Chapter 3
Echocardiography in Acute Coronary Syndrome: Anatomy, Essential Views and Imaging Plains

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Introduction

A plentiful arterial circulation is required for an effective myocardial function during both systole and diastole. This supply/demand coupling is accomplished through regional matching of the arterial supply to a particular portion of the myocardium.

Arterial circulation of the heart consists of two parts: (1) large epicardial coronary arteries which serve as conduit vessels, and (2) medium-size and small intramyocardial coronary arterioles which serve as resistance vessels regulating the amount of coronary flow according to myocardial metabolic needs. Perturbation in any portion of this arterial tree will lead to a regional myocardial dysfunction. Acute coronary syndrome (ACS) is the clinical manifestation of a diminished coronary arterial blood supply in either conduit or resistance coronary vessels that is most commonly caused by atherosclerosis.

In this chapter, we will discuss the epicardial circulation; the anatomy and function of resistance vessels will be discussed in Chapter 5.

Epicardial Conduit Vessels

In most humans, the entire epicardial circulation originates from the two initial branches of the aorta: the left coronary artery (LCA) and the right coronary artery (RCA). They originate from the left and the right sinus of Valsalva, respectively. The initial portion of the LCA is referred to as the left main coronary artery (LMCA); it branches into the left anterior descending artery (LAD) and the left circumflex artery (LCx). Although anatomically there are only two coronary arteries (LCA and RCA) in most individuals, in clinical parlance it is often said that there are three coronary vessels (RCA, LAD, and LCx).

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E. Herzog, F. Chaudhry (eds.), *Echocardiography in Acute Coronary Syndrome*,
DOI 10.1007/978-1-84882-027-2_3,

In a few individuals, there may be anomalies in the origin of the coronary arteries pertaining to the number and location of coronary ostia within the aortic root as well as anomalies in the initial course of the vessels. A more detailed discussion on the anomalous origin of the coronary arteries is beyond the scope of this textbook.

The LAD supplies the largest portion of the left ventricles; the size of the LAD territory tends to be relatively constant among individuals and encompasses about 50% of the left ventricle. The LAD initially runs in the anterior interventricular groove parallel to the long axis of the heart, then turns over the left ventricular apex and terminates in most individuals in the apical region of the posterior interventricular groove. The LAD gives off septal branches that penetrate into the anterior two-thirds of the interventricular septum and diagonal branches which supply large areas of the anterior wall of the left ventricle and much smaller area of the anterior wall of the right ventricle (Fig. 3.1A).

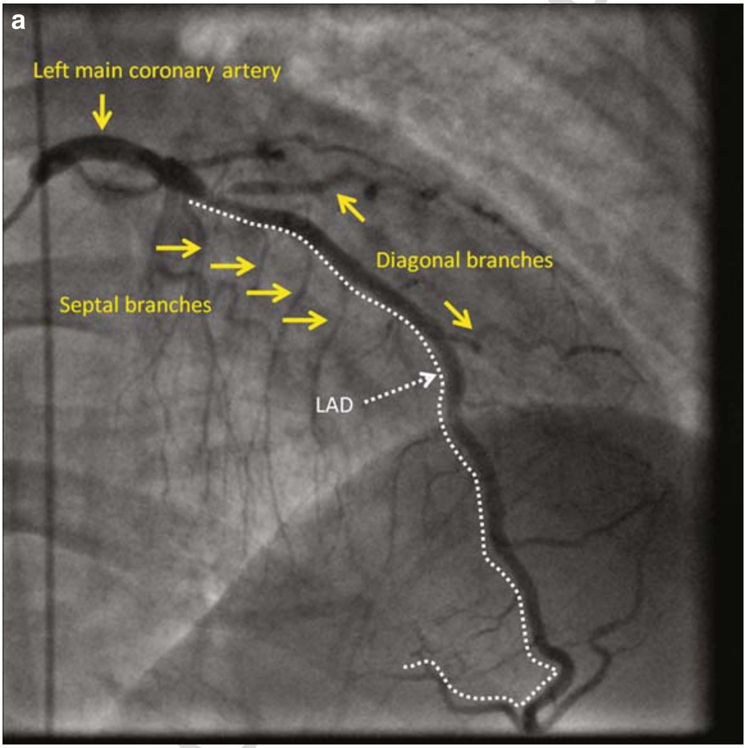


Fig. 3.1 Coronary anatomy as visualized by coronary angiography. **A**: Left anterior descending artery (LAD) and its major branches visualized in a cranially and a slightly rightward angulated view [right anterior oblique (RAO) –9°; cranial +36°]. **B**: Dominant right coronary artery (RCA) and its major branches visualized in a slightly cranially angulated left anterior oblique (LAO) view (LAO +28°; cranial +3°). **C**: Nondominant left circumflex (LCx) artery and its major branches visualized in a caudally and a slightly rightward angulated view [right anterior oblique (RAO) –6°; caudal –21°)

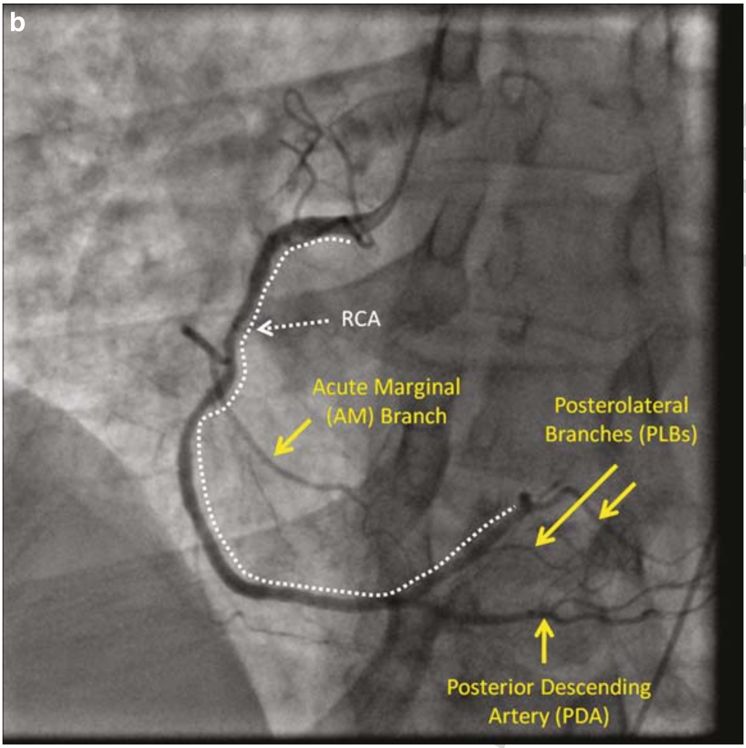


Fig. 3.1 (continued)

