Epicardial Access: Patient Selection, Anatomy, and a Stepwise Approach

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ABSTRACT. Since their first major description in 1996, percutaneous epicardial treatments are becoming more common in clinical practice, especially with the growth of catheter ablations for ventricular arrhythmias. This approach requires a solid knowledge of techniques for pericardial access, along with the indications, clinical and electrocardiographic, the regional anatomy, and specific approaches to minimize potential complications. We review these aspects of pericardial access and illustrate the essential points of knowledge, along with a description of our institutional approach to this important clinical skill.

KEYWORDS. epicardial, stepwise, ventricular.

Background

In 1996, Sosa et al.1 introduced the technique of percutaneous pericardial access to facilitate catheter ablation in patients with Chagas disease and ventricular tachycardia from epicardial substrates. In recent years, use of the technique has grown dramatically, predominantly for catheter ablation of ventricular tachycardia.2–6 Epicardial access is also occasionally used to treat supraventricular tachycardias, including atrial fibrillation following failed endocardial approaches.4 Owing to its unique position to permit access to left-sided structures without the need to enter the central circulation, substantial efforts to develop percutaneous pericardial approaches for left atrial appendage ligation, cardiac resynchronization, and drug delivery techniques are under way.7

Much like trans-septal puncture 10 years ago, percutaneous pericardial access is an anxiety-provoking procedure for many interventionalists. However, with careful attention to detail, a good understanding of anatomy, and experience, it can be performed safely and successfully, resulting in access in 90% of patients without prior cardiac surgery.3,8

Patient selection

The most common indication for percutaneous pericardial access is previous failed ventricular tachycardia (VT) ablation, present in approximately 85% of pericardial procedures in published series and in our own experience. Other clinical characteristics may predict an epicardial arrhythmogenic substrate. These include Chagas disease, arrhythmogenic right ventricular dysplasia, and dilated cardiomyopathy (which is often characterized by mid-myocardial and epicardial basilar scar) (Figure 1).5

Procedural markers of an epicardial substrate include absence of early (>20 ms ahead of QRS) sites and persistence of an R-wave on the unipolar electrogram after extensive mapping of focal arrhythmias. Percutaneous access to the pericardium is difficult in the setting of previous bypass surgery because of dense adhesions; however, we have successfully applied the technique in patients with LV epicardial leads, in patients with isolated left anterior descending artery unroofing procedures (for an intramyocardial bridge), and in select patients with previous multivessel bypass. Although these isolated cases show that the technique is possible, it is important to emphasize that a significant risk is associated with undertaking procedures in the
pericardial space in these patients, and that they should only be attempted by the most experienced operators with immediate surgical back-up available. After surgically placed mechanical valves, we avoid percutaneous access due to the technical challenge, compounded by the clinical need for anticoagulation shortly after the procedure. In our experience, previous pericardial access does not preclude repeat entry, although entry in patients with clinical relapsing pericarditis is extremely difficult, and best performed with surgical assistance. Table 1 summarizes our approach to patient selection for epicardial access.

**Table 1:**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Recommendation</th>
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<tr>
<td>Failed endocardial ablation</td>
<td>++++</td>
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<tr>
<td>Chagas disease</td>
<td>++++</td>
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<tr>
<td>ARVD/DCM with epicardial ECG</td>
<td>+++</td>
</tr>
<tr>
<td>ARVD/DCM without epicardial ECG</td>
<td>++</td>
</tr>
<tr>
<td>Not recommended</td>
<td>--</td>
</tr>
<tr>
<td>Previous CABG</td>
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ARVD: arrhythmogenic right ventricular dysplasia; CABG: coronary artery bypass graft; DCM: ECG: electrocardiogram.

