Diagn Interv Radiol 2009; 15:275–283

CARDIOVASCULAR IMAGING

ORIGINAL ARTICLE

Anatomic variations and anomalies of the coronary arteries: 64-slice CT angiographic appearance

Pınar Koşar, Elif Ergun, Cansu Öztürk, Uğur Koşar

PURPOSE
To retrospectively review the 64-slice computed tomography (CT) appearance of coronary artery anatomic variants and anomalies and determine their incidence in 700 patients.

MATERIALS AND METHODS
CT data of 700 patients who underwent 64-slice CT angiography (CTA) because of known or suspected coronary artery disease were retrospectively reviewed by two radiologists experienced in cardiovascular radiology. In each study, anatomic variants and anomalies were investigated.

RESULTS
The coronary artery system was right dominant in 76%, left dominant in 9.1% and co-dominant in 14.8% of the cases. Ramus intermedius was present in 31%. Conus artery with a separate ostium in the right sinus Valsalva was observed in 22%, and in 0.2% two conus arteries originating with separate ostia were visualized. The sinus node artery (SNA) originated from the right coronary artery (RCA) in 79%, from the circumflex artery (Cx) in 20%, and from the left main coronary artery (LMCA) in 0.4%. In 0.4% of the cases SNA originating from the right sinus Valsalva with a separate ostium was seen. LMCA was absent in 0.4%. Cx was absent in 0.1%, and diagonals were absent in 0.1%. High takeoff of LMCA and RCA were observed in 0.7% and 0.1%, respectively. Myocardial bridging was observed in 37%. Anomalous origin of the coronary artery from the opposite sinus was observed in 1% of the cases.

CONCLUSION
Complex anatomy of the coronary artery system can accurately be depicted by 64-slice CTA. This modality is useful in detecting coronary artery variants and anomalies and is a valid alternative to conventional coronary angiography in their diagnosis.

Key words: • *coronary vessels* • *anomalies* • *computed tomography* • *angiography*

From the Department of Radiology (E.E. ✉ *elifergun72@gmail.com*), Ankara Training and Research Hospital, Ankara, Turkey.

Received 5 January 2009; revision requested 11 February 2009; revision received 22 February 2009; accepted 24 March 2009.

Published online 2 December 2009
DOI 10.4261/1305-3825.DIR.2550-09.1

The small dimensions and rapid movement of coronary arteries have made their evaluation with computed tomography (CT) challenging. However, because of the dramatic development of multislice CT (MSCT) technology in the last decade, coronary CT angiography (CTA) has become an increasingly important noninvasive modality in the diagnosis of coronary artery diseases. High temporal and spatial resolution capabilities of MSCT scanners enable detailed 3D visualization of complex coronary artery anatomy without motion artifact.

To be able to interpret the coronary CTA correctly, radiologists should be familiar with normal anatomy, anatomic variants, and anomalies of the coronary arteries and their cross-sectional appearances. In this study, we aimed to identify the 64-slice CTA appearance of the anatomic variations and anomalies of the coronary arteries and determine their incidence in a population of 700 patients.

Materials and methods

CT data of 700 patients (405 males, 295 females; age range, 17–85 years) who underwent 64-slice coronary CTA in our institution were retrospectively reviewed to identify the coronary anatomy and determine anatomic variants and anomalies. Patients were referred for coronary CTA because of known or suspected coronary artery disease (CAD). The institutional review board approved the study.

CT scan

All CT examinations were performed by a 64-slice CT scanner (Aquillon 64, Toshiba Medical Systems, Tochigi, Japan) with retrospective ECG gating (scan protocol is given in Table 1). Patients with a heart rate greater than 75 beats/min were premedicated with an oral dose of 40 mg propronalol one hour before the scan. Sublingual nitroglycerine was delivered to the patient just before the scan. For venous access, an upper extremity vein (antecubital vein of the right arm) and a 20-gauge IV cannula was used. A total of 80–85 mL of contrast media with high iodine concentration (≥350 mg/mL) was injected with a flow rate of 5 mL/s, followed by a 20 mL saline chaser. The scan timing was determined with automated bolus tracking technique by placing the region of interest over the proximal descending aorta and setting the trigger threshold to 180 HU.

Raw spiral CT data were reconstructed in various phases of the cardiac cycle to obtain images with the highest quality (without motion artifact). Reconstruction performed at 75% of R-R interval was found to be optimal for image analysis in most patients.

Image analysis

Images reconstructed at the optimal phase were transferred to another workstation (Vitrea 2 workstation, Vital Images Inc., Plymouth, Minnesota, USA), where image analysis was performed. All images were reviewed first in axial projection, then with post processing tools such as multiplanar reconstructions (MPR), curved planar reformat (CPR), thin-slab maximum intensity projection (thin MIP), and volume-rendering technique (VRT) with transparent background display. All CT examinations were reviewed by two radiologists experienced in cardiovascular radiology.

After determining the dominance of the coronary artery system, the origin, course, and caliber of the major coronary arteries and their branches were evaluated. Dominance of the coronary artery system was determined according to the origin of the posterior descending artery (PDA). Coronary artery systems with PDA originating from the right coronary artery (RCA) were defined as right dominant, and those with PDA originating from the left main coronary artery (LMCA) were defined as left dominant. Coronary artery systems where PDA was supplied by the RCA and significant portion of the posterior wall of the left ventricle was supplied by posterolateral branches (PLB) from the circumflex artery (Cx) were termed as co-dominant (1).

Coronary artery anomalies were classified according to the classification system developed by Angelini et al. (2) as anomalies of origination and course, anomalies of intrinsic coronary artery anatomy, and anomalies of termination.

Table 1. Scan protocol of 64-slice coronary CT angiography

Scan protocol (Toshiba Aquillon 64)	
Tube current	400 mAs
Tube voltage	120 kV
Tube rotation time	400 ms
Section thickness	0.5
Increment	0.3
Field of view	200–270 mm
ECG gating	Retrospective

Table 2. Prevalence of anatomic variants of the coronary arteries, n (%)

Dominance	
Right	532 (76%)
Left	64 (9.1%)
Co-dominance	104 (14.8%)
Conus artery	
From RCA	544 (78%)
With a separate ostium	154 (22%)
Two with separate ostia	2 (0.2%)
Sinus node artery	
From RCA	554 (79%)
From Cx	140 (20%)
From LMCA	3 (0.4%)
With a separate ostium	3 (0.4%)
Ramus intermedius	221 (31%)

RCA, right coronary artery; Cx, circumflex artery; LMCA, left main coronary artery.

