Anatomic Pitfalls of the Heart and Pericardium

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Recent technologic advances have led to more frequent dedicated cross-sectional imaging of the heart. Faster scanning techniques, cardiac gating, and advanced postprocessing software allow improved visualization of finer anatomic details of the heart and pericardium compared with older techniques and software. Use of thin-section computed tomography (CT) or image reformatting in nonaxial planes may be helpful in some cases. The cardiac and pericardial structures are usually readily demonstrated with CT, even if chest CT is performed for evaluation of noncardiac structures. However, radiologists are expected to evaluate all structures on an image, and incidental findings are common. Radiologists must first be familiar with the normal anatomic structures of the heart and pericardium (eg, atria, ventricles, cardiac valves, pericardial recesses, paracardiac structures) to avoid mistaking them for pathologic processes.

Abbreviations: IVC = inferior vena cava, LHIS = lipomatous hypertrophy of the interatrial septum, SVC = superior vena cava

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Introduction
Recent advances in imaging technology have increased the frequency with which dedicated cross-sectional imaging of the heart is performed. Retrospective and prospective electrocardiographic gating capabilities and advanced postprocessing software have enabled radiologists to perform computed tomographic (CT) angiography of the heart and coronary arteries, determine the coronary artery calcium burden, and perform anatomic and functional analysis. With multi-detector row technology, the anatomy of the heart and pericardium are routinely well displayed even without cardiac gating. Familiarity with normal anatomic structures is necessary to prevent misinterpretation of findings. In some cases, it may be helpful to use thin-section CT or obtain reformatted images in the sagittal, coronal, or oblique plane (1). In this article, we review some of the finer anatomic details of the heart and pericardium (atria, ventricles, cardiac valves, pericardial recesses, paracardiac structures), particularly those structures that can be misinterpreted as pathologic processes at radiologic examination.

Anatomic Structures

Atria
The right atrium forms the right lateral border of the heart. In terms of embryologic development, the right atrium originates from the primitive right atrium, a trabeculate structure that persists as the right atrial appendage, and from the sinus venosus, which forms the smooth-walled portion of the right atrium (2). The left atrium is the most superior and posterior chamber of the heart. It originates from the primitive left atrium, a trabeculate structure that persists as the left atrial appendage, and from the pulmonary veins, which form the smooth-walled portion of the left atrium (2).

The eustachian valve, also known as the valve of the inferior vena cava (IVC), is located at the junction of the IVC and the right atrium (Fig 1). In the fetus, the eustachian valve directs blood from the IVC to the foramen ovale (2–5). The eustachian valve is not routinely seen at echocardiography, CT, or magnetic resonance (MR) imaging. Occasionally, persistent remnants of the valve may be large enough to be identified. At echocardiography, eustachian valve remnants are typically thin, linear, mobile structures attached at the junction of the IVC and the right atrium. They may extend to the fossa ovalis but do not extend across the tricuspid valve (5). When present, the eustachian valve may be mistaken for a pedunculated tumor or thrombus (Fig 2) (5). Cardiac tumors are rare and, when present, are not typically found in this location (6). Thrombus within this region is unlikely due to the high venous flow; thrombi tend to occur within regions of low flow (eg, atrial appendages, ventricular aneurysm).

The crista terminalis is a vertically oriented, smooth muscular ridge within the right atrium (Fig 1). It extends from the superior vena cava (SVC) to the IVC and represents the line of fusion between the anterior trabeculate primitive
The right atrial portion and the posterior smooth-walled sinus venosus portion of the right atrium (2–5). The crista terminalis is often seen extending into the right atrium on routine contrast-enhanced CT scans and may be quite prominent (Fig 3). Care should be taken not to mistake the crista terminalis for a tumor or thrombus.

A ridge of smooth muscle can be seen along the wall of the left atrium at the junction of the left atrial appendage and the entrance of the left superior pulmonary vein. This ridge may have a bulbous tip and can be mistaken for a pedunculated mass or thrombus arising from the lateral wall of the left atrium (5). As with the crista terminalis, the prominence of this left atrial muscular ridge varies (Fig 4).

The interatrial septum is thin and may be difficult to identify on CT scans. A small amount of fat can be present within the interatrial septum, allowing it to be identified at CT (7). Typically, fat within the interatrial septum spares the fossa ovalis. If the amount of fat within the septum is small, the fossa ovalis may not be readily apparent. However, with increasing amounts of fat, the fossa ovalis will be readily identified. Because the portion of the interatrial septum within the fossa ovalis may not be visible, the radiologist may mistakenly perceive the presence of a septal defect. The fossa ovalis is more readily identified in patients with lipomatous hypertrophy of the interatrial septum (LHIS), which can be detected at CT, MR imaging, and echocardiography. LHIS is a condition in which an abnormal amount of fat is deposited within the atrial septum. LHIS is not considered to be a true lipoma in the histologic sense and is typically seen in older or obese adults. The fat in LHIS has a characteristic dumbbell-shaped appearance due to sparing of the fossa ovalis (Fig 5) (5,7,8).
Ventricles
The right ventricle forms the anterior border of the heart. The right ventricular wall is typically more trabeculated and thinner than the left ventricular wall. There are fewer trabeculae in the outflow portion of the right ventricle. The right ventricle contains anterior and posterior papillary muscles and a smaller medial supracristal (conal) papillary muscle (Fig 6). The anterior and posterior papillary muscles attach near the right ventricular apex. The medial supracristal papillary muscle arises from the septal band of the interventricular septum and is usually small in adults.

