Normal, variant and anomalous pattern of coronary vasculature evaluated by multi-detector computed tomographic coronary angiography

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Learning objectives

1. To demonstrate the spectrum of common and uncommon variants of normal coronary artery anatomy.
2. To describe the role of multi-detector computed tomography (MDCT) angiography in evaluation of congenital coronary artery anomalies.
3. To discuss the clinically significant coronary artery anomalies

Background

The prevalence of coronary artery anomalies is approximately 1% in the general population and the vast majority are diagnosed incidentally during coronary angiography or necropsy [1]. The wrong interpretation of a coronary variant or anomaly might cause technical difficulties during interventional procedures or lead to misdiagnosis or major complications during graft surgery. The need for an accurate anatomical evaluation of the coronary artery tree is relevant during angiography for revascularization purposes [2]. Given the increase of interventional procedures, the detection of coronary anomalies is gaining major clinical importance [3]. Coronary artery anomalies are usually asymptomatic; however some may manifest with angina pectoris, syncope, arrythmias or even sudden death, especially in young adults [4].

Conventional angiography is the gold standard for diagnosing coronary anomalies, however it is an invasive procedure. At angiography, the precise course of the anomalous vessel may be difficult to delineate due to its two-dimensional nature. The rarity of these anomalies results in limited experience for many angiographers and this in turn, causes a large percentage of coronary artery anomalies to be categorized incorrectly at coronary catheterization [5].

These limitations can be overcome by using a non-invasive diagnostic modality that acquires full three-dimensional (3D) data from both the heart cavities and the coronary arteries. Magnetic resonance (MR) imaging has often been used to delineate the anomalous coronary arteries in equivocal cases; however, MR imaging can be limited by low spatial resolution and artefacts can be technically challenging [6]. Multi-detector row CT with its faster volume coverage as well as higher spatial and temporal resolution, allows better imaging of the coronary arteries and detection of related diseases [7]. With a three dimensional view, Multi-detector row CT is superior to conventional angiography in delineating the ostial origin and proximal path of an anomalous coronary artery [8].
In this exhibit we will describe the use of CT angiography in illustrating the normal, variant and anomalous pattern of coronary artery anatomy.

**Imaging findings OR Procedure details**

**Procedure Details**

ECG-gated CT angiography was performed in patients with known or suspected coronary artery disease using a Light Speed VCT 64 slice Multi-detector CT. Advantage Workstation 4.2 and 4.3 were used. All patients were thoroughly informed about the examination technique and a written consent was obtained. Patients with a heart rate >70 bpm received 100 mg oral metoprolol 1 hour before scanning. 80-100 ml of iodinated contrast was administered as pulsed bolus with double chamber injector at the rate of 5 ml/sec followed by a chaser bolus of 40 ml saline. Post-processing of the data was done using curved multi-planar reformation, maximum intensity projection and volume rendering techniques.

**Imaging Findings**

The criteria for defining coronary normality/abnormality are as follows: *normal*, any morphological feature observed in >1% of an unselected population; *normal variant*, an alternative, relatively unusual, morphological feature seen in >1% of the population; and *anomaly*, a rare morphological feature seen in <1% of the population [9].

**Normal Coronary Artery Anatomy**

The coronary arteries are conductive vessels located in the epicardium. The right and left coronary arteries originate from the right and left sinuses of Valsalva of the aortic root, respectively. The posterior sinus rarely gives rise to a coronary artery and is referred to as the "noncoronary sinus."

*Left Main Coronary Artery*

The left main coronary artery (LMA) typically arises from the left sinus of Valsalva and quickly bifurcates into the left anterior descending (LAD) and left circumflex (LCX) arteries (Fig. 1).
Fig. 1: Anterior oblique volume-rendered (VR) CT image shows bifurcation of Left Main Coronary Artery (LMA) into left anterior descending and left circumflex (LCX) arteries shortly after its origin from left sinus of Valsalva

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

Left Anterior Descending Artery

The left anterior descending artery (LAD) runs in the anterior interventricular groove and gives off diagonal branches that supply the anterior left ventricular wall. The LAD also gives off septal perforator branches that supply the anterior interventricular system.

Left Circumflex Artery
The left circumflex coronary artery (LCX) courses in the left atrioventricular groove, supplying a portion of the lateral wall of the left ventricle through the *obtuse marginal* branches (Fig. 2).

**Fig. 2:** Anterior oblique volume-rendered (VR) CT image shows the left circumflex (LCX) artery in the left atrioventricular groove. Obtuse marginal arteries are also seen

**References:** P. Kapur; Department of Imaging, New Delhi-110019, INDIA

*Right Coronary Artery*
The right coronary artery (RCA) arises from the right sinus of Valsalva somewhat inferior to the origin of LMA and runs in the right atrioventricular groove towards the posterior interventricular septum. In approximately 50% individuals it gives off the conus branch, which supplies the right ventricular outflow tract. The conus branch acts as an important collateral in proximal LAD obstruction. The right ventricular free wall is supplied through the acute marginal branches of the RCA (Fig. 3). The distal RCA terminates into posterior descending artery (PDA) and posterior left ventricular (PLV) branches in a right dominant anatomy [10,11] Other branches include the sinoatrial nodal and atrioventricular nodal branches.

