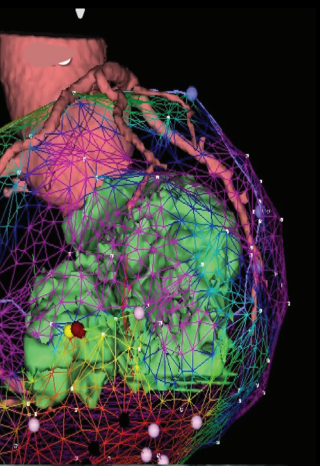
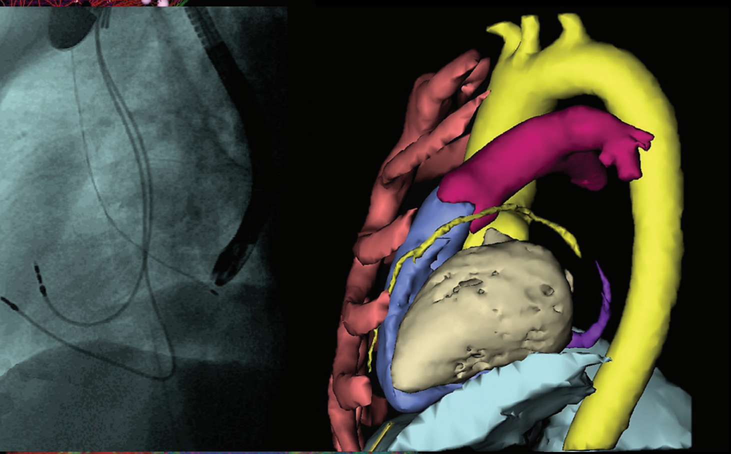
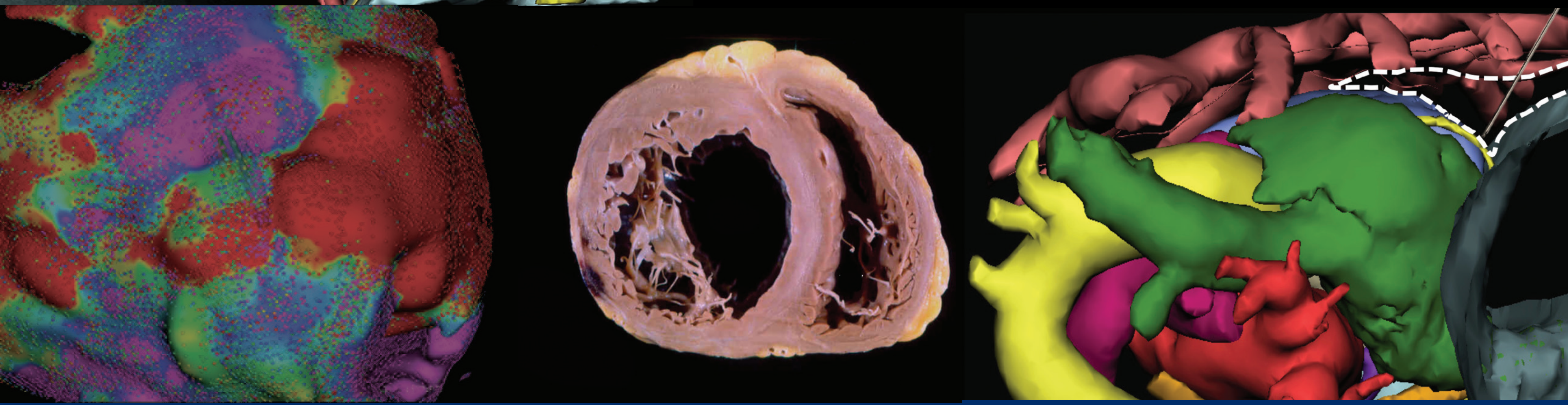
Percutaneous Epicardial Interventions



A Guide for Cardiac Electrophysiologists





Editors André d'Avila • Arash Aryana
Vivek Y. Reddy • Francis E. Marchlinski

Foreword by Roderick Tung

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A Guide for Cardiac Electrophysiologists

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cardiotext®
PUBLISHING
Minneapolis, Minnesota

Cardiotext Publishing, LLC
3405 W. 44th Street
Minneapolis, Minnesota 55410
USA
www.cardiotextpublishing.com

Any updates to this book may be found at: www.cardiotextpublishing.com/electrophysiology-heart-rhythm-mgmt/percutaneous-epicardial-interventions

Comments, inquiries, and requests for bulk sales can be directed to the publisher at: info@cardiotextpublishing.com.

Library of Congress Control Number: 2020932627

ISBN: 978-1-942909-31-6

eISBN: 978-1-942909-44-6

Printed in Canada

20 21 22 23 24 25 7 6 5 4 3 2 1

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Foreword

Roderick Tung, MD

In 1996, the field of catheter ablation changed forever, as the seminal report of percutaneous epicardial access was introduced to the world from Brazil. Numerous thought leaders in the field (many of them contributors to this book) were inspired to witness and learn this seemingly bold and daring technique—and what they observed firsthand completely changed the game for the field of electrophysiology.

The performance of an innovative "dry-tap" pericardiocentesis with a spinal needle in the EP lab symbolized open access to a new, unexplored frontier. Access to the pericardial space not only provided an opportunity to mechanistically examine what lies on "the other side," but also offered a feasible route to deliver therapeutic ablation to patients whose ablation target was simply out of reach from the endocardium. For the first time in the history of cardiovascular interventions, the outer surface of the heart could be investigated and treated without a single surgical tool or incision.

In this breakthrough textbook edited and written by the inventors and experts, the reader will appreciate the historical evolution, pertinent technical aspects, and relevant anatomy, and review the growing knowledge base of epicardial substrate characteristics implicated in human ventricular tachycardia. This is the first authoritative compilation dedicated to epicardial interventions and is a must-read for all students of cardiac anatomy, complex ablation, and interventional cardiology. Importantly, many chapters promote an emphasis on recognizing and minimizing the risk for complications uniquely associated with this approach, from common to rare. As the clinical value of this approach is well-established, ensuring that efficacy is not counterbalanced by safety hazards is of utmost importance.

I am among one of many fortunate students who received indirect tutelage from Drs. Sosa, Scanavacca, d'Avila, and Pilleggi through Kalyanam Shivkumar. The dissemination of knowledge through academic generations is perhaps the most telling sign of the significance of a contribution to medicine. Epicardial intervention has not only transformed my clinical practice of complex ablation, but has fueled our line of scientific questioning and investigation. We have been inspired to gather evidence that supports the incremental value of a two-sided approach to understand the intricacies of the 3D substrate for scar-related ventricular tachycardia, even in postinfarction substrates. Epicardial mapping has opened our eyes to the arrhythmogenic substrate for idiopathic-dilated cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy, Brugada syndrome, and early repolarization syndromes, which are predominantly disease states of the epicardium. Similarly, the field of atrial fibrillation ablation is gaining an increased appreciation of nontransmural lesions created with current technology that may limit the ability to create durable conduction block that involves unique epicardial structures. Even more exciting, there are undoubtedly new applications and unborn interventional techniques that will emerge beyond the horizon as a result.

Both science and society have been equal beneficiaries from the discoveries enabled by epicardial interventions. I have had the privilege of teaching and sharing the experience of epicardial mapping and ablation throughout China over the past seven years and remain indebted to the authors for their contributions that serve as the basis for this global collaboration. Indeed, a "puncture heard around the world" from São Paulo 25 years ago has withstood the test of time and left an indelible mark on the global timeline of EP history. While we collectively pay tribute to the pioneers, this book should also serve to inspire future generations to appreciate that a "crazy" idea can not only change the game, but change the lives and outlook for many of the world's population who suffer from arrhythmias.

Preface

William G. Stevenson, MD

It has been over two decades since Eduardo Sosa, Mauricio Scanavacca, and their colleagues reported successful pericardial access in the absence of overt pericardial effusion for the purpose of catheter mapping and ablation. Their pioneering work is a major contribution to cardiovascular therapeutics that allowed ablation treatment to expand to a new group of arrhythmias that would otherwise have required a surgical ablation approach, or have gone untreated, and has benefited countless patients. This ability to explore the epicardial surface of the heart has also expanded our knowledge of cardiac anatomy and electrophysiology. Although percutaneous pericardial access is now an important and routine procedure in many electrophysiology laboratories, its safe execution requires skill informed by knowledge of anatomy and its variations to minimize the risk of complications. Once access is achieved, effective diagnosis and therapy requires further specialized knowledge of arrhythmias, anatomy, and biophysics relevant to mapping and ablation.

Aspects of this curriculum can be found in hundreds of publications but has not been completely and accessibly summarized until now. In *Percutaneous Epicardial Interventions: A Guide for Cardiac Electrophysiologists*, Drs. d'Avila, Aryana, Reddy, and Marchlinski bring together experts from around the world to summarize the knowledge gained and state of the art. These chapters not only are valuable to practitioners who work in the pericardial space, they also provide important anatomic, physiologic, and pathophysiologic insights to all students of cardiac electrophysiology. Percutaneous epicardial interventions continue to evolve. Therapies now extend to atrial appendage management and will continue to expand in electrophysiology and beyond. Practitioners and scientists will find this unique text to be of great value and utility for many years to come.

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CHAPTER

1 Epicardial Interventions in Electrophysiology: Historical Perspectives

Mauricio I. Scanavacca, MD, PhD; Francis E. Marchlinski, MD

INTRODUCTION

This chapter is based on the experience of two authors of different origins, who work in countries with distinctive realities but who both experienced the introduction and development of numerous techniques for catheter ablation of cardiac arrhythmias. In the next few pages, the historical aspects and motivations that set the stage for the minimally invasive techniques used in arrhythmia management for access and instrumentation of the pericardial space will be reported.

ARRHYTHMIA INTERVENTIONS AND RF ABLATION: THE EARLY YEARS

The interventional treatment of cardiac arrhythmias has experienced major advances in last 40 years. In the Heart Institute (InCor) of São Paulo University Medical School, arrhythmia ablation was initially performed using open-chest surgery, introduced by Dr. Eduardo Sosa and Dr. Miguel Barbero Marcial in 1979. The surgical treatment of supraventricular and scar-related ventricular tachycardias (VTs) were performed with reasonable frequency in that institution until the mid-1990s.[1–9]

Indisputably, radiofrequency (RF) energy delivered by catheters with deflectable tips was responsible for a great revolution in the interventional treatment of tachyarrhythmias in the clinical setting. In a short period of time, conventional open-chest surgery to ablate arrhythmias was replaced by vascular access interventions with very good efficacy and low risk, and this success was reproduced in different centers worldwide.[10–14]

RF application from the endocardium was effective and had low risk of complications, including when applied to patients with recurrent sustained VT associated with previous myocardial infarction.[10–12] Consequently, catheter-based ablation gave rise to a new medical specialty, the "Interventional Electrophysiology," which has been growing over the years and enabling the curative treatment of numerous patients with cardiac arrhythmias.

THE CHAGAS DISEASE CHALLENGE

Although very successful in several types of atrial and ventricular arrhythmias, the efficacy of endocardial ablation has been more limited in patients with nonischemic VT. Deeper intramyocardial circuits, especially those involving subepicardial fibers, preclude effective endocardial RF energy delivery.[15] This limitation was particularly evident in a special type of nonischemic heart disease, very common in Brazil and Latin America: Chagas heart disease, which frequently presents with episodes of recurrent VT and electrical storm.[16,17]

Traditional endocardial activation and entrainment mapping techniques, useful in the identification of VT circuits of ischemic origin, were frequently ineffective in patients with Chagas VT. Although the substrate of these VTs is usually segmental fibrosis, its location and anatomopathological aspects are different when compared to the scars observed in patients with previous myocardial infarction in which subendocardial RF applications can frequently reach the circuits.[19]

It was already known that the mechanism of sustained VT in Chagasic cardiomyopathy was reentry, because of its behavior during programmed ventricular stimulation.[18] However, it was not possible to demonstrate the participation of subepicardial fibers in the reentrant mechanism when doing endocardial mapping and

Percutaneous Epicardial Interventions: A Guide for Cardiac Electrophysiologists. © 2020 André d'Avila, Arash Aryana, Vivek Reddy, Francis E. Marchlinski, eds.
Cardiotext Publishing, ISBN: 978-1-942909-31-6

ablation. Indirect observations, like fractionated late potentials documented from coronary sinus catheter recordings, the absence of presystolic and mid-diastolic activity during extensive endocardial mapping of sustained VT, and endocardially applied RF interruption of sustained VT followed by its easy reinduction, raised the hypothesis that the slow conducting channels could involve subepicardial fibers.