**ECG criteria for epicardial sites**

The electrocardiogram (ECG) has been used to suggest an epicardial origin of VT. The basic premise is that since the His-Purkinje system is endocardial, the wavefront of a VT with an epicardial focus or exit site must initially travel slowly through the myocardium towards the endocardium, away from leads facing the focus. This slow conduction results in a “pseudo delta wave” and a delay to the QRS peak (Figure 2). A number of parameters have been used to measure this delay, including the intrinsicoid deflection, maximum deflection index, and RS time to quantify the delay (Figure 3).

The presence of a Q-wave during tachycardia that is absent during normal conduction via the Purkinje system also suggests an epicardial focus at the site facing the lead, as the wavefront propagates from the epicardial site away from that lead. As shown in Figure 2, if the exit site of a tachycardia focus is directly in line with the surface ECG then a Q wave will be present. However it is important to recognize the limitations of the vectors—a Q-wave in lead I as seen in this example will only be present if the line of conduction from the exit site is directly along the vector measured by lead I, so that with other epicardial exit sites (i.e. those not in line with lead I) there will be a positive initial deflection in lead I. Thus, the ECG findings to suggest an epicardial focus, when present, are site specific. The relevant lead to have a Q-wave will depend on the exit site of the ventricle.

Important caveats exist in ECG determination of whether an arrhythmia is epicardial. The presence of post-infarction Q-waves on the baseline ECG can influence the arrhythmia morphology. Additionally, the ECG morphology indicates the breakout site at which sufficiently large regions of myocardium are activated to register on surface tracings. Thus, a mid-myocardial substrate may have an epicardial exit (and ECG appearance), and be amenable to an endocardial approach that delivers a sufficiently deep lesion. Alternatively, arrhythmias with an epicardial exit may also include critical circuit components that are endocardial or mid-myocardial and treatable endocardially. The same is true for epicardial accessory pathways, where the ablation site may be at a distance from the insertion into the ventricular surface. The ECG findings for right ventri-
Anatomy

Unlike many cardiovascular procedures, to safely perform percutaneous pericardial access an understanding of the anatomy of surrounding extracardiac structures and organs is as important as knowledge of cardiac anatomy. External anatomy can affect percutaneous pericardial access. Significant chest wall deformities may make the procedure challenging. Body habitus may determine the angle of entry, and the ability to manually displace the hepatic edge to allow for subxiphoid access. Pericardial access in obese patients is best left to experienced hands; the steeper entry angle or lower puncture site required bring attendant risks (see below).

We divide a review of anatomy into the surrounding structures below the diaphragm, and above the diaphragm, including the heart itself.

Diaphragm and subdiaphragmatic structures

Diaphragm

The diaphragm is a major respiratory muscle that separates the thoracic from abdominal contents. The anterior attachments of the diaphragm are to the xiphisternum. From here it fans out via a tendinous arch to the fifth and sixth ribs or the transversus abdominis aponeurosis. As a result there exists a potential window lateral to the xiphisternum at the angle it meets the costal margin where puncturing may result in being above the diaphragm directly toward the fibrous pericardium that attaches to the thoracic wall. The size and accessibility of the window depends on the patient’s body habitus and individual anatomy. The diaphragm arches back in a “parachute” shape to a maximum height equivalent to the sternal–xiphisternal junction at the midline. Thus, a needle must be angled parallel to the “parachute,” to reach the heart, which rests on the central tendon (Figure 4).

A puncture delivered to avoid penetrating the diaphragm by running parallel to it will necessarily result in anterior approach (discussed further, below). Since the inferior aspect of the heart sits on the diaphragm, and puncture aimed to enter the inferior wall is more likely to pass through the diaphragm and possibly the liver.

Laterally the diaphragm attaches to the cartilage of the seventh through ninth ribs and along the bony margins of the tenth through twelfth ribs. Arching posteriorly it attaches to tendinous arches from the tenth and eleventh interspaces before becoming crura that connect to the upper lumbar vertebrae.

