Unusual Complications of Percutaneous Epicardial Access and Epicardial Mapping and Ablation of Cardiac Arrhythmias

Running title: Unusual Complications of Epicardial Ablation

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Abstract:

**Background** - Percutaneous epicardial access and mapping/ablation of cardiac arrhythmias are being increasingly performed. While complications such as pericardial effusion are relatively common, other unusual complications may occur due to the complex anatomical cardiac architecture and surrounding tissues. In this manuscript, we report a series of rare and unusual complications related to percutaneous epicardial procedures.

**Methods and Results** - Between 2006 and 2011, 334 patients underwent attempts at percutaneous, subxiphoid access for epicardial mapping/ablation at five experienced centers. Seven selected complications are highlighted in this case series. Patient 1, developed a 1-cm right ventricular (RV) pseudoaneurysm following several unsuccessful attempts at epicardial access. This was successfully managed conservatively. Patient 2, developed intra-abdominal bleeding related to puncture of the left lobe of the liver during access that required surgical repair. Patient 3, developed a subcapsular hepatic hematoma, likely related to percutaneous access and was successfully managed conservatively. Patient 4, developed severe pericardial bleeding followed by ventricular fibrillation (VF), immediately after obtaining percutaneous epicardial access. A lacerated middle cardiac vein was repaired surgically. However, the patient ultimately died from complications. Patient 5, had a prior history of cardiothoracic surgery and developed an RV-abdominal fistula following multiple attempts at percutaneous access. This was surgically repaired without major sequelae. Patient 6, developed cardiac tamponade due to a lacerated coronary sinus branch during epicardial catheter ablation and required surgical repair. Patient 7, sustained severe left coronary vasospasm and VF during catheter manipulation in the pericardium. This complication was successfully managed with intra-coronary nitrates.

**Conclusions** - Though generally safe, percutaneous epicardial access and mapping/ablation can result in uncommon complications. Awareness of these rare complications may facilitate early detection and successful management.

**Key words:** epicardium; pericardium; epicardial access; epicardial ablation; complications
Introduction

Percutaneous epicardial access for catheter mapping and ablation has become an important adjunct and sometimes the preferred strategy for elimination of a wide range of cardiac arrhythmias such as atrioventricular reentrant tachycardia (AVRT), atrial fibrillation (AF), and in particular ventricular tachycardia (VT) (1-4). In addition, this approach is presently also being utilized for other investigational devices (5).

Epicardial mapping and ablation has been performed safely for over a decade at many experienced centers worldwide. A recent multicenter series reported major complication rates of 5% and 2% for acute and delayed complications related to epicardial VT ablation (6). The most common complications associated with this procedure are post-procedure pericarditis and inadvertent RV puncture (6-8). However, certain serious complications can occur rarely.

Herein, we report a series of rare complications related to epicardial puncture and/or catheter mapping and ablation along with the clinical scenario, management and outcomes, knowledge of which will be helpful to the practicing invasive electrophysiologist (Table 1). These cases represent a subset of unusual complications that occurred over 334 epicardial access attempts at five highly experienced centers (>50 cases/year) over a period of 5 years. This denominator includes 291 cases of ventricular tachycardia, 39 cases of atrial fibrillation and 4 case of Wolf Parkinson White syndrome. These complications can be broadly classified into those related to: (i) percutaneous pericardial access, and (ii) epicardial mapping and ablation. The former comprise the majority of complications associated with this procedure. Finally, we also provide our recommendations on how to avoid or minimize such complications.
Complications Related To Percutaneous Access

Patient 1: Right ventricular pseudo aneurysm

A 63-year-old male underwent catheter ablation for recurrent VT associated with several implantable cardioverter-defibrillator (ICD) therapies, under general anesthesia. His past medical history was remarkable for systemic lupus erythematosus and ischemic cardiomyopathy with coronary artery bypass grafting (CABG) and mechanical aortic valve replacement. During the electrophysiology study, several VT morphologies were induced, some with EKG features suggestive of epicardial origin. Mapping revealed a large inferoapical scar. In view of the above, epicardial puncture was attempted. Despite multiple attempts, the pericardial space could not be accessed due to presence of extensive pericardial adhesions. The procedure was therefore completed successfully endocardially. Post-procedure, the patient complained of chest pain that was investigated with a computed tomographic (CT) scan of the chest. A small collection of fluid located anterior to the pericardium with focal pericardial thickening was detected. The patient was observed and remained stable and therefore was subsequently discharged to follow up. A repeat chest CT scan was performed one month later due to persistent chest pain, revealed the presence of a RV pseudoaneurysm with a neck measuring 13 x 10 x 9 mm (Figure 1,Panel A-C) and a small loculated pericardial effusion. Surgical repair was felt to be high-risk and conservative management with close observation was elected. A subsequent scan, showed reduction in the size of the neck of the pseudoaneurysm to 9 x 7 x 7 mm. Follow-up scans over a few weeks eventually showed complete resolution (Figure 1, Panel D).

