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A highly-detailed anatomical study of normal pericardial structures as revealed by in-vivo computed tomography and magnetic resonance images and ex-vivo novel 3D reconstructions from Visible Human Server

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REVIEW ARTICLE



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ABSTRACT

The pericardial cavity, sinuses, and recesses are frequently depicted on Computed Tomography (CT) and Magnetic Resonance (MR).

We here review the normal human pericardial structures as provided by MR imaging of young, healthy subject and CT scans acquired after iatrogenic coronary dissection. We compared such radiological information with cadaveric axial and sagittal sections of the human body provided by the Visible Human Server (VHS), Ecole Polytechnique Federale de Lousanne (EPFL), Switzerland.

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KEYWORDS

pericardium, pericardial recesses, radiological anatomy, magnetic resonance imaging, computed tomography

Learning Objectives

- Acquire an in-depth knowledge of normal human pericardium, its anatomy, sinuses and recesses
- Acquire a clear understanding of the appearance of the normal pericardium on CT and MRI imaging

Introduction - pericardial anatomy

The heart is located within the double walled fibro-serous pericardial sac. The inner serosal layer, named the visceral pericardium (Fig. 1A-D), is a thin, smooth, glossy, and transparent lamina. It is closely attached to the epicardial surface of the heart and covers a subepicardial layer of connective tissue containing fat and coronary vessels [1]. The pericardium covers the epicardial surface of both ventricles and atria completely, except for the roof of the left atrium (Fig. 1C-D) where a *sine epicardio* area lies (this area corresponds to the atrial venous mesocardium, violet area in

Fig. 1D). It also covers the atrial appendages and the intra-pericardial tract of the venae cavae with the exception of the superior (pink and purple area in Fig. 1D) and inferior post-caval mesocardia (Fig. 1D) [1].

The serosal layer reflects back on itself to become the outer fibrous parietal layer and this reflection generate a closed pericardial cavity filled with serous fluid (up to 60 mL). In some specific points pericardial reflection generates sinuses and recesses that have characteristic relationships with the aorto-pulmonary vascular pedicle and with the venous pole of the heart. A thorough knowledge of the pericardial recesses and sinuses morphology, topography and relationships is essential to differentiate these structures from other findings, such as fluid collections due to pathologic pericardial

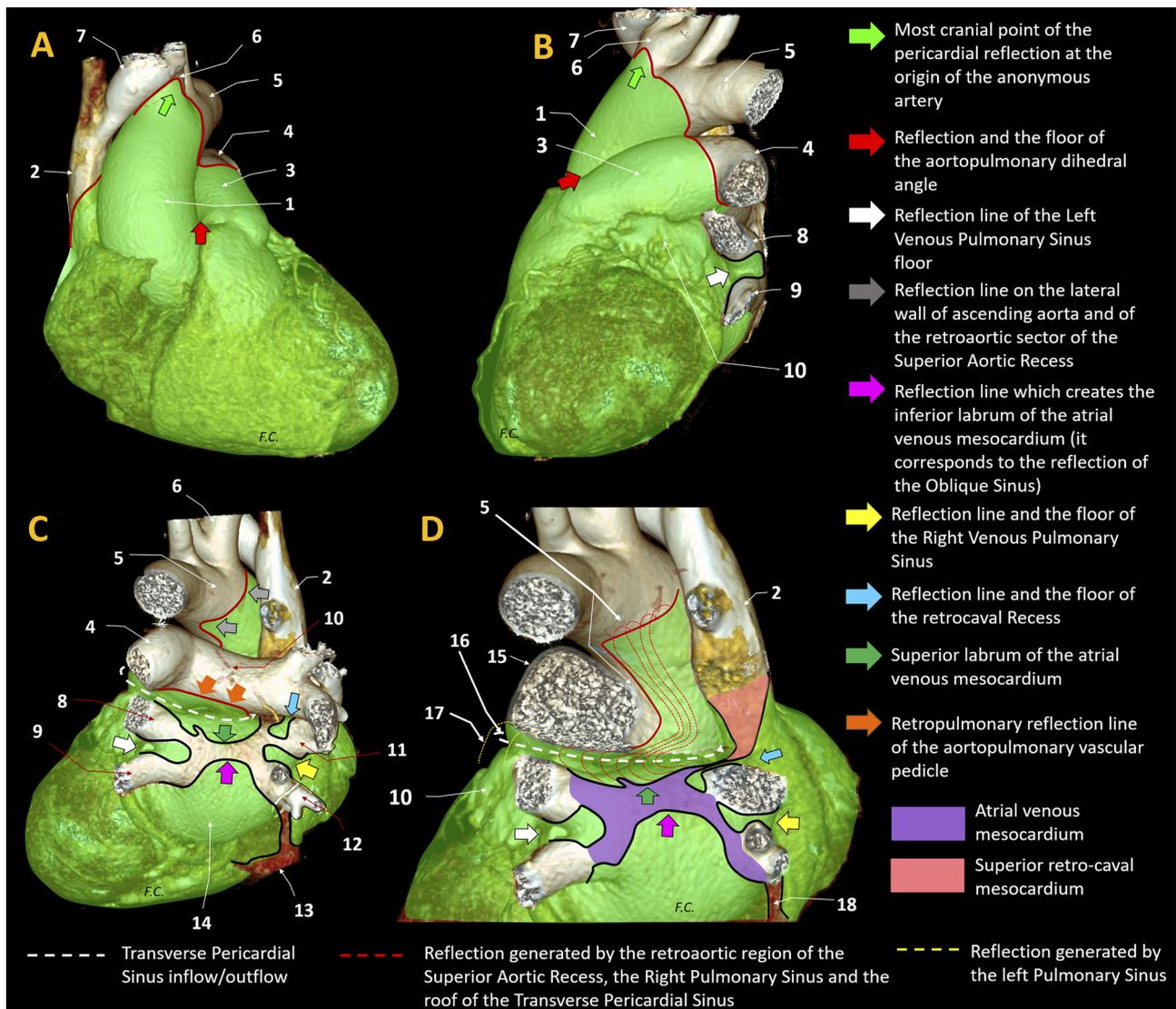


Fig. 1. A-D. 1. Distribution of the pericardial visceral leaflet and the pericardial reflection line. The distribution areas covered by the visceral pericardium are visible in green. In A-C images the heart is rotated to the right along its longitudinal axis in order to show each distribution area. From C to D the Left and Right pulmonary artery have been removed.

Legend - 1. Ascending aorta; 2. Superior vena cava; 3. Pulmonary trunk; 4. Left pulmonary artery; 5. Aortic Arch; 6. Anonymous artery; 7. Left Brachiocephalic vein; 8. Left superior pulmonary vein; 9. Left inferior pulmonary vein; 10. Left atrial appendage; 11. Right superior pulmonary vein; 12. Right inferior pulmonary artery; 13. Inferior vena cava; 14. Left atrium; 15. Dissected bifurcation of pulmonary trunk; 16. Left entrance to the Transverse Pericardial Sinus through the Left Pulmonary sinus; 17. Reflection of the Left Pulmonary Sinus; 18. Inferior Retro-Caval Mesocardium

effusions, normal lymph nodes or paratracheal, subaortic, and hilar lymphadenopathies, ascending aorta dissections and aneurysms, bronchogenic and thymic cysts [2].

Methods

To describe the normal human pericardial cavity, sinuses, and recesses anatomy we used balanced steady-state free precession (bSSFP) and T1-weighted MR sequences acquired in five young, healthy subjects and two CT scans acquired in one patient after iatrogenic dissection of a coronary artery occurred during invasive coronary angiography. In addition, we used ex-vivo cross-sectional photographs of the human body provided by the Visible Human Server (VHS), Ecole Polytechnique Federale de Lousanne (EPFL), Switzerland. We also processed original 3D reconstructions obtained from axial cadaveric sections of the VHS using the Rhinoceros software (version 6.0, McNeel North America, Seattle, WA, USA).