The other half of the left ventricle is supplied by both the RCA and the LCx in proportions that vary between individuals. In about 70% of humans, the RCA subtends a larger section of the left ventricle than the LCx (the so-called right-dominant circulation); in about 20% of individuals the contribution of the two arteries is equal (codominant or balanced circulation), and in the remaining 10% the LCx is larger than the RCA (left-dominant circulation).[1] The dominance type does not affect the initial course of either the RCA or the LCx; it arises from the pattern of terminal branching in the two vessels.

In all individuals, the initial course of the RCA is within the right atrioventricular groove and thus perpendicular to the long axis of the heart. During this initial course, the RCA gives off acute marginal (AM) branches which run roughly parallel to the long axis of the right ventricle to supply the acute margin of the heart made up by the right ventricle. The RCA is the principal source of arterial blood supply to the right ventricle; when there is a right ventricular dysfunction during ACS, it is almost invariably caused by abnormalities in the RCA tree (Fig. 3.1B).

In a roughly mirror-image pattern, the LCx initially runs in the left atrioventricular groove perpendicular to the long axis of the heart and gives off obtuse marginal

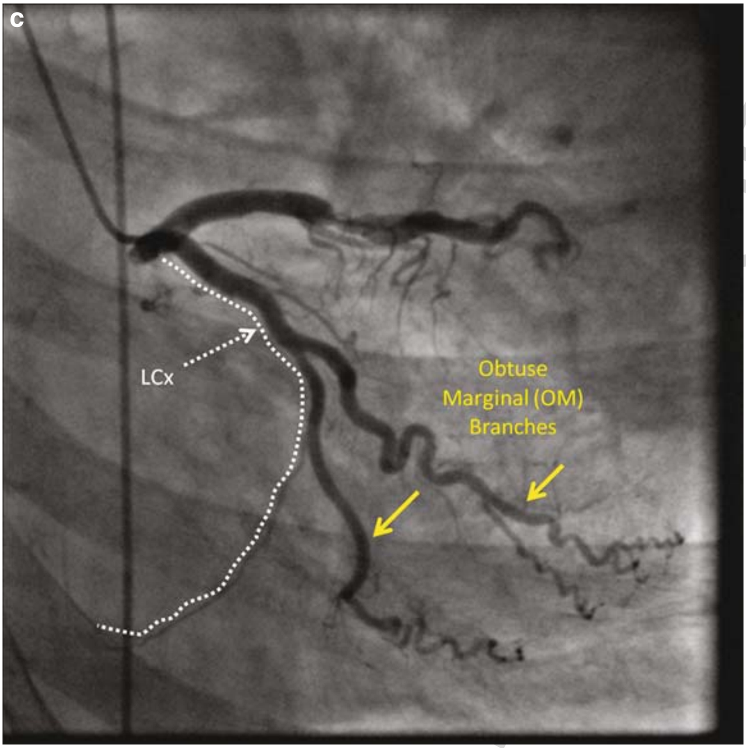


Fig. 3.1 (continued)

(OM) branches. They run parallel to the long axis of the heart and supply the obtuse margin of the heart made up by the lateral wall of the left ventricle (Fig. 3.1C).

The inferoposterior aspects of the interventricular septum and the left ventricle are supplied by the posterior descending artery (PDA) and one or more posterolateral branches (PLBs). The PDA usually runs along the proximal two-thirds of the posterior interventricular groove and its course is parallel to that of the LAD in the anterior interventricular groove. Along its interventricular course, the PDA gives off septal branches to the inferior aspect of the interventricular septum and then meets the LAD in the apical portion of the posterior interventricular septum. PLBs are arterial branches that run along the long axis of the left ventricle and roughly parallel to the course of the PDA and the OMs. PLBs supply the inferior and posterior walls of the left ventricle.

It is the origin of the PDA and the PLBs that determines whether the coronary circulation is right-dominant, left-dominant, or balanced (codominant). In the right-dominant circulation, the PDA and PLBs are branches of the RCA; in the left-dominant circulation, the PDA and PLBs are terminal branches of LCx; in balanced (codominant) circulation, both the RCA and the LCx supply the PDA and/or PLBs.

Imaging of Epicardial Coronary Arteries

Invasive coronary angiography using selective iodinated contrast dye injection into the RCA or the LCA has traditionally been the gold standard for imaging of epicardial coronary circulation. It is now being supplanted by high-resolution noninvasive computed tomographic (CT) angiography. The role of echocardiography in imaging epicardial coronary vessels in ACS remains limited. In adult, the origins of the RCA and the LCA can be visualized occasionally by transthoracic echocardiography and almost always by transesophageal echocardiography.[2] However, such information is rarely valuable in ACS unless an anomalous origin of the coronary arteries or dissection in the proximal coronary arteries is suspected as the cause of the patient's chest pain.

Two-dimensional gray-scale and color Doppler echocardiographic imaging beyond the origins of the coronary arteries is rarely feasible or clinically useful in ACS unless coronary fistulas are suspected. In such instances, coronary arteries are enlarged (often markedly so) and thus detectable by standard gray-scale and color Doppler techniques.

Transthoracic and transesophageal spectral Doppler recordings are feasible and are routinely used for measuring coronary flow reserve in research protocols involving the LAD,[3] the RCA,[4] and the LCx.[5] However, the utility of such recordings in routine clinical evaluation of ACS patients remains limited.