The first plan to clarify this point was to perform surgical mapping, simultaneously exploring the endocardial and epicardial ventricle surfaces, as had already been previously demonstrated in intraoperative studies of patients with ischemic heart disease.[19–21] Due to technical difficulties in the development of an intraoperative mapping system (which were not commercially available at that time in Brazil), exploring the endocardium and epicardium surfaces of the heart would prove challenging. A good-quality intraoperative map was not easy to achieve during open-chest surgery in patients with Chagas disease. In Chagas disease, different VT morphologies were usually induced during programmed stimulation and were difficult to reproduce due to the deep anesthesia and the ventricular incisions required to access the endocardial ventricular surface. Additionally, during surgery, it was not easy to identify the specific 12-lead electrocardiographic morphology of the induced and the clinical VTs, given that complete surface 12-lead ECG registration was not feasible due to the anterior sternotomy used to gain access to the heart.

DEVELOPING THE NONSURGICAL EPICARDIAL MAPPING TECHNIQUES

The first nonsurgical effort designed to investigate the subepicardial origin of cardiac arrhythmias with catheters was suggested by Dr. Warren Jackman and colleagues from Oklahoma City, who used multi-microelectrode catheters through the coronary venous system to access epicardial fibers.[22] The great advantage of this technique was the low risk of complications of the transvenous epicardial mapping. However, although ideal for left-sided atrioventricular (AV) pathways and VT substrate confined to the immediate perivalvular mitral region, detailed epicardial mapping was constrained by the location of large epicardial venous vessels.[23] Currently, only the distal great cardiac veins, the proximal anterior interventricular vein, and the middle cardiac vein are routinely used to map the epicardium in the setting of idiopathic VTs with a suspected epicardial origin.

At the Heart Institute of Sao Paulo University, the initial plan to reach the entire epicardial surface of the ventricles, without open thoracic surgery, was to introduce the catheters by video thoracoscopy, a technique that had just been initiated in the institution for the diagnostic and therapeutic approaches of various thoracic diseases. However, this procedure had to be performed in the surgical center and not in the electrophysiology (EP) laboratory, a fact that displeased the entire team.

Many discussions were made with much debate on how to best access the pericardial space in the EP lab. At that time, after a subxiphoid puncture and drainage procedure of a pericardium tamponade that occurred from perforation during an ablation, Dr. João Luis Piccioni, the anesthesiologist of the EP team, suggested the same access to perform the epicardial mapping despite the difference regarding the pericardial access risk when performing a subxiphoid puncture in a patient with a pericardial effusion compared to another without an effusion. He opened a new opportunity for epicardial space exploration once he remembered that anesthesiologists currently used the Tuohy needle, specially designed to access the virtual space of the epidural membranes and that this needle could also be used to safely access the pericardial space.

With this hypothesis in mind, Dr. Mauricio Scanavacca started to elaborate a method to perform the puncture and then to introduce guidewires, sheaths, and multielectrode catheters into the virtual pericardial space. "We hypothesized that if an accidental perforation and epicardial bleeding occurred, it could be immediately drained through the same access, with a low probability of requiring surgical intervention."

The technical strategy was presented to Dr. Eduardo Sosa, the director of the Arrhythmia Unit, who accepted it immediately and worked to obtain authorization from the ethical committee of the hospital, in order to start a pilot study in Chagasic patients who were already scheduled for surgical treatment of their sustained VTs.

Thus, on April 12, 1995, the first percutaneous epicardial mapping procedure was performed in the Heart Institute's EP lab. "A second and a third procedures were performed in the following 30 days without any complications and we were able to demonstrate the presence of an epicardial circuit in one of the patients." At that time, Dr. André d'Avila, who had just joined the EP team, did a substantial collaboration on manuscript preparation, and the three initial cases were reported and featured on the cover of *Journal of Cardiovascular Electrophysiology* in June, 1996 (**Figure 1.1**).[24]

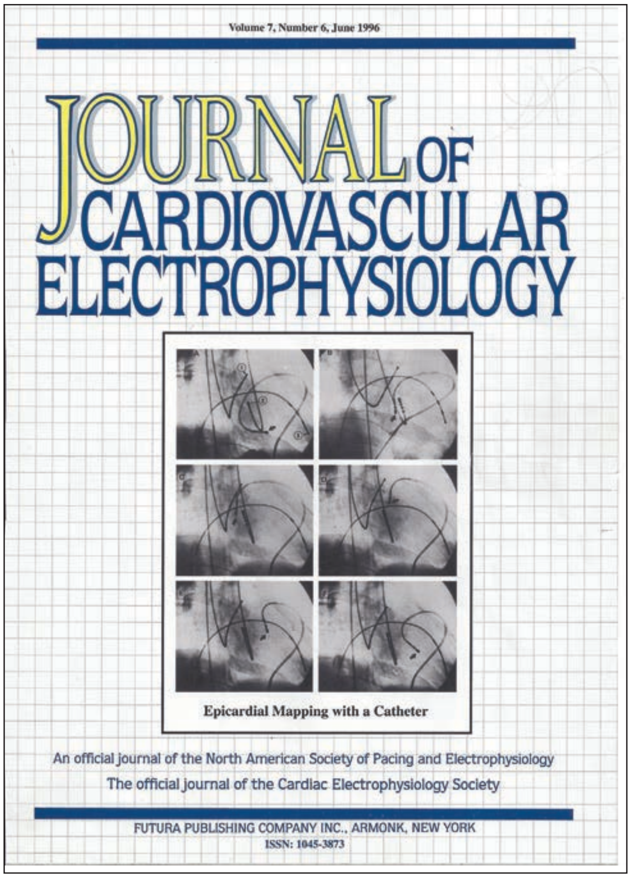

Figure 1.1 The new technique for epicardial mapping was cover of the *Journal of Cardiovascular Electrophysiology,* at that time the official journal of the North American Society of Pacing and Electrophysiology, in its first publication in June, 1996.

EXPANDING THE PROCEDURE

Following this initial observation, during the next year (1996), the epicardial RF ablation based on the epicardial mapping data, was currently used, initially in patients with recurrent sustained VTs secondary to Chagas cardiomyopathy after unsuccessful endocardial ablation and soon after, expanded to other patients with different cardiomyopathies.[25–30]

In the first 100 patients undergoing epicardial mapping procedures, there were no major complications, except one, who underwent abdominal surgery to treat a peritoneal bleeding. The impact of the positive results of this new strategy interrupted the surgical treatment program of VT in that institution.

In the subsequent years, this epicardial access technique crossed Heart Institute borders (**Figure 1.2**) and was gradually embraced by the global EP community. "Electrophysiologists would go to our institution for some focused additional training in the technique and we frequently visited other worldwide centers to help guide the first effort to access the pericardial virtual space." Such was the case for the early experience in the Hospital of the University of Pennsylvania's EP lab in 2003.

Most of the observations related to epicardial mapping and ablation of VT and new indications discussed in this book grew out of the extensive experience in São Paulo, Brazil. The important benefits and low but definite risk were clearly demonstrated early in the experience. As might be anticipated, significant clinical investigation would follow this initial experience as its use spread globally. The probability of epicardial VT by identifying 12-lead ECG characteristics associated with an epicardial origin in nonischemic and idiopathic VTs would be described.[31–34] The use of endocardial unipolar electrograms[35,36] and imaging using intracardiac echocardiography (ICE) and cardiac magnetic resonance imaging (MRI) would be shown to predict the presence of an epicardial arrhythmogenic substrate.[37] The definition of epicardial substrate based on voltage and electrogram criteria, the presence of epicardial channels and unique patterns of layered epicardial activation would facilitate ablation of unmappable VT.[38–40] The impact of fat of variable thickness and coronary arteries on electrogram signal characteristics and the best energy-delivery strategies have been investigated and described.[41–45] Efforts to minimize risk related to phrenic nerve injury and to prevent major coronary injury have been studied and unusual complications identified.[46–48] The success and importance of the epicardial mapping and ablation procedure in unique disease settings such as arrhythmogenic right ventricular cardiomyopathy, hypertrophic obstructive cardiomyopathy with left ventricular (LV) apical aneurysm, and Brugada syndrome have been documented.[49–51] Indications have expanded beyond ventricular arrhythmia ablation to include ablation of atrial arrhythmias and left atrial appendage occlusion.[52]

Figure 1.2 Photo taken by Eric K. Y. Chan documenting the first experimental demonstration of the epicardial access feasibility for electrophysiological mapping and ablation during the famous meeting organized by Robert Svenson in Charlotte, North Carolina in the beginning of the 2000 decade. In the first plane are Dr. Eduardo Sosa and Dr. Mauricio Scanavacca making the puncture. In second plane, from left to right, are Dr. Douglas Packer, unknown, and Dr. Warren Jackman.

Of note, this brief historical perspective provides only an overview and is meant to highlight the origin of the concept, techniques, and initial clinical outcomes. There have been many important contributions related to epicardial interventions in electrophysiology, the details of which are highlighted throughout this text.

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CHAPTER

2 Epicardial Anatomy

Arash Aryana, MD, PhD; Francis E. Marchlinski, MD; André d'Avila, MD, PhD

INTRODUCTION

Understanding the details and complexities of pericardial anatomy is essential when considering a percutaneous, subxiphoid epicardial procedure. The *Nomina Anatomica* recognizes two compartments within the pericardial cavity: the transverse and the oblique sinuses.[1] However, a series of irregular and topographically complex interconnections are formed by the subcompartments of these sinuses giving rise to four recesses (the post-caval recess, the right and left pulmonary vein recesses and the inferior aortic recess) as well as the superior pericardial recess, which is sometimes also referred to as the superior sinus, particularly by invasive Cardiologists. The pericardial sinuses and recesses are located within the basal and the posterior aspects of the heart. Knowledge of their anatomical relationships is critical when performing catheter mapping and ablation within the pericardial space. This chapter will provide a general overview of the pericardial anatomy as well as certain anomalies relevant for the interventional cardiologist and the cardiac electrophysiologist.