The Visible Human Server, in particular, has created a publicly-available, anatomically detailed data set of ex-vivo sections of the human body from the Visible Human Project of The U.S. National Library of Medicine (NLM).

The course of pericardial lines of reflection

There are two pericardial lines of reflection (Fig. 1A–D) localized around the aortopulmonary vascular pedicle [1] (brown line in Fig. 1A–D) and the venous pole of the heart [1] (black line in Fig. 1B–D).

The line of reflection localized around the aortopulmonary vascular pedicle

The line of reflection localized around the aorta and the pulmonary trunk embraces these vessels, with no penetration. This line of reflection extends from the origin of the anonymous artery where it reaches its highest point (green arrow in Fig. 1A and B) (Fig. 1A–C).

From the origin of the anonymous artery to the left. The leftward line of reflection goes obliquely down to the left surface of the aortic arch until the pulmonary trunk, closely to its bifurcation (brown line in Fig. 1A–B; yellow arrow in Fig. 2B and E).

Inferior to the origin of the left pulmonary artery (Fig. 1B and C; Fig. 2C and D) it runs to the right on the postero-inferior surface of the right pulmonary artery (orange arrow in Fig. 1C; green arrow in Fig. 2C and D). This last tract may be defined as “retropulmonary” (or “infrapulmonary”). It goes back to the retroaortic line of reflection (see below) beneath the right pulmonary artery (Fig. 1D; Fig. 2C and D). Along its retropulmonary course, this line of reflection lays right above the left atrium with its limb merging with the other one coming from the superior labrum of the venous

mesocardium forming the transverse pericardial sinus roof (Fig. 1C and D; Fig. 2C and D).

From the origin of the anonymous artery to the right. The rightward line of reflection goes obliquely down along the anterolateral wall of the ascending aorta (gray arrows in Fig. 1C; light blue arrows in Fig. 2C–E). Therefore, it comes posteriorly to the aortic arch (Fig. 1C and D; Fig. 2C and D; Fig. 3B–D) running between the brachiocephalic vein confluence into the superior vena cava. Behind the aortic arch, it goes across the aorta for 1 cm, rejoining with the retropulmonary tract already described, right below the right pulmonary artery (Fig. 1D; Fig. 2D).

In this region, the line of reflection only covers half of the posterior wall of the aorta (light blue arrows in Fig. 2C–E), so that the left postero-lateral surface of the ascending aorta is “bare”, i.e. without the visceral pericardial coating. At this level, the pericardial line of reflection creates the superior aortic recess (Fig. 2C–E; Fig. 3B–D), which can be shown in the VHP as well as in MR and CT images (Fig. 4A and D; Fig. 5A, D and E; Fig. 6A–F).

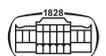
Therefore, the line of reflection around the aorto-pulmonary vascular pedicle is shared by these two vessels, but is not complete; in fact, the left posterolateral surface of the ascending aorta and the first tract of the aortic arch lack the visceral pericardial coating (Fig. 2C–E).

The reflection line around the venous pole of the heart

The venous pole of the heart is embraced by a single continuous line of reflection, but none of the blood vessels of the venous pole is completely surrounded by the visceral pericardium leaflet [1, 3] (black line in Fig. 1B, C and D). Only the lower third of the superior vena cava is surrounded by the visceral pericardium, while the upper two thirds are extrapericardial (Fig. 1D; Fig. 2D).

From the anterior surface of the superior vena cava (Fig. 1A; blue arrows in Fig. 2A and D), this line of reflection goes rightward to its lateral face up to reach the junction between the vena cava and the atrium.

At this level the line penetrates medially between the superior vena cava and the right superior pulmonary vein, creating a “cul de sac” between the two vascular formations, i.e. the bottom of the *Retrocaval Recess* [1, 3] (light blue arrows in Fig. 1C and D; Fig. 3C–D). Therefore, it penetrates between the right superior pulmonary vein and the right inferior pulmonary vein, forming the bottom of a “cul de sac” called *Right Venous Pulmonary Recess* [1, 3] (yellow arrow in Fig. 1C and D; Fig. 4C–E). This line descends on the postero-lateral convexity of the inferior vena cava (Fig. 1C and D; orange arrows in 3B, C, D) and continues with the left inferior retro-caval fold [3]. Therefore, the right inferior pulmonary vein and the inferior vena cava delimit a pericardial “meso”, called “*inferior retro-caval mesocardium*” (which has a vertical course and leaves a narrow central zone of the posterior surface of the inferior vena cava (Fig. 1D; orange arrows in Fig. 3B–D). Once it reaches the inferior vena cava outlet,