Segmental Anatomy of the Left Ventricle

In order to correlate coronary arterial circulation to the myocardial function, the left ventricle is commonly divided into 17 segments according to a standardized American Heart Association consensus model adopted for all forms of modern cardiac imaging including echocardiography, nuclear cardiology, computed tomography, and magnetic resonance imaging.[6]

In this model, the left ventricle is first cut perpendicular to its long axis to create three myocardial rings: basal, mid-cavity, and apical. The basal and the mid-cavity ring each accounts for about 35% of the left ventricular mass, while the apical segments comprise the remaining 30%. This is in general agreement with autopsy studies of human hearts.[7]

The basal and the mid-cavity rings are then cut into six circumferential segments each; every segment accounts for 60° of the left ventricular circumference. These circumferential segments in the basal and the mid-cavity rings are referred to as anterior, anteroseptal, inferoseptal, inferior, inferolateral, and anterolateral in the consensus model. Note, however, that inferolateral and anterolateral segments have traditionally been referred to by echocardiographers as the posterior and the lateral wall, respectively.

The apical ring is subdivided into five segments: an apical cap which does not subtend the left ventricular cavity and four circumferential cuts of 90° each: anterior, septal, inferior, and lateral.

Each segment is given a unique number according to the following three principles:

1. Sequential numbering starts in the basal myocardial ring and ends in the apical portion of the left ventricle.
2. In each myocardial ring, the numbering starts with the anterior segment and proceeds counterclockwise.
3. Segment 17 refers to the apical cap.

Note that the traditional echocardiography model differs slightly from the consensus model; the apical cap is not counted as a separate segment giving rise to a 16-segment model of conventional echocardiography.[8]

In the 2005 guidelines for chamber quantification jointly sponsored by the American Society for Echocardiography and the European Association for Echocardiography,[8, 9] it is stated that:

1. Both the 17- and the 16-segment models can still be used.
2. The 17-segment model should be used for myocardial perfusion studies or when a comparison between echocardiography and other cardiac imaging modalities is necessary.
3. The 16-segment model is appropriate for studies assessing wall motion abnormalities since the apical cap (segment 17) does not move.

The nomenclature of the 17-segment consensus model is summarized in Table 3.1. To represent all 17 segments simultaneously the so-called "bull's eye" plot is used (Fig. 3.2).

Table 3.1 17-Segment left ventricular model

	Basal	Mid-cavity	Apical	
Anterior	1	7	13	Anterior
Anteroseptal	2	8	14	Septal
Inferoseptal	3	9	15	Inferior
Inferior	4	10	16	Lateral
Inferolateral (posterior)	5	11	17	Apical cap
Anterolateral (lateral)	6	12		
Total number of segments	6	6	5	Grand total = 17

Based on data from Cerqueira et al.[6]

A major shortcoming of either the 16-segment or the 17-segment model is their failure to include any right ventricular (RV) segments. The right ventricle is supplied primarily by the RCA branches; only a small portion of the anterior right ventricle may be supplied by the LAD. Since RV dysfunction in ACS has major prognostic implications, echocardiographers should always comment on RV function in ACS patients.

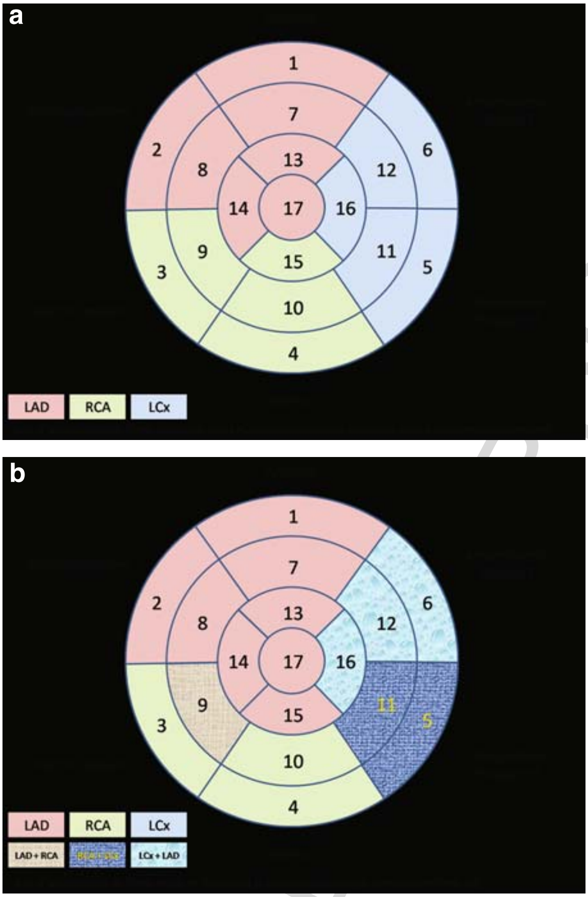


Fig. 3.2 Bull's eye plot of myocardial segments. **A** represents left ventricular assignments to coronary territory based on data from the 2002 American Heart Association consensus statement.[6] **B** represents left ventricular assignments to coronary territory based on data from the 2005 consensus statement by the American Society for Echocardiography and the European Association for Echocardiography[9]

Relating Standard Echocardiographic Views to Segmental Left Ventricular Model

The left ventricle is commonly visualized echocardiographically in three short-axis and three long-axis views. The three short-axis views are obtained at the cardiac base, mid-papillary level, and the cardiac apex. The short-axis views correspond to the three myocardial rings of the consensus model.

In echocardiography, the long-axis views are termed apical four-chamber view, apical two-chamber view, and apical three-chamber view (which is roughly equivalent to the parasternal long-axis views). In radiology, however, different terminology is used; the American Heart Association consensus statement encourages adoption of the radiologic nomenclature by echocardiographers. The relationship between echocardiographic and radiologic views is summarized in Table 3.2.

Table 3.2 Correlation between echocardiographic and radiologic views

Echocardiography	Radiology
Apical four-chamber view	Horizontal long-axis view
Apical two-chamber view	Vertical long-axis view
Apical three-chamber view (parasternal long-axis view)	No equivalent standard view
Short-axis view	Short-axis view

Based on data from Cerqueira et al.[6]

The apical four-chamber view (horizontal long-axis view) and the apical two-chamber view (vertical long-axis view) are roughly 90° apart. The apical three-chamber view (roughly equivalent to the parasternal long-axis view) is wedged in between the apical four- and the two-chamber views.

