Minimally Invasive Resynchronization Pacemaker: A Pediatric Animal Model

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Purpose. We developed a minimally invasive epicardial pacemaker implantation method for infants and congenital heart disease patients for whom a transvenous approach is contraindicated. The piglet is an ideal model for technical development.

Description. In 5 piglets we introduced a needle through subxiphoid approach under thoracoscopic guidance, inserting a wire into the pericardial space. Pacing leads were affixed to the left ventricular free wall and left atrial appendage. After verifying functionality with atrial and ventricular pacing and sensing, animals were euthanized. Pacemaker monitoring occurred daily for 4 days in the fifth animal.

Evaluation. Through minimally invasive pericardial access, we directly visualized and fixed pacing leads to the left ventricle and left atrial appendage, successfully pacing atrium and ventricle. Epicardial structures were visualized. One piglet had contralateral pneumothorax, which resolved with needle decompression. No other adverse events occurred.

Conclusions. Minimally invasive epicardial pacemaker implantation in an infant model is feasible and effective. This innovation may be of value for pacing and resynchronization in infants and congenital heart disease patients. Survival studies with permanent generator implantation are under way.


Cardiac pacemaker implantation in children and patients with congenital heart defects presents unique challenges to the cardiologist and surgeon. These patients are often too small for insertion of pacemaker leads through a standard transvenous approach. Congenital anomalies of the heart or venous system may also prevent transvenous lead placement [1]. In addition to small body habitus and limited venous capacitance, other contraindications to transvenous pacing include intracardiac shunts, venous obstruction, and complex venous anatomy with inability to access the right heart endocardium and mechanical tricuspid valve, as well as endocarditis.

Patients with congenital heart disease (CHD) and device-dependent primary electrical diagnoses are likely to require several invasive procedures over the course of a lifetime, with attendant cumulative risk of venous occlusion. Cardiac resynchronization therapy for left ventricular (LV) failure and dyssynchrony can be performed through transvenous approach in adults and older children with structurally normal hearts, but may necessitate utilization of a sternotomy or thoracotomy for epicardial placement in smaller patients or patients with particular forms of CHD [2]. Although many teenage patients are well served by transvenous pacemakers, epicardial pacing currently remains the conventional technique for infants and for patients with complex CHD [3]. Epicardial pacing currently requires either a median sternotomy or thoracotomy to access the epicardial surfaces. The post-operative recovery typically entails several days in the intensive care unit with the commensurate costs and risks. Patients undergoing sternotomy are also at increased risk of intrathoracic adhesions, with heightened subsequent operative risk of reentry injury should the need for reoperation or exploration arise [4, 5]. Reoperation can be difficult, as the fibrotic tissue must be fully dissected to reach viable cardiac tissue for acceptable pacing thresholds.

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The objective of this pilot feasibility study is to develop a minimally invasive pacemaker lead implantation method in an immature animal model, with particular attention to achieving LV pacing for potential resynchronization therapy.