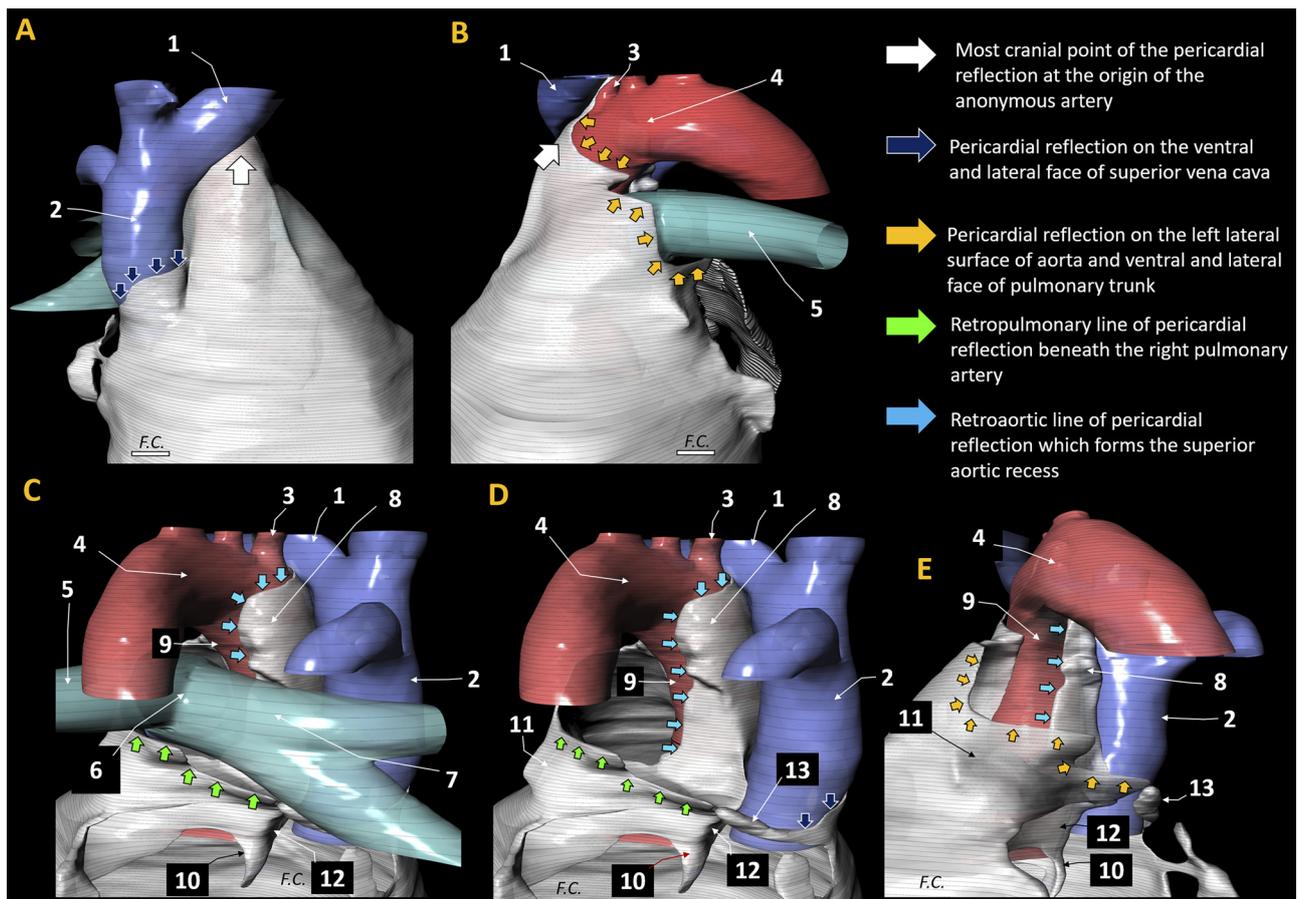


Fig. 2. A–E. The pericardium of the aortopulmonary vascular pedicle: anterior (A, B) and posterior (C–E) views. Original 3D reconstruction based on Visible Human Server axial sections. A. Frontal view of the aortopulmonary vascular pedicle and superior vena cava, with pericardium; B. Aortopulmonary vascular pedicle with pericardium slightly left rotated; C. Posterior view of aortopulmonary pedicle and pulmonary arteries with the superior vena cava, with pericardium. In D, E the right pulmonary artery has been removed in order to evaluate the retroaortic reflection line. The white arrow indicates the position of the highest point of the pericardial sac on the aortopulmonary vascular pedicle, between the left brachiocephalic vein and the origin of the anonymous artery. Blue arrows indicate the pericardial line around the anterior wall of the superior vena cava. Yellow arrows indicate the pericardial reflection line around the left lateral wall of the aortic arch, the aortopulmonary dihedral angle (red arrow) and the left pulmonary artery.

Legend. 1. Left brachiocephalic vein; 2. Superior vena cava; 3. Origin of the anonymous artery; 4. Aortic arch; 5. Left pulmonary artery; 6. Pulmonary trunk bifurcation; 7. Right pulmonary artery; 8. Posterior sector of the superior aortic recess; 9. Bare zone of the ascending aorta; 10. Inferior aortic recess; 11. Parietal surface of the left pulmonary sinus; 12. Surface of the right pulmonary sinus; 13. Retrocaval recess

surrounds him and continues ascending towards the postero-superior surface of the left atrium forming a convex arch that represents the *inferior labrum of the atrial venous mesocardium* (fuchsia arrow in Fig. 1C and D; Fig. 3B and C). The descending portion of this line reaches the base of the lower left pulmonary vein and partially envelops it. Between the two left pulmonary veins this line forms a “cul-de-sac” that represents the bottom of the *Left Pulmonary Venous Recess (RVPS)* [3] (white arrow in Fig. 1B, C and D; Fig. 3B–D). Such line continues forming an incomplete open medial cuff around the left superior pulmonary vein, and goes, on the roof of the left atrium (green arrow in Fig. 1C and D) toward the superior border of right superior pulmonary vein outlet until the base and anterior face of the superior vena cava. Therefore, a meso called *superior retro-caval mesocardium* (pink area in Fig. 1D) is formed behind the inferior

one third of that vein. The whole reflection stretched between the left superior pulmonary vein and the base of the superior vena cava represents the *superior (or antero-superior) labrum of the atrial venous mesocardium* (green arrow in Fig. 1C and D).

Thus, the reflection of the line of the two labra creates a meso at the level of the superior wall of the atrial dome, called *atrial venous mesocardium* (violet area in Fig. 1C and D). The vascular and myocardial territory delimited by such mesocardia is called “*sine epicardio*” due to the absence of pericardial visceral mesothelium.

The inferior labrum of the atrial venous mesocardium is reflected in the parietal leaflet that envelops the postero-inferior wall of the left atrium; such reflection generates a diverticulum, called the *Oblique Sinus of the pericardium* (or *Haller’s diverticulum*) [1], extended between the origins of the two pairs of pulmonary veins (Fig. 3B and C; Fig. 5A;

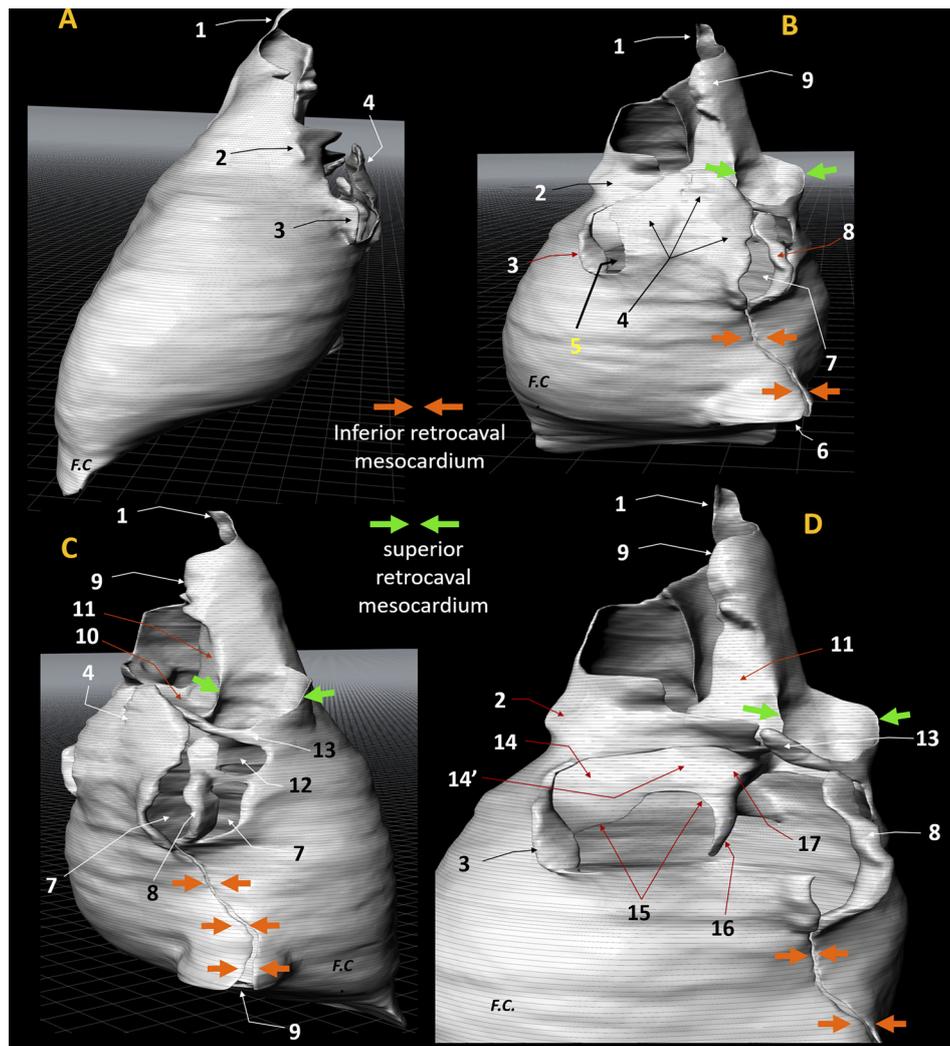


Fig. 3. A–D. Original 3D reconstruction of the pericardium coating the venous pole of the heart, based on Visible Human Server axial sections.

Legend – 1. The higher portion of the superior aortic recess; 2. Parietal surface of the left pulmonary sinus; 3. Left venous pulmonary recess; 4. Oblique sinus; 5. inlet into the pericardial sac of the left pulmonary veins; 6. Inlet of inferior vena cava; 7. Inlet of the inferior right pulmonary vein; 8. Right venous pulmonary recess; 9. Posterior sector of the superior aortic recess; 10. Roof of the transverse pericardial sinus; 11. Aortopulmonary sector of the transverse pericardial sinus at the confluence with the posterior sector of the superior aortic recess and inferior aortic recess; 12. Inlet of the left pulmonary sinus of pericardium; 13. Inlet of the right superior pulmonary vein into the pericardial sac; 14, 14'. Posterior wall of the transverse pericardial sinus; 15. Floor of the transverse pericardial sinus; 16. Inferior aortic recess; 17. Right pulmonary recess

Fig. 6D, E and F; Fig. 7A). The superior labrum of the atrial venous mesocardium merges with the retro-pulmonary line of reflection of the aorto-pulmonary vascular pedicle generating the roof of the Transverse Pericardial Sinus (dashed red line in Fig. 1D).