Patient 2: Hepatic puncture
A 53-year-old lady was referred following two prior failed catheter ablations for Wolf-Parkinson-White syndrome with a history of AF with rapid ventricular rates and one episode of VF-related sudden cardiac death. The first procedure was performed endocardially while the second attempt was performed using a combined endocardial and epicardial approach. The location of the accessory pathway was believed to be right posteroseptal. Given the prior failures, a combined epicardial and endocardial access was repeated. Double epicardial access was obtained. However, in retrospect the operators recalled that the sheaths advanced with some difficulty. The endocardial and epicardial aspects of the posteroseptal region were mapped for earliest ventricular activation during atrial pacing. The pathway was subsequently successfully ablated on the endocardial aspect within the posteroseptal region. During the procedure, a gradual decline in blood pressure was noted in the absence of a pericardial effusion, as confirmed by intracardiac echocardiography (ICE). The ICE probe was then withdrawn into the inferior vena cava which demonstrated presence of intra-abdominal fluid. Taking into consideration the hypotension and the likelihood of the fluid representing hemoperitoneum, surgical consultation was sought. The patient underwent emergent exploratory laparotomy, during which two punctures sites with active bleeding in the left hepatic lobe was discovered (Figure 2). It was concluded that the dual epicardial access was obtained with inadvertent “through and through” puncture of the left lobe of the liver. The puncture sites were surgically repaired and the patient was subsequently discharged to follow up without recurrent evidence of pre-excitation.

**Patient 3: Intra-Hepatic Hematoma**

A 16-year-old male underwent catheter ablation for symptomatic orthodromic AVRT via an epicardial approach under general anesthesia after having failed previous endocardial attempts.
His past medical history was significant for a small congenital coronary artery-pulmonary artery fistula. An epicardial puncture using an inferior approach was performed. The accessory pathway was successfully ablated using radiofrequency (RF) epicardially in the posteroseptal region. Shortly after the procedure, the patient complained of intense epigastric pain. A 4-unit drop in the hematocrit was noted and this led to an emergent abdominal CT scan that revealed the presence of a subcapsular hematoma in the left lobe of the liver measuring 6 x 7 x 11 cm (Figure 3). This complication was thought to be secondary to puncture of the liver during one of the epicardial puncture attempts. This was managed conservatively with complete resolution of the hematoma over a period of weeks.

**Patients 4: Coronary Vascular Injury**

A 59-year-old male, underwent catheter ablation of VT under general anesthesia. His past medical history was significant for Chagasic cardiomyopathy and recurrent, drug-refractory VT requiring repetitive ICD therapies. Pericardial access was obtained using an anterior approach. Minutes later, but prior to performing catheter mapping or ablation, the patient’s blood pressure rapidly declined. VF eventually ensued, requiring external defibrillation. A pericardial pigtail catheter drained a total of 2.5 liters of dark blood that was thought to be venous. Intra-pericardial bleeding however persisted and the patient subsequently required emergent cardiac surgery. Open thoracotomy revealed large amounts of venous blood and thrombus within the pericardial space. A large-caliber, severely lacerated middle cardiac vein was identified as the source of active bleeding. This was surgically repaired and the pericardial thrombus was evacuated. However, the patient’s post-operative course was complicated by a hospital-acquired pneumonia, systemic inflammatory response syndrome, and renal failure. Despite aggressive
resuscitation, the patient’s clinical status continued to decline and the patient eventually died two weeks later from unresponsive septic shock.

**Patient 5: Right Ventricle to Abdomen Fistula**

A 65-year-old male with a history of a prior lateral and inferior wall myocardial infarction and sternotomy for RV perforation sustained during a prior ICD implant, presented with multiple ICD shocks for VT, despite the use of multiple antiarrhythmic agents. He was referred for a VT ablation. Although the clinical VT had features indicating an epicardial origin, given his history of prior sternotomy, he initially only underwent endocardial ablation. Despite extensive mapping and ablation, the clinical VT could not be terminated endocardially. In addition, endocardial electroanatomical mapping suggested presence of an epicardial circuit.