Fig. 3: Anterior oblique volume-rendered (VR) CT image shows the right coronary artery (RCA) arising from the right sinus of Valsalva and giving off acute marginal (AM) branches to the right ventricular wall. Conus artery is also seen arising from RCA

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

Posterior Descending Artery

The posterior descending artery (PDA) runs in the posterior interventricular groove and supplies the inferior wall and inferior one third of the interventricular septum. The PDA may arise from distal RCA (70%) or distal LCX (10%) or both (20%).

CORONARY DOMINANCE

The artery that supplies the PDA and PLV branches determines the coronary dominance. A right dominant system (70%) is one where the PDA and PLV arise from distal RCA (Fig. 4). In a left dominant (10%) system the PDA and PLV arise from distal LCX. If the PDA comes from RCA and PLV from the LCX, the system is codominant (20%)
Fig. 4: Posterior oblique volume rendered (VR) image shows the distal right coronary artery (RCA) terminating into posterior descending artery (PDA) and posterior left ventricular (PLV) branches, making the coronary circulation "Right dominant".

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

Coronary Artery Variants

Inferior Wall Supply

The origin of PDA is variable depending on the coronary dominance pattern. Some patients show early takeoff of the PDA, when it arises from the RCA before the crux of the heart (Fig. 5). Some individuals may have a small PDA with branches from distal RCA, LCX and obtuse marginal branches supplying the inferior wall.
Fig. 5: Posterior oblique VR image shows "early takeoff" of the posterior descending artery (PDA) from the right coronary artery (RCA)

*References:* P. Kapur; Department of Imaging, New Delhi-110019, INDIA

*Ramus Intermedius*

In some patients the LMA trifurcates to give rise to the ramus intermedius apart from LAD and LCX (Fig 6,7).
Fig. 6: Anterior oblique volume-rendered (VR) image of the heart shows left main artery (LMA) trifurcating into the left anterior descending (LAD), left circumflex (LCX) and ramus intermedius arteries

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA
Fig. 7: Axial thin maximum-intensity-projection CT image shows left main artery (LMA) trifurcating into the left anterior descending (LAD), left circumflex (LCX) and ramus intermedius arteries.

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

Sinus Node Branch

This vessel arises from the RCA (Fig. 8) in 60% of people; however it can also arise from proximal LCX (Fig. 9) or even distal RCA or LCX artery in rare cases.
Fig. 8: Axial thin maximum-intensity-projection CT image shows sinoatrial nodal branch (arrow) as it arises from proximal right coronary artery (RCA).

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA
Fig. 9: Axial thin maximum-intensity-projection CT image shows sinoatrial nodal branch (red arrow) as it arises from proximal left circumflex artery (asterix).

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

Supernumerary Coronary Ostia

In some patients there may be separate origins of the LAD and LCX from left coronary sinus with no LMA. Origin of the conus branch directly from the aorta rather than from proximal RCA is another example in this category.

Duplication of branches

There may be duplication of branches of the main coronary arteries, e.g., two PDAs arising from the RCA (Fig. 10).
Fig. 10: Posterior oblique VR image shows duplication of the posterior descending artery, with two PDAs (PDA 1, PDA 2) arising from the right coronary artery (RCA) and entering into the posterior interventricular septum.

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

Myocardial Bridging

This occurs when a segment of a coronary artery has an intramyocardial course (Fig. 11). It is most commonly seen in the middle segment of LAD artery. Interestingly, the bridged coronary segment is often spared of atherosclerotic disease [12]. However, in some cases myocardial bridging may be responsible for angina pectoris, myocardial infarction, life threatening arrhythmias, or even death. This condition is better visualized on curved multiplanar reformatted images in diverse planes.
Coronary Artery Anomalies

Ectopic Coronary Artery Origin

Ectopic coronary origin is the most frequently seen coronary anomaly. Some of these anomalies are associated with angina and risk of sudden cardiac death. Hence, the origin based anomalies have been divided into benign and malignant categories.

• BENIGN ECTOPIC CORONARY ARTERY ANOMALIES

Origin from opposite sinus of Valsalva

This includes the following patterns:
-the LCX arising from the right coronary sinus (Fig. 12,13).
-the RCA arising from the left coronary sinus with a retroaortic course.
-the LAD arising from the right coronary sinus with a prepulmonic course.

**Fig. 12**: Three-dimensional volume-rendered multidetector CT image of the aortic root shows origin of the left circumflex (LCX) artery from the right sinus of Valsalva and a retroaortic course

**References**: P. Kapur; Department of Imaging, New Delhi-110019, INDIA
Fig. 13: Maximum Intensity Projection multidetector CT image shows origin of left circumflex (LCX) artery from the right sinus of Valsalva and a retroaortic course (Ao=aorta, RCA=right coronary artery).