Liver

The anterior margin of the liver extends to a line approximately on the upper third of the abdomen between the xiphisternum and umbilicus, roughly at the level of the costal cartilage of the ninth ribs. From there it arcs posteriorly in the midline and comes to the diaphragm at the level of the sternal–xiphisternal junction. The left lobe of the liver crosses the midline and represents a possible site of injury should the access needle enter the peritoneum. The liver and abdominal contents can often be displaced posteriorly.
with a guiding hand while the other hand is used for the puncture. Hepatomegaly is a potential risk factor for complication, increasing the risk of liver puncture with the subxiphoid approach. Puncture of the liver with just the needle is often well tolerated, but is best avoided.

**Spleen**

In the absence of splenomegaly there is little risk of splenic puncture. The spleen lies lateral to the right lobe of the liver, between the gastric fundus and the diaphragm and is deep relative to the liver.

**Other structures**

Potential complications can also arise from puncture of the diaphragmatic vessels or the colon. Although an uncommon complication, this may necessitate surgical intervention for intraperitoneal hemorrhage.

**Supradiaphragmatic structures**

**Thorax**

In close proximity to the sternum, intercostal ligaments can make placement of needle and sheath technically challenging; a subcostal approach eliminates this consideration (Figure 5). The internal mammary artery originates in the subclavian artery and passes posteriorly, parallel to the sternal border. Classic descriptions of the vessel are that it runs almost vertically 1.25 cm (1/2 inch) from the sternal edge, giving off perforating vessels to the chest wall and mammary tissue and is accompanied by a pair of veins. At the sixth intercostal space it divides into the musculophrenic and superior epigastric arteries. Inferior to the bifurcation, the distance from the internal mammary artery to the sternum and inferiorly to the xyphoid process increases, minimizing risk of inadvertent injury at lower intercostal or subcostal access sites; however, the range of actually distances and angles from the standard access sites has not been well studied. Cases of intrathoracic hemorrhage

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**Figure 3:** Electrocardiogram (ECG) of an epicardial focus and established criteria. The left panel shows an ECG of a patient with an epicardial focus. Note the pseudo delta wave in multiple leads (arrows), and the MDI of 0.6. The right panel shows an ECG to which published criteria associated with an epicardial VT have been applied (from Valles et al. *9*). MDI: maximum deflection index, defined as time to V2 peak divided by precordial QRS duration; IDT: intrinsicoid deflection time defined as time from QRS onset to peak R or S wave, duration of pseudo-delta wave, and shortest RS duration in any lead. Figure 3 reprinted, with permission from Wolters Kluwer Health.
during percutaneous transthoracic procedures caused by internal mammary artery injury have been reported. 18,19

Lungs and pleura

Most of the lateral surfaces of the heart are covered by lungs, so that direct access at these sites is not possible in the absence of a large effusion, without lung deflation. Anteriorly, predominantly over the right ventricle, a window exists through which a needle can pass from the body surface to the pericardial space without traversing the pleura or lung tissue (Figure 6). While the size of the window varies with respiration, with tidal volume respiration the changes are modest. The left lung anteriorly follows the sternal line to the fourth rib where the pericardial cavity begins. It turns laterally to a point approximately 2.5 cm (1 inch) from the sternal border from where it turns inferiorly and medially as the lingula to the sixth costal cartilage. Thus, a laterally placed puncture may result in a pneumothorax, although in our experience if the puncture is initiated in the paraxyphoid triangle (Figures 4 and 5) it is unlikely that the needle will reach the pleura provided the needle in not angulated too far in the lateral direction.

Pericardium

The pericardium is composed of a thick, outer, fibrous layer, and a dual inner serosal layer, with parietal and visceral components. The pericardial space, the “target” for percutaneous pericardial access, is a potential space between the parietal and visceral serosal surfaces that normally contains 20–30 ml of serous fluid (Figure 7). The fibrous pericardium is continuous with the adventitia of the
great vessels. Anterior to the pericardium is the sternum; sternopericardial ligaments form the anterior attachments. Lateral and posterolateral structures in juxtaposition to the pericardium are the lungs, and posterior is the descending thoracic aorta and the esophagus. Inferior to the pericardium is the diaphragm, to which it attaches.

