT image replicates superior-to-inferior projection of heart with aorta (A) cut away at root. Left side of image is left side of patient. There are separate origins of LAD and left circumflex (LCX) arteries from aorta. Right coronary artery (RCA) has normal origin.

Coronary Vasculature Configurations

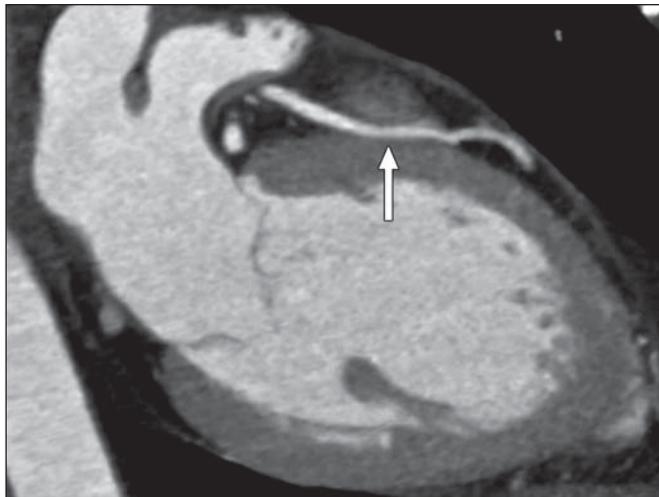


Fig. 18—Myocardial bridging. Oblique long-axis reformatted CT image shows middle left anterior descending (LAD) artery segment (*arrow*) is surrounded by medium-gray myocardium; this finding is evidence of typically benign condition called “myocardial bridging” or “muscular bridging.”

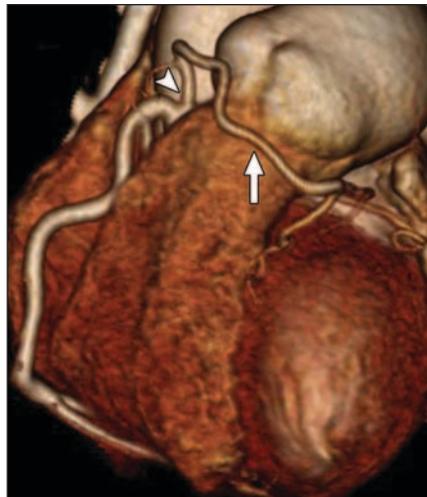


Fig. 19—Left anterior descending artery arising from proximal right coronary artery (RCA). Left anterior oblique volume-rendered CT image shows left anterior descending artery (*arrow*) arising from proximal RCA (*arrowhead*) and running anterior to pulmonary outflow tract to its perfusion territory. This coronary anomaly is considered to be benign because it is not associated with increased risk of sudden cardiac death.

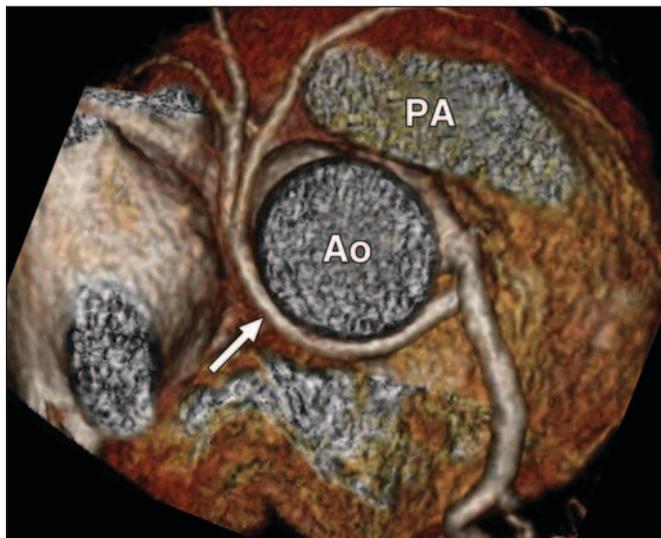


Fig. 20—Anomalous coronary artery arising from contralateral sinus. Craniocaudal volume-rendered CT image replicates superior-to-inferior projection of heart, with aorta (Ao) cut away at root. Left side of image is left side of patient. This image shows origin of left coronary artery (*arrow*) from proximal right coronary artery and taking retroaortic to its perfusion territory. This coronary anomaly is also considered benign (i.e. without increased risk of sudden cardiac death). PA = pulmonary artery.

