Epicardial exposure provided by a novel thoracoscopic pericardectomy technique compared to standard pericardial window

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Abstract

Objective: (1) To describe a novel technique for thoracoscopic pericardectomy using a pericardial window with vertical pericardial fillets (PW+F). (2) To compare epicardial exposure between a standard pericardial window (PW) and PW+F.

Study design: Experimental study.

Animals: Purpose-bred research dogs (n = 12).

Methods: PW was performed through a 3-port subxiphoid thoracoscopic approach. After PW, vertical fillets were made in the pericardium for PW+F. Thoracoscopic images from 3 views were acquired after each procedure, and percentage of epicardial surface exposed (PESE) was compared. Epicardial exposure and iatrogenic damage to surrounding structures were directly assessed via postmortem gross examination.

Results: The exposed epicardial surface (PESE) was increased with our novel compared to the standard technique. Median surgery time for PW+F was 25 minutes. The procedure was performed in 11 of 12 dogs without iatrogenic damage to surrounding structures. In 1 dog, the electrosurgery device contacted the epicardium and caused fatal ventricular fibrillation while performing PW+F. Based on postmortem assessment in all dogs with PW+F, the pericardium could move freely away from the heart, exposing the majority of the epicardial surface.

Conclusion: Thoracoscopic PW+F is a novel technique that improves the exposure of the epicardium compared to standard PW. While PW+F can be performed successfully and in an efficient manner, the surgeon must be aware of the risk of iatrogenic trauma to thoracic structures when using electrosurgery.

Clinical relevance: PW+F offers a relatively safe, efficient, and effective minimally invasive method that improves the exposure of the epicardium compared to PW.

1 | INTRODUCTION

Pericardial effusion is the most prevalent pericardial disease process in dogs, reported in 7% of dogs with clinical signs of cardiac disease. Accumulation of fluid within the pericardial sac can lead to an equilibration between intrapericardial and intracardiac pressures, with subsequent cardiac tamponade, decreased cardiac output, and eventual cardiogenic shock. Various etiologies of pericardial effusion have been identified, the most common including neoplastic and idiopathic diseases. Pericardectomy can be indicated to palliate neoplastic effusions or as definitive treatment for idiopathic effusions and restrictive pericarditis. Subtotal pericardectomy (STP) involves removal of the pericardium ventral to the phrenic
nerves, and has traditionally been performed to address pericardial effusion. This procedure can be performed after median sternotomy to allow concurrent visualization of both phrenic nerves. Alternative surgical approaches include right lateral thoracotomy or a transdiaphragmatic approach.\textsuperscript{3,7} Thoracotomy allows direct exposure and extensive excision of the pericardium, but the invasive nature of such approach may increase the risk of complications and morbidity compared to minimally invasive surgery. The potential complications of thoracoscopy are similar to those of a thoracotomy, but were less frequent in one study.\textsuperscript{8} This study evaluated postoperative thoracoscopy are similar to those of a thoracotomy, but were minimal invasive surgery. The potential complications of thoracotomy allows direct exposure and extensive excision of the pericardium, but the invasive nature of such approach may increase the risk of complications and morbidity compared to minimally invasive surgery. The potential complications of thoracoscopy are similar to those of a thoracotomy, but were less frequent in one study.\textsuperscript{8} This study evaluated postoperative pain and morbidity in dogs undergoing open thoracotomy and STP versus a thoracoscopic pericardial window (PW), which involves removal of only a small portion of pericardium to allow for drainage of pericardial fluid. Dogs treated with thoracoscopic PW experienced less postoperative pain, fewer wound complications, and a more rapid return to function.\textsuperscript{8} Based on these findings, a minimally invasive procedure may also decrease hospitalization time, which is especially relevant in dogs with neoplastic pericardial effusion in light of their limited survival time.\textsuperscript{1}

While a minimally invasive technique may improve immediate postoperative outcomes, its long-term benefits have been questioned in dogs with idiopathic pericardial effusion, who experienced shorter survival time and disease free interval when treated with thoracoscopic PW rather than STP via median sternotomy.\textsuperscript{5} The authors theorized that the PW was not large enough and allowed the edges of the window to heal to the epicardium, causing reaccumulation of pericardial effusion.\textsuperscript{5} It is also conceivable that the $3 \times 3$ cm pericardial opening, suggested as an appropriate pericardial window size for large breed dogs,\textsuperscript{3} could be easily obstructed by fibrous tissue or mediastinal tissue within the thoracic cavity. Another concern for the smaller defect created with PW is the risk of cardiac herniation and entrapment, a fatal condition that has been reported in the human and veterinary literature.\textsuperscript{9-13}