Pericardial sinuses and recesses

The pericardial sinuses and recesses are pericardial cavity dilations located along the lines of reflection between the visceral and the parietal pericardium around the venous pole of the heart and the aortopulmonary vascular pedicle. Many articles describe these structures [1–14].

The Superior Aortic Recess [4–7, 9, 10, 12]

The highest point of the pericardium is the visceral-parietal reflection located at the level of the origin of the anonymous artery. On axial planes, the pericardium partially covers the cranial tract of the ascending aorta and the most anterior tract of the aortic arch, like a horseshoe (Fig. 4C; Fig. 6B and C).

Behind the cranial portion of the ascending aorta, the pericardial cavity reflection creates a well-defined cavity called the Superior Aortic Recess (Fig. 2C and D; Fig. 3B–D) located anteriorly to the trachea (Fig. 4A and C; Fig. 5A; Fig. 6D–F). Mediastinal fibrous-fatty tissue stands between the pericardium and the trachea. Some inferior para-tracheal and subcarinal lymphnodes are located in the pre-tracheal mediastinal fibrous-fatty tissue.

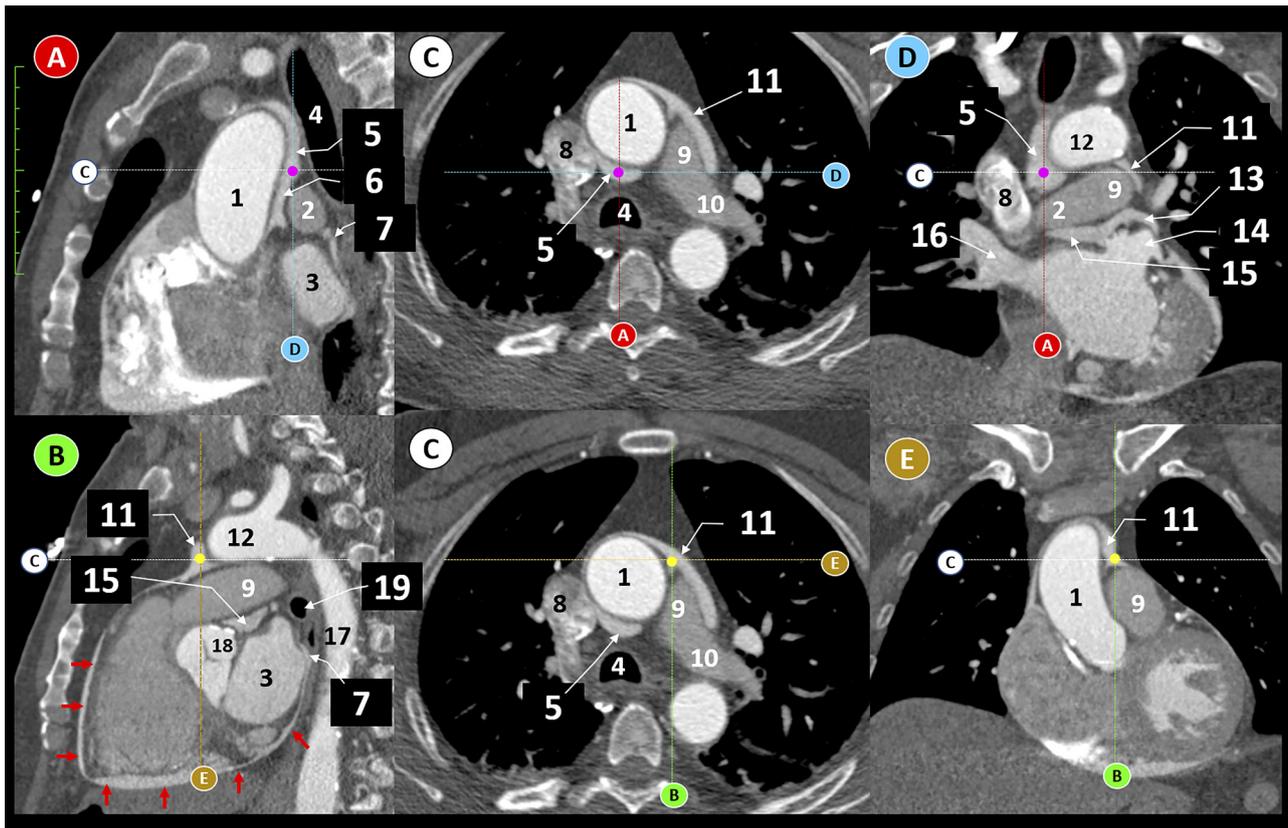


Fig. 4. A–E. CT scans acquired after catheter-induced iatrogenic coronary dissection in which the sinuses and pericardial recesses are clearly visible thanks to the presence of contrast medium. CT axial view through the pulmonary arterial bifurcation (C) exhibits the retroaortic region of the superior aortic recess and the sovrapulmonary region of the superior aortic recess. The distribution of the pericardial lumen around the aortopulmonary vascular pedicle is noticeable. A and B are correlated sagittal sections intersecting respectively the red and green dots in C. D and E are correlated coronal sections intersecting the blue and violet dots in C. Red arrows in B indicate the pericardial line course around the right ventricle and its outflow tract.

Legend – 1. Ascending aorta; 2. Right pulmonary artery; 3. Left atrium; 4. Trachea; 5. Posterior (retroaortic) sector of the superior aortic recess; 6. Aortopulmonary region of the superior aortic recess; 7. Oblique sinus; 8. Superior vena cava; 9. Pulmonary trunk; 10. Left pulmonary artery; 11. Retraction of the visceral pericardium in the aortopulmonary angle, and pericardial envelope of the pulmonary trunk; 12. Aortic arch; 13. Left pulmonary sinus; 14. Left atrial appendage; 15. Right pulmonary sinus; 16. Right superior pulmonary vein; 17. Descendent thoracic aorta; 18. Right coronary sinus; 19. Left main bronchus

On sagittal planes, the superior aortic recess extends along the entire posterior surface of the ascending aorta (Fig. 4A; Fig. 5A). It sneaks between the anterior wall of the anonymous artery and the posterior wall of the aorta, continuing downwards in the Transverse Pericardial Sinus (TPS).

Figures 2 and 3 show the original 3D reconstruction of the Superior Aortic Recess.

The Transverse Pericardial Sinus (TPS) [4–13].

The merger between the anterior-superior labrum of the venous atrial mesocardium and the retro-pulmonary reflection of the aorto-pulmonary pedicle forms a connecting flap, which represents the roof of the TPS (dashed red line in Fig. 1D). The TPS is a sort of narrow “horseshoe tunnel” (dashed white line in Fig. 1C and D). Its walls consist of visceral epicardial mesothelium which embraces the posterior surface of aorto-pulmonary vascular pedicle (which

forms the anterior wall of TPS) and the surface of the anterosuperior surface of the left atrium (which forms the posterior wall of TPS) (Figs 1D and 3D). The TPS has direct communications with other pericardial sinuses or recesses that can be considered fully-fledged in its dependencies: the Left Pulmonary Sinus (Fig. 1D; Fig. 2D and E; Fig. 3A and B; Fig. 4D; Fig. 5C–E), the Right Pulmonary Sinus (Fig. 3C; Fig. 4D; Fig. 5D and E; Fig. 6D–F; Fig. 7A–F), the Inferior Aortic Recess (Fig. 2C–E) and the Superior Aortic Recess (Fig. 2D; Fig. 4A, C and D; Fig. 5A–E; Fig. 6D–F; Fig. 7A–F). It does not allow the direct passage, posteriorly, to the intra-pericardial superior vena cava.