PERICARDIAL SAC

The normal pericardium consists of a double-layered, flask-shaped sac comprised of an outer fibrous envelope and an inner serous sac that is invaginated by the heart itself.[2] The serous pericardium can be divided into a visceral layer, an epicardial layer that overlies the heart and the great vessels, and a parietal layer that lines the fibrous pericardium.[2] The epicardium is reflected from the heart onto the parietal pericardium along the great vessels in tube-like extensions that include the aorta, the pulmonary artery and its primary branches, the proximal pulmonary veins, and the vena cavae.[3,4] The thickness of the parietal pericardium varies from 0.8–2.5 mm. The epicardial cavity is a virtual space that lies between the two serous pericardial layers.[3,4] At the point of pericardial reflections and at the posterior walls between the great vessels, the pericardial space is apportioned into a contiguous network of recesses and sinuses. The pericardium typically contains 15–25 mL of physiologic fluid within this space.[3,4] Upon imaging in the supine position, this fluid can sometimes be detected in the superior and the transverse sinuses. Of note, all pericardial reflections are located basally in relation to the great vessels. Thus, there are no obstacles during epicardial catheter manipulation along the anterior or apical ventricular surfaces of the heart.[3]

The fibrous pericardium is attached to the central tendon of the diaphragm by loose fibroareolar tissue, except for fusion over a small area of the central tendon and the pericardium. The pericardium is also attached to the posterior sternal surface by superior and inferior sternopericardial ligaments that anchor the fibrous pericardium and maintain the general position of the heart inside the thorax.[4]

PERICARDIAL SINUSES

As mentioned, in the human, invasive cardiologists recognize three sinuses within the pericardial space: the superior sinus, the transverse sinus, and the oblique sinus (**Figure 2.1**).[5–7]

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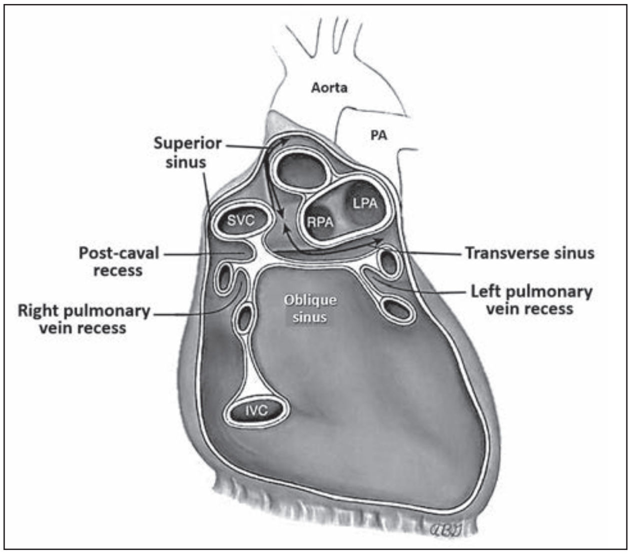

Figure 2.1 The anatomy of the pericardium. The superior sinus (superior aortic recess) lies anterior to the ascending aorta and the main pulmonary artery (PA). The transverse sinus is limited by the pericardial reflection between the superior pulmonary veins and contains the right pulmonary artery (RPA). The oblique sinus is defined by the pericardial reflections around the pulmonary veins and the inferior vena cava (IVC). The post-caval recess lies behind the superior vena cava (SVC), the RPA, and the right superior pulmonary vein. The right and the left pulmonary veins recesses extend between their respective superior and inferior pulmonary veins. Images modified with permission from: d'Avila A, et al. *J Cardiovasc Electrophysiol.* 2003;14:422–30. Abbreviation: LPA denotes left pulmonary artery.

Superior Sinus

The superior sinus is situated along the most superior aspect of the transverse sinus. As such, it is considered to be a recess by anatomists and is also commonly referred to as the superior aortic recess. Several investigators have referred to the superior sinus as the *recessus aorticus*, *aortocaval recess*, or *superior pericardial recess*. The superior sinus extends upward along the right aspect of the ascending aorta to the origin of the right innominate artery, commonly at the level of the sternal angle. At the level of tracheal bifurcation, the superior sinus is seen as a semicircular recess surrounding the ascending aorta and, along its left lateral portion, the pulmonary artery. On the right, the superior sinus is continuous with a recess around the superior vena cava. Additionally, the transverse sinus joins the superior sinus behind the aorta on the right, and this connection extends down to the level of the aortic root.

Transverse Sinus

The transverse sinus lies posterior to the ascending aorta and the main pulmonary artery. Its posteroinferior boundary is formed by a pericardial reflection extending transversely between the right and the left superior pulmonary veins at its junction with the left atrium (**Figure 2.2**). Therefore, the dome of the left atrium forms the anterior boundary of the transverse sinus. It is important to also note that the right pulmonary artery is essentially a transverse sinus structure. As it courses laterally toward the right hilum, the right pulmonary artery protrudes into the transverse sinus. As such, exploration of the transverse sinus allows access to segments of the left atrium relevant to the pathogenesis of atrial fibrillation, including the posterior aspect of the left atrium. The transverse sinus also contains several recesses that extend as diverticulae between the major vessels: the superior aortic (also designated as the superior sinus), the inferior aortic, the right pulmonary vein and the left pulmonary vein recesses. Most relevant to interventional cardiac electrophysiology is the inferior aortic recess which affords epicardial access to the noncoronary aortic cusp and also the inferior aspect of the right coronary cusp (Figure 2.2).

Some investigators have proposed that the transverse sinus has a 3D configuration and may be divided into three different segments: anterior vertical, middle horizontal, and posterior vertical segments. Knowledge of these anatomic details can be helpful during interpretation of computed tomography/magnetic resonance scans as presence of pericardial effusion or cysts within these spaces can rarely simulate mediastinal or intracardiac lesions.[8–10] Nonetheless, exploring these details is beyond the scope of this review as they are unlikely to markedly impact intrapericardial cardiac electrophysiologic therapies.

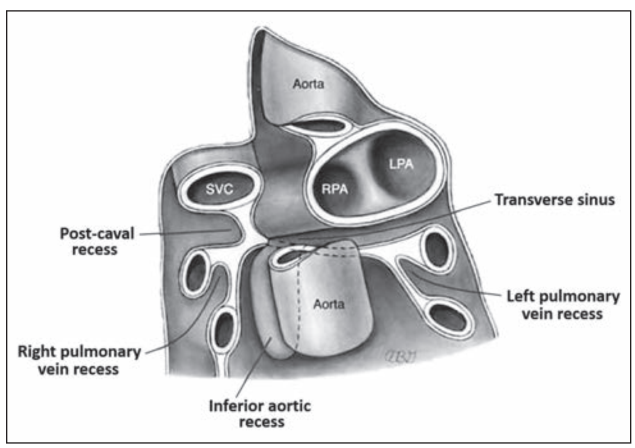

Figure 2.2 The anatomy of the transverse sinus and its inferior extension. The inferior aortic recess allows access to the epicardial portions of the ascending aorta related to the noncoronary cusp and the inferior aspect of the right coronary cusp of the aorta. Illustrations modified with permission from: d'Avila A, et al. *J Cardiovasc Electrophysiol.* 2003;14:422–430.

CHAPTER

3

Inferior and Anterior Approaches Using a Tuohy Needle

Arash Aryana, MD, PhD; André d'Avila, MD, PhD;
Mauricio I. Scanavacca, MD, PhD

INTRODUCTION

In contrast to surgical ablation, percutaneous catheter ablation of cardiac arrhythmias has evolved from the endocardium to the epicardium. The limitations of an endocardial-only ablation approach are highlighted by certain conditions such as Chagas disease, which is frequently associated wtih an epicardial substrate. Since its initial description by Sosa et al,[1] subxiphoid percutaneous epicardial mapping and ablation has become an important adjunct, and in some instances even the preferred strategy, for treatment of a wide range of cardiac arrhythmias, including scar-mediated ventricular tachycardia,[2,3] atrial fibrillation,[4,5] accessory pathways,[6,7] and idiopathic ventricular tachycardia.[8] Additionally, the subxiphoid percutaneous approach has also been exploited for epicardial left atrial appendage closure,[9] cardiac pacing,[10,11] drug delivery,[12,13] and displacement/protection of mediastinal collateral structures (such as the esophagus and the phrenic nerve) from the path of energy delivery during catheter ablation.[14,15] This chapter will examine the subxiphoid percutaneous approaches to epicardial access and puncture.

ACCESSING THE PERICARDIUM

The pericardial space normally contains 15 to 25 mL of serous, physiologic fluid.[16,17] The percutaneous approach to the pericardium is the only technique available that can afford unrestricted catheter access, mapping, and ablation of the epicardial surface. The percutaneous epicardial puncture is the most important step in this approach and one that can be performed safely in the electrophysiology laboratory. While the subxiphoid puncture technique remains the most widely described and used method for percutaneous epicardial access, other approaches to accessing the pericardium have also been reported, including the parasternal,[18,19] the apical,[19] the transatrial,[20,21] transesophageal,[22] and transbronchial[23] methods.

SUBXIPHOID APPROACH

Little has changed with regard to the technique of subxiphoid epicardial puncture for catheter mapping and ablation since its introduction by Sosa et al. over two decades ago.[1] Due to the high level of patient discomfort associated with a percutaneous epicardial puncture, it is recommended that this procedure be performed under deep procedural sedation or general anesthesia. Furthermore, urgent and on-site access to echocardiography, blood products, and cardiothoracic surgery is strongly advised.

A history of cardiac surgery or epicardial instrumentation may suggest the presence of diffuse pericardial adhesions. Hence, knowledge about the patient's medical history as well as baseline blood coagulation profile is crucial. As a rule, a history of cardiac surgery represents the most common cause of access failure and a significant predictor of adverse events and complications during an epicardial procedure. Moreover, this necessitates an inferior epicardial puncture approach, as an intact anterior pericardial space is typically not encountered in patients with a history of anterior sternotomy. In such cases, a surgical subxiphoid pericardial window may prove helpful in performing epicardial mapping and ablation.

Before the puncture, the cutaneous tissue at the site of entry within the subxiphoid area should be cleansed and anesthetized. The site of the puncture is identified based on anatomical landmarks shown in **Figure 3.1**, and through accurate palpation. The "triangle" formed between

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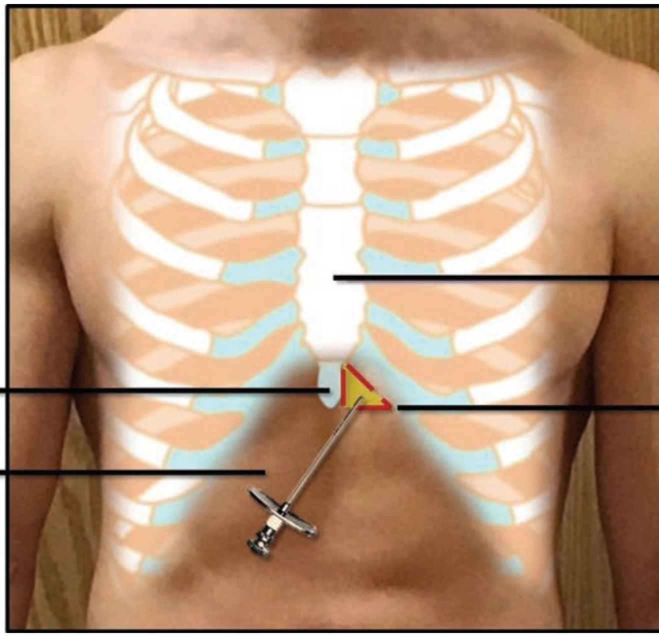

Figure 3.1 The subxiphoid approach is the most frequently used for percutaneous epicardial access. In this approach, the site of the puncture consists of a "triangle" formed by the left border of the xiphoid process and the lower left rib. The epicardial needle must always be introduced at an angle pointing toward the left shoulder.

the left border of the xiphoid process and the lower left rib represents the optimal puncture site. Next, a 17-/18-gauge, 120-/150-mm-long Tuohy needle is inserted under the skin and the rib cage, directed toward the left shoulder, and oriented according to the targeted ventricular surface (i.e., anterior versus inferior). Designed originally for epidural access, the Tuohy needle has a curved and relatively blunt, spatula-like tip intended to minimize vascular injury when accessing the epidural space (**Figure 3.2**). The angle between the needle and the skin determines the surface of the ventricle being accessed. Even though feasible as illustrated by Miyamoto and colleagues[24], the epicardial puncture should be performed preferably prior to the administration of systemic anticoagulation.

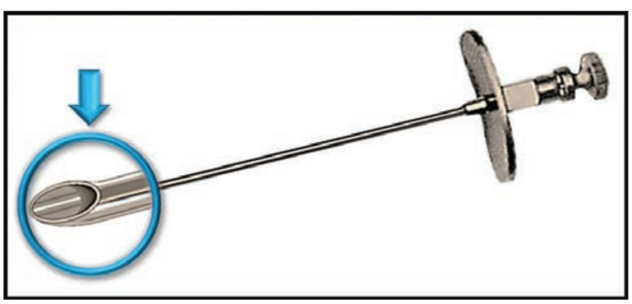

Figure 3.2 The Tuohy needle was originally designed for epidural access. It has a curved and relatively blunt, spatula-like tip (**arrow**) intended to minimize vascular injury when performing an epidural puncture.