The phrenic nerves run bilaterally along the borders of the pericardium, between the fibrous pericardium and the mediastinal pleural layers. The right phrenic nerve descends along the right brachiocephalic vein to the superior vena cava, and then falls immediately anterior to the right superior pulmonary vein, along the posterolateral right atrium, to the diaphragm. The left phrenic nerve passes over the aortic arch and pulmonary trunk and onto the pericardium overlaying the left atrial appendage, then anterolaterally over the left ventricle to the diaphragm. Both phrenic nerves travel with the pericardiophrenic vessels, and are external and adherent to the fibrous pericardium. Within the pericardial space, ablation overlying the posterolateral right atrium (or in the right superior pulmonary vein), or ablation over the left atrial appendage or lateral left ventricle may damage the phrenic nerves, which are immediately external to the pericardium (Figure 7).

**Coronary arteries**

The coronary arteries are covered by epicardial fat along the atrioventricular (AV) groove and the interventricular septum. With the typical anterior approach, needle puncture of the coronary arteries is very uncommon (Figure 7). More common may be limited bleeding from disruption of epicardial fat. With an inferior approach (discussed further below), there is an increased but still small risk of damage to the posterior descending artery. This risk is mitigated by avoiding advancement of the needle towards the septum. Rare reports of vascular spasm associated with manipulation of tools over coronary arteries exist, which appear more likely in patients prone to spasm.

**Right ventricle**

The anterior wall of the right ventricle is the most vulnerable cardiac structure to perforation during the anterior approach. In the absence of anticoagulation, however, the right ventricle generally tolerates needle and wire access relatively well unless the needle is held stiffly and significant myocardial laceration takes place. In one multicenter study, inadvertent RV entry occurred in 17% of punctures. Inadvertent RV puncture does not

Figure 5: Relationship of internal mammary artery to sternum. Note that the distance is approximately 1 cm at more superiorly, but becomes greater at the level of the xiphoid process.

Figure 6: Relationship of lungs to the heart. The top panels show a reconstructed computed tomography (CT) scan from a patient during inspiration and expiration. During expiration the lungs become smaller (note the atrioventricular groove is more “visible” and the distance from the left lung to the heart border is smaller) as air is exhaled. Note that the right ventricle is anterior, and is the structure encountered with a perixyphoid puncture as depicted in Figure 4. The bottom left panel contains an axial CT image showing the region anteriorly at which the heart can be accessed without traversing lung tissue. The bottom right panel is an inferior slice, showing the relationship of the liver to the epigastric region. Note that the left lobe of the liver extends well across the midline.
preclude mapping and ablation in most cases, and bleeding is typically less than 80 ml. Another potential complication to consider is RV counterperforation, i.e. the needle or wire passes in and then out of the right ventricle. Under these circumstances, with the sheath in place there may be little bleeding; however, upon removal of the sheath hemodynamic collapse could ensue with life threatening tamponade.

**Procedural method**

**Equipment**

Prior to beginning the puncture all necessary equipment should be on hand. As with any procedure the equipment selected will be determined to some degree by the experience and preference of the operator. Attention to the of sheath is important as movement of too stiff a sheath in the epicardial space may lead to coronary artery compression or myocardial laceration, whereas an unbraided or soft sheath may become too difficult to maneuver after some time inside the body. At our institution we have fond that the use of hydrophilic sheaths has helped with access and maneuverability.

**Patient preparation**

For elective procedures, anticoagulation is withheld prior to percutaneous pericardial access. Physical examination identifies hepatomegaly and the key bony
landmarks: the xyphoid process and costal margins. Coumadin is stopped 3–5 days and dabigatran 24 h before elective access. Following access and sheath placement, anticoagulation is administered as needed for the concomitant procedure. In the absence of endocardial catheters and, in particular, left-sided ablation, anticoagulation need not be given.