Figure 6. (a) Drawing illustrates a cut-away view of the right ventricle. Arrowheads indicate the anterior and posterior papillary muscles, open arrow indicates the moderator band. Note the smaller conal papillary muscle (solid arrow). (b, c) Axial contrast-enhanced CT scans show the anterior papillary muscle (arrowhead in b) and the moderator band (arrow in c).

The anterior papillary muscle has chordae tendineae that attach to the anterior and posterior cusps of the tricuspid valve, the posterior papillary muscle has chordae tendineae that attach to the posterior and medial (septal) cusps, and the
medial papillary muscle has chordae tendineae that attach to the anterior and medial (septal) cusps. A ridge of tissue known as the moderator band is often seen. The moderator band extends across the right ventricular apex from the anterior papillary muscle to the interventricular septum and contains the right bundle branch (Fig 6).

The left ventricle forms the left border of the heart. Papillary muscles and chordae tendineae can be visualized on both routine contrast-enhanced CT scans and cardiac-gated CT scans. The left ventricle contains anterior and posterior papillary muscles. The anterior papillary muscle is more easily seen on axial images. Reformatted images will depict both papillary muscles and their connections to the left ventricular wall. The left ventricular papillary muscles have chordae tendineae that attach to the anterior and posterior mitral valve leaflets (Fig 7).
Cardiac Valves
The aortic valve is often identified on contrast-enhanced CT scans. The aortic valve is usually oriented oblique to the axial plane. This nonaxial orientation can cause distortion of the cusps and may be misinterpreted as an aneurysm of a sinus of Valsalva. Coronal reformatted images will help confirm that the valve is oriented oblique to the axial plane of the CT scanner and that the sinuses of Valsalva are normal (Fig 8). The pulmonary valve is also oriented oblique to the axial plane. The pulmonary valve leaflets are not as easily identified on contrast-enhanced CT scans as is the aortic valve. The pulmonary valve leaflets may be only partially demonstrated and should not be mistaken for thrombus or an intimal flap. Reformatted images will better depict the pulmonary valve (Fig 9). The tricuspid valve leaflets are often obscured by the high-attenuation contrast material entering from the SVC; the mitral valve leaflets are usually better visualized.

Pericardial Recesses
The pericardium surrounds the heart and extends superiorly to cover the main pulmonary artery,
ascending aorta, and SVC (Fig 10). The pericardium can be identified at cross-sectional imaging when it is outlined by mediastinal and subepicardial fat or when it contains fluid or is thickened. The visceral pericardium (epicardium) adheres to the heart and great vessels. It forms recesses and sinuses, which can be visible at cross-sectional imaging if they contain enough fluid, even in the absence of pericardial effusion. Knowledge of the location of these recesses and sinuses will prevent mistaking them for enlarged lymph nodes or other masses (9–18). Knowledge of the pericardial anatomy is also important because tumors and pericardial cysts may arise in these locations. The pericardial recesses can be categorized on the basis of whether they arise from the pericardial cavity proper, the transverse sinus, or the oblique sinus. The transverse sinus lies posterior to the ascending aorta and main pulmonary artery, just above the left atrium. The oblique sinus is the posterior extension of the pericardium and lies posterior to the left atrium and anterior to the esophagus. The transverse sinus lies superior and anterior to the oblique sinus. However, the transverse and oblique sinuses do not communicate at this level and are separated by two pericardial reflections (Fig 11).
Figures 10, 11. (10) Drawing illustrates a cutaway view of the anterior aspect of the heart. Note how the pericardium extends superiorly to cover the great vessels (arrows). AA = ascending aorta, LV = left ventricle, PA = pulmonary artery, RA = right atrium, RV = right ventricle, SVC = superior vena cava. (11) Pericardial recesses and sinuses. (a) Drawing illustrates the pericardial sac with the heart removed. Note that the transverse sinus (T) and oblique sinus (*) are separated by pericardial reflections. Note also the extension of the pericardium superiorly. The pulmonic vein recesses (arrows) lie between the superior and inferior pulmonary veins. (b, c) Axial contrast-enhanced cardiac-gated images of the heart obtained at (b) and inferior to (c) the level of the right inferior pulmonary vein show areas of fluid attenuation anterior, posterior, and inferior to the vein (arrowheads). (d, e) Sagittal (d) and coronal (e) reformatted images from CT data show the relationship between the fluid in the pulmonic vein recess (arrowhead) and the pulmonary vein.
Recesses Arising from the Pericardial Cavity Proper.—The pulmonic vein recesses, which are usually small, lie along the lateral borders of the heart between the superior and inferior pulmonary veins (Fig 11). These recesses are located where the pericardium is attached to the venous adventitia. At CT, the left pulmonic vein recess is identified more frequently than the right pulmonic vein recess (12). However, the latter is usually deeper than the former, possibly because the left pulmonary veins often form a common trunk (13). The pulmonic vein recesses are in proximity to and can be mistaken for bronchopulmonary lymph nodes (18). The postcaval recess lies posterior to and to the right of the SVC and is also usually small.

