Beyond the Plate: Proven Clinical TPLO Outcomes

The ONLY AO-approved TPLO System worldwide

The **DePuy Synthes** TPLO System has been designed for you and your patients in conjunction with and approved by the AO Technical Commission† to ensure best possible outcomes[1] and is the ONLY AO Approved TPLO System worldwide.

There is a rigorous development process in place, including product initiation and voice of customer, assessment, usability testing, and AO approval of the product.

*DePuy Synthes TPLO Plates compared to commercially available TPLO Plates.

†The AO Foundation is a third-party a guided, not-for-profi t organization led by an international group of surgeons, specialized in the treatment of trauma and disorders of the musculoskeletal system.

1. Kowaleski MP, Boudrieau RJ, Beale BS, Piras A, Hulse D, Johnson KA. Radiographic outcome and complications of tibial plateau leveling osteotomy stabilized with an anatomically contoured locking bone plate. *Vet Surg.* 2013;42:847-852.

DePuy Synthes
THE ORTHOPAEDICS COMPANY OF Johnson & Johnson

Received: 16 April 2021 | Revised: 18 January 2022 | Accepted: 10 February 2022

DOI: 10.1111/vsu.13795

ORIGINAL ARTICLE - CLINICAL

WILEY

The development of ventricular fibrillation as a complication of pericardiectomy in 16 dogs

Joseph S. Raleigh DVM[1] | Philipp D. Mayhew BVM&S, DACVS[1] | Lance C. Visser DVM, MS, DACVIM (Cardiology)[2] | Milan Milovancev DVM, DACVS-SA[3] | Charles A. Kuntz DVM, DACVS[4] | Luca Formaggini DVM[5] | Hsien-Chieh Chiu DVM[6] | Owen T. Skinner BVSc, DECVS, DACVS-SA[7] | Jaron H. Naiman DVM, DACVS-SA[8] | Michelle L. Oblak DVM, DVSc, DACVS[9] | Jonathan F. McAnulty DVM, MS, PhD[10] | Christopher L. Hoffman DVM[11] | Michael Brückner DVM, DECVS, EBVS[12] | Ameet Singh DVM, DVSc, DACVS[9]

[1]Department of Surgical & Radiological Sciences, University of California-Davis, School of Veterinary Medicine, Davis, California, USA

[2]Department of Medicine and Epidemiology, University of California-Davis, School of Veterinary Medicine, Davis, California, USA

[3]Department of Clinical Sciences, Carlson College of Veterinary Medicine, Oregon State University, Corvallis, Oregon, USA

[4]Southpaws Specialty Surgery Animals, Moorabbin, Victoria, Australia

[5]Clinica Veterinaria Lago Maggiore, Dormelletto, Italy

[6]Tzuoo-Ann animal hospital, New Taipei City, Taiwan

[7]Department of Veterinary Medicine and Surgery, University of Missouri, Columbia, Missouri, USA

[8]Lloyd Veterinary Medical Center, Iowa State University college of Veterinary Medicine, Ames, Iowa, USA

[9]Department of Clinical Studies, Ontario Veterinary College, Guelph, Ontario, Canada

[10]Department of Surgical Sciences, School of Veterinary Medicine, University of Wisconsin, Madison, Wisconsin, USA

[11]University of Minnesota, College of Veterinary Medicine, St. Paul, Minnesota, USA

Abstract

Objective: To describe the clinical characteristics, perioperative protocols, and outcomes in dogs diagnosed with ventricular fibrillation (VF) while undergoing pericardiectomy.

Study design: Retrospective, multi-institutional study.

Animals: Sixteen client-owned dogs.

Methods: Cases were accrued through a listserve request posted to 3 subspecialty veterinary societies. Dogs were included if they developed VF during a pericardiectomy performed through an open or thoracoscopic approach. Data collected included signalment, history and physical examination, surgical approach, histopathology, treatment, and outcome.

Results: Indications for pericardiectomy included idiopathic chylothorax ($n = 7$), neoplasia (4), idiopathic pericardial effusion (4), and foreign body granuloma (1). Surgical approaches included thoracoscopy (12), intercostal thoracotomy (3) and median sternotomy (1). Electrosurgical devices were used to complete at least part of the pericardiectomy in 15 of 16 dogs. Ventricular fibrillation appeared to be initiated during electrosurgical use in 8/15 dogs. However, in 5/15 dogs it was not obviously associated with electrosurgical use. In 3/16 dogs the timing of initiation of VF was unclear. In 7/16 dogs, cardiac arrhythmias were noted prior to the development of VF. Fourteen of 16 dogs died from intraoperative VF.