Once the needle is advanced under the skin, the stylet within the needle may be removed. The needle is then advanced gradually under fluoroscopy toward the cardiac silhouette with gentle aspiration to avoid vascular puncture, typically either in an anteroposterior or left anterior oblique projection. However, the operator may confirm the orientation of the needle in different projections. A left anterior oblique view confirms an anterior versus posterior orientation (right versus left cardiac chambers), whereas a right anterior oblique projections confirms a superior versus inferior orientation (atria versus ventricles). The *space of Larrey* is the target of the needle, which is bounded by the sternum anteriorly, the pericardium posteriorly, and the dome of the diaphragm inferiorly (**Figure 3.3**). It is important to note that the internal mammary artery passes through this space as it becomes the superior epigastric artery with its associated vein and lymphatics. The needle should always be advanced over the diaphragm, and never through it, as it is a highly vascular organ. The aorta gives rise just below the aortic hiatus to the inferior phrenic arteries that supply the diaphragm and in turn give rise to the suprarenal vessels to supply the adrenal glands. As such, a diaphragmatic puncture could lead to significant arterial bleeding complications. Fluoroscopic visualization of the needle in the left lateral projection can greatly aid to circumvent a diaphragmatic puncture (**Figure 3.4**). Furthermore, if the patient is intubated and placed under general anesthesia, the control of respirations through an "inspirational breath hold" can sometimes facilitate an epicardial puncture (**Figure 3.5**). Since the diaphragm moves away from the heart inferiorly at end-inspiration, the likelihood of a diaphragmatic puncture is further reduced by advancement of the needle toward the pericardium during end-inspiration. Another maneuver used by some operators is to apply gentle downward pressure at the epigastrium in order to reduce the distance that the needle has to advance to reach the pericardium (**Figure 3.6**). While this technique can prove helpful when performing an epicardial puncture in obese patients and also helps steer the left lobe of the liver away from the needle's path, it may also unintentionally displace the diaphragm toward the heart and increase the likelihood of a diaphragmatic puncture.

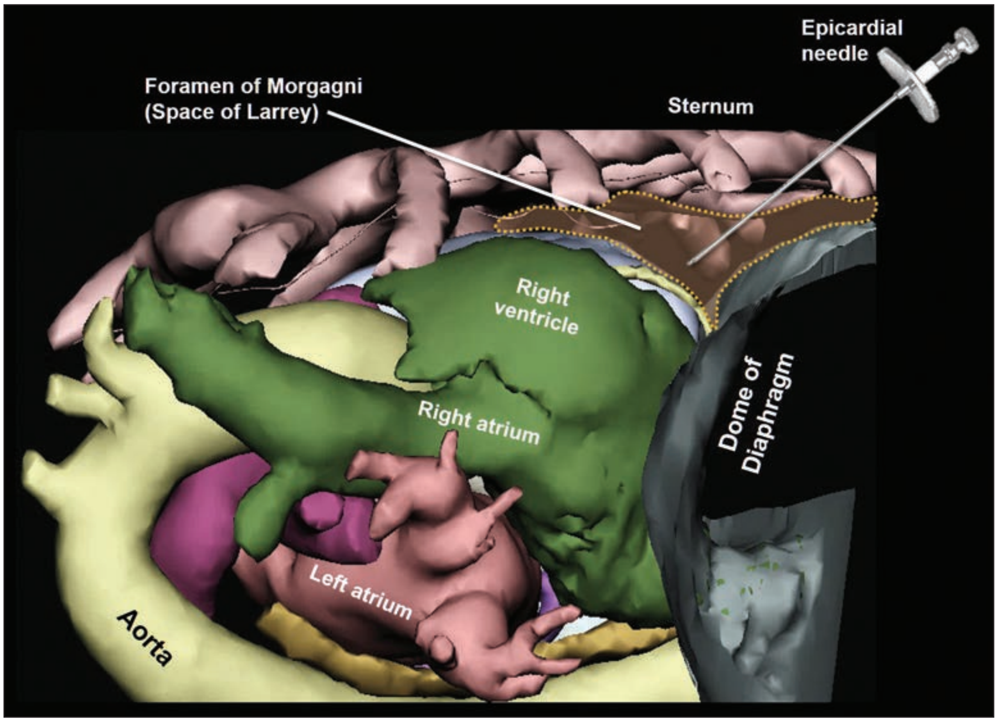

Figure 3.3 When performing an epicardial puncture, the target is the space of Larrey, which is enclosed by the sternum anteriorly, the pericardium posteriorly, and the dome of the diaphragm inferiorly. The internal mammary artery passes through this space as it gives rise to the superior epigastric artery. Therefore, when performing an epicardial puncture, the needle should always be advanced over the diaphragm and never through it.

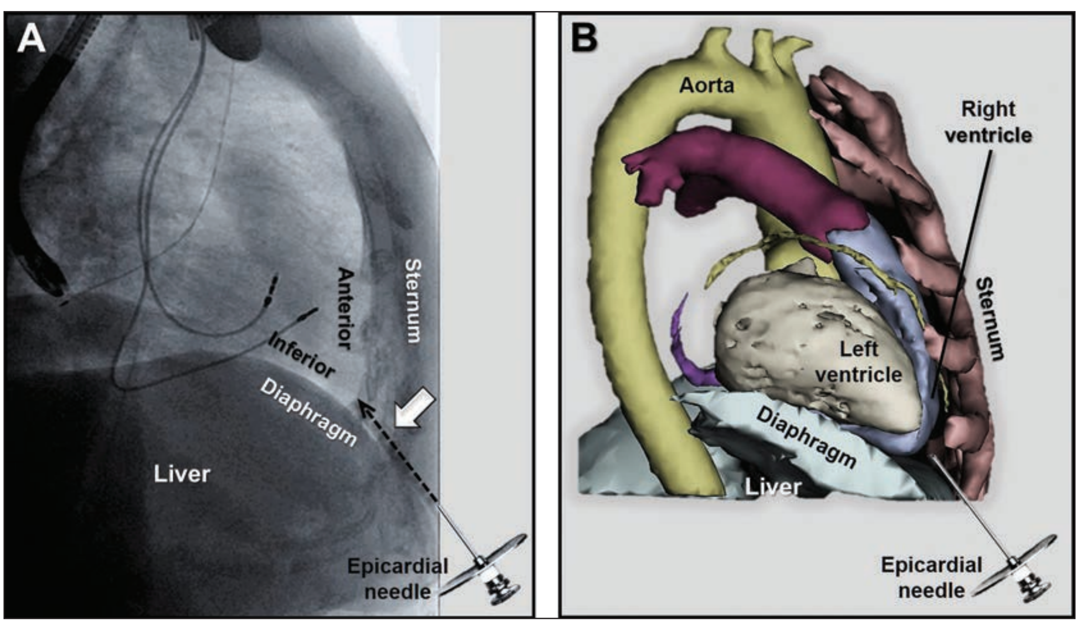

Figure 3.4 Fluoroscopic visualization of the needle in the left lateral projection can greatly facilitate epicardial access and help circumvent an unintended diaphragmatic puncture. As shown, a left lateral view can demonstrate the precise path of the needle in relation to the diaphragm and aid in validating the epicardial approach ("anterior" versus "inferior").

CHAPTER

4 Micropuncture Needle for Epicardial Access

Kasun De Silva, MBBS; Saurabh Kumar, BSc (Med), MBBS, PhD; Timothy Campbell, BSc; Ivana Trivic, BSc; William G. Stevenson, MD

INTRODUCTION

Percutaneous epicardial access is now widely used to mapping and ablation for ventricular tachycardia (VT), especially in idiopathic dilated cardiomyopathy, arrhythmogenic right ventricular dysplasia, sarcoidosis, and Brugada syndrome. It is increasingly used in ischemic VT substrates and, occasionally, epicardial atrioventricular accessory pathways. The ability to access the pericardium also offers the potential for alternative means of ablation of atrial fibrillation, esophageal protection during endocardial atrial fibrillation, for targeting epicardial structures during atrial fibrillation ablation, phrenic nerve protection in ventricular or atrial tachycardias, and for left atrial appendage closure.

Since Sosa and colleagues described the use of an 18-gauge Tuohy needle for entering epicardial space,[1] efforts have been made to improve the safety and ease of epicardial access. One such technique is the use of a micropuncture, "needle-in-needle" approach.[2,3] This chapter will describe the rationale for micropuncture access, outline the technical aspects of the micropuncture needle-in-needle approach, and describe outcomes of this approach, as published in the literature.

RATIONALE FOR MICROPUNCTURE ACCESS

The traditional method of epicardial access, described in the previous chapter, uses an 18-gauge, 6-inch Tuohy needle (**Figure 4.1**). This needle has a side-facing, bevelled lumen that facilitates access to potential spaces, such as the epidural space. A subxiphoid percutaneous approach is used, similar to the traditional subxiphoid access used for pericardiocentesis. During routine pericardiocentesis, a supraphysiological volume of pericardial fluid expands the pericardial space and provides a buffer between the parietal and visceral pericardium protecting the heart from injury. In comparison, only the physiologic amount of serous fluid (20 to 60 mL) that lubricates the movement of the visceral on parietal pericardium is present during epicardial access. Consequently, the feared complication of access into this dry space is puncture or laceration of the right ventricle or coronary arteries causing hemopericardium and/or cardiac tamponade.

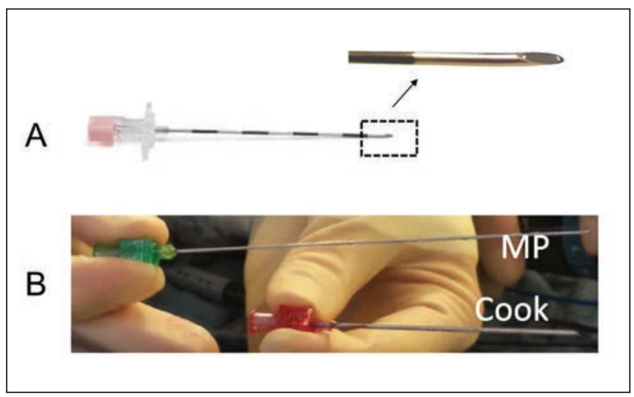

Figure 4.1 Tools for epicardial access. **Panel A:** Standard 18-gauge Tuohy needle with bevelled edge. **Panel B:** Green 21-gauge micropuncture (MP) needle, which can be inserted inside the pink 18-gauge guiding Cook needle. (Figure 4.1, Panel B obtained from Kumar et al., with permission.)

The gauge of the needle used is an important consideration when obtaining epicardial access. In theory, compared to a smaller needle, a larger-bore needle will require higher force to penetrate the tough parietal pericardium. When the parietal pericardium gives way, the forward force may propel the needle into contact with the

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epicardial surface. In addition, with cardiac and respiratory motion present as the needle is moving forward with force, there may be higher shearing force that could result in a laceration rather than a simple puncture. Compared to the traditionally used 18-gauge needle, a 21-gauge micropuncture needle has 58% less surface area and hence exerts less shearing force as it enters the pericardium (**Table 4.1**).

Table 4.1 Comparison of 18-Gauge Tuohy and 21-Gauge Micropuncture Needle Sizes

	Outer diameter (mm)	Surface Area (mm_2)	Length (mm)
18-gauge Tuohy	1.27	1.27	152
21-gauge micropuncture	0.82	0.53	2000

Studies have demonstrated a substantial risk of right ventricular puncture with standard percutaneous epicardial access approaches, which can occur in 17% of cases.[4] Despite this relatively high rate of injury, only 3.5% to 5% of patients develop major epicardial bleeding.[4,5] This difference may be due to "auto-seal" of the puncture site.[2] We suggest that inadvertent myocardial puncture with a smaller-bore micropuncture needle, compared to relatively larger-bore needles, will cause less injury and allow more opportunity for an auto-seal to form without hemodynamically significant bleeding.

TECHNIQUE OF NEEDLE-IN-NEEDLE MICROPUNCTURE EPICARDIAL ACCESS

We found that there is a tendency for a long 21-gauge micropuncture needle to flex during the course of insertion through the tissue beneath the sternum as it approaches the pericardium. This made it difficult to maintain the needle on a straight path, crucial for safe epicardial access. Additionally, tactile perception of force and cardiac motion was also limited. To improve control and tactile feel with the micropuncture needle, a "needle-in-needle" approach was developed.[3]

In this method, an 18-gauge Cook needle (percutaneous entry thin wall needle, 18-gauge, 7 cm, Cook Medical, Bloomington, IN) is inserted in the subxiphoid space well outside the pericardium. Subsequently either a 21-gauge micropuncture needle (Cook medical) or 21-gauge long spinal needle (Chiba Biopsy needle, Cook Medical) is inserted to telescope through the larger needle. This improves the stability of the micropuncture needle and the tactile feedback. The technique is an extension of the Sosa technique with some important variations.