Results

Prevalence of normal variants and anomalies of coronary arteries observed in this study population is outlined in Tables 2 and 3. In 532 cases (76%), the RCA was dominant; in 64 cases (9.1%), the LMCA was dominant; and in 104 cases (14.8%) co-dominance was observed (Fig. 1). In

Table 3. Prevalence of anomalies of the coronary arteries, n (%)

Anomalies of origination and course	
Absent LMCA	3 (0.4%)
Absent Cx	1 (0.1%)
High takeoff	6 (0.8%)
of RCA	1 (0.1%)
of LMCA	5 (0.7%)
Anomalous origin from the opposite sinus	7 (1%)
RCA originating from the left coronary sinus	4 (0.5%)
LMCA originating from the right coronary sinus	2 (0.2%)
Cx originating from the right coronary sinus	1 (0.1%)
Anomalies of intrinsic coronary arterial anatomy	
Myocardial bridging	259 (37%)

LMCA, left main coronary artery; Cx, circumflex artery; RCA, right coronary artery.

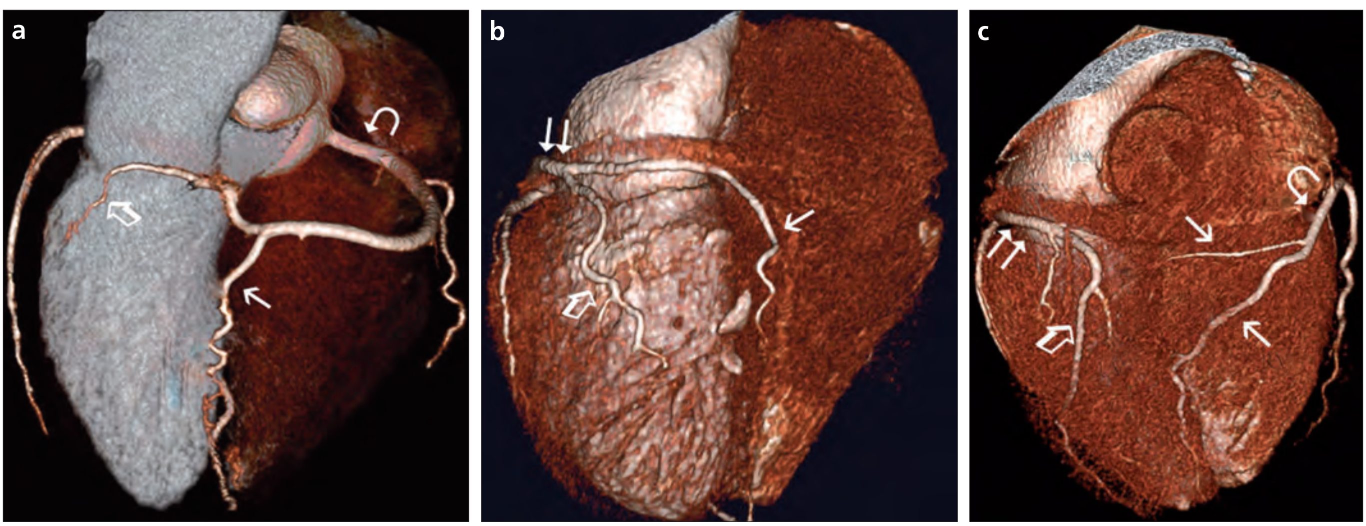


Figure 1. a–c. 3D volume-rendered CT angiography images of different patients. Posterior view of the heart **(a)** shows a right dominant system with the posterior descending artery (PDA) *(arrow)* and posterolateral branch (PLB) *(open arrow)* originating from the right coronary artery (RCA) *(curved arrow)*. Second image **(b)** shows a left dominant system with the PDA *(arrow)* and PLB *(open arrow)* originating from the circumflex artery (Cx) *(double arrow)*. Third image **(c)** shows a co-dominant system where RCA *(curved arrow)* supplies the PDA *(arrow),* and left ventricle posterolateral wall is supplied (posterolateral branch, *open arrow*) by branches of the Cx (*double arrow*).

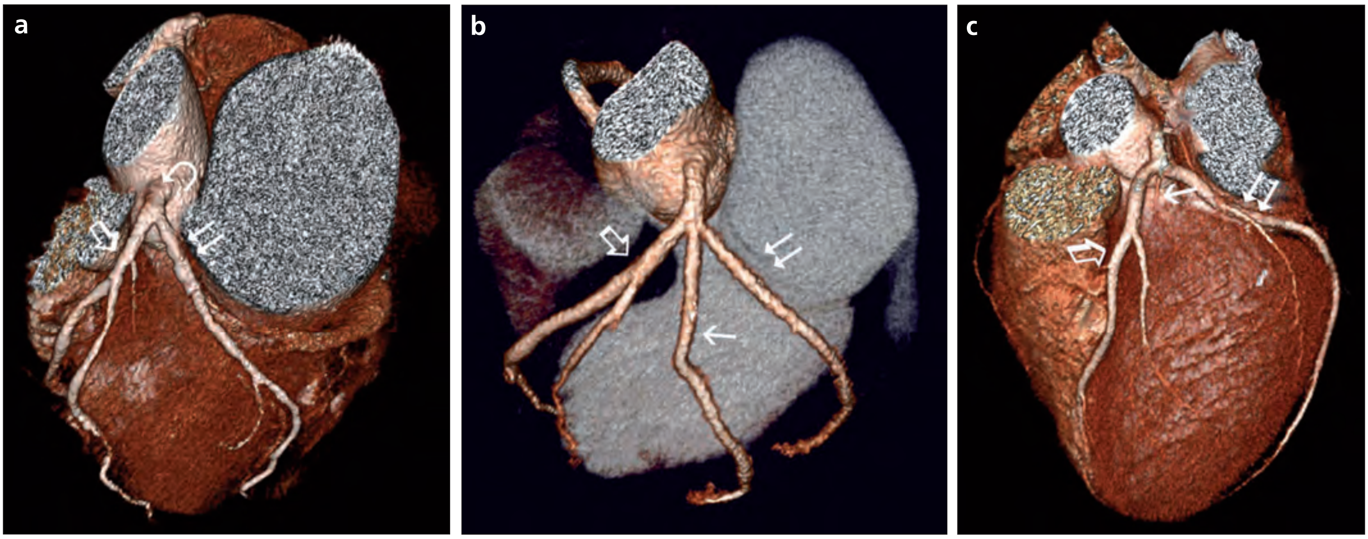
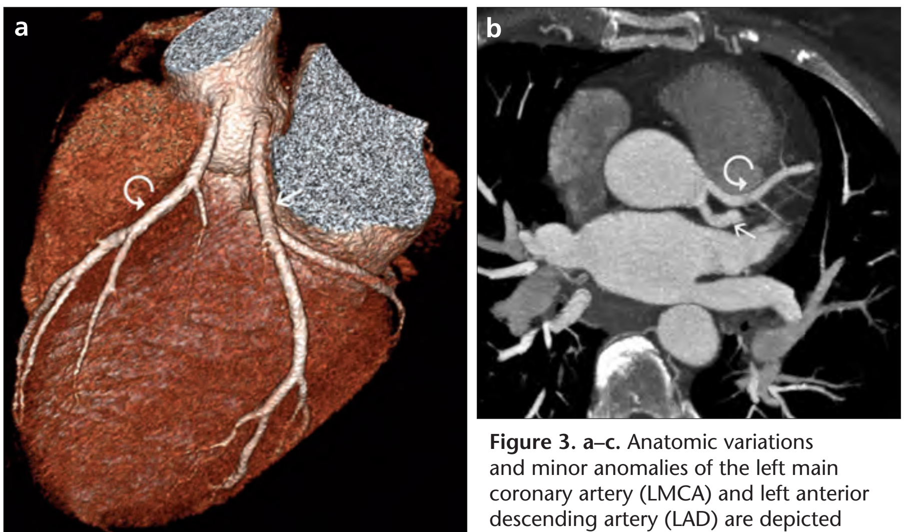


