A transatrial pericardial access: lead placement as proof of concept

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A transatrial pericardial access: lead placement as proof of concept. Am J Physiol Heart Circ Physiol 298: H287–H293, 2010. First published October 23, 2009; doi:10.1152/ajpheart.00575.2009.—A safe, easy, and quick access into the pericardial space may provide a window for diagnostics and therapeutics to the heart. The objective of this study was to provide proof of concept for an engagement and access catheter that allows access to the pericardial space percutaneously. A multilumen catheter was developed to allow navigation and suction fixation to the right atrial appendage/wall in a normal swine model. Advancement through the multilumen catheter using a second catheter with a distal needle tip allows access to the pericardial space without pericardial puncture and advancement of a standard guide wire into the space. Navigation into the pericardial space was undertaken by fluoroscopy alone and was accomplished in 10 swine (5 acute and 5 chronic). As a specific application of this pericardial access method, a pacing lead was implanted on the epicardial surface. Five chronic swine experiments were conducted with successful pacing engagement verified by lead impedance and pacing threshold and sensitivity. Lead impedance exceeded 1,000 Ω preengagement and dropped by an average of 200 Ω upon implant (769 ± 498 Ω). Pacing thresholds at 0.4 ms ranged from −0.5 to 2.1 V acutely (1.03 ± 0.92 V). No cardiac effusion or tamponade was observed in any of the acute or chronic studies. The ability to engage, maintain, and retract the right atrial appendage/wall and to engage an epicardial lead was successfully demonstrated. These findings support the feasibility of safe access into the pericardial space in a normal swine model and warrant further investigations for clinical translation.

epicardial surface; lead placement; pericardial pressure; effusion

A NONSURGICAL, PERCUTANEOUS device that permits rapid and safe access into the pericardial space is highly desirable and would have significant potential for expanding cardiac diagnostics and therapies. These applications may extend from identification of diagnostic markers in the pericardial fluid, administration of therapeutic factors with angiogenic, myogenic, and antiarrhythmic potential, and epicardial pacing lead delivery and tissue ablation (1, 2, 4, 5, 15–17, 20, 25).

Clinically, the only nonsurgical means for accessing the pericardial space is the subxiphoid needle approach (ultrasound-guided apical and parasternal needle catheter) (18, 21). The method includes a sheathed needle with a suction tip designed for grasping the pericardium and accessing the pericardial space through the right atrium or appendage (14, 22–24). Although successful attempts have been made, the translation of this approach to the clinic has not been realized. There is clearly a need for a safe and easy device for accessing the epicardial surface for various diagnostic and therapeutic applications.

The objective of this study is to demonstrate the feasibility of a pericardial access device that allows safe entry into the pericardial space with no effusion complications. To demonstrate the feasibility, we implanted pacing leads on the RV or left ventricular (LV) epicardial surfaces chronically, for up to 12 wk, using a new transatrial pericardial access device and method. The results confirm the feasibility of this approach with no effusion complications. Further developments to ensure optimum utility and clinical efficacy warrant attention.

METHODS

Pericardial access device. The percutaneous catheter device includes an elongated tube having two channels. The outer channel is connected to an external source of vacuum (~40 mmHg), which transmits to the plunger-type tip of the catheter to aspirate the atrial wall or appendage. The inner shaft, which does not communicate with the suction, is used to advance a needle-tip (access) catheter to puncture the atrium once it is aspirated by the engagement catheter. Finally, a guide wire can be advanced through the lumen of the perforated needle for accessing the pericardial space. The three components of the platform device are shown in Fig. 1A.

Animal preparation. Ten domestic swine of either sex, with body weight of 50–60 kg (mean of 54 kg), were used in this study. The animals were fasted overnight, and an injection of tiletamine-zolezepam (100 mg/ml), ketamine (50 mg/ml), and xylazine (50 mg/ml) was administered intramuscularly before endotracheal intubation. Ventilation with 100% O2 was provided with a respirator to maintain PCO2 at ~35 Torr. General anesthesia was maintained with 1–2% isoflurane. A dose of 10,000 units of heparin was given intravenously to prevent excessive clotting. An arterial line was established in a carotid artery through a 7-Fr sheath to measure blood pressure. The right jugular vein was exposed for insertion of the engagement catheter, as described below. Five of the ten animals were chronic studies to evaluate safety and feasibility of chronic lead placement. Those studies were carried out under sterile conditions and followed for up to 12 wk in one animal (mean period of 7 wk).