The ideal pericardectomy technique would combine the benefits of minimally invasive surgery with maximal epicardial exposure. A method that frees the pericardium from the heart would alleviate concerns over fibrosis and cardiac herniation. The objectives of this study were: (1) to describe a novel technique for thoracoscopic pericardectomy that combines PW with pericardial fillets (PW+F); (2) to evaluate the ability of this new technique to improve epicardial exposure over standard PW; and (3) to evaluate the difficulty of the procedure when performed by a novice surgeon in minimally invasive surgery. We hypothesized that the novel technique for thoracoscopic pericardectomy would improve the exposure of the epicardial surface and could be successfully performed by a surgeon without prior training for the technique.

2 | MATERIALS AND METHODS

Twelve adult purpose-bred Beagles that were scheduled for euthanasia as an endpoint for an unrelated study underwent PW followed by fillet (PW+F). Prior to their scheduled euthanasia, the dogs were approved for use in the present study by the Institutional Animal Care and Use Committee.

2.1 | Anesthesia

Each dog received morphine (0.5 mg/kg IM), acepromazine (0.05 mg/kg IM), and atropine (0.04 mg/kg IM) before surgery. General anesthesia was induced with propofol administered IV to effect and maintained with isoflurane in oxygen following orotracheal intubation. All dogs were mechanically ventilated when the first port was placed in the thoracic cavity. Heart rate, respiratory rate, indirect systolic blood pressure, oxygen saturation, and anesthetic plane were monitored throughout anesthesia in all dogs. An adequate anesthetic plane was maintained via adjustments in inspired isoflurane or administration of additional propofol or morphine as deemed necessary. Upon completion of the surgical procedures, each patient was humanely euthanatized while under general anesthesia using pentobarbital (1 mL/4.54 kg IV). Euthanasia was confirmed via thoracoscopic visualization of cessation of cardiac activity and lack of a palpable femoral pulse. Anesthetic time was defined as the time from induction to administration of pentobarbital.

2.2 | Surgical technique

Each dog was positioned in dorsal recumbency and prepared for a 3-port subxiphoid thoracoscopic approach to the thorax. The thorax and cranial abdomen were clipped of hair and aseptically prepared and draped from the level of the manubrium to the umbilicus, and bilaterally to the dorsal third of the thoracic wall. A 2-cm, right paraxiphoid skin incision was made for placement of the camera port. A 6-mm, threaded cannula (Karl Storz, Goleta, California) was placed to the right of the base of the xiphoid process and was directed craniodorally under endoscopic visualization using a 5-mm, 0° endoscope into the right hemithorax. A 5-mm, 30° endoscopic camera was then introduced into the thorax, and the first instrument port was established with a 6-mm threaded cannula in the ventral third of the 8-10th intercostal space under endoscopic visualization. A 5-mm bipolar electrosurgery sealing device was introduced through the first instrument port, and the attachments of the ventral mediastinum were dissected from the sternum so that both hemithoraces could be evaluated. Care was taken to avoid the internal thoracic vessels cranially. The second instrument port was placed in a similar
fashion on the contralateral side in the 7-9th intercostal space (ICS) (slightly more cranial to the first instrument portal).

The thoracic structures were evaluated and a 5-mm grasping forceps (Karl Storz) was introduced through the second instrument port to firmly grasp the apical region of the pericardium. The pericardium was elevated toward the sternum (Figure 1A), and the bipolar electrosurgery sealing device was used to perforate the pericardium (Figure 1B). The sealing device was then placed with one side of the jaw on the internal and the other on the external surface of the pericardium, and the incision was extended in a circular fashion to excise a PW from the apical region that was approximately \( \frac{3}{4} \) cm. Constant tension was maintained on the pericardium by intermittently rotating the grasping forceps to wrap the pericardium around the instrument. The excised pericardial tissue was removed via the instrument port and measured. Still images of the exposed epicardium were acquired using the endoscopic camera from 3 pre-established views, using each of the ports. The following 3 views were acquired: (1) a mid-line view (MV) of the apical region of the heart with the endoscope directed dorsally in the subxiphoid port; (2) a right-sided view (RV) with the endoscope directed to the left in the right instrument port; (3) a left-sided view (LV) with the endoscope directed to the right in the left instrument port. A palpation probe with 1-cm markers was included in each image for calibration purposes. The maximum amount of the pericardium and heart that could be visualized was included in each image.