On standard tomographic views of transthoracic echocardiography, only a subset of the 17-segment model is visualized in each view. Segmental analysis of all standard 2D transthoracic views is given in Fig. 3.3. With the advent of real-time 3D

a

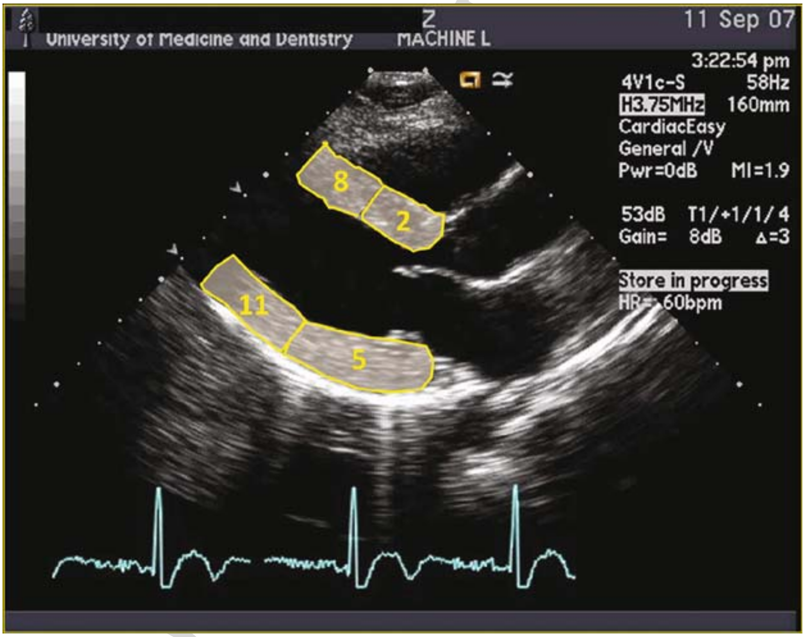
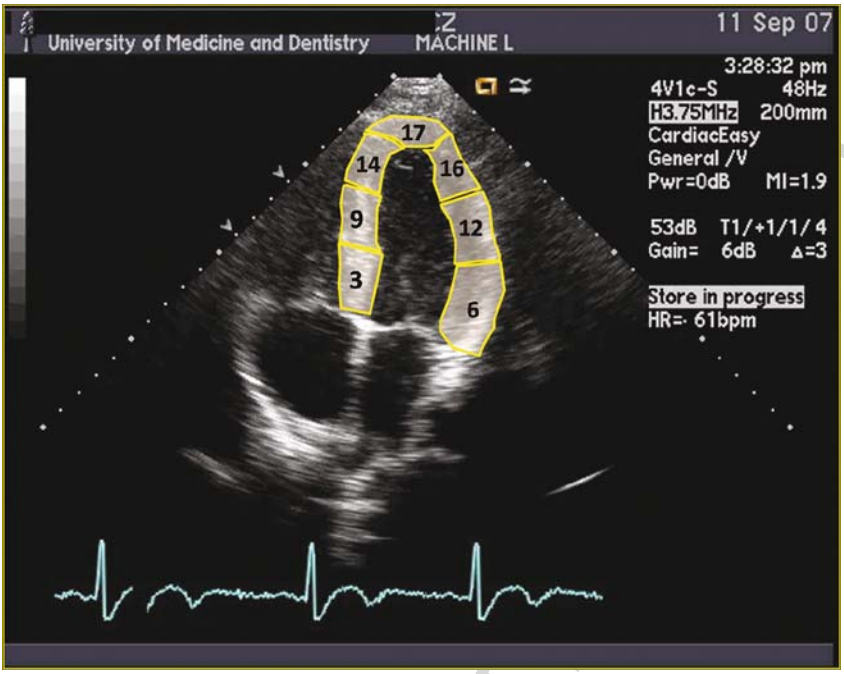


Fig. 3.3 Left ventricular segments on standard 2D echocardiographic views. **A**: Parasternal long-axis view. **B**: Apical four-chamber view (horizontal long-axis view). **C**: Apical two-chamber view (vertical long-axis view). **D**: Parasternal short-axis view at the basal left ventricular level. **E**: Parasternal short-axis view at the mid-papillary level. **F**: Apical short-axis view