This study was conducted in accordance with national and local ethical guidelines, including the Institute of Laboratory Animal Research Guide, the Public Health Service policy, and the Animal Welfare Act. The study was also approved by the Institutional Animal Care and Use Committee on the campus of Indiana University Purdue University Indianapolis.
Pericardial access procedure. The access of the pericardial space requires several sequential steps: 1) advancement of the transvenous engagement catheter; 2) application of suction (wall vacuum at \(-40\) \text{ mmHg}) to the right atrial appendage or wall; 3) advancement of the access catheter through the center of the engagement catheter; 4) puncture of the right atrial appendage or wall; 5) passage of the guide wire and removal of the access catheter; and 6) dilatation of the puncture site if needed and advancement of a fixed-shape navigation catheter. The following is a brief summary of each of these steps.

The plunger-like tip of the engagement catheter was initially collapsed by a sliding shaft (Fig. 1A, left), which also straightens out the catheter. Once the shaft was placed into the vein and advanced to the atrium under fluoroscopic guidance, the shaft was retracted to expose the tip of the catheter and to restore the "J" curved shape of the catheter. The tip of the catheter was then positioned against the right atrial appendage or wall under fluoroscopic guidance. Suction was initiated to aspirate a portion of the atrial appendage away from the pericardium, as shown in Fig. 2. Evidence of atrial aspiration was confirmed when no blood was drawn from the suction portion of the engagement catheter. The access catheter was then inserted through the center lumen of the engagement catheter to create a needle perforation. A step change or notch in the tip of the catheter prevents overperforation (only 2 mm). A standard 0.014-in. guide wire was then advanced through the needle catheter into the pericardial space to secure the point of entry and facilitate the entry and placement of a fixed-shaped catheter into the space. The wire was advanced sufficiently to verify pericardial access throughout the entire space and beyond what would be seen, if the wire was only in the right side of the heart. The access catheter was then removed, and a 5-Fr fixed-shape catheter was advanced over the wire into the pericardial space with no need for a dilatation catheter. The intrapericardial pressure was then measured at the catheter tip to verify access.

Lead placement. A Medtronic 5-Fr catheter was inserted into the pericardial space to deliver the Medtronic 10538 model 2.6-Fr lead. A schematic of the interface of the Medtronic catheter and lead assembly and the engagement catheter is shown in Fig. 1B. Once in the pericardial space, the tip of the 5-Fr catheter was made perpendicular to the epicardial surface of the LV or RV wall under fluoroscopic guidance. After the tip of the fixed-shape catheter engaged the epicardium, the active fixation portion of the lead (helix) was screwed into the myocardium (RV or LV) and confirmed by fluoroscopy and pacing capture and impedance values. Once the lead was engaged, a strength duration amplitude test was carried out. Electrical recordings were made weekly unless the animal was terminated when the lead failed to capture, which implied disengagement.

Histological preparations. Samples from the puncture site in the atrium were fixed with 10% buffered formalin phosphate for at least...
24 h. They were rinsed three times with a buffer solution and processed by dehydration in increasing concentrations of alcohol (70, 80, 95, and 100%). The samples were then embedded in glycol methacrylate (JB-4 solution), and sections 3 μm thick were cut using a conventional microtome (HM 340 E from Microm), mounted on glass slides, and stained with 0.1% Toluidine blue for histological evaluation with light microscopy.