For the PW+F, grasping forceps were used to elevate the edge of the PW. The right and left phrenic nerves were identified, and the bipolar electrosurgery sealing device was used to make a vertical incision from the edge of the pericardial window, directed toward the base of the heart, extending to approximately 1 cm ventral to the phrenic nerve. Three incisions were created with an attempt to evenly space the incisions 120° from each other (Figure 2). Once PW+F was complete, still images of the exposed epicardium were acquired using the same technique and pre-established views as described for the PW. Surgery time was defined as start of port placement to completion of the final thoracoscopic images and removal of trocars. All surgical procedures were performed by a first-year surgery resident under the guidance of a board-certified surgeon.

### 2.3 | Postmortem evaluation

Following humane euthanasia, a median sternotomy was performed on each dog and the thoracic cavity was evaluated for degree of epicardial exposure and evidence of iatrogenic damage to the heart and surrounding structures.

### 2.4 | Epicardial surface exposure

Thoracoscopic still images were acquired from the 3 predetermined viewpoints (MV, RV, and LV) for each procedure (PW and PW+F). The percentage of epicardial surface exposed (PESE) was calculated for each image with an image-processing and analysis software (ImageJ 1.49, US National Institutes of Health, Bethesda, Maryland). For each image, a palpation probe with 1-cm markers was included for calibration purposes. The maximum amount of the pericardium and heart that could be visualized was included in each image.
patient, images were separated into those acquired following PW and those acquired following PW+F. The images were further categorized into the specific predetermined viewpoint (MV, RV, or LV). For each viewpoint, the mean PESE was determined for PW and for PW+F. Measurements following PW were compared to measurements following PW+F to assess the difference in PESE.

2.5 | Statistical analysis

The mean PESE was calculated for each predetermined endoscopic viewpoint (MV, RV, and LV), and PW and PW+F values were compared. Using the Kolmogorov-Smirnov test, PESE was normally distributed for MV and RV measurements, but not for LV measurements. Paired 2-tailed Student’s t test was applied to MV and RV data, and 2-tailed Mann-Whitney test was applied to LV data. The PESE data were evaluated as mean with standard deviation, and values of $P < .05$ were considered significant. Linear regression was used to evaluate surgery order versus surgery time and surgery order versus pericardial window size.

3 | RESULTS

3.1 | Demographics

Dogs in this study included 8 intact females and 4 intact males. Median age of the dogs was 12 months (range, 10-14 months), and median weight was 6 kg (range, 4.6-8.7 kg). All 12 dogs underwent thoracoscopic PW followed by the addition of vertical fillets to the pericardium to achieve PW+F.

3.2 | Intraoperative findings

Median surgical time was 25 minutes (range, 14-56 minutes). There was a trend toward a faster surgical time with an increase in the number of surgeries performed ($P = 0.08$). Median anesthesia time was 30 minutes (range, 17-58 minutes).

The median dimensions of the excised pericardium for the PW were 2 cm × 2 cm (range, 1.5 cm × 1.0 cm to 3.5 cm × 3 cm). The data showed a trend toward larger excised pericardial tissue dimensions with an increase in the number of surgeries performed, but this was not statistically significant ($P = .11$). In 1 dog, partial herniation of the right auricle through the initial PW was appreciated immediately after creation of the PW, and this resolved once the 3 vertical fillet incisions were created. One dog developed ventricular fibrillation when the bipolar electrosurgery sealing device contacted the heart while creating the final fillet during PW+F, which led to cardiac arrest and death.