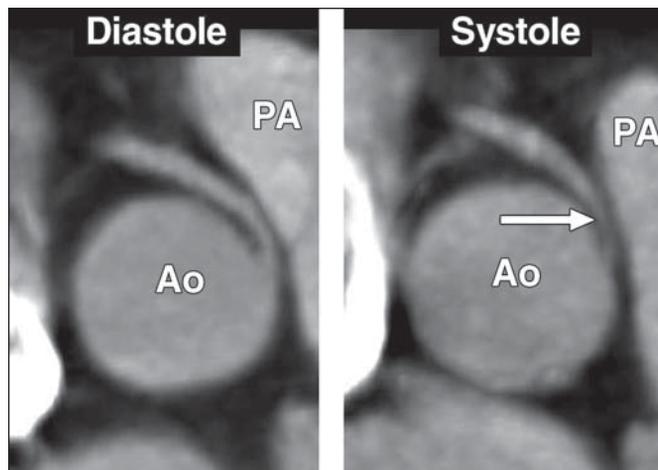


Fig. 21—Systolic compression of proximal portion of anomalous right coronary artery arising from left sinus of Valsalva. Multiplanar reformations of aortic root in diastole and systole taken from 4D dataset show transient compression of proximal right coronary artery (*arrow*) during systole. Flattening of artery proximally suggests intramural course of anomalous artery. Interarterial coronary artery such as this one is risk factor for sudden cardiac death. PA = pulmonary artery, Ao = aorta.

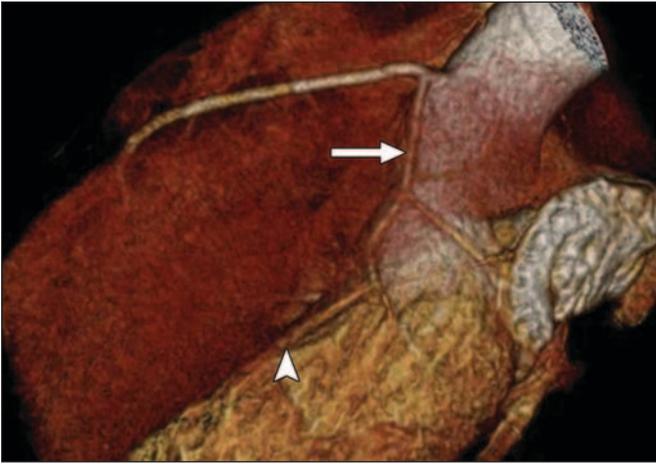


Fig. 22—Anomalous left coronary artery (LCA) arising from proximal right coronary artery and taking course through interventricular septum to its perfusion territory. Obliquely oriented volume-rendered CT image with windowing adjusted to “see through” translucent right ventricular outflow tract shows anomalous left coronary artery (*arrow*) traveling through interventricular septum in course analogous to right superior septal perforator, before bifurcating to supply left ventricle. Arrowhead shows LAD in interventricular groove distal to intraseptal artery.