RESULTS

The time sequence of steps for pericardial access was captured with fluoroscopy, as shown in Fig. 3. Figure 3A shows the contact of the engagement catheter, with the appendage followed by puncture with the access catheter (Fig. 3B). This was then followed by the passage of the guide wire through the lumen of the access catheter (Fig. 3C). A fixed-shape lead delivery catheter was fed over the wire into the pericardial space. After removal of the guide wire, a catheter-delivered lead was screwed into the epicardial (LV or RV) surface (Fig. 3D). Figure 4 shows strength duration amplitude data for a representative animal. At implant, all animals had successful ECG recordings showing pacing spike and corresponding waveform activation.

The pericardial pressure was measured in the intact pericardial sac, as shown in Fig. 5. The cardiac and respiratory changes can be observed in this pressure recording. The pericardial pressure waveforms are distinct from the right atrial pressure waveforms and can also be used to confirm pericardial access. The mean pericardial pressure was 7.8 ± 1.3 mmHg, whereas the mean right atrial pressure was 8.3 ± 1.6 mmHg.

The first five acute studies were used to refine the catheter and access method. The second set of five studies were chronic, and the data below corresponds to those studies. The most significant finding is that no pericardial effusion was observed in any of the chronic studies (Fig. 6A). Even after multiple entries across the atrium in some of the animals, the puncture sealed. Figure 6, B and C, shows complete healing of the puncture site around the lead. Fibrotic tissue developed over the lead as an extension of the appendage tissue (inside and outside of appendage). Histological sections show complete healing of the tissue and fibrosis surrounding the puncture (Fig. 7). Chronically, mild-to-moderate pericarditis was observed (Fig. 6) in both parietal and visceral epicardial layers in response to the leads.

Although lead performance was not the focus of this study, we obtained standard sensing and pacing thresholds to demonstrate feasibility of the implant (Fig. 8). Before proper engagement, lead impedance exceeded 1,000 Ω and decreased by an average of 200 Ω upon implant (769 ± 498 Ω), while acute pacing thresholds at a 0.4-ms pulse width ranged from −0.5 to 2.1 V (1.03 ± 0.92 V). Although all leads were safely implanted (in RV or LV), as determined by pacing capture, the leads disengaged at different time points (mean of 7 wk; longest at 12 wk), as determined electrically weekly. This is not unexpected, as these 2.6-Fr leads were not designed for this application, and future improvements in lead coil length and design for epicardial fixation are warranted. In one animal that had very stable capture and was easily paced at low thresholds, the lead was extracted by the animal and had a subsequent...
scheduled termination with no effusion and a healed puncture site.

**DISCUSSION**

The major finding of this study is that a percutaneous catheter with suction platform allows access to the pericardial space safely with no pericardial effusion. A particular application of this access in relation to lead placement was explored. Although the data on the lead implant is exploratory (small and delicate helix tip), this device shows significant promise for pericardial access with some future refinement. Also, development of superior maneuverability of the fixed-shaped catheters and more optimal fixation mechanisms for the epicardial pacing leads will improve chronic lead performance.

The basic premise of this device rests on a mechanical observation. Unlike the relatively stiff pericardium, the atrial appendage is rather soft and deformable. Hence, suction of the appendage can provide significantly more clearance of the cardiac structure from the pericardium compared with suction of the pericardium. This observation allows the present nonsurgical device to enhance access safely and effectively.

The key distinction of this study over previous attempts (14, 19, 22–24) at transvenous or transatrial pericardial access is the engagement catheter, which enables suction of the wall and hence isolation of the entry region of interest. This platform feature provides several advantages: 1) safe and controlled access into the pericardial space; 2) isolation of the puncture from the blood in the right atrium; 3) ease of visualization for pericardial access; 4) ease of engagement of the right atrium; 5) anchorage for access and delivery of therapies; and 6) promotion of coagulation at the puncture site.

The importance of the engagement catheter was noted when the device did not adequately engage due to a lack of sufficient suction or when leakage occurred between the inner and outer portions of the catheter. In those instances, puncture of the appendage was more difficult and less controlled. The “pull” and “push” of the engagement and access catheters, respectively, was best for easy, controlled, and safe access into the pericardial space.