**Technology and Technique**

Five piglets (weight 4 to 5 kg) were weighed and sedated using ketamine and xylazine. The animals were intubated and ventilated for the procedure, with inhaled isoflurane for intraoperative anesthesia. Continuous vital sign monitoring parameters included color, heart rate, rhythm, and pulse oximetry. In the supine position, the chest and abdomen were prepared and draped in routine sterile fashion. A 4-mm trocar (KARL STORZ Endoscopy-America [KSEA], El Segundo, CA) was introduced along the left anterior axillary line at the sixth to seventh intercostal space. A thoracoscope (KARL STORZ Hopkins II 4 mm, 30-degree telescope) was utilized through this trocar to visualize epicardial structures (coronary arteries, veins) from the pleural cavity through the thin pericardial tissue. The pericardial space was then accessed through a subxiphoid approach under direct thoracoscopic visualization by inserting a micropuncture pericardiocentesis needle (7 cm) into the pericardial space. Normal saline (3 cc to 5 cc) was injected to separate the parietal pericardium from the epicardium. Using a modified Seldinger technique, a guidewire was delivered followed by a microdilator, and an S4 sheath (40 cm, 8F) with dilator was then introduced over the wire. Landmark structures were visualized with the thoracoscope. The dilator was then removed, and the pacing lead (Medtronic 3830 SelectSecure; Medtronic, Minneapolis, MN) was advanced through a C315S4 delivery catheter (Medtronic 3830 SelectSecure; Medtronic, Minneapolis, MN) was introduced into the pericardial space. A 4-mm trocar was utilized to direct and position the pacing lead to the epicardial surface under direct visualization. The Medtronic 3830 SelectSecure is a thin bipolar, steroid-eluting, polyurethane-coated, lumenless screw-in fixation pacing lead typically utilized (and labeled) for transvenous pacing. The pacing lead was fixed to the LV epicardium and alternatively to the left atrial appendage (Fig 2). Direct visual inspection confirmed placement, and function was tested by connecting to an external Medtronic 2090 Programmer. Pacing and sensing thresholds were determined, and lead impedances were measured. Images and video were recorded with an AIDA HD Connect (KSEA, El Segundo, CA). Using blunt dissection, the pacing lead was tunneled subcutaneously to a small midabdominal subcutaneous pocket to house the generator (Medtronic EnPulse DR E2DR01), and the incision closed using 2-0 nylon suture and Dermabond (Ethicon Endo-Surgery, Cincinnati, OH). The piglets were humanely euthanized electively at the end of the case or after a postoperative period of observation up to 4 days. Pacing and sensing parameters and lead impedance were noninvasively measured daily. We performed all experiments in compliance with the National Institutes of Health “Guide for the Care and Use of Laboratory Animals.” The study was approved by the Animal Care and Use Committee at Children’s National Medical Center (IACUC 293-12-06).

**Clinical Experience**

Using a minimally invasive approach, we fixed a lumenless pacing lead to the LV (Fig 1) and left atrial appendage, successfully pacing the atrium and ventricle. Total procedural time was approximately 30 minutes. Pacing parameters including lead impedance, atrial and ventricular sensing, and stimulation thresholds were within normal acceptable limits at the time of implantation and remained stable during the postoperative period in the survival piglet experiment with a downward trend in ventricular sensing threshold and lead impedance (Table 1). In the non-survival studies, acute capture occurred at 2 V or less at a duration of 0.5 ms and ventricular sensing threshold of 5 mV or more. A ventricular electrogram in the survival surgery demonstrated effective capture and successful pacing (VVI pacing rate 160 beats per minute) of the ventricle as evidenced by conversion to a wide QRS complex with loss of capture below 0.5 V (Fig 3). Coronary arteries and critical epicardial structures (ie, epicardial veins) were clearly visualized and avoided when accessing the pericardial space and fixing the pacing lead to the epicardium (Fig 1). The curved sheath allowed for improved angulation and positioning of the pacing lead and facilitated epicardial lead fixation. One piglet (the fifth animal) was kept alive for a 4-day period of observation with pacemaker function maintained throughout the postoperative course with stable pacing capture thresholds and electrical measurements. One piglet (the first animal) had pneumothorax on the contralateral side that resolved with
needle decompression. There were no other acute adverse events.

Comment

Because of its size and anatomic similarity to human infants, the piglet serves as an ideal, widely accepted pediatric animal model for surgical technical development [6]. We demonstrate with a minimally invasive approach the ability to access the piglet pericardial space (Figs 1, 2) and reach the LV free wall, an important site for cardiac resynchronization therapy in advanced heart failure. While resembling the human heart structure, the porcine heart lies in a relatively mesocardiac position well above the diaphragm and subxiphoid area with the long axis oriented in a more dorsal-ventral trajectory in comparison with the normal human heart.