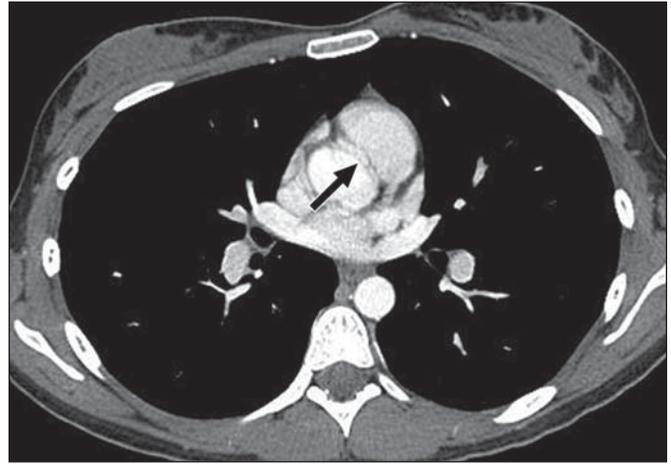


Fig. 23—Motion artifact simulating anomalous interarterial coronary artery on ungated study. Ungated CT image shows motion artifact (*arrow*) that simulates interarterial coronary. This artifact can occur with varying frequency depending on number of detectors and scanning speed. This image was obtained on 16-MDCT scanner.

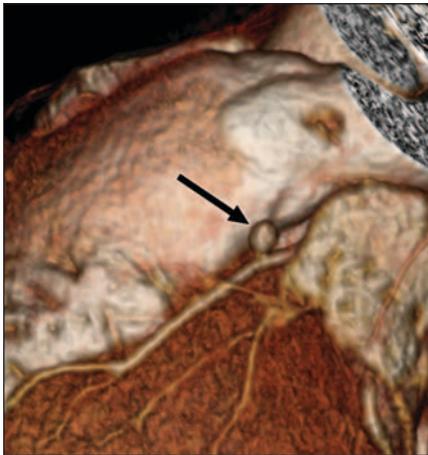


Fig. 24—Coronary aneurysm. Oblique volume-rendered CT image shows small aneurysm (*arrow*) in middle segment of left anterior descending artery. This patient had medical history of Moyamoya disease and had coronary aneurysm incidentally noted on MR image (not shown) obtained for pulmonary valve fibroelastoma workup before surgery.

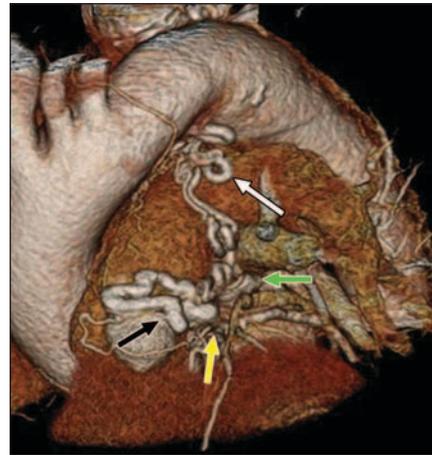


Fig. 25—Coronary arteriovenous malformation. Volume-rendered CT image from anterior projection shows tortuous hypertrophied bronchial arteries arising from undersurface of aortic arch (*white arrow*) that travel inferiorly and communicate with left atrial appendage (*green arrow*), left main coronary artery (*yellow arrow*), and finally terminate in pulmonary artery (*black arrow*).

FOR YOUR INFORMATION

The reader’s attention is directed to part 1 accompanying this article, titled “Cardiac Imaging: Part 1, MR Pulse Sequences, Imaging Planes, and Basic Anatomy” which begins on page 808.

FOR YOUR INFORMATION

The Self-Assessment Module accompanying this article can be accessed via www.ajronline.org at the article link labeled “CME/SAM.”

The American Roentgen Ray Society is pleased to present these Self-Assessment Modules (SAMs) as part of its commitment to lifelong learning for radiologists. Each SAM is composed of two journal articles along with questions, solutions, and references, which can be found online. Read each article, then answer the accompanying questions and review the solutions online. After submitting your responses, you’ll receive immediate feedback and benchmarking data to enable you to assess your results against your peers.

Continuing medical education (CME) and SAM credits are available in each issue of the *AJR* and are **free to ARRS members. Not a member?** Call 1-866-940-2777 (from the U.S. or Canada) or 703-729-3353 to speak to an ARRS membership specialist and begin enjoying the benefits of ARRS membership today!