The TPS communications and dependencies

The TPS is located behind the aorto-pulmonary pedicle and anteriorly the left auricle and the antero-superior wall of the left atrium (white dashed line in Fig. 1C and D). The whole

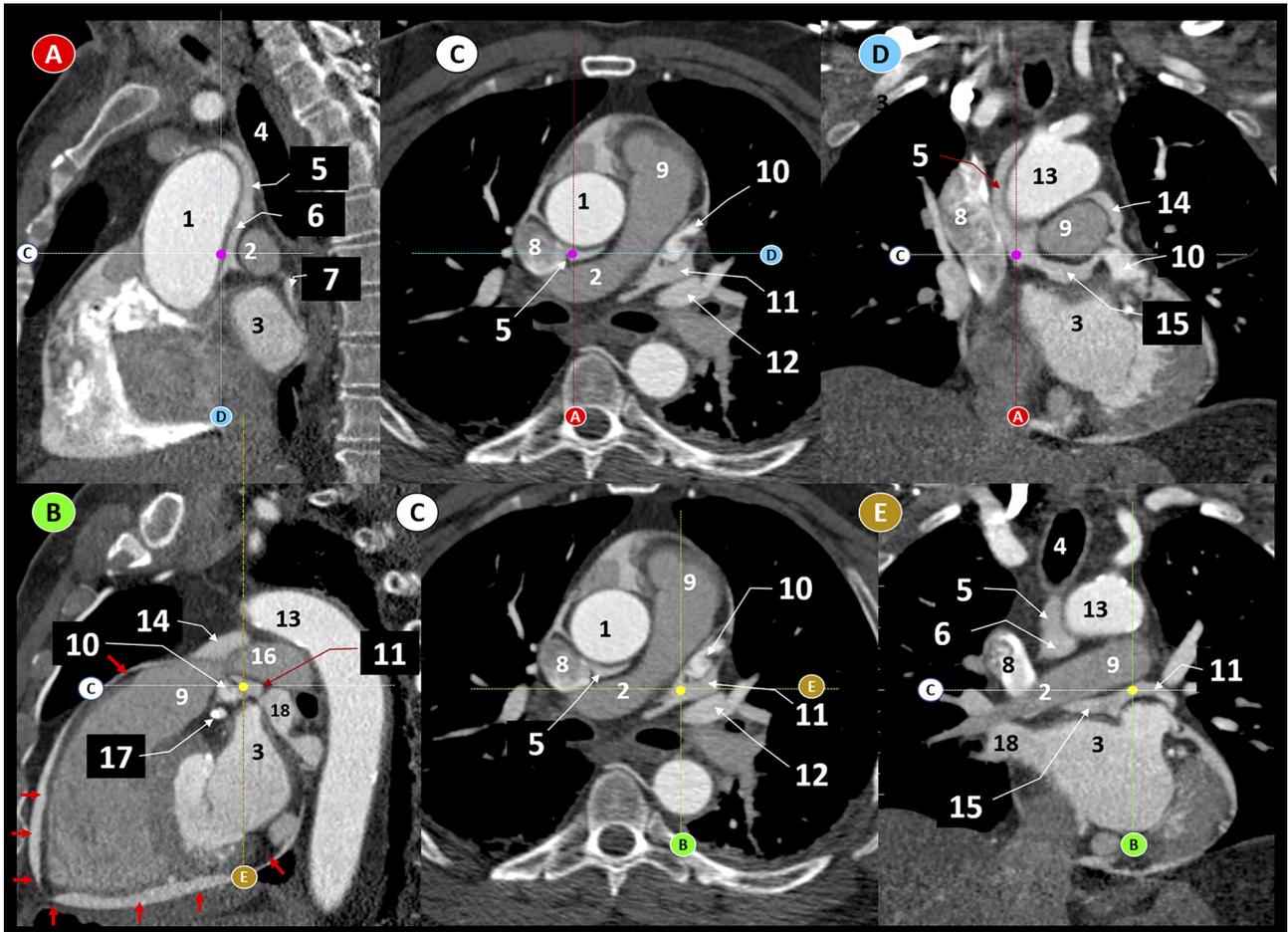


Fig. 5. A–E. CT scans acquired after catheter-induced iatrogenic coronary dissection in which the sinuses and pericardial recesses are clearly visible thanks to the presence of contrast medium. CT axial view (C), slightly caudal compared to Fig. 4, exhibits the Superior Aortic Recess coating the first tract of the aortic arch. A and B are correlated sagittal sections intersecting respectively the red and green dots in C. D and E are correlated coronal sections intersecting the blue and violet dots in C. Red arrows in B indicate the pericardial line course around the right ventricle and its outflow tract.

Legend. 1. Ascending aorta; 2. Right pulmonary artery; 3. Left atrium; 4. Trachea; 5. Posterior (retroaortic) sector of the superior aortic recess; 6. Aortopulmonary region of the retroaortic sector of the superior aortic recess; 7. Oblique sinus; 8. Superior vena cava; 9. Pulmonary trunk; 10. Left atrial appendage; 11. Left pulmonary sinus; 12. Left pulmonary vein; 13. Aortic arch; 14. Pericardial envelope of the pulmonary trunk; 15. Right pulmonary sinus; 16. Left pulmonary artery; 17. Origin of the left coronary artery; 18. Right superior pulmonary vein

extension of the TPS can be subdivided in the *Left TPS or Intrapulmonary Region*, because it takes place below the proximal portion of the left pulmonary artery and the bifurcation of the common pulmonary trunk (fuchsia dashed line in Fig. 7B and E). Hence, the TPS continues rightwards and runs posteriorly to the ascending aorta and aortic root. This area can be defined as *Right TPS or Retroaortic Region* and here it provides two important communications (green dashed line in Fig. 7B and E). The first one goes upward, directed between the aorta and the right pulmonary artery, and then it continues with the posterior sector of the superior aortic recess. This vertical section of the TPS retro-aortic region can be defined as the TPS aorto-pulmonary sector (Fig. 2D and E). The second communication is directed caudally and joins the Inferior Aortic Recess (Fig. 2C–E; Fig. 3D) like a thin cul-de-sac evagination of the TPS floor that runs along the right postero-lateral wall

of the caudal ascending aorta and the aortic root, close to the non-coronary sinus of Valsalva. Ultimately, in the retro-aortic region of the TPS, the Right Pulmonary Sinus converges in connection with the Left Pulmonary Sinus. *The Right Pulmonary Sinus* [4–6, 10–12] (Fig. 3C and D; Fig. 4D; Fig. 5D and E, Fig. 6D–F; Fig. 7A–F) is a TPS extension, which originates from its retroaortic region and develops below the proximal portion of the right pulmonary artery (hence the name) and superiorly to the anterior portion of the left atrial roof, in continuity, leftwards, with the left pulmonary sinus and the pericardial cavity that surrounds the medial portion of the left atrial auricle. *The Left Pulmonary Sinus* [4–6, 10–12] is located inferiorly to the proximal left pulmonary artery (hence the name), postero-laterally to the pulmonary trunk, and it is the pericardial casing that surrounds the superior part of the left atrial appendage (Fig. 1D; Fig. 2D and E; Fig. 3A–C; Fig. 4D; Fig. 5C–E; Fig. 7B and C).