The patient is placed in the supine position and given adequate anesthesia, either heavy sedation with midazolam and fentanyl or general anesthesia. We often use

Figure 8: Obtaining pericardial access. Top left panel depicts inferior pressure to displace abdominal contents while advancing the needle towards the cardiac silhouette, as described in text. The right panel highlights the orientation of the bevel away from the cardiac epicardium, and injection of contrast, which layers in the pericardial space. The bottom left panel is a right anterior oblique projection of an inferior approach (note inferior entry mid way between the apex and the base, which is more basal than the more common, apical entry). A layer of contrast is seen (arrows) and the wire is seen in the pericardial space.

Figure 9: Importance of right anterior oblique (RAO) and left anterior oblique (LAO) imaging to confirm wire position. It is critical to confirm an epicardial wire position by assessing it the LAO view. The RAO view (top panels, with graphic left, fluoroscopic image centre, and actual heart, right) shows the cardiac orientation with comparative radiographic view. The wire is within the cardiac shadow. This view does not confirm epicardial wire position, as a similar image could be acquired by passage of the wire into the right ventricle and atrium. The bottom row shows the equivalent in LAO images. Note that the wire passes over both left and right cardiac structures, which is not feasible with an intracardiac wire in the absence of a septal defect. Thus, LAO imaging is mandated to confirm epicardial wire positioning prior to sheath advancement.
propofol for rhythms that may be suppressed by anesthetic agents due to its rapid reversibility. If needed for the planned procedure, a right ventricular and coronary sinus catheter are position before epicardial access, as they serve as useful fluoroscopic landmarks. The coronary sinus catheter clearly delineates the AV groove and position of the coronary arteries in the right anterior oblique (RAO) view, and the RV catheter can provide guidance as to the septum and apex, although variability in catheter position makes this guide less reliable. Standard sterile preparation and draping is applied to a large enough area to permit confident confirmation of the xyphoid process and costal margin with manual palpation. Local anesthetic and a small incision are made in the left paraxyphoid space, as shown in figures 4 and 5.

The orientation of the needle is determined based on whether an anterior or inferior puncture is planned, with the needle positioned so that the bend points away from the heart (Figure 8). Thus, with an anterior approach, the bevel is pointed up, while for an inferior approach the bevel is directed inferiorly. An inferior puncture may at times be desirable based on the structures to be ablated or accessed, but may have a higher risk of passing through the left lobe of the liver or the diaphragm, and of coronary injury, and is less commonly used in our practice (Figure 8).

For an anterior puncture the needle is directed at the left mid-clavicle, although depending on cardiac rotation it may be in line with the vertical. The left hand applies gentle inferior pressure to displace abdominal contents from the desired needle path, and the needle is angled inferiorly at an angle of 15–30 degrees (Figure 8). For posterior access the Tuohy needle is directed at 45 degrees from the horizontal, with the bevel directed inferiorly. Fluid is kept in the shaft of the needle, and when its tip enters the thorax a rise in fall in fluid level may be seen. Imaging is performed in the RAO and left anterior oblique (LAO) projections with a goal of directing the needle tip within 1–2 cm of the apex, and generally towards the lateral wall, away from the septum. This approach minimizes the small risk of encountering a coronary artery (mainly a concern with the inferior approach).