b



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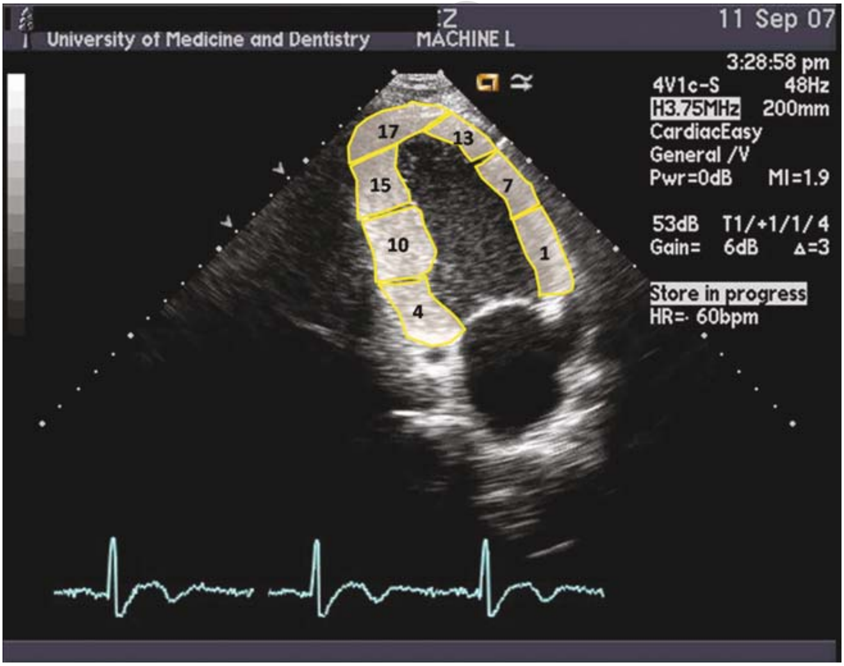
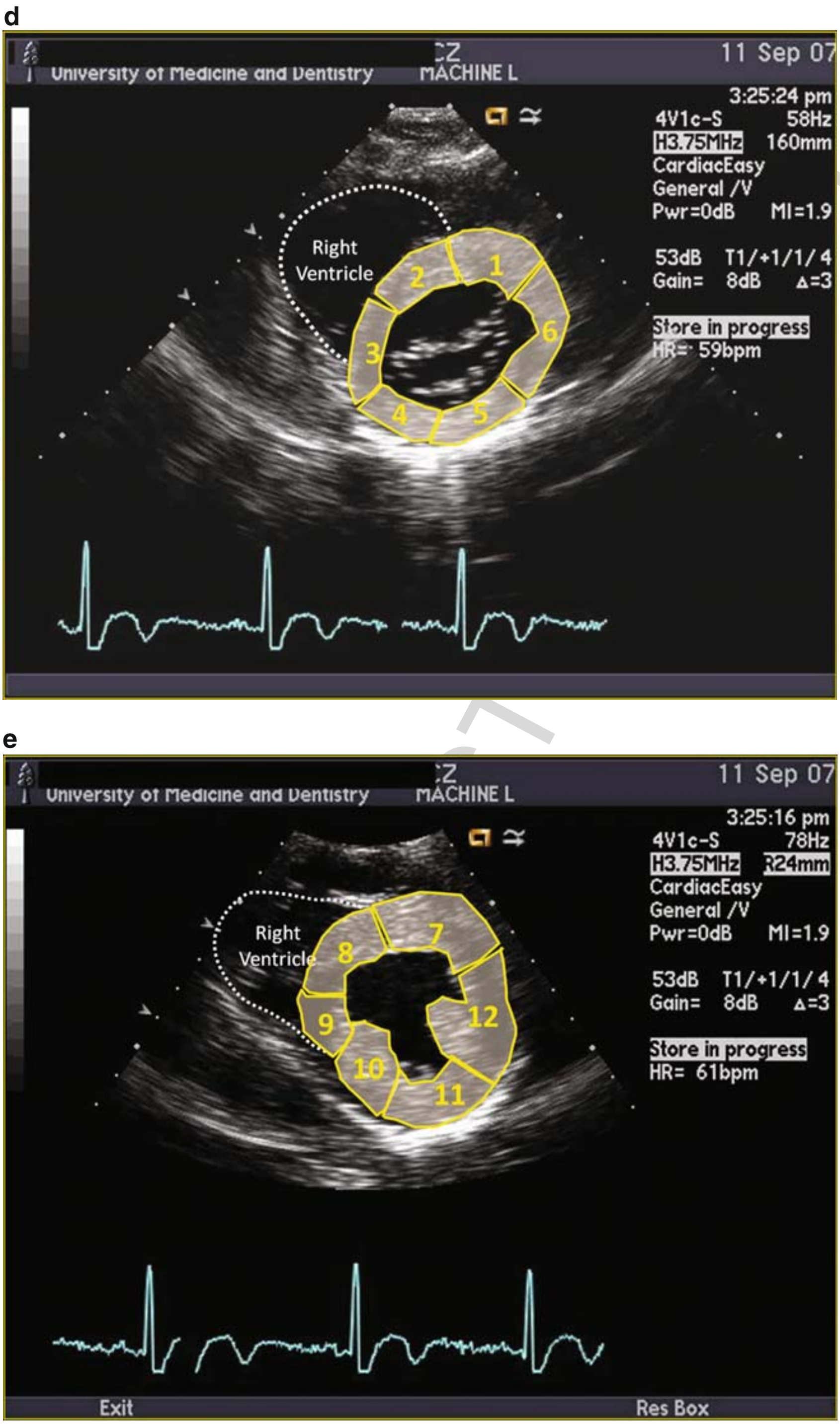


Fig. 3.3 (continued)



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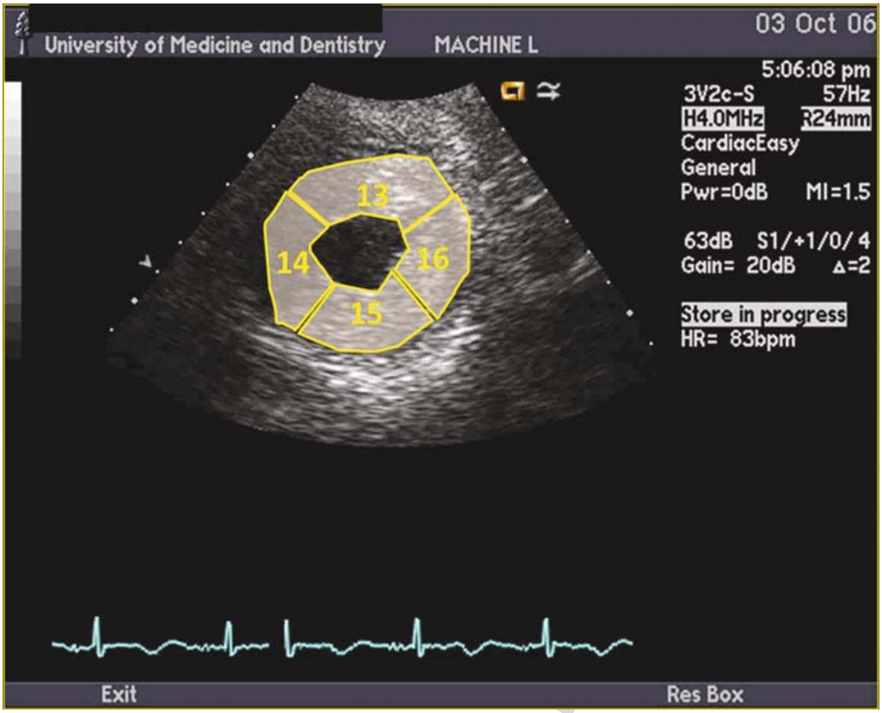

Fig. 3.3 (continued)

transthoracic echocardiography, the entire left ventricle can be reconstructed which allows for visualization of the 17-segment model in a 3D space (Fig. 3.4).