Figure 2. a–c. 3D volume-rendered CT angiography images of 3 different patients **(a–c)** show the left main coronary artery *(curved arrow)* that bifurcates to the left anterior descending artery (LAD) *(open arrow)* and circumflex artery (Cx) *(double arrow)* **(a)** and trifurcates where ramus intermedius *(straight arrow)* is seen in between the LAD *(open arrow)* and Cx *(double arrow)* **(b)**. Ramus intermedius *(straight arrow)* may be variable in size, changing from a well-developed branching artery to a small one **(c)** (LAD, *open arrow*; Cx, *double arrow*).



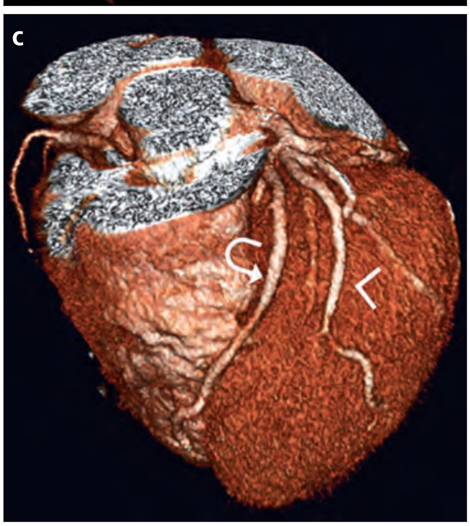


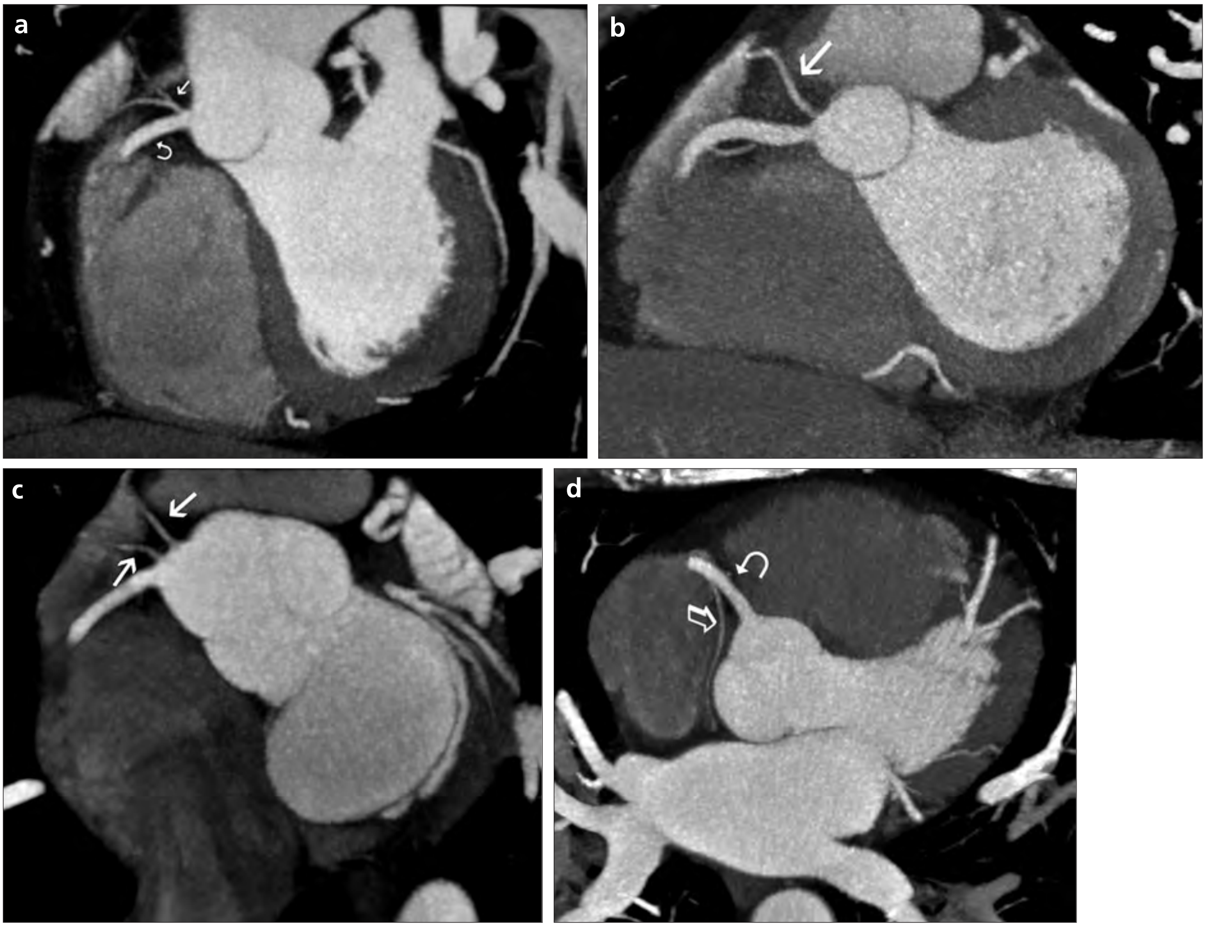
Figure 3. a–c. Anatomic variations and minor anomalies of the left main coronary artery (LMCA) and left anterior descending artery (LAD) are depicted in two different patients. Volume-rendered **(a)** and MIP **(b)** CT images of the same patient show that the LMCA is absent and the LAD *(curved arrow)* and circumflex artery *(arrow)* originate from the left coronary sinus with separate ostia. Volume-rendered CT image **(c)** of another patient where diagonal branches of the LAD *(curved arrow)* are absent and a well-developed, branching ramus intermedius *(arrowhead)* is seen.