He was subsequently referred for an epicardial ablation four days later, due to recurrent VT. In view of his prior cardiac surgical history a percutaneous epicardial access was obtained using a Tuohy needle, via a posterior approach by a cardiothoracic surgeon. However catheter movement within the pericardial space was restricted by adhesions. Therefore, repeat percutaneous access was attempted further laterally. The guide wire and a 5-Fr sheath were advanced inadvertently into the RV and were then withdrawn. The patient was observed for an additional 45 minutes and no accumulation of blood was noted in the pericardial space. Given the multiple attempts at epicardial access with RV puncture, a RV angiogram was performed to evaluate for possible contrast extravasation from the RV cavity. This revealed contrast extending beyond the border of the RV free wall in the region of the apex, into a crypt-like structure extending inferiorly (Figure 4 and Data Supplement Loop 1) which at the time was felt
to most likely represent a pseudoaneurysm. Since there was no evidence of active accumulation of blood within the pericardial space, endocardial ablation was pursued. Heparin anticoagulation was initiated and endocardial mapping and ablation were performed. Near the end of the procedure, the blood pressure suddenly declined. Absence of pericardial effusion was confirmed by echocardiography. However, the abdomen was noted to be distended. An emergent CT scan performed (Figure 4), revealed extravasation of contrast from the RV extending through the diaphragm into the abdominal cavity. Emergent surgical repair was successfully performed via a redo sternotomy with repair of the RV and epicardial cryoablation of the inferolateral scar.

Complications Related To Epicardial Mapping and Ablation

Patients 6: Coronary Vascular Injury

A 65-year-old male, underwent catheter ablation of permanent drug-refractory AF under general anesthesia. His past medical history was remarkable for cardiomyopathy with moderately impaired left ventricular function. During the procedure, pulmonary vein isolation was performed along with ablation of the cavotricuspid isthmus. This was followed by epicardial atrial ablation as part of a research protocol. An uncomplicated anterior epicardial puncture was performed. In order to gain access to the oblique sinus, an SL-3 sheath (St. Jude Medical, St Paul, Minnesota) was advanced into the pericardial space to facilitate catheter manipulation. However, during epicardial catheter manipulation along the left atrial roof, a sudden drop in blood pressure was noted. A pigtail catheter drained approximately 2 liters of venous blood over an hour which was auto-transfused. However, despite reversal of anticoagulation bleeding persisted and surgical intervention was pursued. Intra-operative findings revealed a significant laceration of a large-caliber posterolateral branch of the coronary sinus (Figure 5). The lacerated
vessel was successfully repaired. The vascular injury was believed to have occurred while advancing the SL-3 sheath into the pericardial space. The patient recovered without sequelae and was discharged home one week later.

**Patient 7: Profound Coronary Arterial Vasospasm**

A 51-year-old man with ischemic cardiomyopathy underwent catheter ablation for VT under general anesthesia. His past medical history was significant for ischemic cardiomyopathy with multiple ICD shocks for VT, vasospastic angina, and one episode of severe left coronary vasospasm during percutaneous coronary intervention of the left anterior descending artery (LAD). At electrophysiology study, a monomorphic VT was induced with EKG features suggesting an epicardial origin. Percutaneous epicardial access was obtained successfully. Prior to ablation, catheter mapping along the anterior left ventricular epicardium resulted in sudden hemodynamic collapse with concurrent diffuse precordial ST segment elevations, followed by shock-refractory-VF. Cardiopulmonary resuscitation was begun immediately. The mapping catheter was removed from the pericardial space and was replaced with a pigtail catheter. This drained minimal amounts of serous fluid only. Coronary angiography (Figure 6) demonstrated a patent but normal caliber right coronary artery and marked vasospasm involving the entire left main, left anterior descending and circumflex arteries with absence of flow to the distal coronary bed as reflected by dye “hang-up”. Repeated injections of intra-coronary nitrates and insertion of an intra-aortic balloon pump eventually resulted in gradual resolution of the coronary vasospasm. In spite of several external defibrillations and prolonged CPR, the patient recovered completely without any sequelae.
Discussion

Complications Related To Percutaneous Access

Complications related to epicardial access can be further subdivided into those related to: (i) RV puncture and (ii) vascular injury. RV puncture during epicardial access can occur in up to 17% percent of cases where percutaneous access is attempted (6, 7). Approximately half of these will result in pericardial bleeding (7). While most cases are self-limiting, in rare instances larger RV perforations may require surgical repair due to persistent bleeding. There are no clear recommendations on when to proceed with surgical intervention when dealing with hemopericardium associated with epicardial procedures. However, the rate and quantity of pericardial bleeding along with the overall clinical picture are often taken into consideration when deciding on the need for surgical intervention.