Step 1: Insertion of the Cook Needle

Typically, the 18-gauge Cook needle is inserted 2 finger breadths below and slightly to the left of the xiphoid-sternal junction. Using a lateral fluoroscopic view, it is guided under the sternum, but remains well outside the pericardial silhouette. Care is taken to avoid any visible loops of bowel and to maintain an angle that keeps the needle in the space of Larrey, above the diaphragm and liver (**Figure 4.2**, Panel B).

Step 2: Insertion of the Micropuncture Needle

A 21-gauge micropuncture needle is inserted through the 18-gauge Cook needle (**Figure 4.2**, Panels B and C).

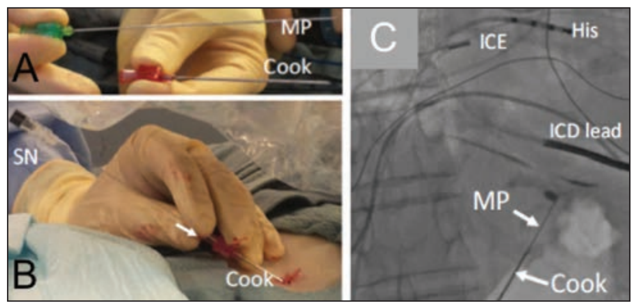

Figure 4.2 Steps for initial access of the pericardial space using the needle-in-needle technique. **Panel A:** 21-gauge micropuncture (MP) needle, 18-gauge Cook needle. **Panel B:** Micropuncture spinal needle (SN) inserted through Cook needle. **Panel C:** Micropuncture spinal needle (SN) inserted through Cook needle approaching cardiac silhouette. Abbreviations: ICD, implantable cardioverter-defibrillator; ICE, intracardiac echocardiography.

Step 3: Access the Pericardial Space

The 21-gauge micropuncture needle alone is used to enter the pericardial space while maintaining the position of the Cook needle steady, aided by contrast, fluoroscopy, and tactile sensation (**Figure 4.3**). The tactile sensation of pericardial entry afforded by large-bore needles is often not well appreciated with the micropuncture needle. When the needle approaches the pericardium, a small amount of radiographic contrast is injected. This typically distributes along tissue planes. The needle is advanced slightly until a site is identified where the needle is clearly tenting the tissue. The needle is then advanced through that plane. On entry into the pericardium, the tenting relaxes, and the needle remains in the pericardial space. The contrast that has accumulated outside the pericardium may also enter the pericardium. Additional contrast

CHAPTER

5 Pressure Sensor Needle for Epicardial Access

Jorge Romero, MD; Andrea Natale, MD, PhD; Luigi Di Biase, MD, PhD

INTRODUCTION

Percutaneous epicardial access is widely used in the field of electrophysiology for the treatment of complex arrhythmias as well as for closure of the left atrial appendage.[1] Nonetheless, epicardial access into the "virtual" pericardial space requires expertise and extensive knowledge of the anatomy to prevent complications. Different techniques have emerged as well as different percutaneous approaches, including subxiphoid, parasternal, intercostal, apical,[2] transesophageal,[3] transatrial,[4,5] and transbronchial.[6] Among all these approaches, the subxiphoid access is the most frequently used, as multiple studies have assessed its efficacy and safety. Despite being a minimally invasive access, subxiphoid approach still carries the risk of inadvertent right ventricular perforation causing pericardial bleeding, which is the most common complication of epicardial access, having an incidence ranging from 3.7% to 10%.[7–9] Several efforts have been made to minimize complications arising from epicardial access, including use of different access needles, multimodality image integration, and evaluation of changes in pressure frequency to recognize pericardial entry.

Originally, epicardial procedures were performed using a 17- to 18-gauge Tuohy needle. However, in recent years, a modification of this approach has emerged with a 21-gauge micropuncture needle with or without a short 18-gauge needle ("needle-in-needle" technique), leading to a significant reduction of major bleeding when cardiac and vascular puncture accidentally occurs.[11]

The pressure frequency concept is based on the variation of pressure within different tissues during the epicardial access. This strategy was first approached by Mahapatra et al. In this small study (n = 20 patients), the investigators identified a signature pressure frequency to enable easy recognition of the pericardial space and help guide access. In order to record the pressure inside the pericardium and pleural space, a 10-Fr long sheath was used. Pressures were evaluated using a fast Fourier transform to establish dominant frequencies in each chamber. The pericardium and the pleural space had very similar mean pressures (7.8 ± 0.9 mmHg vs. 7.7 ± 1.9 mmHg, respectively). Nevertheless, the pericardial space in each patient revealed two frequency peaks corresponding to both heart rate (1.16 ± 0.21 Hz) and respiratory rate (0.20 ± 0.01 Hz), while the pleural space had a single peak correlating with respiratory rate (0.20 ± 0.01 Hz).[10] This finding represented the key principle, which facilitated the development of a novel access needles in order to decrease complications from epicardial access procedures.

Based on the high risk of inadvertent right ventricle (RV) puncture and the initial findings of Mahapatra et al., a novel technique for epicardial access emerged: the EpiAccess System (EpiEP, Inc., New Haven, CT).

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NEEDLE DESCRIPTION

Briefly, the EpiAccess System consists of an apparatus that enables the use of the Tuohy needle along with a sensor that displays the pressure waveform, allowing electrophysiologists to confirm the location of the needle in the pericardial sac in real time. The EpiAccess System has the following key components: access needle with a fiberoptic pressure frequency sensor encased in a stainless steel tube (**Figure 5.1**) and a monitor with a patent software that captures the real-time pressure frequency signal from the sensor (**Figure 5.2**) and delivers it to a computer with a graphical user interface (**Figure 5.3**). The way pressure and frequency data are displayed helps in the positioning of the needle adjunctive to fluoroscopic imaging.

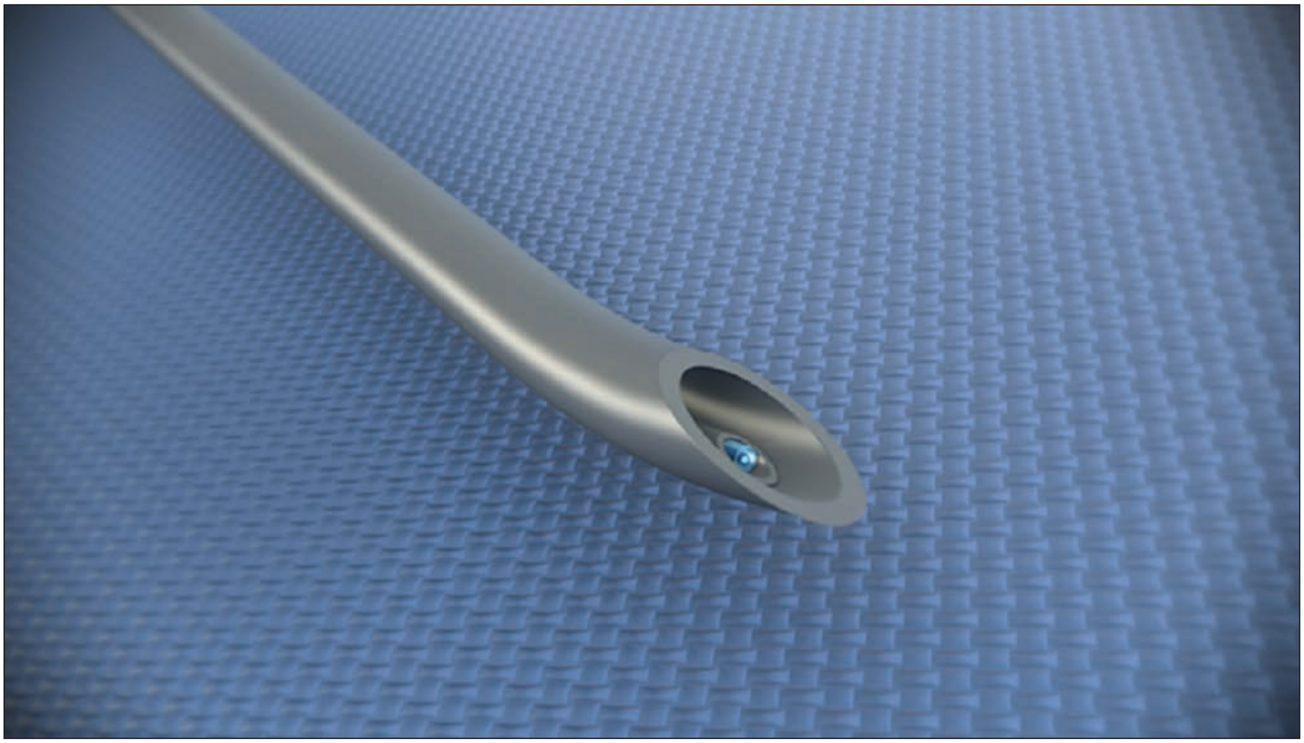

Figure 5.1 EpiAccess needle. The needle has a pressure frequency fiberoptic sensor contained within a stainless steel tube welded inside the lumen of the cannula and a monitor with a software that displays the real-time pressure frequency signal from the sensor.

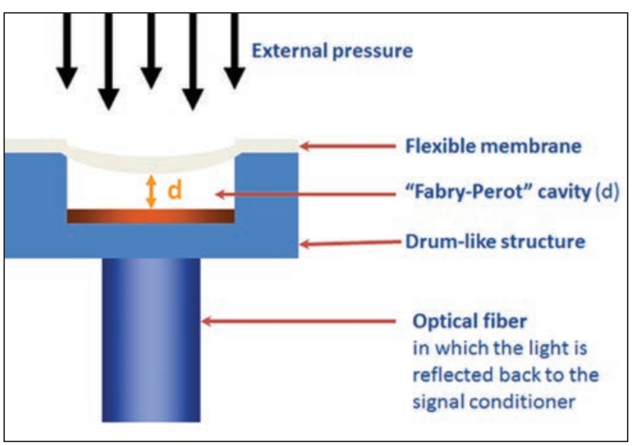

Figure 5.2 Diagram showing the sensor at the tip of the EpiAccess needle. The EpiAccess needle has a fiberoptic sensor that transmits the pressure frequency measurements at the tip of the needle. The sensor is accessible to detect pressure frequency based on the concept of a Fabry-Perot interferometry, where the transducer membrane deflects under pressure as the needle traverses different media.

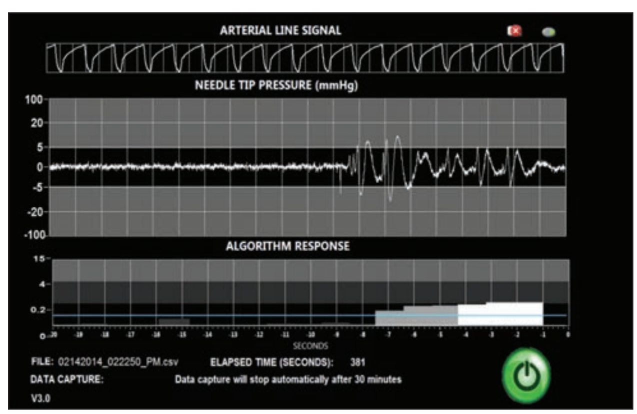

Figure 5.3 EpiAccess monitor displays the arterial blood pressure and the pressure at the tip of the needle. This tracing shows the change in needle-tip pressure once the pericardial space has been touched. An algorithm conducts a beat-to-beat evaluation of the needle-tip pressure frequency using the arterial pressure signal as a gate and graphs the pulsatility pattern within the needle-tip pressure signal.