As the needle is advanced under fluoroscopic guidance to the level of the cardiac silhouette, very small (<1 ml) puffs of contrast are delivered. Contact with the fibrous pericardium is met with pulsatile resistance and can be seen as tenting on fluoroscopy. As the needle advances further a palpable “give” is appreciated as the needle penetrates the fibrous pericardium. Additional contrast injection demonstrates layering, consistent with needle tip position in the pericardial space (Figure 8, bottom left panel). Aspiration of <30 ml of straw colored or blood-tinged fluid is common. A guidewire is then advanced generously to form multiple loops, to provide confirmation of wire position and support for sheath advancement. An 0.032 or larger wire is used to ensure adequate mechanical support. The wire is examined fluoroscopically in the RAO and LAO views. It is imperative that the wire appear pericardial in both views; assessment in the RAO view alone does not satisfactorily exclude an intracardiac wire position. The presence of ectopy with wire manipulation further suggests an intracardiac position due to RV puncture. If the wire has entered the RV, the needle is slowly withdrawn while gingerly...

Table 2: Tools used for percutaneous pericardial access

<table>
<thead>
<tr>
<th>Equipment type</th>
<th>Items</th>
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<tr>
<td>Sheaths</td>
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</tr>
<tr>
<td>Needles</td>
<td>17G × 12.5 cm Arrow</td>
</tr>
<tr>
<td></td>
<td>18G × 15.2 cm Braun</td>
</tr>
<tr>
<td>Wires</td>
<td>0.035” × 145 cm Amplatz extra stiff (Cook)</td>
</tr>
<tr>
<td></td>
<td>0.032” × 145 cm Amplatz (Cook)</td>
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<tr>
<td>Catheters</td>
<td>6Fr 65 cm Pigtail catheter (Cordis)</td>
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<tr>
<td>Other</td>
<td>1050 Sticky Drape (3M)</td>
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<tr>
<td></td>
<td>Syringes (60 ml slip lock, 12 and 20 ml Luer lock)</td>
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<tr>
<td></td>
<td>Three-way stopcock</td>
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<tr>
<td></td>
<td>Small beaker with 50 ml contrast</td>
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Figure 10: Use of computed tomography (CT) imaging to identify organ positions: A radio-opaque mesh placed prior to the CT gives a grid that is marked simultaneously using an indelible pen on the skin. Subsequent three-dimensional reconstructions show the grid location and depth expected for pericardial entry at the time of access, as well as the position and orientation of surrounding structures.
probing with the wire, which may permit the wire’s advancement into the pericardial space.

Inadvertent RV puncture is managed with vigorous aspiration for 5 min to generate a vacuum that adheres the pericardium to the puncture site. This form of bleeding rarely precludes subsequent mapping and heparin administration, in the absence of continued bleeding.

To minimize pericardial irritation, as smooth, non-abrasive 8 Fr sheath with a sidearm is used with a graduated transition from dilator to sheath. Sheaths with multiple dilators to minimize trauma at the sheath dilator interface are preferred (Table 2). Blood pressure is monitored and the pericardium periodically drained if open irrigation catheters are used for ablation. Dual access can be obtained with a second puncture, in which case a small amount of fluid or air can be introduced into the pericardial space to facilitate entry.

Imaging and ancillary technologies
Intracardiac echocardiography is useful to continuously assess for the presence of an effusion, and to quantify fluid accumulation with open irrigation catheters. Devices in the pericardial space are poorly seen in the absence of an effusion. Three-dimensional reconstruction of computed tomography (CT) images identify internal organ positions, and provide useful ancillary information when used with skin markers (Figure 10). Early experimental work has used the frequency detected at the needle tip to differentiate thorax (no high frequency component) from pericardial (cardiac high frequency component) position21–23 (Figure 11).

Once access is obtained, mapping and the planned intervention proceeds. The gross and fluoroscopic anatomy of the pericardium for catheter manipulation has been previously reviewed.24,25

Summary
Percutaneous access increase options for ablative therapies, and opens the door to new approaches for left atrial appendage closure, cardiac resynchronization, and localized cardiac drug delivery. Additionally, the ability to perform percutaneous pericardial access in the absence...
of an effusion permits ready access when an effusion is present. A detailed understanding of anatomy and its imaging permit the procedure to be safely performed in the electrophysiology laboratory.

References