Conclusion: In most dogs ventricular fibrillation was a fatal complication of pericardiectomy. Ventricular fibrillation might be associated with the use of electrosurgical devices and cardiac manipulation during pericardiectomy although a causal link could not be established from the data in this study.

[12]Evidensia Specialistdjursjukhuset, Helsingborg, Sweden

Correspondence
Philipp D. Mayhew, BVM&S, DACVS, Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California-Davis, One Shields Avenue, Davis, CA 95616, USA.
Email: philmayhew@gmail.com

Clinical significance: Surgeons must be aware of the risk of VF during pericardial surgery. Electrosurgery might need to be used judiciously during pericardiectomy, particularly in dogs exhibiting cardiac arrythmias.

1 | INTRODUCTION

Surgical removal of the pericardium is commonly performed for the treatment of dogs with pericardial effusions and as adjunctive treatment for chylothorax.[1–5] Some examples of neoplastic and non-neoplastic causes of pericardial effusion in dogs include right atrial hemangiosarcoma, chemodectoma, mesothelioma, various coagulopathies as well as fungal and rarely septic pericarditis.[1–5] The goal of pericardiectomy in these patients is to resect diseased tissue, harvest samples for biopsy and/or to relieve cardiac tamponade that can develop as fluid accumulates in the pericardium and restricts normal chamber expansion.[6,7] In dogs with chylothorax, it has been postulated that impaired diastolic filling from a fibrosed and thickened (ie, constrictive) pericardium can lead to central venous hypertension, which in turn could lead to lymphatic hypertension and chyle leakage.[8]

A variety of pericardiectomy techniques have been described using both open and minimally invasive surgical approaches.[9–16] Life-threatening complications associated with open and thoracoscopic pericardiectomy have been documented and include hemorrhage, iatrogenic nerve or lung damage, and cardiac arrhythmias.[9–16] The majority of the arrhythmias detected have minimal effect on the patient's hemodynamic status but ventricular fibrillation (VF) can result in immediate life-threatening consequences. Ventricular fibrillation is a condition characterized by turbulent cellular electrical activity resulting in mechanical incoordination and subsequent pump failure. Broad causes can be categorized as cardiac or noncardiac in origin, and include structural heart disease, hypoxemia, electrolyte disturbances, neurological disease, various surgical diseases, and physical, or electrical manipulation.[17] Immediate treatment is aimed at defibrillation, antiarrhythmic medications, and addressing any predisposing conditions. However, most cases are rapidly fatal. The clinical presentation of dogs that develop VF while undergoing pericardiectomy procedures is poorly described in the veterinary literature although a small number of cases have been reported in dogs.[16,17] Two of these cases occurred in dogs undergoing pericardiectomy for treatment of idiopathic effusion[18] and 1 occurred during pericardiectomy in a healthy research dog.[16]

The objectives of this study are to describe the perioperative characteristics, and overall outcomes in a cohort of dogs diagnosed with VF while undergoing pericardiectomy and to investigate any potential factors involved in the initiation of VF in these dogs.

2 | MATERIALS AND METHODS

2.1 | Animals

A call for cases to the listserves of the Veterinary Endoscopy Society (VES), the Society for Veterinary Soft Tissue Surgery (SVSTS), and the Veterinary Society for Surgical Oncology (VSSO) was posted in March of 2020. Respondents were asked to submit case data for the study if cases met the following inclusion criteria: dogs that underwent an open or thoracoscopic pericardiectomy procedure without epicardial stripping and developed VF during the procedure. Cases were excluded if VF developed at a time other than intraoperatively or if the medical record was incomplete.

Data collection – Data obtained from the medical records included signalment, nature and duration of clinical signs, history of comorbidities, medications administered, physical examination findings and indications for surgery. The results of preoperative diagnostic evaluation including clinical pathology, fluid analysis, diagnostic imaging, and echocardiography were recorded. Relevant preoperative diagnostic findings, such as fluid analysis results, from referral institutions were included for tests that were not repeated at the surgical appointment. Perioperative variables including anesthetic protocols, surgical approach employed (open versus thoracoscopic), surgical findings and histopathology results were also recorded. Data specific to VF events including timing of fibrillation events and their temporal association with different components of the surgical procedures were recorded.

2.2 | Outcomes

Details of intravenous medications, manual cardiac compressions and defibrillation administered were recorded.