CHAPTER

7

Epicardial Access for Left Atrial Appendage Occlusion: Techniques and Challenges

Sharan Prakash Sharma, MD; Mohit K. Turagam, MD;
Dhanunjaya Lakkireddy, MD

INTRODUCTION

Percutaneous epicardial access was first described by Sosa and coworkers in 1996 for the management of recurrent ventricular tachycardia from an epicardial substrate in Chagas cardiomyopathy.[1] Since then, this approach has expanded for the management of various cardiac arrhythmias, including atrial fibrillation, atrial tachycardia, accessory pathways and ventricular tachycardias especially after a failed endocardial ablation.[2–5] Due to its unique capability to access the left sided-cardiac structures by this approach several novel innovations such as left atrial appendage (LAA) ligation, epicardial lead implantation and drug-delivery techniques are currently being studied.[6]

Percutaneous epicardial LAA ligation using the LARIAT system (SentreHEART, Inc., Redwood City, CA) is one such technique that has emerged in the past decade for stroke prevention and reducing AF burden. The LARIAT utilizes the anterior pericardial puncture to deliver the preformed suture through the epicardial delivery snare that aligns with the magnet-tipped wire endocardially via transeptal access. While performing the LARIAT procedure, there are several anatomical challenges and pericardial anomalies that needs careful consideration from an interventional electrophysiologists' perspective.

ANATOMICAL CONSIDERATIONS AND PREPROCEDURAL PLANNING

The pericardium is a fibrous sac that surrounds the heart and is attached to the walls of the great vessels and the diaphragm. It consists of two layers: the visceral pericardium and the parietal pericardium. The visceral pericardium is adherent to the epicardial surface of the heart. The parietal pericardium (0.8–2.5 mm thick) consists of an outer fibrous layer and an inner serosal layer, which is the reflection of the visceral pericardium. The potential space between the parietal and the visceral pericardium is called pericardial space and normally contains 15–50 mL of serous fluid. The visceral pericardium continues posteriorly to form the transverse sinus and the oblique sinus. The transverse sinus is bounded by the aorta and the pulmonary artery anteriorly and the superior vena cava posteriorly, while the oblique sinus bounded by the inferior vena cava and the right and left pulmonary veins.

While performing LAA ligation, it is critical to have a thorough understanding of the cardiac structures surrounding the LAA in order to access the pericardium at the optimal anterior location. Otherwise, it would be impossible to gain access to the LAA by negotiating the cardiac structures that lie in between the puncture site and the LAA. A preprocedural cardiac computed tomography (CT) is invaluable for careful planning of the procedure including the epicardial access route. **Figure 7.1** demonstrates the ideal trajectory of the pericardial puncture and access to the LAA. The angle between the needle and the chest wall determines the site of the ventricle accessed; a steeper (less acute angle) tends to access the posterior right ventricle, while a less steep angle (more acute angle) tends to access the anterior right ventricle.

Once pericardial access is obtained, the catheter must negotiate the adjoining blood vessels that lie in close vicinity to the LAA. **Figure 7.2** demonstrates the relationship of the various blood vessels in relationship with the LAA.

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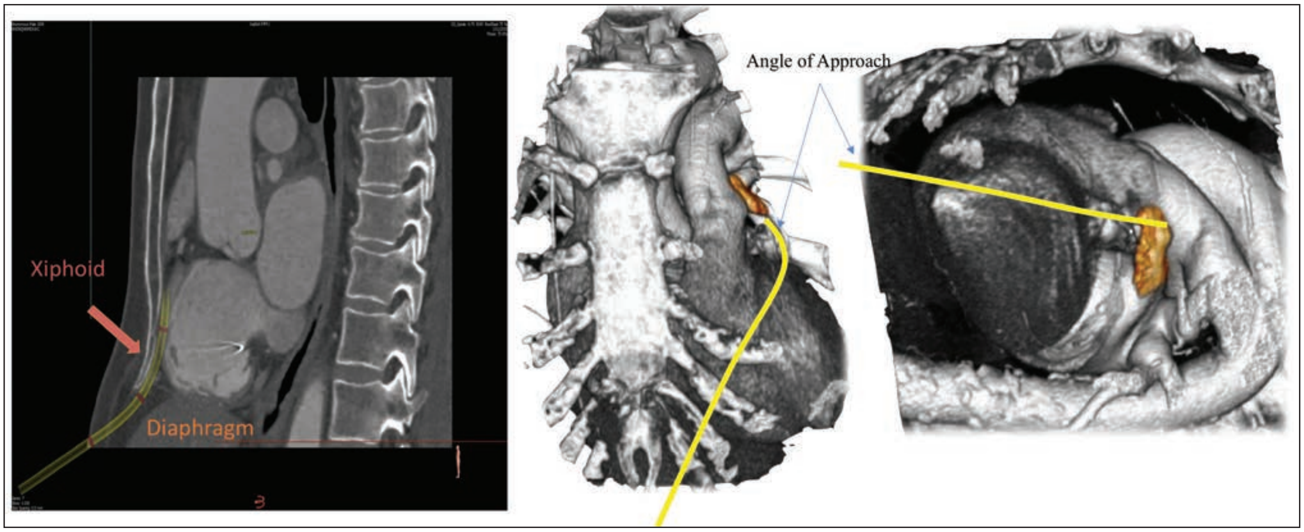

Figure 7.1 CT roadmap showing orientation of important structures and preferred angle of approach.

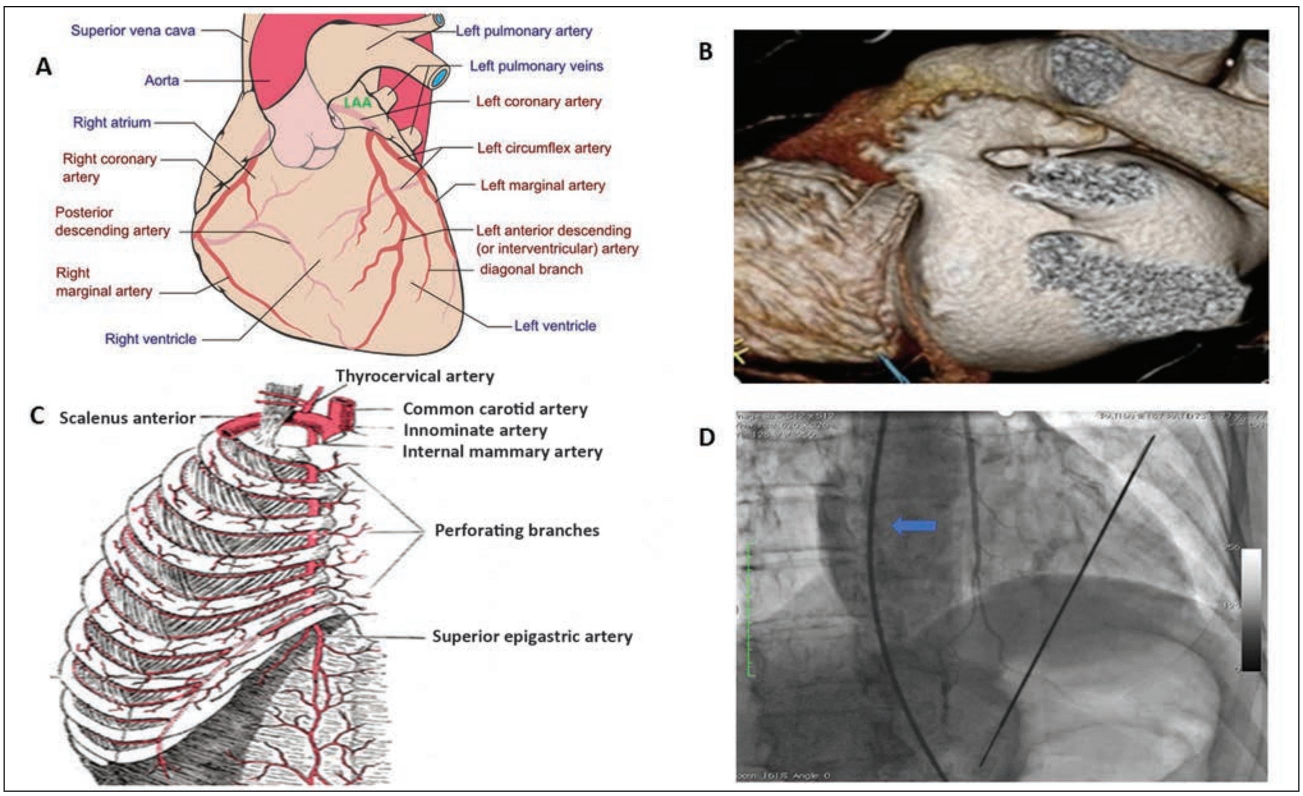

Figure 7.2 Anatomical relationship of left atrial appendage with various vascular structure. **Panel A:** LAA relationship with pulmonary artery, pulmonary vein, and coronary artery. From Shahoud JS, Tivakaran VS. Cardiac Dominance. [Updated 2020 Feb 21]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2020 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537207/ **Panel B:** The pulmonary artery is shown lying in front of LAA; epicardial exclusion should be avoided in such instance. **Panels C** and **D:** The course of superior epigastric artery and left internal mammary artery (**blue arrow**) are shown. The movement of the needle must be tailored to avoid injury to these vessels.

The pulmonary artery is typically located superior and medial to the LAA, but anatomic variations in pulmonary artery in relation to LAA have been described. In addition, the internal mammary artery courses vertically and parallel to the sternal border, giving off perforating vessels to the chest wall. The internal mammary artery bifurcates into the superior epigastric artery and the musculophrenic artery around the sixth intercostal space. Inferior to the bifurcation, the distance between the inferior mammary artery and the sternum and the xiphoid is the maximum pericardial access at that location that can minimize collateral damage.

For epicardial LAA closure, the needle is advanced towards the one o'clock position in the left anterior oblique view, so that it lies lateral to the pulmonary artery (**Figure 7.3**). In addition, inferior access, or apical access, creates a secondary curve in the soft tip and device that negatively affects the control of the LARIAT. Hence, coming into the right ventricle at a more shallow angle reduces the likelihood of perforations or over advancement of the device, as shown in **Figure 7.4**. The left circumflex coronary artery is the other important structure that courses in the atrioventricular groove and lies at the ostium of the LAA. Coronary angiography may be required during the procedure in the setting of diffuse precordial ST elevation, ventricular arrhythmias, or hemodynamic instability. The proximity of the left phrenic nerve needs careful consideration as it runs over the aortic arch and the pulmonary trunk anterior to the LAA and then passes anterolateral as it courses along the left ventricle.

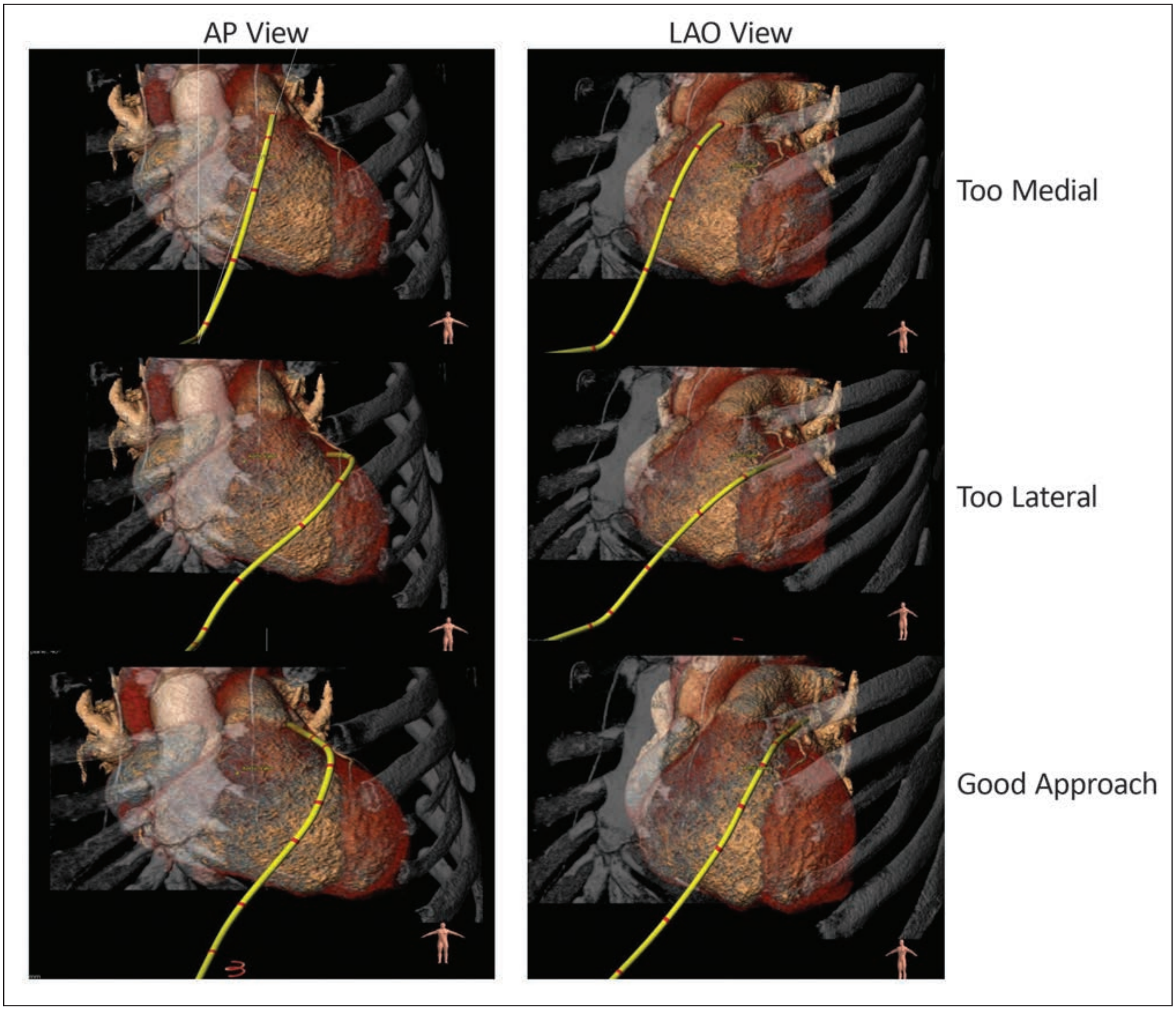

Figure 7.3 A good approach has catheter tip aiming right down the center of LAA in the left anterior oblique view.