3.3 | Epicardial surface exposure

The addition of vertical fillets (PW+F) consistently increased the PESE compared to PW, regardless of the view (MV, RV, and LV, Figure 3). For MV, PESE was 57.5 ± 22 for the PW and 94.5 ± 4.7 for the PW+F ($P < .0001$). For RV, PESE was 25.1 ± 18 for the PW and 87.5 ± 5.2 for the PW+F ($P < .0001$) (Figure 4A,B). For LV, PESE was 45.6 ± 39 for the PW and 99.3 ± 1.8 for the PW+F ($P = .0001$). Some degree of bulging of the heart was noted...
on examination of thoracoscopic images in all dogs after PW, but was not observed after PW+F.

3.4 | Postmortem evaluation

Following PW+F in each dog, the remaining pericardium was freed from the heart, and the majority of the epicardial surface was exposed (Figure 5). For the dog that arrested intraoperatively, postmortem evaluation showed a lesion on the left ventricular free wall epicardial surface at the termination of a left ventricular artery and vein. This lesion was consistent with thermal damage from contact of the bipolar electrosurgery sealing device with the epicardium. In the remaining 11 dogs, there was no evidence of iatrogenic damage to surrounding structures.

4 | DISCUSSION

Pericardial window with vertical pericardial fillets consistently improved the exposure of the epicardial surface for all thoracoscopic views compared to the standard pericardial window technique. The PESE was greater after PW+F in all dogs and for all views.

To the authors’ knowledge, the PW+F technique has been briefly described in only one other study. In that study, the technique was used in conjunction with thoracic duct ligation for dogs undergoing treatment for chylothorax. Complete resolution was achieved in approximately 85% of dogs with idiopathic chylothorax. PW+F may be applicable in a variety of disease processes where pericardectomy is indicated. In another study comparing thoracoscopic PW to open STP, dogs with idiopathic pericardial effusion had a significantly shorter survival time and disease free interval after PW. The authors concluded that an open STP may be superior to treat idiopathic pericardial effusion in dogs, and suggested that modifications of the thoracoscopic technique be considered. Creation of a larger pericardial window was proposed, although an exact size was not suggested. However, enlarging the diameter of the PW may not eliminate the intimate contact between the pericardium and the heart. Such close contact with the heart could lead to fibrosis between the edges of the PW and the epicardium, or obstruction of the window by thoracic adhesions. In our study, the addition of 3 vertical pericardial incisions (fillets) allowed the remaining pericardium to move completely away from the heart when the dogs were positioned in dorsal recumbency. Presumably, this would make the edges of the pericardium more mobile, less susceptible to adhere to the epicardium and would, therefore, decrease the risk of disease recurrence. On the other hand, the remaining pericardium could fall ventrally and adhere together, or to the heart when the dog is in ventral recumbency. Clinical investigation is needed to evaluate these possibilities.

Another alternative to standard thoracoscopic PW consists of thoracoscopic STP, aiming for a 360° pericardectomy, leaving approximately 1 cm of pericardium ventral to the phrenic nerves. Thoracoscopic STP without pulmonary exclusion has been successfully performed without iatrogenic damage, but with the median surgery time doubling that of the present study. In a more recent study of thoracoscopic STP, the authors proposed that 1 lung ventilation was mandatory to allow sufficient observation of important anatomic structures during the procedure. Even with 1 lung ventilation, inadvertent phrenic nerve transection occurred in 1 dog. Furthermore, the median surgery time in that report was 3.5 times longer than the present study. We believe that PW+F technique is technically easier than thoracoscopic STP, as it requires less dissection adjacent to the phrenic nerves. This advantage may allow for efficient and repeatable execution of PW+F, even by novice surgeons. In the present study, PW+F was performed by a first-year surgery resident without previous experience with this procedure. The surgical time tended to decrease with experience, approaching 60 minutes for the first dog, and 20 minutes for the last dog in the study. Although a novice at minimally invasive surgery could successfully complete PW+F, the surgeries were performed in a research setting, repeatedly over a short period of time, and on healthy dogs of similar size. Given these specific circumstances, the authors must use caution when recommending PW+F to the novice surgeon in a clinical setting.