221 cases (31%), the LMCA trifurcated to include a third vessel between the left anterior descending artery (LAD) and Cx, termed ramus intermedius (Fig. 2). The LMCA was absent in 3 cases (0.4%) in which the LAD and Cx originated from the left sinus of Valsalva with separate ostia (Fig. 3a, b). Diagonal arteries were absent in one case (0.1%), in which a well-developed ramus intermedius that supplied the anterolateral wall of the left ventricle was seen (Fig. 3c).

The conus artery was the first branch of the RCA in 544 cases (78%); it originated from the right sinus of Valsalva with a separate ostium in 154 cases (22%); while in two cases (0.2%), two conus arteries originating with separate ostia from the right sinus of Valsalva were observed (Fig. 4a–c).

The sinus node artery originated from the RCA as its second branch in 554 cases (79%), from the Cx in 140 cases (20%), and from the LMCA in 3 cases (0.4%). In three cases (0.4%), the sinus node artery originated from the right sinus of Valsalva with a separate ostium (Fig. 4d, e). High takeoff of the RCA and LMCA were observed in one (0.1%) and five cases (0.7%), respectively (Fig. 5).

The RCA split into two arteries just after originating from its ostium in the right sinus of Valsalva (termed duplication of RCA) in one case (0.1%). In one case, the Cx was absent and the RCA flowed in the posterior aspect of



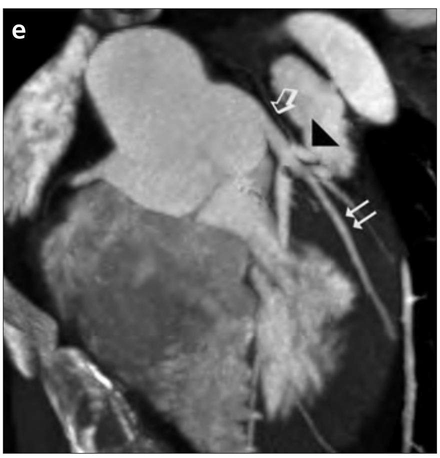


Figure 4. a–e. MIP CT angiography images display variable origins of the conus artery and sinoatrial node artery (SNA). The conus artery *(arrow)* is seen branching from the right coronary artery (RCA) *(curved arrow)* **(a)**. Second image **(b)** shows the conus artery *(arrow)* originating from the right coronary sinus with a separate ostium. Third image **(c)** shows two conus arteries *(arrows)* originating with separate ostia from the right coronary sinus. On the fourth image **(d)** the SNA *(open arrow)* is seen as a branch of the RCA *(curved arrow)*. Fifth image **(e)** depicts the SNA *(open arrow)* originating from the circumflex artery *(black arrowhead)* where a well-developed ramus intermedius *(double arrow)* is also observed.

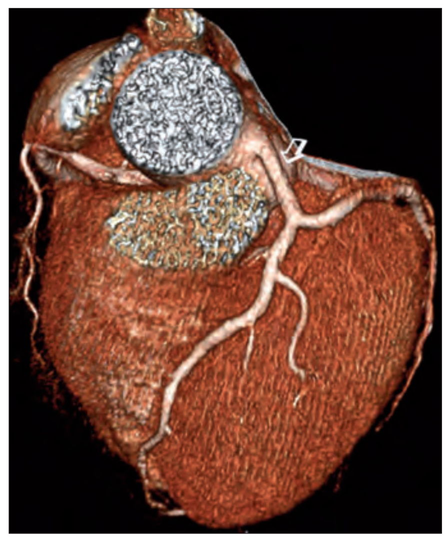


Figure 5. Volume-rendered CT image of the heart displays the left main coronary artery (LMCA) *(open arrow)* with an ostium above the sinotubular ridge, named "high takeoff". The LMCA (>2 cm) is also longer than normal.

the left A-V groove through the track of the Cx (Fig. 6).

Myocardial bridging was observed in 259 cases (37%) (Fig. 7). In four cases (0.5%), the RCA originated from the left sinus of Valsalva: all had an interarterial course (Fig. 8a). In two cases (0.2%), the LMCA originated from the right sinus of Valsalva: one had an interarterial course, and the other had a pre-pulmonic course (Fig. 8b, c). In one case (0.1%), Cx originated from the right sinus of Valsalva, which had a retroaortic course (Fig. 8d, e) (Table 4).

Discussion

Conventional coronary angiography (CCA) has been the technique of choice for visualization of the coronary artery system for several decades. Despite its common use, alternative methods of visualizing the coronary arterial system are desired; in addition to being invasive, CCA has disadvantages in detecting coronary artery anomalies because of the limited number of 2D projection images obtained during catheterization and because of the absence of soft tissue information.