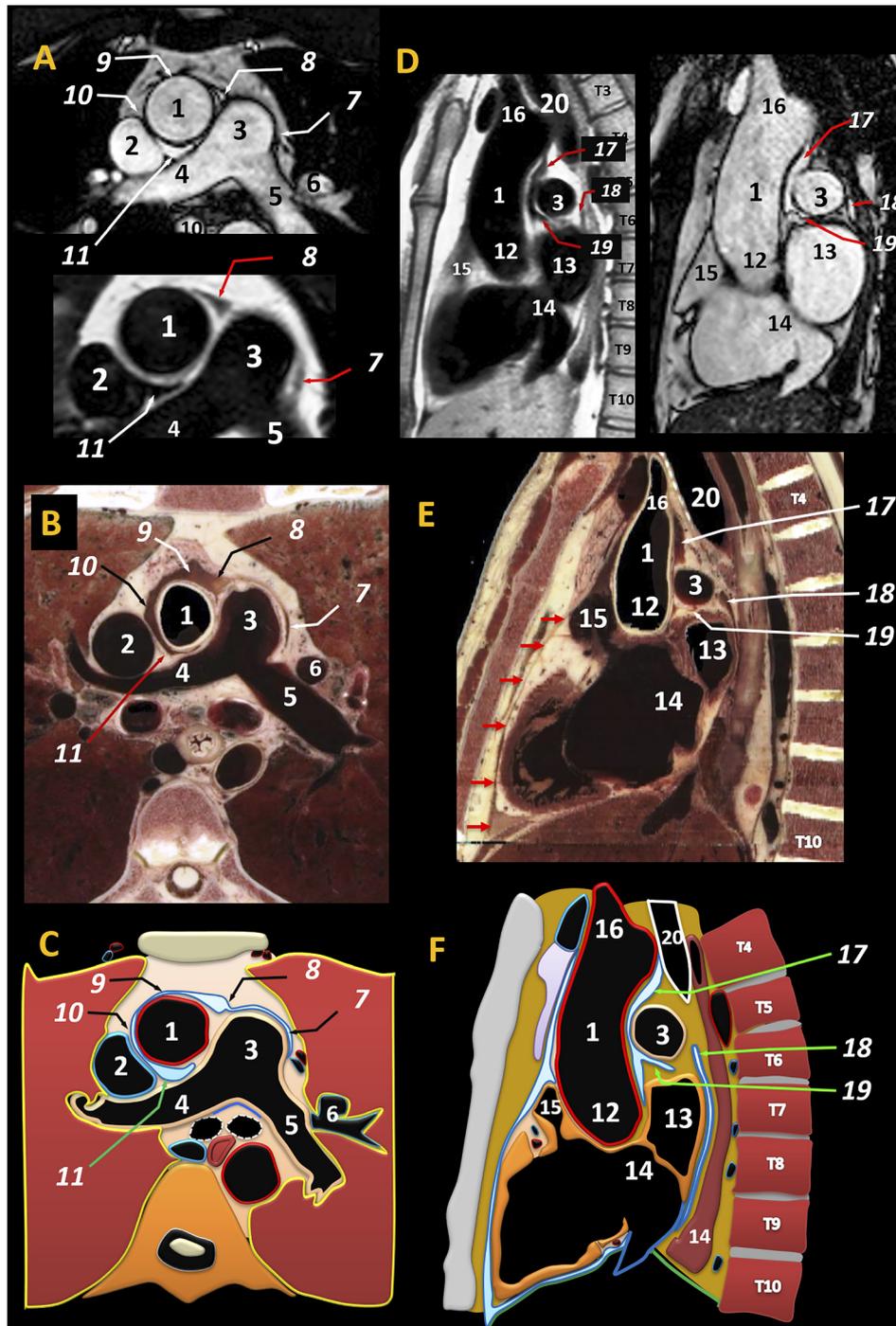


Fig. 6. A–F. Bright (bSSFP) and dark (T1-weighted Turbo Spin Echo) blood MR axial section (A) acquired in end-diastole, intersecting the pulmonary arterial bifurcation exhibits the retroaortic region of the superior aortic recess and the sovrapulmonary region of the superior aortic recess. The scheme (C), related to MR axial image (A) and Visible Human Server axial section (B), exhibits the pericardial course (in light-blue) around the aortopulmonary vascular pedicle. Black (T1-weighted Turbo Spin Echo) and bright (bSSFP) blood MR sagittal section (D) in mid-diastole. The scheme (F), related to MR sagittal image (D) and Visible Human Server sagittal section (E), exhibits the posterior region of the Superior Aortic Recess and of the Right Pulmonary Sinus. Figure 6B and E are courtesy of Prof. Hersch, Ecole Polytechnique Federale de Lousanne (EPFL), Switzerland. Visible Human Server. <http://visiblehuman.epfl.ch>.

Legend. 1. Ascending aorta; 2. Superior vena cava; 3. Pulmonary trunk; 4. Right pulmonary artery; 5. Left pulmonary artery; 6. Left superior pulmonary vein; 7. Pericardial envelope of the pulmonary trunk; 8. Region of Superior Aortic Recess corresponding to the aorto-pulmonary dihedral angle; 9. Anterior Region of Superior Aortic Recess; 10. Aortocaval sector of Superior Aortic Recess; 11. Retroaortic sector of Superior Aortic Recess; 12. Aortic root; 13. Left atrium; 14. Right atrium; 15. Right atrial appendage; 16. Anomalous artery origin; 17. Retroaortic Region of Superior Aortic Recess; 18. Top of the Oblique sinus of the pericardium; 19. Right pulmonary sinus; 20. Trachea

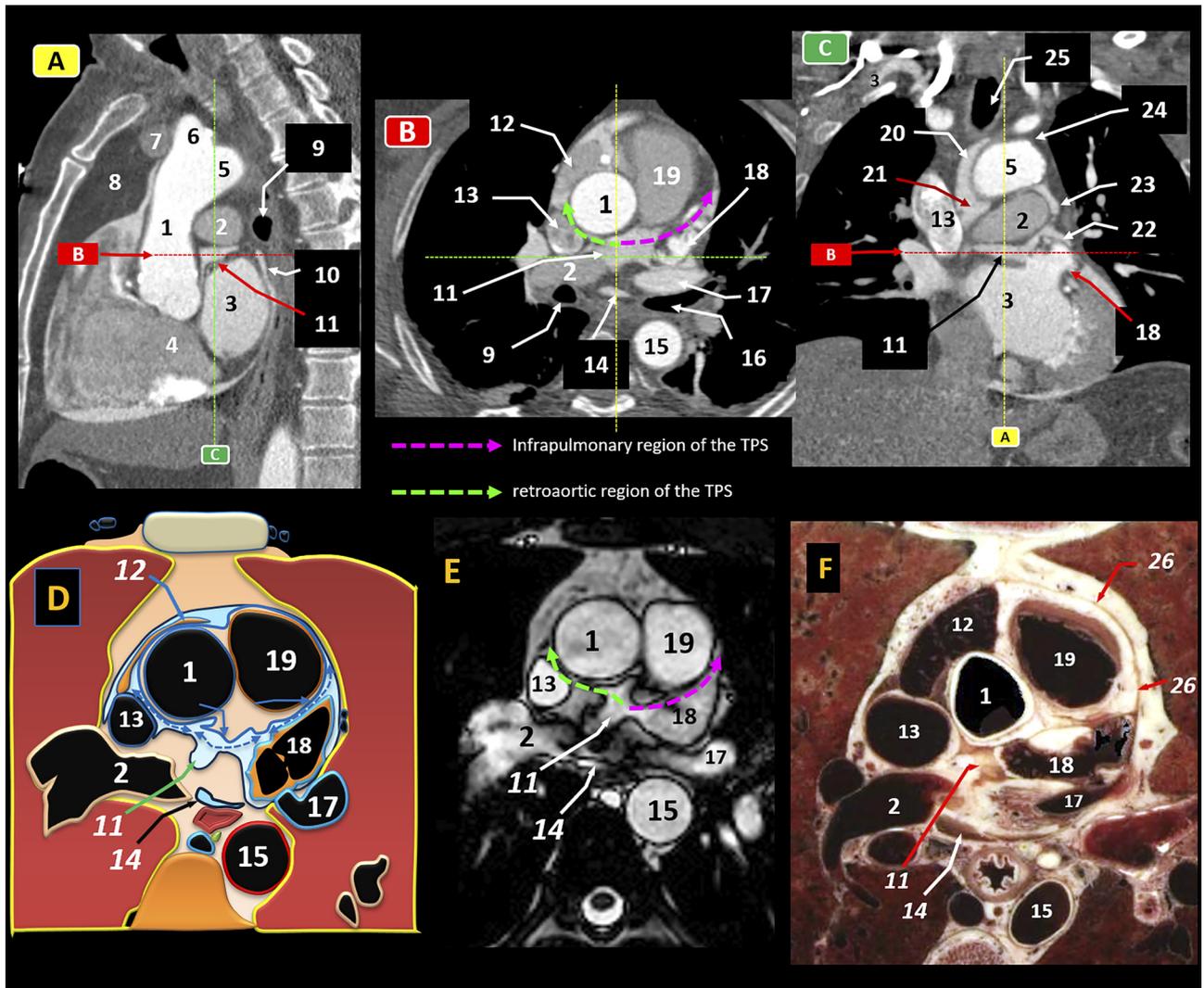


Fig. 7. A–F. CT (A–C) and bright blood (bSSFP) MRI axial (E) section clearly demonstrating the Right Pulmonary Sinus disposition and its relationship with the Transverse Pericardial Sinus. Figure 7F is courtesy of Prof. Hersch, Ecole Polytechnique Federale de Lousanne (EPFL), Switzerland. Visible Human Server. <http://visiblehuman.epfl.ch>.