CHAPTER 11

Totally Endoscopic Robotic Epicardial Surgical Ablation (TERESA) Procedure to Treat Arrhythmias from the Left Ventricular Summit

Roderick Tung, MD; Husam H. Balkhy, MD

INTRODUCTION

Ventricular arrhythmias arising from the left ventricular (LV) summit are increasingly recognized and referred for catheter ablation. Symptoms include palpitations, but the indication for catheter ablation is strongest in the setting of drug-refractory PVC-induced cardiomyopathy.

The LV summit is defined as the epicardial cap of the basal anterior LV ostium, delineated by the left anterior descending artery as the septal boundary and the left circumflex artery as the lateral boundary.[1] The proximity to the coronary arteries provides both a method to access this region through the coronary venous system (accessible) but also anatomic limitations for mapping and ablation due to perivascular fat and concern for coronary artery injury.

While PVCs are more common in idiopathic substrates without structural heart disease, sustained VT is less commonly seen as the presenting arrhythmia. Unlike arrhythmias that arise from the right ventricular (RV) outflow tract due to excessive intracellular calcium (cAMP-mediated afterdepolarization), the mechanism and rationale behind the proclivity for a ventricular arrhythmia to originate from the LV ostium and LV summit is unknown. In this chapter, we describe the rationale and approach to the ablating ventricular arrhythmias refractory to traditional approaches using a novel, totally endoscopic robotic approach with standard electrophysiologic (EP) catheters for mapping and ablation.

RATIONALE

The two most common reasons for failure during endocardial ablation are sites of origin that are midmyocardial or epicardial. By anatomic definition, the LV summit is an epicardial structure, and arrhythmias that have activation from the left coronary cusp or aorto-ventricular junction earlier than the epicardium are not technically LV summit ventricular arrhythmias. Ablation, however, can be effective from an anatomic approach at sites are that are closest in proximity from the best endocardial vantage point.[2] Sites that are typically sampled that best approximate the corresponding endocardial adjacent regions of the LV summit include the left coronary cusp, the basal anterior LV anterior to the aorto-mitral commissure, and the most anterior and leftward portion of the RV outflow tract, including the pulmonary artery (**Figure 11.1**). High power, long duration application of radiofrequency may have higher attendant risks but allow for deeper penetration from the endocardium. Lower ionic irrigation provides a higher impedance to decreases dispersion of current and may be an effective strategy.[3]

The coronary venous system provides a convenient method accessible via the right atrium to sample the epicardial activation of a ventricular arrhythmia by recording local electrograms from within the great cardiac vein and anterior interventricular vein.[4–6] The course of the great cardiac vein as it turns into the anterior interventricular vein in the interventricular septum is variable, and the inaccessible region of the LV summit has been described as the space between the great cardiac vein–anterior interventricular vein junction and the left main bifurcation (**Figure 11.2**).[7] It is important to note that the earliest recorded activation timing does not necessarily denote the earliest site of activation in the heart. Sites with early activation within the coronary venous system may be even earlier on the adjacent subepicardium. For this reason, strategies to address the region of the inaccessible portion

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(via coronary venous approach) of the LV summit are necessary in select patients when other first-line approaches are unsuccessful.

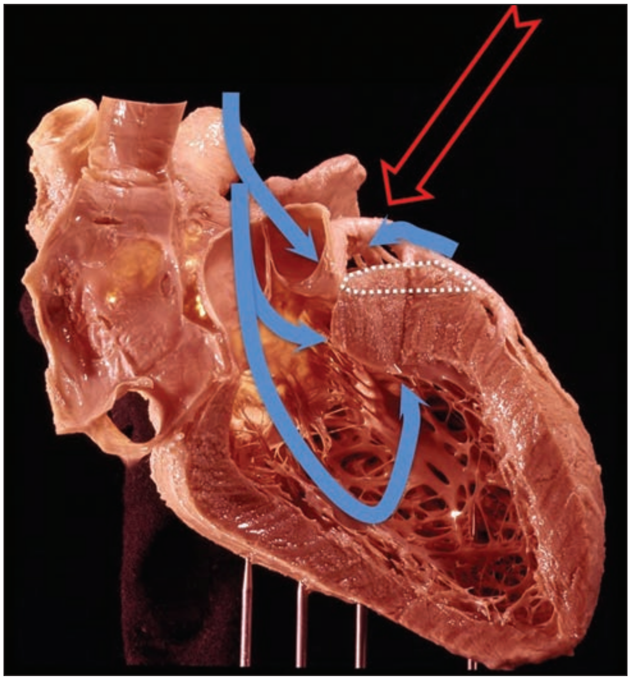

Figure 11.1 Percutaneous approaches to the LV summit with four angles of attack (**blue arrows**). Mapping and ablation is typically performed via retrograde approach in the left coronary cusp, or prolapsed underneath the aortic root with a small curve immediately or with a large curve underneath the left coronary cusp in the LV ostium anterior to the aorto-mitral continuity. Mapping via the coronary sinus is performed within the great cardiac vein to the anterior interventricular vein junction. Robotic surgical approach (**red arrow**) allows a direct approach to the LV summit with visualization and catheter orientation perpendicular to the epimyocardium.

The percutaneous epicardial approach pioneered by Sosa et al.[8] has been demonstrated to be a paradigm shift to characterize the epicardial components of arrhythmogenic substrate in ischemic cardiomyopathy, nonischemic cardiomyopathy, and arrhythmogenic right ventricular cardiomyopathy. In cases of idiopathic arrhythmias, the yield is much lower as the sites of earliest activation are typically adjacent to the coronaries.[9,10] In general, the 5-mm safety margin from the coronary arteries that is most likely to prevent injury during radiofrequency application is violated in this region. The complexity of this region is compounded by the presence of large intervening ramus intermedius branches that bisect the LV summit triangle. More important, epicardial fat up to 1 cm in thickness has been reported, which impairs contact for accurate mapping and the ability to delivery effective radiofrequency energy (**Figure 11.3**). Cryoablation has been shown to be a potential alternate energy source, although epicardial fat also provides a similar barrier to create an effective lesion. For this reason, the percutaneous approach should be discouraged as a general principle, as the coronary venous system, which is typically underneath or embedded within the epicardial fat, provides a closer vantage point to the subepicardium.

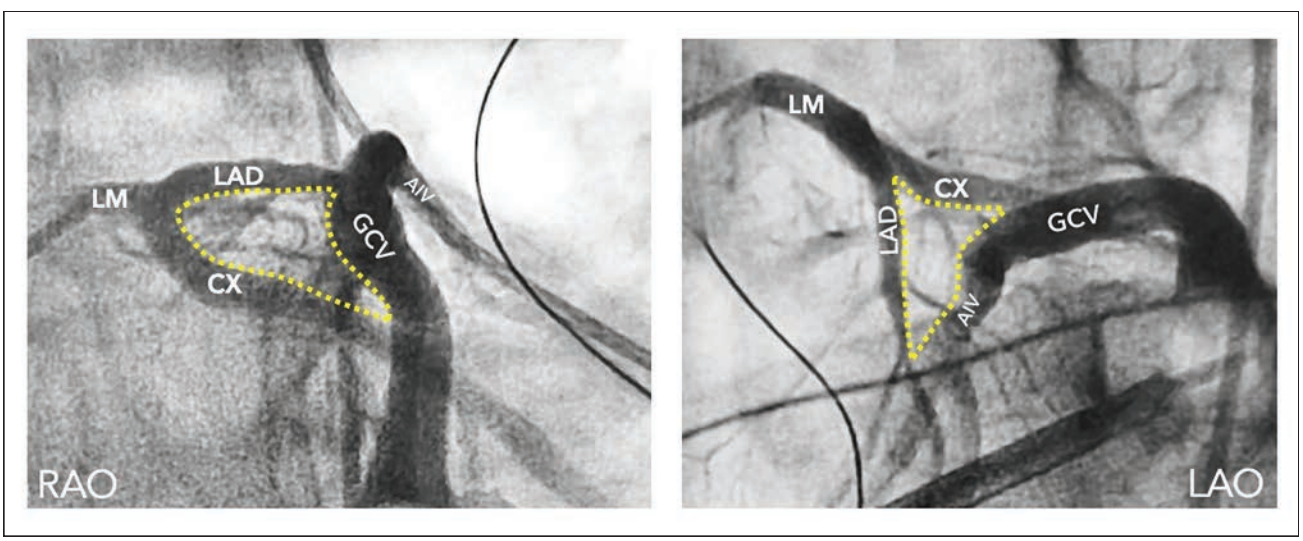

Figure 11.2 Coronary angiography with dual injection into the left main artery simultaneously with coronary venography showing the relationship of the great cardiac vein and anterior interventricular vein to the LV summit. The inaccessible region (**yellow dashed**) is the portion that cannot be mapped or ablated through the coronary venous system.

CHAPTER

47 Unusual Complications

Arash Aryana, MD, PhD; Vivek Y. Reddy, MD; André d'Avila, MD, PhD

INTRODUCTION

Percutaneous epicardial puncture and access are increasingly utilized for mapping and ablation of certain cardiac arrhythmias, left atrial appendage closure, and, rarely, even myocardial pacing. This approach necessitates advancement of a needle through and in juxtaposition to several extracardiac structures. The two most commonly reported techniques utilized by cardiac electrophysiologists include the subxiphoid approach[1] and the anterior parasternal approach.[2] The anterior parasternal approach is designed to access the anterior region of the pericardium through the left intercostal space. However, this is a less frequently practiced method due a higher propensity for adverse events. Thus, the preferred and most frequently employed method is the subxiphoid technique as reported by Sosa et al.[3] While generally deemed safe, various studies have reported a complication rate ranging between 5–10%.[4–7]

It should be emphasized that the vast majority of epicardial complications are due to epicardial access itself. Along these lines, a history of cardiac surgery and/or presence of pericardial adhesions serve as important risk factors for epicardial complications. Thus, patient selection, careful planning, and detailed knowledge of the underlying anatomy are key to preventing them. While the most common adverse events associated with epicardial puncture, mapping, and ablation consist of inadvertent right ventricular puncture and postprocedure pericarditis, both of these are typically self-limiting and without major sequelae. Nonetheless, several rare and distinct complications not otherwise encountered during an endocardial procedure may exclusively occur in the context of an epicardial procedure. Some of them may even be catastrophic or life-threatening. In this chapter, we will review in detail a variety of rare and unusual adverse events that may ensue from percutaneous epicardial puncture and catheter mapping and ablation as well as means to mitigate them.