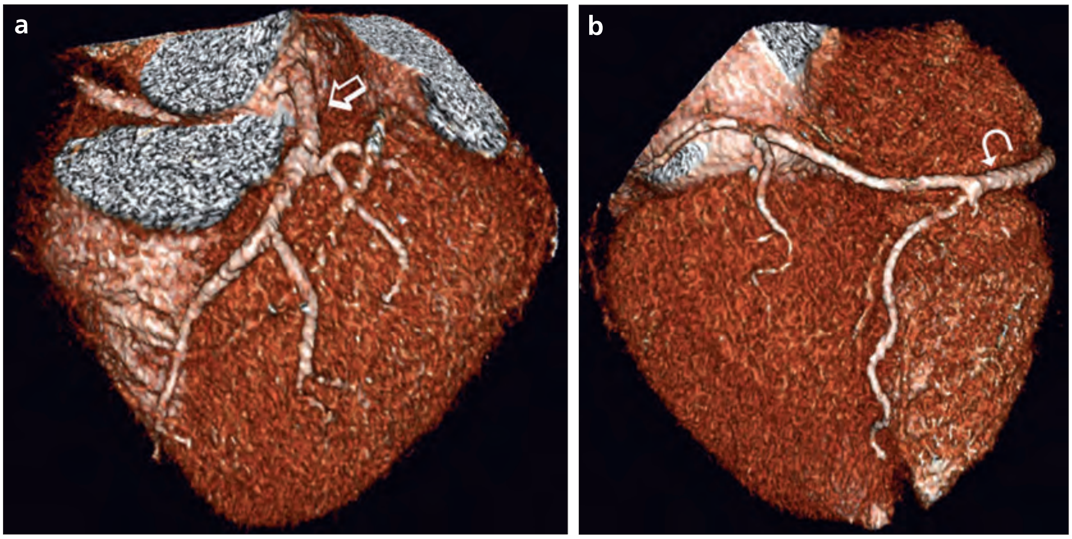
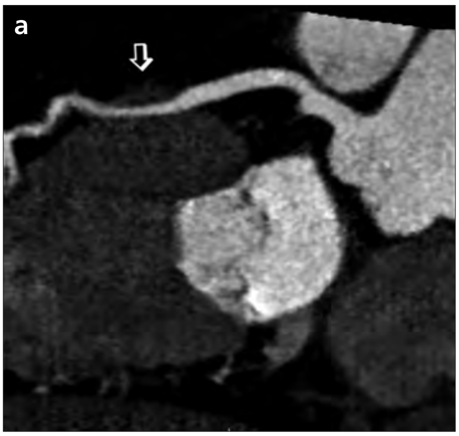


Figure 6. a, b. Volume-rendered CT angiography image **(a)** shows that the circumflex artery (Cx) is absent and the left anterior descending artery *(open arrow)* originates from the left coronary sinus. Posterior view volume-rendered CT angiography image **(b)** of the same patient demonstrates the right coronary artery *(curved arrow)* coursing within the atrioventricular groove on the track of the Cx.



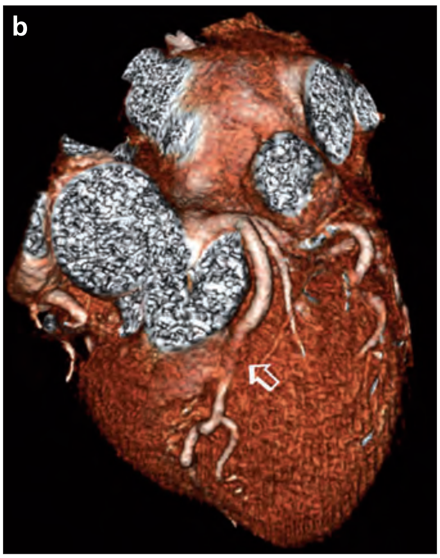


Figure 7. a, b. MIP **(a)** and volume rendering **(b)** CT angiography images display myocardial bridging in the middle segment of the left anterior descending artery *(open arrow)*.

Over the last decade, substantial advances have been made in noninvasive cardiac imaging. New technological modalities include coronary MR angiography, electron beam CT (EBCT), and coronary CTA. Coronary CTA had an increasingly important role in the diagnosis of coronary artery disease. Cardiac CT applications were limited to the myocardium, cardiac chambers, and gross coronary calcifications with conventional CT scanners (3). More detailed assessment of the cardiac structures was made possible with the introduction of single-slice helical CT systems in 1996. However, with this technique, temporal and spatial resolution are insufficient to delineate the anatomic features and pathology of coronary arteries without motion artifact. Since that time, successive generations of CT scanners have been developed; the introduction of MSCT technology provided a significant improvement in spatial and temporal resolution. Section thickness that was in the range of 3–5 mm with single-slice helical technology has improved to 0.5 mm–0.6 mm with 64-slice CT systems. Data acquisition time of 50 s with single-slice CT has decreased to 5 s with 64-slice CT (4). These technological improvements provided CT acquisition of near-isotropic volume data within a single breath hold, which enabled visualization of smaller and smaller coronary branches and delineation of coronary artery anatomy in 3D devoid of motion artifact with the help of various post-processing tools such as VR, MIP, CPR, and MPR. Depiction of origin and course of anomalous vessels along with the complex anatomic relations with the adjacent structures is excellent with MSCT. Kacmaz et al. (5) reported a sensitivity of 100% for 16-slice CTA in detecting coronary artery anomalies. Shi et al. (6) detected anomalous origin and abnormal course of the coronary arteries with 16-slice CTA in 100% of the cases in their series, while CCA detected the abnormality in only 53% of the cases. MSCT angiography is considered a first-line imaging modality in detecting coronary artery anomalies (5–8).

Correct interpretation of coronary CTA examinations requires familiarity with the anatomy, normal variants, and anomalies of the coronary arter-

Table 4. Anomalies of origination and course of the coronary arteries, n (%)

LMCA originating from the right coronary sinus	2 (0.2%)
Interarterial course	1/2 (50%)
Pre-pulmonic course	1/2 (50%)
RCA originating from the left coronary sinus	4 (0.5%)
Interarterial course	4/4 (100%)
Cx originating from the right coronary sinus	1 (0.1%)
Retroaortic course	1/1 (100%)

LMCA, left main coronary artery; RCA, right coronary artery; Cx, circumflex artery.