To the best of our knowledge, this case series represents the only reported complications of: i) post-epicardial access RV pseudoaneurysm (Patient 1) and ii) RV-abdominal fistula (Patient 5). Traumatic pseudoaneurysms of the RV have been previously reported following corrective surgery for congenital heart disease, myocardial infarction, cardiac tumors, and endomyocardial biopsy (9). Large RV pseudoaneurysms often require surgical repair (10). If uncorrected, they could potentially increase in size and lead to life-threatening complications such as a thromboembolism or rupture (10). On the contrary, as illustrated in patient 1, smaller pseudoaneurysms can be managed conservatively with close follow-up. Therefore, the decision regarding the need for intervention in cases of RV pseudoaneurysm may be guided by its size and stability. However, it should be emphasized that this recommendation is based on a single
case that was successfully managed in this manner. From a mechanistic point of view, it is unclear what factors led to the development of the pseudoaneurysm in Patient 1. The multiple attempts at percutaneous access and presence of prior adhesions related to past cardiac surgery likely played a role. Consideration must be given to pursuing a limited sub-xiphoid (11) surgical approach to obtain epicardial access in patients with prior cardiac surgery to limit the incidence of complications such as the bleeding from multiple attempts.

The occurrence of RV–abdominal fistula in patient 5 was likely related to RV myocardial puncture by the needle/sheath in a patient with intra-pericardial adhesions from prior cardiac surgery. Although, RV puncture with the needle/guide wire leads to transient pericardial bleeding in the vast majority of cases, the additional injury from the sheath and presence of prior intra-pericardial adhesions likely facilitated the persistence of a small tract leading into the abdominal cavity resulting in fistula formation. Restricting percutaneous epicardial access in patients with a prior history of cardiac surgery to only rare situations, coupled with a general preference for the surgical subxiphoid approach in this patient subset (11), may help avoid such complications.

Another uncommon complication related to epicardial access is that of vascular injury. Such injury may involve either arterial or venous structures encountered along the route taken by the needle used in percutaneous access. These may include, but are not limited to, superficial arteries and veins in the abdominal wall, vessels in or near the diaphragm and on the epicardial surface of the heart itself (i.e. coronary veins and arteries). Infra-diaphragmatic injury like that to the liver would presumably occur more commonly with the inferior epicardial puncture.
approach (Figure 7). The occurrence of progressive hypotension during or after percutaneous epicardial access in the absence of pericardial effusion or other obvious causes, should therefore raise the operator’s suspicion of intra abdominal bleeding caused by infra-diaphragmatic injury (as was the case in the second patient). In these patients, emergent abdominal imaging and surgical consultation should be performed.

Patient 3, who developed a subcapsular hematoma, likely sustained direct injury to the liver from the epicardial needle. The small size of the hematoma and its relative stability allowed successful conservative management without the need for surgical intervention. With regard to patient 4, who sustained coronary venous laceration, the severity of bleeding and the patient’s hemodynamic status ultimately dictated the clinical management. Most vascular injuries require surgical repair. However, alternative percutaneous catheter-based treatments have been recently described in coronary artery-related bleeding (12). These vascular complications are largely unpredictable and perhaps unavoidable.

Several ‘learning points’ can be gleaned from these cases. In the case of patient 2, when difficulty is encountered during advancing a sheath over a guide wire into the epicardial space, one must be aware that this may indicate the sheath may be traversing through intra-abdominal structures. Additionally we believe that the inferior percutaneous approach (given the regional anatomy) has a likely higher incidence of intra-abdominal injury as opposed to the anterior approach, where the incidence of inadvertent RV free wall puncture may be higher.