Other centers have succeeded in placing epicardial pacemaker leads in adult pigs and adult human populations using various minimally invasive percutaneous approaches [7, 8]. To the best of our knowledge, no group to date has reported achieving this minimally invasive approach in infants or an infant-sized animal model. We anticipate this approach may lead to shorter hospital stays, decreased infection rates, less pain, and fewer complications after the procedure at a considerable cost savings when compared to the current standard of care using the median sternotomy or thoracotomy approach for epicardial pacemaker lead implantation.

This series of piglet operations demonstrates proof of concept and feasibility of a minimally invasive epicardial approach for pacemaker implantation. Importantly, the left side of the heart could be reached and pacing leads secured to the epicardium under direct visualization to avoid injuring the coronary arteries. The SelectSecure 3830 pacing lead has a screw-in fixation mechanism and steroid elution that are favorable for epicardial fixation. Its outer polyurethane coating allows for maneuverability within the pericardial space and has the additional benefit of wide use throughout the electrophysiology community. Longer term evaluation with a larger number of immature animals is necessary to ensure adequacy of long-term pacing parameters before translating to human clinical trials. These initial data and previously published work [9] support minimally invasive surgical pacemaker implantation for patients’ initial and repeat procedures. This early feasibility study also provides an impetus for manufacturers to consider development of a new pacemaker lead specifically designed for this purpose. Further surgeries involving postoperative animal models should address potential challenges related to reentry that are anticipated in the population of CHD patients requiring repeat procedures.

With improved surgical outcomes and survival among the CHD population, the need for nontransvenous pacing is expected to increase. Minimally invasive epicardial pacemaker implantation has the potential to reduce the necessity of primary and repeat open surgery for infants and other patients who are contraindicated for transvenous access, such as venous anomalies, endocarditis, intracardiac shunts, and prosthetic tricuspid valves. Further reductions in repeat sternotomies and thoracotomies should further reduce rates of reentry injuries in this population. Were this to become the standard approach for pacemaker implantation, there would also be a significant reduction in radiation exposure for infants and small children, as this technique does not rely upon any ionizing radiation that is currently utilized for transvenous pacemaker implantation procedures. The enhanced susceptibility to the effects of ionizing radiation in small children is well established. Patients with congenital arrhythmias and CHD are an understudied patient population with unique anatomic constraints making it difficult to perform adequately powered clinical trials. These patients are often excluded from the more expansive pacemaker multicenter studies [10]. These challenges offer further impetus for the pursuit of this work.

This pediatric animal model demonstrates, for the first time, a unique value of developing capability to pace the left side of the heart without transvenous access into the branches of the coronary sinus or an open

Table 1. Postoperative Ventricular Sensing Threshold and Lead Impedance in Survival Surgery After Minimally Invasive Left Ventricular Epicardial Lead Placement

<table>
<thead>
<tr>
<th>Survival Surgery Postoperative Day</th>
<th>Ventricular Sensing Threshold</th>
<th>Lead Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.6 mV</td>
<td>715 Ω</td>
</tr>
<tr>
<td>2</td>
<td>8 mV</td>
<td>523 Ω</td>
</tr>
<tr>
<td>3</td>
<td>8 mV</td>
<td>478 Ω</td>
</tr>
<tr>
<td>4</td>
<td>5.6 mV</td>
<td>460 Ω</td>
</tr>
</tbody>
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Fig 2. Thoracoscopically guided epicardial pacemaker lead fixation to the left atrial appendage.
chest approach to the epicardium. A simple pericardial puncture, already done commonly for other cardiac procedures such as pericardiocentesis and catheter ablation, can be utilized to deliver pacing leads to the LV epicardium and left atrial appendage. This concept allows for a minimally invasive means to provide cardiac resynchronization therapy or permanent pacing for infants and CHD patients, who may not be candidates for a transvenous approach.

Disclosures and Freedom of Investigation

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References


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