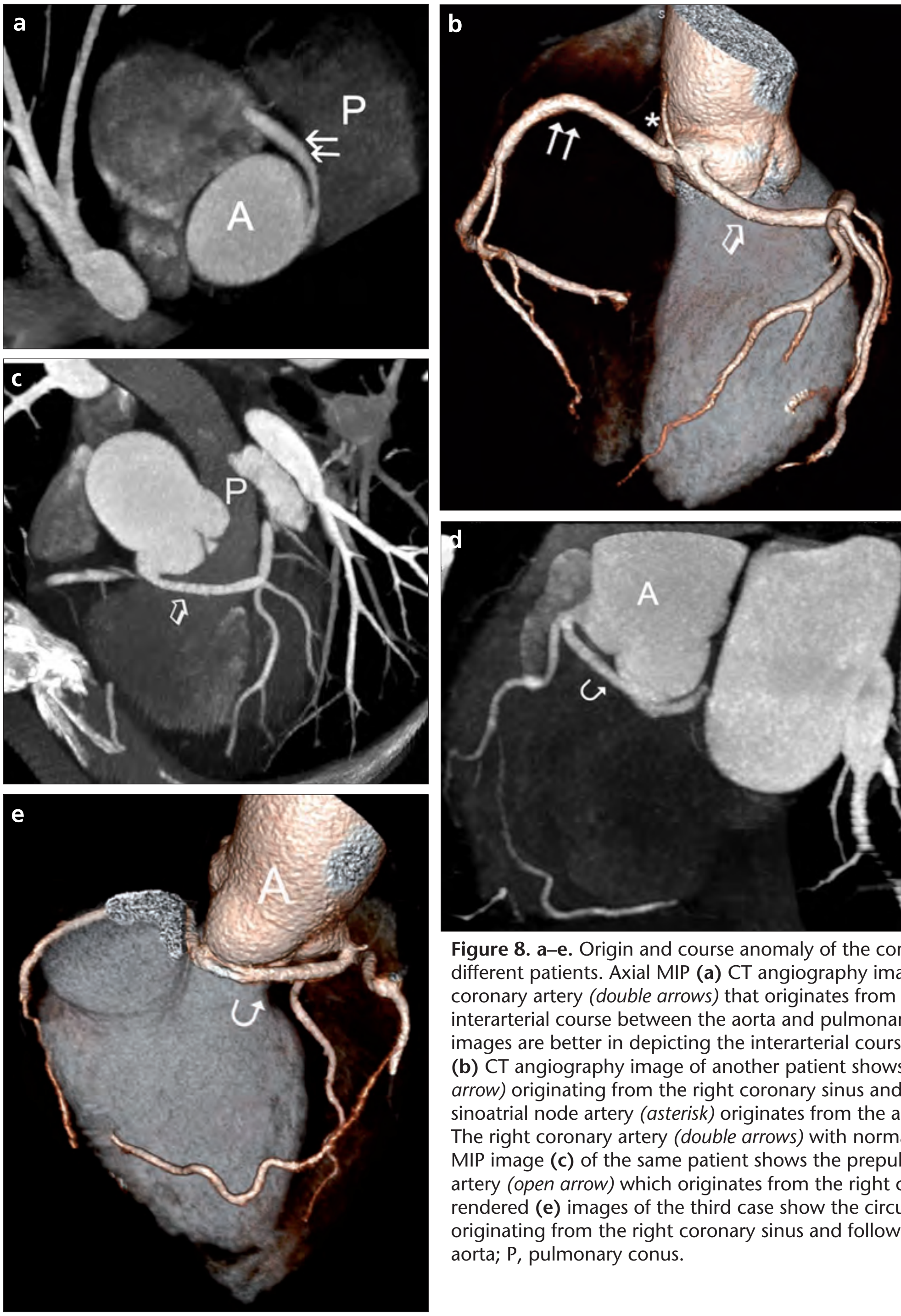


Figure 8. a–e. Origin and course anomaly of the coronary arteries are depicted in three different patients. Axial MIP **(a)** CT angiography image of a patient displays the right coronary artery *(double arrows)* that originates from the left coronary sinus and follows an interarterial course between the aorta and pulmonary artery. Axial MIP CT angiography images are better in depicting the interarterial course of the vessel. Volume-rendered **(b)** CT angiography image of another patient shows the left main coronary artery *(open arrow)* originating from the right coronary sinus and following a prepulmonic course. The sinoatrial node artery *(asterisk)* originates from the anomalous left main coronary artery. The right coronary artery *(double arrows)* with normal origination and course is also seen. MIP image **(c)** of the same patient shows the prepulmonic course of left main coronary artery *(open arrow)* which originates from the right coronary sinus. MIP **(d)** and volume-rendered **(e)** images of the third case show the circumflex artery *(curved arrow)* that is originating from the right coronary sinus and following a retroaortic course. A, ascending aorta; P, pulmonary conus.

ies. There is an extreme variability in coronary artery anatomy in normal subjects. Definition of normality and establishing boundaries between normal and abnormal with characterization of anomalies are mandatory (2, 9). However, no consensus has yet been reached on the boundary between normal variant and anomaly. A number of classification systems of the coronary artery anomalies have been suggested (2, 5, 10–12). According to these systems, anomalies of the coronary arteries are generally divided into anomalies of origin and course, anomalies of intrinsic coronary arterial anatomy, and anomalies of termination. Additional studies examining the coronary artery anomalies in large populations are needed to resolve this classification problem, as well as to determine the precise features indicating normal anatomy, anatomic variants, and anomalies (2). In our opinion, with high spatial resolution and depiction of anatomic details in 3D, MSCT may assist in answering the above-mentioned questions.

Analysis of coronary CTA images should be initiated by the determination of dominance of the coronary artery system. Every report of coronary CTA examination should include a comment on this issue (13). The incidence of right and left coronary dominance has been reported to be 80% to 85%, and 7% to 9%, respectively (7, 14, 15). In the present study, the RCA was dominant in 76% of cases, and the LMCA was dominant in 9.1% of cases. The incidence of co-dominance was 14.8% in the present study, which is slightly higher than the reported ranges of 5–8% (7, 14, 15). The lack of consensus on the definition of the co-dominant coronary artery system in the literature may explain this discrepancy. Co-dominance is usually defined as origination of the PDA from the RCA and the PLB from the Cx (14). Other authors define it with respect to the artery supplying the inferolateral portion of the posterior septum. They state that if both arteries supply this portion of the septum the system is referred to as co-dominant (11, 15). We named the coronary artery system co-dominant when the PDA originated from the RCA and the branches of Cx supplied a significant portion of the posterior wall of the left ventricle (1).

The evaluation of coronary CTA examination should continue by the assessment of coronary artery anatomy. During this process, the focus should be given to the location, distribution, length, and caliber of major coronary arteries and their branches (1).

The LMCA originates from the left sinus of Valsalva. A range of 0.5–2 cm has been reported as its normal length by some authors, while others gave 10 mm as the upper limit of normal (11, 14, 15). The LMCA bifurcates to the LAD and Cx. Occasionally the LMCA trifurcates and an artery named ramus intermedius is present between the LAD and Cx. Presence of ramus intermedius is the most common anatomic variation observed in the left coronary system and its prevalence is 33% (16). The size of ramus intermedius varies greatly from a very small vessel to a very large branching vessel, which may supplant the need for significant LAD diagonals or Cx marginals (1, 17). In the present study population, the presence of ramus intermedius was observed in 31% of the cases.

Origination of the LMCA outside the coronary sinus, above the junctional zone is referred to as a high takeoff (11, 18, 19). Montaudon et al. (18) stated that the LMCA originating from the proximal 1-cm segment of the ascending aorta might be considered as a normal variant, while a takeoff distal to the first 1-cm segment of the ascending aorta should be considered as an anomaly. The prevalence of a high takeoff is reported as 6% (11, 18, 19). We referred to the origination within the proximal 1-cm segment of the aorta above the junctional zone as a high takeoff and included this pathology in the group of anomalies of origination. It was observed in 0.7% of the present study population.