Legend. 1. Ascending aorta; 2. Right pulmonary artery; 3. Left atrium; 4. Right atrium; 5. Aortic Arch; 6. Anonymous artery origin; 7. Right brachiocephalic vein; 8. Right lung; 9. Right Bronchus; 10. Oblique Sinus of pericardium; 11. Right pulmonary sinus; 12. Right atrial appendage; 13. Superior vena cava; 14. Top of the oblique sinus of the pericardium; 15. Thoracic descending aorta; 16. Left Bronchus; 17. Superior left pulmonary vein; 18. Left atrial appendage; 19. Pulmonary trunk; 20. Retroaortic region of Superior Aortic Recess; 21. Aortopulmonary region of Superior Aortic Recess; 22. Left pulmonary sinus; 23. Pericardial envelope of the pulmonary trunk; 24. Origin of the left common carotid artery; 25. Trachea; 26. Pericardial line

Computed Tomography (CT) imaging of the pericardium

On CT, the pericardium appears as a thin hypodense line enveloping the heart [2, 10, 15–16]. It extends superiorly from the great vessels; inferiorly to the diaphragm, although there may be certain areas where it is poorly visualized, such as overlying the lateral surface of the left ventricle. The pericardium is often thin, measuring only 1–2 mm in thickness, although a thickness less than 4 mm is considered normal [16]. A small amount of fluid is often present between the layers of the pericardium.

Here we used CT scans acquired after a catheter-induced iatrogenic coronary artery dissection, in which the sinuses and pericardial recesses are clearly visible due to the extravasation of iodinated contrast medium (Figs 4, 5 and 7).

Magnetic Resonance (MR) imaging of the pericardium

On bSSFP, T1- (Fig. 6A and D; Fig. 8) and T2-weighted MR sequences, the serous pericardium appears as a narrow hypointense band surrounded by the hyperintense

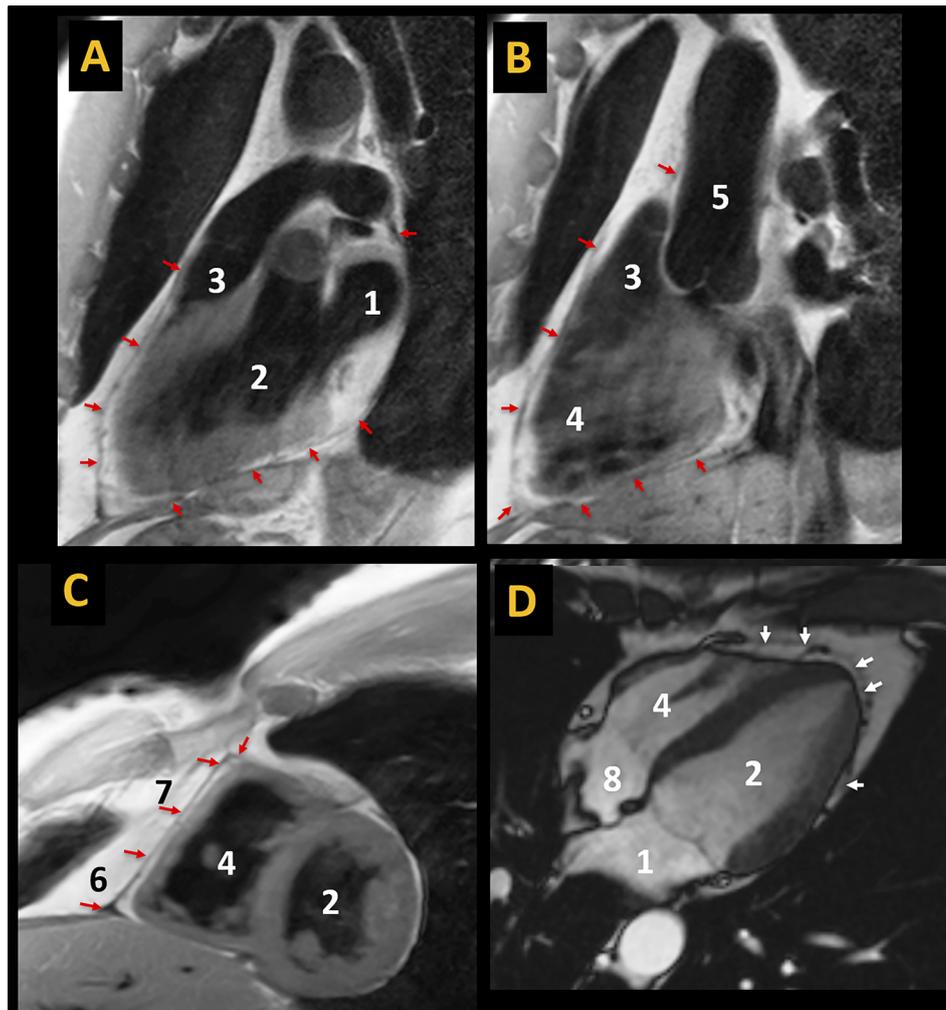


Fig. 8. A–D. Dark (T1-weighted Turbo Spin Echo) blood sagittal (A, B) and short axis (C) and four-chamber bright (bSSFP) blood (D) MR images clearly demonstrating the pericardial line around ventricles (highlighted by red and white arrows).

Legend. 1. Left atrium; 2. Left ventricle; 3. Right ventricle outflow; 4. Right ventricle; 5. Ascending aorta; 6. Pleuropericardial fat; 7. Retro-sternal fat; 8. Right atrium

signal of the surrounding retro-sternal and pleuro-pericardial mediastinal fat and subepicardial fat (Fig. 8). bSSFP sequences are generally preferred for cardiac structures evaluation because of their superior signal-to-noise ratio and high spatial resolutions, and as a combined T1-weighted and T2-weighted sequence, provide optimal tissue differentiation, making the identification of the pericardium particularly accurate [17–18].

Additional sequences can be used to visualize the pericardium, especially when certain diseases are suspected. T1-weighted post contrast sequences, and delayed enhancement sequences can all be used to assess for various pathologic processes.

The pericardial line is more easily visible where the pericardium is interposed between the subepicardial and mediastinal fatty tissue [16, 19–21]. On the contrary, the pericardial line is more difficult to distinguish from the underlying muscle where the subepicardial fat is poor or absent and the serous pericardium is very close to the myocardial profile.

Criteria for the identification of pericardial sinuses and recesses by MR: The example of the superior aortic recess

MR allows the identification of many of the sinuses and recesses visible by examining the cadaveric VHP/VHS sections. MR imaging criteria are: 1) the typical topographical localization; 2) morphology; 3) MR signal feature (e.g. intensity, homogeneity) compatible with the presence of fluid.