VASCULAR INJURY

During a percutaneous epicardial procedure vascular injury may involve (1) the phrenic vessels during an inferior epicardial puncture with the needle traversing through the diaphragm, (2) the mediastinal vessels, or (3) the epicardial vessel as a consequence of a direct puncture using the epicardial needle, poor catheter/sheath management or manipulation, or direct delivery of energy to the vessel during catheter ablation. As discussed in the previous chapters, the diaphragm is a highly vascular organ. As a result, diaphragmatic puncture during a percutaneous epicardial procedure could lead to significant bleeding complications. Hence, care should be taken to avoid advancement of the needle or an introducer through the diaphragm.

Rarely, bleeding may occur as a result of injury to the internal mammary artery. The internal mammary artery passes through the space of Larrey as it gives rise to the superior epigastric artery. It lies at the margins of the sternum, ~1 cm from the sternal edge. As such, a very anterior and lateral approach can result in the puncture of this vessel. Khan et al.[8] reported on left internal mammary arterial injury using an anterior puncture approach in 2 patients referred for epicardial ventricular tachycardia ablation. While one patient was managed conservatively, the other required thoracotomy with urgent repair of the lacerated vessel.

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In rare cases, inadvertent puncture and/or perforation of an epicardial vessel may occur during epicardial access. Although theoretically, injury to the bypass grafts can also occur in patients with a history of coronary artery bypass surgery, this has never been reported. However, a marginal artery is typically situated at the acute margin of the right ventricle, which may rarely continue along the diaphragmatic wall of the ventricle to give rise to a short posterior descending artery. In cases of right ventricular dilatation, this marginal artery may be at increased risk of puncture when attempting to gain epicardial access. Such a complication typically manifests as persistent, unremitting intrapericardial bleeding. The diagnosis may be difficult and it sometimes requires surgical intervention. Additionally, in several cases the onset of intrapericardial bleeding has appeared late after epicardial access, suggesting an unpredictable timeline. In one case, coronary angiography precisely identified the site of the bleeding and allowed for successful treatment through repeated angioplasty balloon occlusions proximal to the site of bleeding in the target vessel, eventually leading to thrombosis of the distal segment and control of the bleeding.[9] In cases where an injury to an epicardial vessel is suspected, manipulations of the mapping/ablation catheter and the epicardial sheath should be avoided to prevent further adverse events.

Vascular injury can also occur as a consequence of poor sheath management. After the placement of an introducer into the pericardial space, the sheath should never be left unprotected, as this can introduce a risk of myocardial or vascular laceration. To avoid such a complication, a blunt catheter (i.e., a diagnostic mapping or an ablation catheter) should be left at all times through the introducer inside the pericardium. Cases of coronary arterial and venous injury using an unprotected pericardial sheath have been reported (**Figure 47.1**).[10] Typically, the treatment involves surgical repair. Additionally, arterial stenosis through intimal hyperplasia can also occur as a result of epicardial energy delivery in close proximity to a vessel during catheter ablation. Both radiofrequency[4,7] and cryothermy[11] have been shown to result in such a complication. In general, the distance between the ablation catheter tip and the coronary vessel and the diameter of the epicardial vessel are the most important determinants of vascular injury in such a setting.[11]

Lastly, a case of diffuse and profound coronary artery spasms has been reported with epicardial mapping in patient with a history of ventricular tachycardia in the setting of ischemic cardiomyopathy and vasospastic angina.[10] In this patient, prior to catheter ablation, epicardial mapping along the anterior left ventricular wall adjacent to the main coronary arteries, was immediately followed by sudden hemodynamic collapse, diffuse precordial ST segment elevations, and shock-refractory ventricular fibrillation. Coronary angiography (**Figure 47.2**) demonstrated diffuse vasospasm involving the left main, left anterior descending, and circumflex arteries with absence of flow to the distal coronary bed. The patient was treated with cardiopulmonary resuscitation, repeated injections of intracoronary nitrates, and intra-aortic balloon pump support, and eventually fully recovered from this complication. While no clear etiology for this adverse event was found, it was believed to have been elicited by catheter manipulations and epicardial mapping over and adjacent to the epicardial arteries.

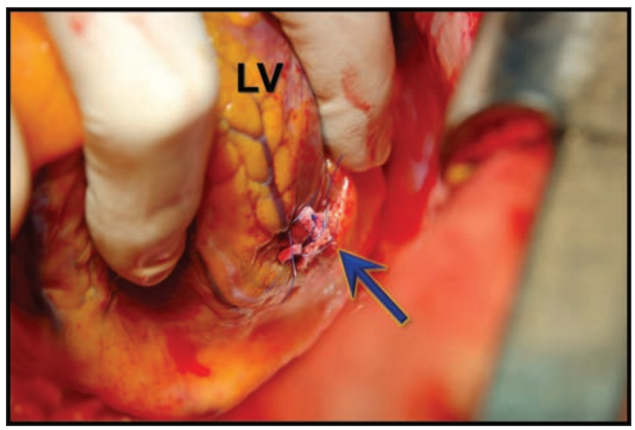

Figure 47.1 Coronary sinus laceration during epicardial mapping. An intraoperative image of a surgically repaired laceration (**arrow**) to a large-caliber posterolateral branch of the coronary sinus. This vascular tear occurred during epicardial advancement of an SL-3 introducer along the posterior left atrium. This was followed by a sudden drop in the blood pressure and drainage of 2 L of venous blood, ultimately requiring urgent thoracotomy with surgical repair of the lacerated vessel. Image was reproduced with permission from Koruth et al., *Circ Arrhythm Electrophysiol*. 2011;4:882–888. Abbreviation: LV, left ventricle.

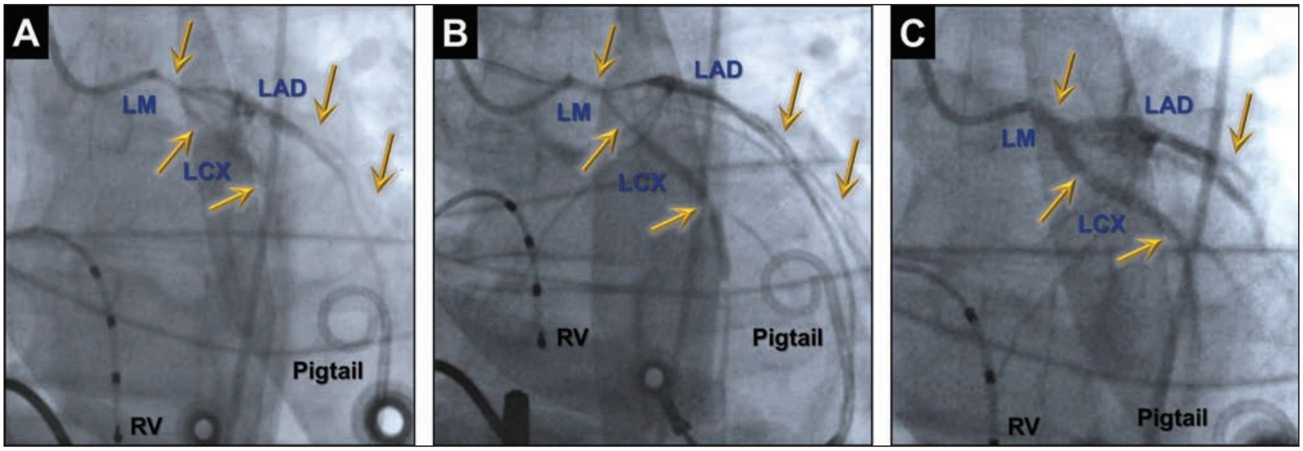

Figure 47.2 Diffuse coronary spasm during epicardial mapping. During epicardial mapping of ventricular tachycardia in a patient with a history of ischemic cardiomyopathy and vasospastic angina, manipulations of the epicardial mapping catheter along the left ventricular summit resulted in sudden hemodynamic collapse, diffuse ST segment elevations, and ventricular fibrillation. **Panel A:** Emergency coronary angiography demonstrated diffuse vasospasm (**arrows**) involving the left main (LM), the left anterior descending (LAD), and the left circumflex (LCX) arteries with absence of blood flow to the distal coronary bed. Repeated injections of intracoronary nitrates resulted in gradual resolution of vasospasm over 15 minutes. **Panels B** and **C:** Angiographic findings at 5 (B) and 15 (C) minutes following the event. The patient eventually recovered without long-term sequelae. Images were reproduced with permission from Koruth et al., *Circ Arrhythm Electrophysiol.* 2011;4:882–888. Abbreviation: RV, right ventricular catheter.

MYOCARDIAL INJURY

Two rare types of cardiac injury in the setting of epicardial ablation have been observed. One has involved a case of double right ventricular puncture in which an epicardial introducer enters and exits the right ventricular wall in two different sites. It is believed that such a complication would primarily occur with an inferior epicardial puncture, such that the needle may be advanced unnoticed through the inferior wall and subsequently through the free wall of the right ventricle. Consequently, the needle is then exchanged for an epicardial introducer over a guidewire, and epicardial mapping and ablation may be completed without immediate sequelae via the introducer placed through and through the right ventricle. But upon its removal at the end of the procedure, catastrophic intrapericardial bleeding will ensue (**Figure 47.3**). Another rare case of cardiac injury has been reported during epicardial mapping in a patient with a history of prior cardiac surgery undergoing catheter ablation of ventricular tachycardia. In this case, percutaneous subxiphoid access was obtained using an inferior approach without sequelae. However, during disruption of the epicardial adhesion performed using the curved elbow ("blunt" portion) of the catheter, a sudden drop in the blood pressure and hemodynamic collapse was observed. Consequently, patient underwent a repeat sternotomy, which revealed a left ventricular tear likely as a result of disruption of the adhesions (**Figure 47.4**). Both patients were successfully treated with surgical intervention and eventually made full recovery.

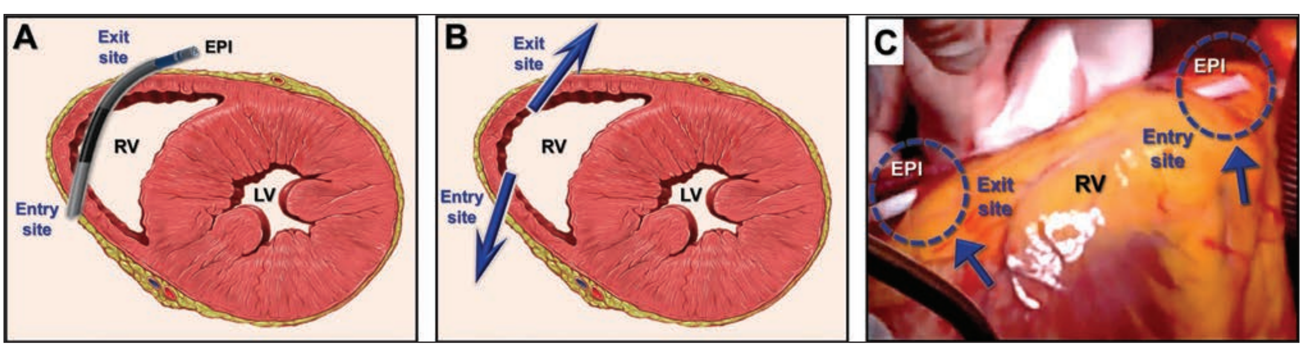

Figure 47.3 Double right ventricular puncture. **Panel A:** A cross-sectional schematic of the heart showing advancement of an epicardial introducer (EPI) into the pericardium using an inferior puncture approach. The catheter is seen entering and exiting the right ventricle. **Panel B:** A cross-sectional schematic of the heart showing perforation of the right ventricle at the entry and exit sites following removal of the introducer. Removal of the sheath would be followed by immediate and torrential intrapericardial bleeding from the two puncture sites within the right ventricle (**blue arrows**). **Panel C:** A case of a double right ventricle puncture confirmed at cardiac surgery in a patient who underwent epicardial catheter ablation of ventricular tachycardia. The epicardial introducer (EPI) is visible at the entry and exit sites (**dotted circles**) in the right ventricle as marked by blue arrows. Figure was modified with permission from Aryana et al., *Card Electrophysiol Clin.* 2017;9:119–131. Abbreviations: LV, left ventricle; RV, right ventricle.