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

*Origin from another coronary artery*

The following patterns may be seen:

-LCX arising from RCA (Fig. 14,15).

-LAD arising from RCA with a prepulmonic course.

-RCA arising from LMA with a retroaortic course.
Fig. 14: Anterior oblique volume rendered (VR) CT image shows absence of the origin of the left circumflex (LCX) artery from the left main coronary artery (LMA). However LCX artery is seen in the left atrioventricular groove following a retroaortic path.

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA
Fig. 15: Three-dimensional volume-rendered image of the aortic root (Ao) shows the origin of left circumflex (LCX) artery from the right coronary artery (RCA). The LCX is seen to be following a retroaortic course.

**References:** P. Kapur; Department of Imaging, New Delhi-110019, INDIA

*Origin from non coronary sinus*
Fig. 16: Anterior oblique volume-rendered image of the heart shows origin of right coronary artery (RCA) from a point between both the aortic cusps (arrowhead). The RCA has an interarterial course here.

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

High take off

This refers to the origin of either the RCA or LMA at a point above the junctional zone between its sinus and the tubular part of the ascending aorta (Fig. 17).
Fig. 17: On anterior oblique volume rendered (VR) CT image, the left main coronary artery (LMA) shows "high takeoff" (arrow) above the left sinotubular junction.

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

- MALIGNANT ECTOPIC CORONARY ARTERY ANOMALIES

1. Malignant RCA - This occurs when the RCA arises from the left sinus of Valsalva and courses between the aorta and pulmonary artery (Fig. 18,19). This anomaly has been associated with sudden cardiac death in up to 30% patients [13]. It has been suggested that when dilation of the aorta occurs during exercise, the anomalous ostium of the RCA
becomes narrower. This limits the coronary blood flow leading to myocardial infarction. [14,15].

Fig. 18: Anterior oblique volume rendered (VR) CT image shows the origin of right coronary artery (RCA) from the left sinus of Valsalva (arrow).

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA
Fig. 19: Multiplanar reformatted CT image of the aortic root shows the interarterial course of the anomalous right coronary artery (RCA) with compression of its proximal part (arrow). A=aorta, PA=pulmonary artery.

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

2. **Malignant LMA** - This occurs when the LMA arises from the right sinus of Valsalva and courses between the aorta and pulmonary artery.

There is some evidence that anomalous RCAs with an interarterial course are associated with a more benign prognosis than interarterial LMAs [16]. This may be due to the larger volume of myocardium put at risk in case of malignant LMA.

3. **Bland-White-Garland Syndrome** - Anomalous origin of left coronary artery from pulmonary artery (ALCAPA). Seen in infants and children, it causes 90% mortality in
first year of life [17]. Young patients present with myocardial ischemia due to coronary steal phenomena.

**Coronary Aneurysms and Ectasia**

Coronary artery aneurysms and ectasia are characterized by an abnormal dilatation of a coronary artery. The term ectasia is reserved to mean a diffuse dilatation of a coronary artery (Fig. 20), and an aneurysm is a focal dilatation of the vessel (Fig. 21)[18].

![Fig. 20: Anterior oblique volume rendered CT image of the heart showing ectasia of the left anterior descending artery (white arrow) and left circumflex artery (red arrow).](image)

**References:** P. Kapur; Department of Imaging, New Delhi-110019, INDIA
Fig. 21: Anterior oblique volume rendered CT image of the heart shows a focal aneurysm of the proximal right coronary artery (arrow).

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

**Coronary artery fistulae**

This is a condition in which a communication exists between one or two coronary arteries and either a cardiac chamber, the coronary sinus, the superior vena cava, or the pulmonary artery. It is seen more commonly in RCA (60%) than LMA (40%) [19]. The volume of shunt depends on site of fistula and resistance in receiving chamber. Coronary fistulae vary widely in their presentation, from being small and asymptomatic to large shunts with coronary steal or heart failure.

**Absent Left Circumflex artery**

Congenital absence of left circumflex coronary artery (LCX) is a vascular anomaly in which the artery fails to develop in the atrioventricular groove (Fig. 22).
Fig. 22: Anterior oblique volume rendered (VR) image of the heart demonstrating absent left circumflex artery (black arrow) with left main coronary artery (LMA) continuing as left anterior descending artery (LAD).

References: P. Kapur; Department of Imaging, New Delhi-110019, INDIA

Conclusion

Coronary variants and anomalies are a relatively frequent finding in the current scenario of non invasive cardiac imaging. ECG-gated Multi-detector CT is a reliable non invasive technique for evaluating the origin and course of anomalous coronary arteries. With improvements in spatial and temporal resolution and better post processing softwares, CT Coronary angiography has helped in understanding the clinical significance of these
anomalies. Knowledge of the CT appearances of various coronary artery anomalies can be helpful for planning future therapeutic approaches.

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**References**