Occasionally the LMCA is absent and the LAD and Cx originate separately from the left sinus of Valsalva. The incidence of this abnormality is 0.41% to 0.52% (18–20). It was observed in 3.3% of the study population in one study performed by Cademartiri et al. (7). In the present study its incidence was 0.4%.

Short or absent LMCA and trifurcation of the LMCA have no adverse hemodynamic effects and therefore have no clinical significance. On the other hand, they cause technical difficulties in coronary artery catheterization and may be a source of complication or misdiagnosis. For instance, short or absent LMCA may result in nonopacification of a totally normal LAD or Cx in CCA and may lead to a false interpretation of occlusion of the LAD or Cx. Such a mistake is not possible with MSCT coronary angiography (20). Therefore, recognition of these types of anomalies before interventional procedures on the left coronary arterial system is important (1, 18, 19).

The LAD has two groups of branches, referred to as septal perforators and diagonals. Diagonal arteries are variable in number and size. In one case of the present study diagonal branches were absent where a well-developed ramus intermedius supplying the territory of the diagonal arteries was present. The Cx is a smaller vessel than the LAD. Obtuse marginals, which are variable in size and number, are the major braches of Cx. In one case of the present study the Cx was absent and the RCA ran from the posterior of the left A-V groove to the region of Cx. Ortale et al. (17) reported that obtuse marginal arteries, diagonal arteries and ramus artery have a complementary role to each other, and when one is absent or small in caliber the others supply its territory. A similar relation was observed between ramus intermedius and diagonal arteries by Cademartiri et al. (7).

The RCA originates from the right sinus of Valsalva. The conus artery is the first branch and the sinus node artery is the second branch of RCA. It gives rise to acute marginal arteries, which supply the right ventricle before turning posteriorly to flow in the posterior right A-V groove. Its terminal branches are the PDA and PLB in the right dominant system. As in the LMCA, a high takeoff and multiple ostia may also be observed in the RCA. In multiple ostia typically the conus artery originates from the right coronary sinus with a separate ostium, adjacent to the ostium of RCA. Incidence of this type of origination is between 22% and 50% and is classified as a normal variant (7, 18). In the present study its incidence was found to be 22%, and in two cases (0.2%), two conus arteries originating with separate ostia from the aorta were observed. Multiple ostia with sinoatrial node artery originating with a separate ostium were observed in three cases (0.4%). Awareness of the presence of multiple ostia and high takeoff abnormalities is important because they may cause problems in interventional procedures. Presence of multiple ostia in the right sinus Valsalva may also lead to surgical problems in cases requiring right ventriculotomy for ventricular septal defect or pulmonary stenosis (9, 18).

The above-mentioned conditions of the left and right coronary artery systems are classified as normal variants or minor anomalies by various authors (7, 8, 11, 14, 15, 18, 19). These conditions result in no hemodynamic abnormality. Conversely, there are hemodynamically significant coronary artery anomalies of origin, course, and termination that may be associated with an adverse outcome. Approximately 20% of coronary anomalies may have a life-threatening presentation, including myocardial infarction, arrhythmia, or sudden death (15, 21). The Task Force on Sudden Death of the American Heart Association reported that coronary artery anomalies are the cause of 19% of deaths in athletes (22). The hemodynamically significant anomalies are: anomalous origin of the coronary artery from the opposite sinus with a course between the aorta and pulmonary artery, anomalous origin of the coronary artery from the pulmonary artery, myocardial bridging, and coronary artery fistula (11, 15).

Intramyocardial course of a coronary artery, which normally has an epicardial course, is referred to as myocardial bridging. The incidence of myocardial bridging varies greatly and is reported as 0.5% to 2.5% in conventional angiographic studies and 15% to 85% in pathologic studies (15, 19). Its incidence has been reported between 3.5% and 38.5% in various studies made with 4- or 16-slice CTA (23, 24). Patients with myocardial bridging generally do not have overt symptoms and, as a result, are not referred for CCA; this may explain this discrepancy. Angelini et al. stated that "if diagnosed with micro dissection, myocardial bridging might be common enough to be considered a normal variant" (2). Myocardial bridging is considered a benign finding and in the vast majority of patients does not cause myocardial ischemia. Rarely, it is the cause of acute myocardial infarction, fatal arrhythmias, and sudden death (11, 15, 18, 19). This pathology should be ruled out in young patients with chest pain and arrhythmia (25). In the present study, myocardial bridging was observed in 37% of the cases. The segments of coronary arteries with this anomaly were easily depicted by MSCT angiography. Using thin-slab MIP images was particularly helpful in their detection.

Anomalous origin of the coronary artery from the opposite sinus is a potentially serious anomaly. Four patterns of anomalous origin can be observed with this anomaly: the LMCA arising from the right coronary sinus (0.09% to 0.11%); the RCA arising from the left coronary sinus (0.03% to 0.17%); the LAD or Cx arising from the right coronary sinus (0.32% to 0.67%); and the RCA, LMCA, or a branch of them arising from the non-coronary sinus (26–29). It is reported that MSCT coronary angiography is superior to CCA in delineating the course of the anomalous artery (30). In our study, anomalous origin of the coronary artery from the opposite sinus was observed in 7 cases (1%).

There are four common pathways that an anomalous vessel may follow before resuming its normal position: (a) interarterial course, (b) retroaortic course, (c) pre-pulmonic course, and (d) sub-pulmonic course. Anomalous RCA originating from the left coronary sinus generally follows the interarterial course (26). In the present study an interarterial course of RCA was observed in all cases with this anomaly (n = 4). An interarterial course is reported in 75% of patients with an anomalous LMCA originating from the right coronary sinus (28). Anomalous LMCA may also follow subpulmonic, retroaortic, or pre-pulmonic course (29). In the present study, two cases with this anomaly were observed: the LMCA followed an interarterial course in one (50%) and a pre-pulmonic course in the other. The most common course of anomalous Cx arising from the right coronary sinus is retroaortic (26, 27, 31). We had only one case with this anomaly in which the course of Cx was retroaortic. With an interarterial course (also called a "malign course"), the vessel crosses between the aorta and pulmonary artery. This type of anomaly carries the risk of sudden death. The possible pathological mechanism underlying this clinical outcome is explained by the increase in vascular tone of the great vessels under physical exercise leading to compression of the coronary artery. Acute angle (<45°) of the ostium, stretch of the intramural segment by the distending aortic or pulmonary root, and presence of an abnormal slit-like ostium are other pathologic mechanisms reported as the reason of sudden death (11, 15, 18, 19).