Relating Coronary Circulation to Segmental Left Ventricular Model

Because there is a great variability in human coronary arterial circulation, a precise correlation between myocardial segments and coronary arterial branches cannot be established in a way that would be applicable for every individual. However, it is generally agreed upon that it is appropriate to assign individual left ventricular segments to specific coronary territories.[10] Below we will discuss the left ventricular assignments to coronary territories based on the 2002 American Heart Association consensus statement.[6] Note, however, that the 2005 consensus statement by the American Society for Echocardiography and the European Association[9] for Echocardiography provides a more complex view which emphasizes significant overlap in border zones between different coronary territories. The difference between the two schemes is summarized in Fig. 3.2 and in Table 3.3.

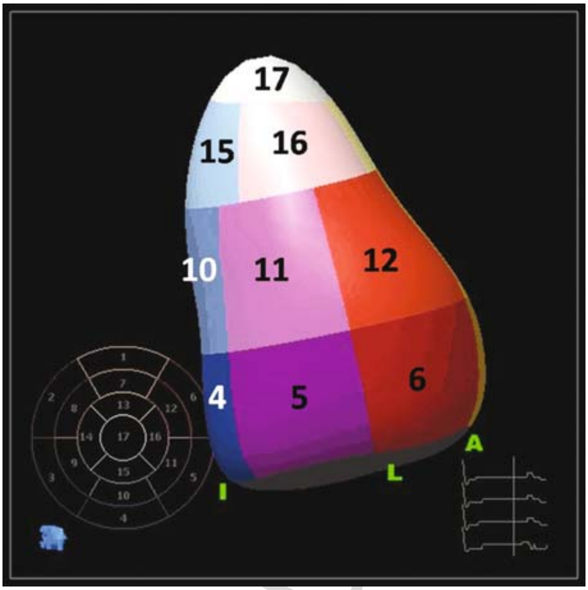

Fig. 3.4 Left ventricular segments on 3D echocardiography. With real-time 3D transthoracic echocardiography, the entire 17-segment model can be visualized in a 3D space

Of the three coronary arteries, the LAD probably exhibits the least amount of variability. It supplies the entire anterior wall (segments 1, 7, and 13), the entire anterior septum (segments 2, 8, and 14), and most often the apical cap (segment 17). However, one has to bear in mind that the segment 17 exhibits the greatest variability in blood supplies compared to all other left ventricular segments and that it can be supplied by any of the three coronary arteries.

Given the variability of the PDA origin, there is a great variability in the supply of the segments in the RCA and the LCx territories. Since the PDA is the branch of the RCA in the majority of humans, the RCA territory generally covers more left ventricular segments than the LCx. In most individuals, the RCA territory supplies the entire inferior wall (segments 4, 10, and 15) as well as the basal and the mid segment of the inferior septum (segments 2 and 9). In a left-dominant or codominant circulation, many of these segments may be supplied by the LCx.

Since the majority of humans have right-dominant coronary circulation, the LCx territory is restricted to the anterolateral wall (lateral wall in traditional echocardiography parlance; segments 6, 12, and 16) as well as the basal to mid portion of the inferolateral wall (posterior wall in traditional echocardiography parlance; segments 5 and 11).

Since in acute coronary syndrome echocardiographic imaging is often done before coronary angiography, echocardiographers cannot a priori determine whether the coronary circulation is right-dominant, left-dominant, or codominant. Without this information, an inevitable misassignment of myocardial segments in the RCA vs. the LCx territory will occasionally arise. In order to avoid misunderstandings with coronary angiographers, it is customary in our echocardiography laboratory to

Table 3.3 Correlation between left ventricular segments and coronary artery territories

Coronary artery	Left ventricular region	Basel segments	Mid-cavity segments	Apical segments	Apical cap	Total number of segments	Percentage of all left ventricular segments
Left anterior descending (LAD)	Anterior	1	7	13	17		
	Anteroseptal or septal	2	8	14			
	Total LAD segments					7	41
Right coronary artery (RCA)	Inferoseptal	3	9				
	Inferior	4	10	15			
	Total RCA segments					5	29
Left circumflex artery (LCx)	Inferolateral (posterior)	5	11				
	Anterolateral (lateral)	6	12	16			
	Total LCx segments					5	29
	Grand total					17	100

Based on data from the 2002 American Heart Association consensus statement.[6] Please note that the 2005 consensus statement by the American Society for Echocardiography and the European Association for Echocardiography[9] assigns segments somewhat differently: segment 15 (apical inferior wall) is assigned to the LAD territory; segment 9 (mid inferior septum) is shared between the LAD and the RCA; segments 5 and 11 [basal and mid inferolateral (posterior) wall] are shared between the RCA and the LCx; segments 6, 12, and 16 [anterolateral (lateral) wall] are shared between the LAD and the LCx. Interestingly, the 2005 statement assigns no left ventricular segments exclusively to the LCx.

refer to segments supplied by the PDA as being in the non-LAD territory without specifying whether such segments are in the RCA or in the LCx territory.

It is also important to emphasize that the above assignments of LV segments to particular coronary artery assume the absence of significant native collateral circulation or surgical bypass grafting.

Overlap Zones Between Coronary Territories

The RCA/LCx dominance pattern is not the only cause of significant variability among humans in coronary arterial supply to individual LV segments. The variability is particularly pronounced in border zones where one coronary territory meets another.

ALL THREE TERRITORIES: The three coronary territories converge at the LV apex. The apical cap (segment 17 seen in all apical long-axis views) thus may be supplied by any of the three arteries although most commonly is supplied by the LAD.

LAD MEETS PDA TERRITORY: The distal LAD usually wraps around the LV apex to meet the PDA in the distal portion of the posterior interventricular groove. Since the magnitude of the LAD wraparound is variable, the border zone segments of the apical to mid inferior wall (segments 15 and 10 seen on the apical two-chamber view) and the inferior septum (segments 14 and 9 seen on the apical four-chamber view) may be supplied by either the LAD or the RCA. Most commonly, the mid segments (9 and 10) are in the PDA territory, while the apical segments (14 and 15) are in the LAD territory.

LAD MEETS LCx TERRITORY: The two territories meet around the segment 16 (apical lateral wall seen on the apical four-chamber view) and thus both LAD and LCx can contribute to its arterial supply. The overlap may even extend to the mid and basal segments of the lateral wall (segments 12 and 6).