Complications Related To Epicardial Mapping and Ablation
The most common complication related to epicardial catheter mapping and ablation is post-procedure pericarditis. Pericarditis following an epicardial procedure occurs in varying degrees in most patients, as a result of a local inflammatory response. The clinical manifestations can vary from mild pericarditis to large hemorrhagic pericardial effusions and, rarely even cardiac tamponade. Most cases can be managed successfully using oral non-steroidal anti-inflammatory drugs and/or corticosteroids. Moreover, in our opinion this complication can be reduced or largely prevented by empiric instillation of intra-pericardial corticosteroids at the completion of the procedure (8).

Other infrequently encountered complications related to epicardial mapping and ablation includes vascular injury and coronary vasospasm. Injury to the coronary arteries from inadvertent radiofrequency application is well described and specific recommendations for the minimum distance (>5 mm) between ablation catheter tip and coronary artery have been suggested (13, 14). The sharp edges of intra-pericardial sheaths can be traumatic (as was thought to be in the case of Patient 6), and therefore, soft tipped sheaths are preferred. Ensuring that the sheath lumen is always occupied, by an ablation catheter or pig tail catheter can also help prevent inadvertent injury from the sheath tip. In our opinion, it is generally prudent not to use sheaths with preformed curves such as SL-2/SL-3 sheaths (St. Jude Medical Inc., Daig Division, Minnesota, USA) within the pericardial space to prevent injury to fragile structures such as coronary veins. If there is a need for directional sheath support, a deflectable straight sheath is preferable, in our opinion.
As illustrated in this series, severe coronary vasospasm can occur with catheter manipulation in the vicinity of an epicardial artery. Similar reports of coronary vasospasm from intra-operative surgical manipulation during coronary artery bypass surgery have also been reported (15, 16). Diffuse coronary vasospasm in such cases can be profound and can lead to VF. Vasospasm can be successfully managed with intra-coronary vasodilators and intra-aortic balloon counterpulsation. Therefore, caution should be exercised when manipulating the catheters in the vicinity of coronary arteries in patients with a history of vasospastic angina or documented coronary vasospasm.

Conclusions

Percutaneous epicardial access and catheter ablation can be performed safely in most patients for treatment of a variety of cardiac arrhythmias. However, it can be associated with unusual and rare complications (Table 1) that on occasion can be life-threatening. It is important to recognize the importance of any unusual or persistent symptoms following an epicardial procedure such as persistent chest pain, abdominal pain or hypotension. Table 2, enlists certain preprocedural and intraprocedural measures that may prove beneficial for the early detection of complications.

Complications may be related to either percutaneous access or catheter mapping and ablation, and include RV pseudoaneurysm, hepatic injury, epicardial vascular laceration, RV-abdominal fistula formation, and coronary arterial vasospasm. Awareness of these complications may help early detection and successful management.
Conflict of Interest Disclosures: None

References:


Table 1. Table listing complications and type of management

<table>
<thead>
<tr>
<th>Patient</th>
<th>Complication</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>Right Ventricular pseudoaneurysm</td>
<td>Conservative</td>
</tr>
<tr>
<td></td>
<td>Liver puncture</td>
<td></td>
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<tr>
<td>Patient 2</td>
<td>Intra-abdominal bleeding</td>
<td>Surgical intervention</td>
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<td></td>
<td>Liver puncture</td>
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<td>Patient 3</td>
<td>Subcapsular Hepatic Hematoma</td>
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<td>Patient 4</td>
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<td>Middle cardiac vein laceration</td>
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<tr>
<td>Patient 5</td>
<td>Right Ventricular-abdominal fistula</td>
<td>Surgical intervention</td>
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<tr>
<td></td>
<td>Pericardial bleeding</td>
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<tr>
<td>Patient 6</td>
<td>Pericardial bleeding</td>
<td>Surgical intervention</td>
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<tr>
<td></td>
<td>Coronary sinus branch laceration</td>
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<tr>
<td>Patient 7</td>
<td>Coronary spasm</td>
<td>Conservative</td>
</tr>
</tbody>
</table>