Complex anatomy of the coronary arteries in 3D can be accurately depicted by 64-slice CTA. It is a valid alternative to CCA in the diagnosis of the coronary artery anomalies. It also acts as a road map to the interventional cardiologist and cardiovascular surgeon, providing information about variations and anomalies in a patient before cardiac intervention or surgery to prevent possible complications of the procedure.

References

1. Zimmet JM, Miller JM. Coronary artery CTA: imaging of atherosclerosis in the coronary arteries and reporting of coronary artery CTA findings. Tech Vasc Interv Radiol 2006; 9:218–226.
2. Angelini P, Velasco JA, Flamm S. Coronary anomalies: incidence, pathophysiology, and clinical relevance. Circulation 2002; 105:2449–2454.
3. Lipton MJ, Brundage BH, Higgins CB, Boyd DP. CT scanning of the heart. Cardiovasc Clin 1983; 13:385–401.
4. Hurlock GS, Higashino H, Mochizuki T. History of cardiac computed tomography: single to 320-detector row multislice computed tomography. Int J Cardiovasc Imaging 2009; 25(Suppl 1):31–42.
5. Kacmaz F, Isiksalan N, Alyan O, et al. Imaging of coronary artery anomalies: the role of multidetector computed tomography. Coron Artery Dis 2008; 19:203–209.
6. Shi H, Aschoff AJ, Brambs HJ, Hoffmann MH. Multislice CT imaging of anomalous coronary arteries. Eur Radiol 2004; 14:2172–2181.
7. Cademartiri F, La Grutta L, Malagò R, et al. Prevalence of anatomical variants and coronary anomalies in 543 consecutive patients studied with 64-slice CT coronary angiography. Eur Radiol 2008; 18:781–791.
8. Schmitt R, Froehner S, Brunn J, et al. Congenital anomalies of the coronary arteries: imaging with contrast-enhanced, multidetector computed tomography. Eur Radiol 2005; 15:1110–1121.
9. Trivellato M, Angelini P, Leachman RD. Variations in coronary artery anatomy: normal versus abnormal. Cardiovasc Dis 1980; 7:357–370.
10. Greenberg MA, Fish BG, Spindola-Franco H. Congenital anomalies of the coronary arteries: Classification and significance. Radiol Clin North Am 1989; 27:1127–1146.
11. Kim SY, Seo JB, Do KH, et al. Coronary artery anomalies: classification and ECG-gated multi-detector row CT findings with angiographic correlation Radiographics 2006; 26:317–333.
12. van Ooijen PM, Dorgelo J, Zijlstra F, et al. Detection, visualization and evaluation of anomalous coronary anatomy on 16-slice multidetector row CT. Eur Radiol 2004; 14:2163–2171.
13. Bluemke DA, Achenbach S, Budoff M, Gerber TC, et al. Noninvasive coronary artery imaging: magnetic resonance angiography and multidetector computed tomography angiography: a scientific statement from the American Heart Association committee on cardiovascular imaging and intervention of the council on cardiovascular radiology and intervention, and the councils on clinical cardiology and cardiovascular disease in the young. Circulation 2008 29; 118:586–606.
14. Kini S, Bis KG, Weaver L. Normal and variant coronary arterial and venous anatomy on high-resolution CT angiography. AJR Am J Roentgenol 2007; 188:1665–1674.
15. Patel S. Normal and anomalous anatomy of the coronary arteries. Semin Roentgenol 2008; 43:100–112.
16. Dewey M, Kroft LJM. Anatomy. In: Dewey M, ed. Coronary CT angiography. Berlin: Springer, 2009; 11–26.
17. Ortale JR, Filho JM, Paccola AMF, et al. Anatomy of the lateral, diagonal and anterosuperior arterial branches of the left ventricle of the human heart. Braz J Cardiovasc Surg 2005; 20:149–158.
18. Montaudon M, Latrabe V, Iriart X, Caix P, Laurent F. Congenital coronary arteries anomalies: review of the literature and multidetector computed tomography (MDCT)-appearance. Surg Radiol Anat 2007; 29:343–355.

19. Earls JP. Coronary artery anomalies. Tech Vasc Interv Radiol 2006; 9:210–217.
20. Duran C, Kantarci M, Subasi Durur I, et al. Remarkable anatomic anomalies of coronary arteries and their clinical importance: a multidetector computed tomography angiographic study. J Comput Assist Tomogr 2006; 30:939–948.
21. Datta J, White CS, Gilkeson RC, et al. Anomalous coronary arteries in adults: depiction at multi-detector row CT angiography. Radiology 2005; 235:812–818.
22. Maron BJ, Thompson PD, Puffer JC, et al. Cardiovascular preparticipation screening of competitive athletes. Circulation 1996; 94:850–856.
23. Kantarci M, Duran C, Durur I, et al. Detection of myocardial bridging with ECG-gated MDCT and multiplanar reconstruction. AJR Am J Roentgenol 2006; 186:391-394.
24. Canyigit M, Hazirolan T, Karcaaltincaba M, et al. Myocardial bridging as evaluated by 16 row MDCT. Eur J Radiol 2009; 69:156–164.
25. Hazirolan T, Canyigit M, Karcaaltincaba M, et al. Myocardial bridging on MDCT. AJR Am J Roentgenol 2007; 188:1074–1080.
26. Yamanaka O, Hobbs RE. Coronary artery anomalies in 126,595 patients undergoing coronary angiography. Cathet Cardiovasc Diagn 1990; 21:28–40.
27. Donaldson RM, Raphael M, Radley-Smith R, Yacoub MH, Ross DN. Angiographic identification of primary coronary anomalies causing impaired myocardial perfusion. Cathet Cardiovasc Diagn 1983; 9:237–249.
28. Chaitman BR, Lesperance J, Saltiel J, Bourassa MG. Clinical, angiographic, and hemodynamic findings in patients with anomalous origin of the coronary arteries. Circulation 1976; 53:122–131.
29. Bunce NH, Lorenz CH, Keegan J, et al. Coronary artery anomalies: assessment with free-breathing three-dimensional coronary MR angiography. Radiology 2003; 227:201–208.
30. Manghat NE, Morgan-Hughes GJ, Marshall AJ, Roobottom CA. Multidetector row computed tomography: imaging congenital coronary artery anomalies in adults. Heart 2005; 91:1515–1522.
31. Page HL Jr, Engel HJ, Campbell WB, Thomas CS Jr. Anomalous origin of the left circumflex coronary artery: recognition, angiographic demonstration and clinical significance. Circulation 1974; 50:768–773.