RCA MEETS LCx TERRITORY: The two territories converge at the basal to mid inferolateral (posterior) left ventricular wall (segments 5 and 11 seen on the apical three-chamber view or the parasternal long-axis view). These segments are supplied by the posterolateral branches (PLBs), which may come from either RCA or LCx depending on the coronary dominance pattern.

Overlap zones are illustrated in Fig. 3.2B.

Conclusion

Regional myocardial systolic and diastolic function is dependent on regional arterial blood supply. Although there is a significant variability in coronary arterial anatomy, it is generally agreed that individual left ventricular segments can be paired with branches of one of the three major coronary arteries (LAD, LCx, and RCA). If on an echocardiogram of a person suspected of having ACS one observes regional left ventricular dysfunction in a segmental pattern consistent with expected coronary artery distribution, one may conclude that the dysfunction is indeed ischemic in origin, thus confirming the diagnosis of ACS.

Clinical Case

Gerard Oghlakian, MD, and Yuliya Kats, MD have contributed to the following clinical case.

Subjective

An 87-year-old man with history of systemic hypertension and benign prostatic hypertrophy was brought in to our tertiary hospital by Emergency Medical Service (EMS) after sustaining multiple bruises and a forehead laceration in a car accident. According to the bystanders, the patient was involved in a single, unprovoked car accident where his car drove off the road and into a street-side pole. He had no recollection of the car accident itself; however, he did recall having lightheadedness just prior to the crash. There were no other symptoms such chest pain, shortness of breath, or palpitations. He had no prior established cardiovascular disease aside from systemic hypertension for which he was taking doxazosin. He denied any use of tobacco, alcohol, or illicit drugs.

Objective

In the emergency department, his physical exam showed a blood pressure of 180/50 mmHg and a heart rate of 105 beats per minute. His respiratory rate was 20 respirations per minute and his oxygen saturation was 99% on a 100% nonrebreather mask. On a physician exam he had a normal jugular venous pressure. Lung auscultation revealed diffuse rhonchi in the right lung fields. Cardiac exam demonstrated normal S1 and S2; no murmurs or gallops were appreciated. There was no lower extremity edema.

Electrocardiogram performed in the emergency department revealed sinus tachycardia with frequent premature ventricular complexes and mild ST depressions in inferior and lateral leads (Fig. 3.5). On laboratory exam, complete blood count and basic chemistries were unremarkable. With respect to cardiac markers, the troponin I level at time of presentation was 2.06 ng/mL (normal $<$0.4 ng/mL); creatine phosphokinase at 365 units per liter (normal $<$200 units per liter), and MB isoenzyme at 23 ng/mL with an MB index of 6.3%. Computed tomography (CT) of the head revealed no intracranial pathology. CT of the chest showed right-sided lung contusion and multiple right and left rib fractures.

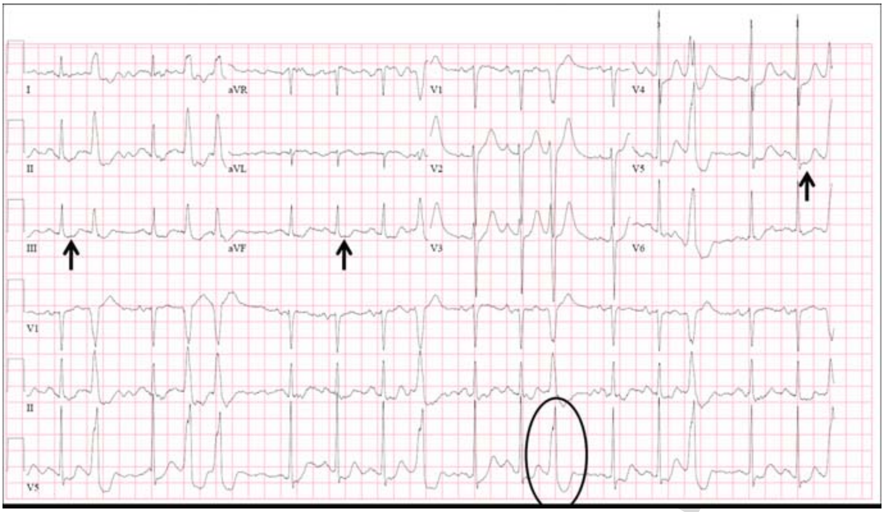

Fig. 3.5 Electrocardiogram (EKG) performed in the emergency department. EKG revealed sinus tachycardia with frequent premature ventricular complexes (*oval*) and mild ST depressions in inferior and lateral leads (*arrows*)

Assessment and Plan

Patient was suspected of having a non-ST elevation myocardial infarction that likely led to ventricular arrhythmia, syncope, and the car accident. An alternative explanation for his preadmission course was syncope of a noncardiac etiology leading to a car accident, traumatic cardiac contusion, and subsequent release of cardiac markers.

Indication for the Echo

A transthoracic echocardiogram was ordered to determine the presence, the location, and the extent of regional left ventricular wall motion abnormalities that would support or refute the clinical diagnosis of a non-ST elevation myocardial infarction.

Echo Imaging

Transthoracic echocardiogram (Fig. 3.6) performed in the emergency department revealed hypokinesis of the basal to mid segments of the inferior wall (segments 4 and 10; Fig. 3.6A) and the posterior (inferolateral) wall (segments 5 and 11; Fig. 3.6B). The pattern of left ventricular wall motion abnormalities was consistent with an ischemic damage in the distribution of either the right coronary artery