Recesses Arising from the Transverse Sinus.—The superior aortic recess extends anterior to the ascending aorta and has anterior, posterior, and right lateral portions (Fig 12). The
anterior portion of the superior aortic recess has a characteristic triangular shape as it insinuates itself between the ascending aorta and the main pulmonary artery. The lateral portion similarly insinuates itself between the ascending aorta and the SVC. The posterior portion lies posterior to the ascending aorta, where it is sometimes referred to as the superior pericardial recess or superior sinus (9,11,19). The inferior portion of the superior aortic recess communicates with the transverse sinus. The posterior extension of the superior aortic recess can be mistaken for a lymph node. Distinguishing features of the posterior portion of the superior aortic recess are its location directly posterior to the ascending aorta, its crescent shape, and the fact that it has fluid attenuation. These features help distinguish fluid in the pericardial recess from precarinal lymph nodes, which tend to be round or oval and of soft-tissue attenuation. The superior aortic recess attaches directly to the aorta so that intervening fat is not identified. This lack of a fat plane also helps distinguish fluid in the pericardial recess from precardinal lymph nodes. Occasionally, the superior pericardial recess extends more superiorly than expected to lie in a right paratracheal location, where it may be mistaken for a right paratracheal lymph node or bronchogenic cyst (Fig 12) (11,18). Use of thin sections and two-dimensional reformatted images can help demonstrate the connection of the recess to the pericardium. The presence of fluid attenuation is also helpful in distinguishing pericardial fluid from a right paratracheal lymph node. Fluid in the anterior portion of the superior aortic recess has also been described as mimicking the appearance of aortic dissection (14,20).

Figure 13. (a) Axial contrast-enhanced CT scan shows a small amount of fluid in the transverse sinus (T) posterior to the ascending aorta (AA). The transverse sinus extends laterally, where it communicates with the left pulmonic recess (arrow) inferior to the left pulmonary artery. PA = main pulmonary artery. (b) Axial contrast-enhanced CT scan obtained slightly superior to a shows fluid in the left pulmonic recess (arrow). LSV = left superior pulmonary vein, PA = main pulmonary artery, RPA = right pulmonary artery.
The inferior aortic recess extends inferiorly from the transverse sinus posterior to the aorta and anterior to the left atrium, extending inferiorly to the level of the aortic valve (17). The right and left pulmonic recesses lie inferior to the right and left pulmonary arteries, respectively. Fluid collections within the pulmonic recesses can mimic the appearance of lymphadenopathy (Fig 13) (14).

Recesses Arising from the Oblique Sinus.— The oblique sinus extends superiorly behind the right pulmonary artery and medial to the bronchus intermedius, where it is called the posterior pericardial recess. Fluid in the posterior pericardial recess may be mistaken for peribronchial or subcarinal lymph nodes (Fig 14).

Paracardiac Structures
The pericardiophrenic (or pericardiacophrenic) arteries and veins and phrenic nerves course along the lateral aspects of the pericardium. Although these structures are not usually visible, knowledge of them is important. The phrenic nerves lie along the lateral aspect of the mediastinum and heart. These nerves are not typically visualized. Knowledge of the location of the phrenic nerves is important, however, since nerve sheath tumors may arise from them (21,22). The pericardiophrenic veins arise from the brachiocephalic veins and drain into the inferior phrenic veins. The pericardiophrenic veins may be single or multiple and can enlarge due to collateral flow when the SVC or IVC is obstructed (Fig 15) (23–25). A persistent left SVC occurs in less than 1% of the general population but is more prevalent in patients with congenital heart disease (24,26,27). The left SVC arises from the left anterior cardinal vein and courses along the left lateral aspect of the heart (2). In the majority of cases, the left SVC empties into the coronary sinus (2). Although it
may be difficult to identify the left SVC along its entire course, enlargement of the coronary sinus helps confirm drainage of the left SVC into the right atrium (Fig 16). When a left SVC is present, the left brachiocephalic vein is absent in 65% of cases. The right SVC is absent in 10%–18% of patients with a left SVC and may be diminished in size when present (24,26,27).

**Conclusions**

Faster scanning techniques and cardiac gating allow improved visualization of finer anatomic details of the heart and pericardium compared with older scanning techniques. Knowledge of the cardiac anatomy will prevent mistaking normal anatomic structures for pathologic processes.

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**References**

Figure 16. Sequential axial contrast-enhanced CT scans demonstrate the bilateral venae cavae. The left vena cava (arrow in a and b) courses along the lateral aspect of the heart and drains into the right atrium via the coronary sinus, which is enlarged (arrowhead in c). RA = right atrium, * = right SVC.


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