There are several indications for successful pericardial access. First, pericardial access is confirmed through the advancement of the guide wire beyond the right atrial and RV geometries and into the left side of the heart. Second, proper engagement of the right atrium should show no blood being aspirated back into the suction system. Finally, the measurement of pressure after pericardial puncture shows pericardial waveforms, which are distinct from atrial pressures, as seen in Fig. 5.

An accurate measurement of pericardial pressure has been of significant interest to understanding the effect of pericardial space on diastolic and systolic function of the heart (10, 13). The major challenge has been that the measurement of peri-
Cardial pressure, which requires perforation of the pericardial sac, can alter the pressure of interest (6). This is the first report of a pericardial pressure measurement in an intact pericardial sac. The utility of this approach for understanding the role of pericardial pressure on physiology and pathophysiology of the heart is a laudable goal for future studies.

Active closure of the atrial puncture was not necessary in this study with a 5-Fr catheter. Although the majority of these studies were completed with a single puncture and a pacing lead fed through the puncture site, there were some instances where multiple punctures were made and access with the 5-Fr catheter had been passed through the wall and then retracted. It appears that the recoil from the elasticity of the vessel, as well as the active contraction of the atrium, promotes closure around the puncture site (Fig. 6). Furthermore, the tip of the engagement catheter at the suction site (stagnant blood) promotes coagulation, which may contribute to closure of the puncture site, as well as long-term fibrosis (Fig. 7).

Cardiac resynchronization therapy (CRT) is a significant potential application, as this has become a treatment of choice for patients with severe heart failure and signs of intraventricular dyssynchrony (3, 8, 9). Thirty percent of currently indi-
placement, despite the fact that placement of LV lead at the region of latest delay may require the more invasive pericardial access method. Our findings verify the feasibility of catheter-delivered leads (Medtronic model 10538 unipolar 2.6F) to the epicardial surface via a unique percutaneous approach to allow complete access to the heart surface.

Current transvenous lead placement has enabled broad therapy adoption with some of the following limitations: 1) difficulty of coronary sinus access; 2) LV access is limited by cardiac venous anatomy; and 3) elevated pacing thresholds compared with direct myocardial stimulation. Epicardial mapping and lead placement hold the promise of significantly improving responder rates and improving CRT therapy adoption (11). Epicardial lead placement techniques (thoracotomy, full or mini) are a significant procedural barrier for implanting electrophysiologists and cardiologists (7). Transvenous epicardial access may also enable sensor placement on the epicardium without crossing the tricuspid valve. The proposed device may provide a solution to remedy some of these issues, including rapid access to the pericardial space, unlimited access to the entire epicardial surface, and direct myocardial stimulation (Fig. 8).

There are a number of theoretical advantages to the present device and procedure such as the following: 1) the introduction through a percutaneous intravascular approach; 2) the approach is safe with no incident of pericardial effusion in normal swine; 3) the puncture of the right atrial wall or appendage is made easy by localization (suction) of a small wall area; 4) the atrial tissue can be easily retracted to increase the local space between the pericardium and the atrium for easy and safe introduction into the pericardial sac (this will avoid heart structures and hence minimize lesions); 5) the catheter can be easily positioned in different heart regions with the aid of X-ray imaging or ultrasound; 6) the access method avoids percutaneous subxiphoid puncture and hence reduces the risk of RV lesions; and 7) the approach avoids an anterior thoracotomy for a pericardial window procedure.

Areas for future assessment and development to enhance the utility of this device and approach include active closure of the site of puncture, appropriate visualization, and navigation of the engagement and delivery catheters. Although active closure was not necessary in the present studies, it may be generally desirable and necessary for applications where a larger puncture is made. A visualization tool may also be necessary to...
better visualize the epicardial structures, including coronary arteries and veins. A specifically designed navigation catheter that can maneuver around the surface of the heart to the region of interest would be highly desirable for CRT lead placement or epicardial ablation. These and other developments will be made in future studies in heart failure animal models to establish the utility and safety of this platform technology for future clinical applications.

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DISCLOSURES

No conflicts of interest are declared by the author(s).

REFERENCES