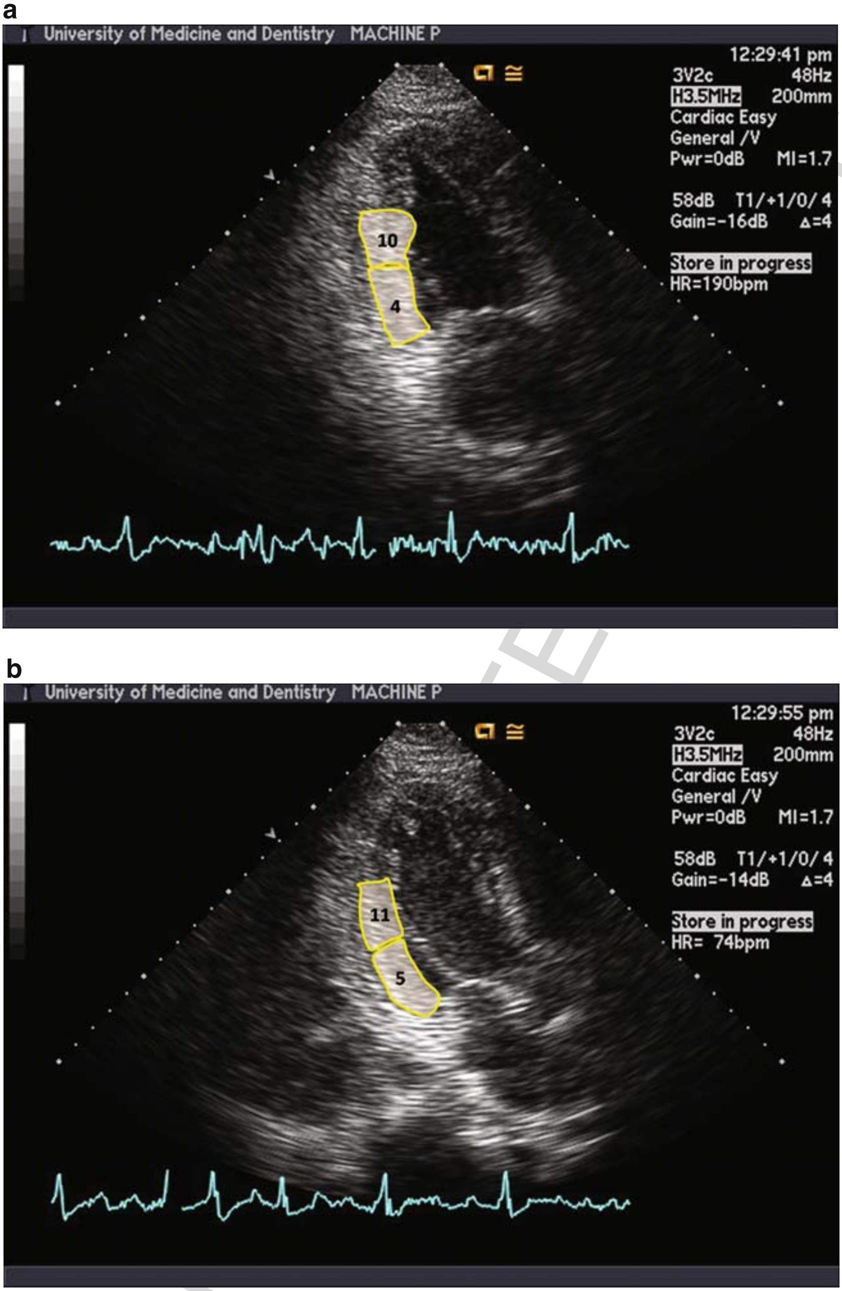

Fig. 3.6 Transthoracic echocardiogram. **A**: Apical two-chamber view revealed hypokinesis of the basal and the mid segment of the inferior wall (segments 4 and 10). **B**: Apical three-chamber view revealed hypokinesis of the basal and the mid segment of the posterior (inferolateral) wall (segments 5 and 11)

(RCA) or the left circumflex artery (LCx) depending on the dominance of the coronary circulation.

Other left ventricular segments were hyperkinetic and the global left ventricular ejection fraction was preserved. The size and function of the right ventricle – the chamber that is most likely to suffer contusion in a car accident – was normal. The study demonstrated neither pericardial effusion nor a significant valvular disease.

Management

Given the combination of elevated cardiac serum markers and the echocardiographic findings of regional wall motion abnormalities in the distribution of the PDA, patient was referred for prompt coronary angiography. His coronary circulation revealed a left-dominant pattern with the PDA being a branch of the left circumflex artery. LCx had a critical 98% stenosis in its mid course just at the bifurcation of the OM_2 branch (Fig. 3.7). There were no left-to-left or right-to-left collaterals, suggesting that the LCx stenosis was acute.

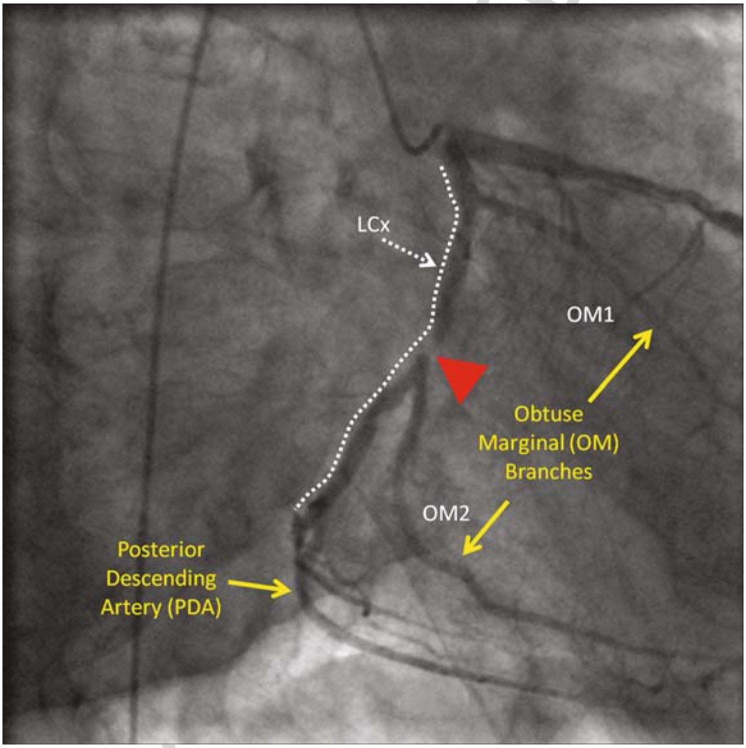

Fig. 3.7 Coronary angiogram. Coronary angiogram reveals severe stenosis of the left circumflex (LCx) artery (*arrow head*) just prior to the origin of the second obtuse marginal branch (OM2)

Outcome

LCx stenosis was successfully treated with a percutaneous placement of a bare-metal stent. After stenting, he underwent an electrophysiologic study which revealed no arrhythmia. His subsequent hospital course was uneventful. He was sent home in good condition and was free of symptoms on follow-up.

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