Retro-aortic sector of the superior aortic recess

The application of the above mentioned four identification criteria leads to the following conclusions:

1. *Topographic criteria.* On axial sections, the *posterior sector* of the superior aortic recess is located behind the ascending aorta and in front of the right pulmonary artery (Fig. 6A). The posterior sector of the superior aortic

recess is easily identifiable behind the ascending cranial aorta and the proximal tract of the aortic arch, above the origin of the proximal right pulmonary artery, on sagittal planes (Fig. 6D). In black-blood sagittal images (Fig. 6D left), we can see a thin strand of mediastinal fatty tissue between the posterior wall of the aorta and the visceral leaflet of the posterior sector of the Superior Aortic Recess. The superior part of that recess continues in the pericardium surrounding the aortic arch, like a narrow pedicle, and goes on to the origin of the anonymous artery (Fig. 6D).

2. *Morphologic criteria.* In MR axial images, both in bright and black-blood images, the retro-aortic sector of the superior aortic recess appears as a semilunar-shaped large cavity, with concavity contiguous to the posterior wall of the ascending aorta. It appears different from the equivalent sector identified in the VHP/VHS sections, which is smaller due to the preferential in vivo fluid collection caused by the aorto-caval bottleneck, which hampers the fluid flow during the cardiac cycle. Another hypothesis is that the supine position adopted during the MR acquisition moves the pericardial fluid to the posterior sectors of the superior aortic recess by a gravitational effect. On MR sagittal planes, the posterior sector of the superior aortic recess (Fig. 6D) looks like a uniformly cranium-caudally elongated strand, with posterior concavity.
3. *MR criteria.* On axial and sagittal images acquired through bright bSSFP sequences (Fig. 6A and D) the posterior sector of the superior aortic recess is characterized by a strongly and homogeneously hyperintense signal. The signal hyperintensity in bSSFP images is comparable to blood vessel, and it is compatible with the presence of fluid within the sector (Fig. 6A and D). On T1-weighted images, the superior aortic recess appears strongly and homogeneously hypointense (Fig. 6A and D), comparable to the blood vessels lumen.

Physiopathology of pericardial sinuses and recesses

Pericardial sinuses and recesses are well defined virtual cavities which may show, on CT scans, low-attenuation near water density (10-30 HU) when distended by a certain amount of fluid. In the vast majority of cases their identification is a paraphysiological finding since they may be viewed even without significative pericardial effusion, both in CT and MRI. They may present small linear peripheral rings that limit them and have different shapes: round, ovoid, triangular, linear, et cetera and some of them are more typical of certain recesses. No intravenous contrast enhancement is shown. They may mimic pathological structures as abovementioned and they are considered as recurrent diagnostic pitfall. Some imaging features may help to differentiate them from abnormal findings, and they include: contiguity with other pericardial spaces on axial, coronal and sagittal planes, characteristic morphology, density, absence of a definable wall and lack of mass effect on adjacent structures.

Conclusion

A highly-detailed anatomical comparison between radiologic and cadaveric imaging of the human pericardium provided by the Visible Human Server (VHS) is fundamental for a throughout knowledge of the normal pericardial structures. A fully understanding of pericardial anatomy, including its sinuses and recesses, is important in interpreting CT and MRI imaging in order not to confuse them with pathology.

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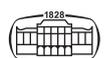
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REFERENCES

- [1] Bannister LH, Berry MM, Collins P, et al.: Gray's Anatomy – section 10: cardiovascular system, pericardium. 38th edition ed. Churchill Livingstone, New York Edinburgh, 1995, pp. 1471–2.
- [2] Shroff GS, Viswanathan C, Godoy MC, Marom EM, Sabloff BS, Truong MT: Pitfalls in oncologic imaging: pericardial recesses mimicking adenopathy. *Semin Roentgenol* 2015; 50: 235–40.
- [3] Chaffanjon P, Brichon PY, Faure C, Favre JJ: Pericardial reflection around the venous aspect of the heart. *Surg Radiol Anat* 1997; 19: 17–21.
- [4] Budoff MJ, Lu B, Mao S, Bakhsheshi H, Zhuang N, Liu S C, et al.: Evaluation of fluid collection in the pericardial sinuses and recesses: noncontrast-enhanced electron beam tomography. *Invest Radiol* 2000; 35: 359–65.
- [5] Groell R, Schaffler GJ, Rienmueller R: Pericardial sinuses and recesses: findings at electrocardiographically triggered electron-beam CT. *Radiology* 1999; 212: 69–73.



- [6] Kodama F, Fultz PJ, Wandtke JC: Comparing thin-section and thick-section CT of pericardial sinuses and recesses. *AJR Am J Roentgenol* 2003; 181: 1101–8.
- [7] Kubota H, Sato C, Ohgushi M, Haku T, Sasaki K, Yamaguchi K: Fluid collection in the pericardial sinuses and recesses. Thin-section helical computed tomography observations and hypothesis. *Invest Radiol* 1996; 31: 603–10.
- [8] Im JG, Rosen A, Webb WR, Gamsu G: MR imaging of the transverse sinus of the pericardium. *AJR Am J Roentgenol* 1988; 150: 79–84.
- [9] Ozmen CA, Akpınar MG, Akay HO, Demirkazık FB, Ariyurek M: Evaluation of pericardial sinuses and recesses with 2-, 4-, 16-, and 64-row multidetector CT. *Radiol Med* 2010; 115: 1038–46.
- [10] Levy-Ravetch M, Auh YH, Rubenstein WA, Whalen JP, Kazam E: CT of the pericardial recesses. *AJR Am J Roentgenol* 1985; 144: 707–14.
- [11] Truong MT, Erasmus JJ, Gladish GW, Sabloff BS, Marom EM, Madewell JE et al.: Anatomy of pericardial recesses on multidetector CT: implications for oncologic imaging. *AJR Am J Roentgenol* 2003; 181: 1109–13.
- [12] Vesely TM, Cahill DR: Cross-sectional anatomy of the pericardial sinuses, recesses, and adjacent structures. *Surg Radiol Anat* 1986; 8: 221–7.
- [13] Zurada A, Ustymowicz A, Loukas M, Michalak M, Czyzewska D, Gielecki J: Computerized tomography of the transverse pericardial sinus: normal or pathologic? *Clin Anat* 2017; 30: 61–70.
- [14] Black CM, Hedges LK, Javitt MC: The superior pericardial sinus: normal appearance on gradient-echo MR images. *AJR Am J Roentgenol* 1993; 160: 749–51.
- [15] Shroff GS, Boonsirikamchai P, Viswanathan C, Godoy MC, Marom EM, Truong MT: Differentiating pericardial recesses from mediastinal adenopathy: potential pitfalls in oncological imaging. *Clin Radiol* 2014; 69: 307–14.
- [16] Bogaert J, Francone M: Cardiovascular magnetic resonance in pericardial diseases. *J Cardiovasc Magn Reson* 2009; 11: 14.
- [17] Mantini C, Di Giammarco G, Pizzicannella J, Gallina S, Ricci F, D’Ugo E, et al.: Grading of aortic stenosis severity: a head-to-head comparison between cardiac magnetic resonance imaging and echocardiography. *Radiol Med* 2018; 123: 643–54.
- [18] Mantini C, Mastrodicasa D, Bianco F, Bucciarelli V, Scarano M, Mannetta G, et al.: Prevalence and clinical relevance of extracardiac findings in cardiovascular magnetic resonance imaging. *J Thorac Imaging* 2019; 34: 48–55.
- [19] Bogaert J, Taylor AM: Cardiac anatomy. In: *Clinical cardiac MRI* (eds: Bogaert J, Dymarkowski S, Taylor AM, Muthurangu V). 2nd edition ed. Springer; 2012.
- [20] Francone M, Dymarkowski S, Kalantzi M, Bogaert J: Magnetic resonance imaging in the evaluation of the pericardium. A pictorial essay. *Radiol Med* 2005; 109: 64–74; quiz 5–6.
- [21] Pontone G, Di Cesare E, Castelletti S, De Cobelli F, De Lazzari M, Esposito, A: Appropriate use criteria for cardiovascular magnetic resonance imaging (CMR): SIC-SIRM position paper part 1 (ischemic and congenital heart diseases, cardio-oncology, cardiac masses and heart transplant). *La radiologia medica* 2021. <https://doi.org/10.1007/s11547-020-01332-6>. 33629237.