Table 2. Measures to detect early complications related to epicardial access

<table>
<thead>
<tr>
<th>Intra-procedural</th>
<th>Use of intra-procedural ICE with periodic survey of the pericardial space to detect pericardial fluid accumulation</th>
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<tbody>
<tr>
<td></td>
<td>Periodic aspiration of pericardial pigtail catheter to detect bloody aspirate</td>
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<tr>
<td></td>
<td>Hypotension in the absence of pericardial effusion should be further investigated: i) assess for intra-pericardial clot, ii) quick survey to detect intra-abdominal fluid can be performed by withdrawing the ICE probe into the IVC</td>
</tr>
<tr>
<td></td>
<td>If epicardial puncture was associated with significant/persistent bleeding, then consider retaining pericardial drain overnight</td>
</tr>
<tr>
<td></td>
<td>If ablation is to be performed in proximity to coronary arteries – perform post ablation angiography to assess for coronary involvement</td>
</tr>
<tr>
<td>Post-procedural</td>
<td>Transthoracic echocardiogram 24 hrs after removal of pericardial drain: to assess for early re-accumulation of pericardial fluid</td>
</tr>
<tr>
<td></td>
<td>If post-procedure anticoagulation is considered especially if the patient has other risk factors (anti-platelet therapy, renal failure etc) consider follow up echocardiogram to detect late-onset effusion</td>
</tr>
<tr>
<td></td>
<td>Attention to patient sign/symptoms in the post-procedure period, with a low threshold for cardiac imaging especially if h/o multiple epicardial access attempts</td>
</tr>
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Figure Legends:

Figure 1. Panels A and B illustrate transverse and sagittal reformatted maximum intensity CT projections, showing an RV pseudoaneurysm (arrows) with a narrow neck measuring 13 x 10 x 9 mm. Panel C shows a 3-D volume rendered image from a contrast-enhanced CT scan showing the RV pseudoaneurysm (arrow). Panel D illustrates the same image from a repeat contrast-enhanced CT scan performed during follow-up, showing complete resolution of the pseudoaneurysm. AO = aorta; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

Figure 2. Panel A illustrates the location of two puncture sites (black arrows) within the left hepatic lobe, in an image obtained during laparotomy. Panel B illustrates a fluoroscopic view of an ablation and a multispine catheter (white arrows) placed through two separate sheaths within the pericardial space. The inlet in the left upper corner shows the site of successful radiofrequency ablation.

Figure 3. This image illustrates a transverse view of an abdominal CT scan with contrast, showing a large heterogeneous lesion in the left hepatic lobe (arrows), measuring 6 x 7 x 11 cm. The lesion had a thin rind of surrounding it anteriorly and laterally, while indenting the hepatic parenchyma posteriorly. These characteristics are most consistent with a subcapsular hematoma. The diagnosis was confirmed by ultrasonography.

Figure 4. Panel A) A right ventricular angiogram reveals contrast entering a crypt (arrow pointing to structure encircled) extending inferiorly below the RV wall. A cine loop (Data Supplement Loop 1) is also provided. On initial review, contrast was not noted to exit into the abdominal cavity. However, a CT scan (image shown in the upper right corner inlet) later revealed presence of an RV-abdominal fistula.

Figure 5. Shown, is an intra-operative image of the surgically repaired laceration (arrow) to a large-caliber posterolateral branch of the coronary sinus. The vessel was most likely traumatized
while advancing an SL-3 sheath into the pericardial space during catheter mapping. The active bleeding ceased with surgical repair of the lacerated vessel.

**Figure 6.** Panel A illustrates a left anterior oblique view of right coronary angiography. The angiogram shows a small-caliber but patent right coronary artery without evidence of vasospasm. Also seen, are a 5-Fr quadripolar catheter and an ICD lead positioned in the RV cavity and apex, respectively. Panel B shows a right anterior oblique view of left coronary angiography shortly after onset of hemodynamic collapse and VF. There is profound spasm (arrows) involving diffusely the left main, LAD, and circumflex arteries with no flow to the distal coronary bed, reflected by dye ‘hang-up’. Panels C and D illustrate repeat right anterior oblique angiograms of the left coronary system at 5 and 15 minutes after administration of intra-coronary nitrates. As noted in these panels, gradual resolution was seen in the severity of coronary vasospasm with repetitive injections of intra-coronary nitrates. LAD = left anterior descending artery; LCx = left circumflex artery; LM = left main artery; RCA = right coronary artery.

**Figure 7.** Shown, is a sagittal section of a cadaveric specimen. The epicardial surface and the overlying pericardium are outlined with dotted lines. Two white arrows indicate the two separate routes (anterior and inferior) taken by the epicardial needle from the skin to the pericardial space. The arrow that is interrupted with the dotted line, exhibits the potential for hepatic injury with the more ‘inferior’ approach as was the case in patients 2 and 3.
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Supplemental Material

Data supplement File

Video 1) RV angiogram reveals contrast extending beyond the border of the RV free wall in the region of the apex, into a crypt-like structure extending inferiorly.