In spite of the uniform size of dogs enrolled in this study, the size of pericardial tissue excised for the PW varied, and was likely influenced by multiple factors. First, there was a
trend toward excision of larger portions of pericardium as the novice surgeon gained experience, the smallest pericardial excisions occurring during the first 3 surgeries. Although this was not statistically significant, additional experience could lead to excision of larger portions of pericardium. Second, tissue measurements could have been affected by tissue retraction after excision, and by thermal damage to the tissue margins from the bipolar electrosurgery sealing device. Direct visualization of cardiac structures during surgery is relevant, as cardiac masses are not detected by echocardiography in 8% of dogs with pericardial effusion. Skinner et al demonstrated that there is limited access and visualization of cardiac structures with the PW+F technique, the significant increase in epicardial exposure would be expected to improve the visualization of cardiac structures. Furthermore, the cardiac atria were completely visible in each dog at postmortem evaluation of the thorax.

Cardiac herniation through small pericardial defects that are congenital, traumatic, or iatrogenic in etiology has been reported in the human and veterinary literature. While veterinary reports of cardiac herniation through a pericardial defect are rare, one source has suggested that PW dimensions of 3 × 3 cm² may decrease the risk of cardiac herniation in large breed dogs. In one case report, a dog suffered herniation of the left auricle through a 2.5 × 2.5 cm pericardial defect, assumed to be a congenital abnormality. The defect dimensions in that report are similar to those previously recommended for a PW. Although cardiac herniation has not yet been reported as a complication of PW in the veterinary literature, multiple accounts have been reported in man as a postoperative complication of thoracic surgery that involves creating an opening in the pericardium. In the present study, partial herniation of the right auricle was noted immediately after creation of the PW in 1 dog, which resolved with the addition of fillets to the PW. Although cardiac herniation is a rare sequela, it is a potentially fatal condition that may be avoided by widening the PW with fillets.

One dog developed ventricular fibrillation and subsequent cardiac arrest when the bipolar electrosurgery sealing device briefly contacted the epicardial surface of the left ventricular free wall during creation of the final pericardial fillet. Although bipolar electrosurgery sealing devices have widespread applications in minimally invasive surgery, surgeons should be aware of the risk of iatrogenic tissue damage from thermal burn. Whenever the device is discharged, the surgeon should elevate the device away from surrounding tissues. This may be more challenging when working near cardiac structures due to motion. Thus, the surgeon should concentrate on synchronizing the discharge of the device with the motion of the heart. Alternatively, harmonic devices or thoracoscopic dissecting scissors can decrease the risk of thermal burn. Harmonic technology may be advantageous over electrosurgery, as lateral thermal damage is reduced and visualization improved by reducing smoke formation. Thoracoscopic dissecting scissors could be used to perform the PW+F, although pericardial hemorrhage may obstruct visualization.

While this report describes and evaluates a novel pericardectomy technique, various limitations are present. The study population included dogs with normal pericardia and pleura, which does not represent the clinical population. Idiopathic pericardial effusion as well as chylothorax are often associated with thickening and inflammation of the pericardium. Chylothorax can also cause thickening and inflammation of the pleura throughout the thoracic cavity. Thickening of the pericardium or the surrounding pleura may make it more difficult to grasp tissues with thoracoscopic instruments, and inflammation can increase tissue vascularity, increasing hemorrhage, and affecting intraoperative visualization. In clinical cases, these 2 issues can be addressed using appropriate equipment. Aggressive endoscopic graspers can be used to securely grasp a thickened pericardium; hemostasis can be achieved with a bipolar electrosurgery device, which can seal vessels up to 7 mm in diameter. While PW+F was successfully and efficiently performed in small dogs, our study population is not representative of all breed conformations. The procedure may be more challenging in dogs with a low thoracic depth to width ratio, such as brachycephalic breeds. In these breeds, it may be more difficult to elevate the pericardium away from the heart. Finally, the experimental nature of this study prevented the evaluation of postoperative outcomes.

PW+F is a minimally invasive pericardectomy that increases the exposure of the epicardial surface compared to PW, without extensive dissection or prolonged surgical time. A bipolar electrosurgery sealing device should be applied with extra care near the heart, as thermal damage can lead to ventricular fibrillation and cardiac arrest. A prospective clinical trial is needed to compare postoperative complications and outcomes after PW+F compared to other pericardectomy techniques.

**CONFLICT OF INTEREST**

The authors declare no conflicts of interest related to this report.

**REFERENCES**


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