In survivors, long-term follow up was collected from the medical record or from telephone contact with the owner. For each institution that submitted clinical data on a dog that suffered from VF during pericardiectomy, the contributing author was asked to search the institutional medical records database to record the number of pericardiectomy procedures that had been performed during the study period. This data allowed an estimate of the incidence of the development of VF during pericardiectomy procedures to be calculated.

3 | RESULTS

3.1 | Signalment

Sixteen dogs from 11 veterinary clinics that underwent surgery between December 18, 2004 and October 21, 2020 were included in the study. Components of the clinical data from affected dogs are summarized in Table 1. Seven dogs were spayed females, 1 was an intact female, 5 dogs were castrated males and 3 were intact males. Median age was 9 years (range 3 to 14 years). Median weight was 28 kg (range 9 to 82 kg).

3.2 | History and physical examination

Pre-existing cardiac disease was identified in a single dog with a history of myxomatous mitral valve disease and subaortic stenosis. The most common clinical signs included exercise intolerance ($n = 10$), lethargy (9), and dyspnea (9). Physical examination findings included weight loss (5), pale mucous membranes (4), and decreased ventral lung sounds (4). Relevant preoperative medications included furosemide (2), pimobendan (1), sotalol (1), atenolol (1), and lidocaine (1).

TABLE 1 Clinical data from 16 dogs that underwent ventricular fibrillation during thoracoscopic or open pericardiectomy

Breed	Indication for pericardiectomy	Surgical approach	Electrosurgical device used	VF initiated during ES use	Arrhythmia noted prior to VF initiated	Outcome
Golden retriever	Chylothorax	Thoracoscopy	Bipolar vessel-sealing	Unclear	Yes	Died
Mastiff	Chylothorax	Thoracoscopy	Bipolar vessel-sealing	Unclear	Yes	Died
Mixed breed	Chylothorax	Intercostal thoracotomy	Bipolar vessel-sealing	Yes	Yes	Died
Golden retriever	Neoplasia	Thoracoscopy	Bipolar vessel-sealing	No	Yes	Died
Mixed breed	Chylothorax	Thoracoscopy	Bipolar vessel-sealing	Yes	No	Died
Labrador retriever	Granuloma secondary to migrating FB	Median sternotomy	Bipolar vessel-sealing and monopolar ES	Yes	No	Died
Boston Terrier	Idiopathic pericardial effusion	Thoracoscopy	Bipolar vessel-sealing	Yes	Yes	Died
English Mastiff	Chylothorax	Intercostal thoracotomy	Bipolar vessel-sealing	Yes	No	Died
Mixed breed	Idiopathic pericardial effusion	Thoracoscopy	Bipolar vessel-sealing	Yes	No	Died
Boxer	Neoplasia	Thoracoscopy	Bipolar vessel-sealing	Yes	No	Died
Golden retriever	Idiopathic pericardial effusion	Thoracoscopy	None	n/a	No	Discharged
Greyhound	Idiopathic pericardial effusion	Thoracoscopy	Bipolar vessel-sealing	Yes	No	Discharged
Cane Corso	Neoplasia	Thoracoscopy	Bipolar vessel-sealing	No	No	Died
Boxer	Neoplasia	Thoracoscopy	Bipolar vessel-sealing	No	No	Died
Greyhound	Chylothorax	Intercostal thoracotomy	Bipolar ES	No	Yes	Died
Queensland heeler	Chylothorax	Thoracoscopy	Bipolar vessel-sealing	No	Yes	Died

Abbreviations: ES, electrosurgical; FB, foreign body; n/a, not applicable; VF, ventricular fibrillation.

3.3 | Laboratory evaluation and diagnostic imaging

Results of serum biochemical screens and complete blood counts were nonspecific and are not reported in detail.

Thoracic radiographs were performed on 13 dogs; important findings included pleural effusion (8), pneumothorax (2), globoid cardiac silhouette (2), suspected cardiac mass (2), abdominal effusion (1), and possible lung lobe torsion (1). Abdominal ultrasound was performed on 7 dogs with 2 cases demonstrating ascites suspected to be secondary to right-heart failure from cardiac tamponade. No other abnormalities were noted on abdominal ultrasound. Contrast-enhanced computed tomography (CT) was performed on 9 dogs; 2 dogs diagnosed with chylothorax, where a contrast lymphangiogram was performed at the time of CT, were noted to have tortuous and aberrant lymphatic vessels in the cranial mediastinum. One dog was diagnosed on CT with a $10 \times 10 \times 5$ cm caudal intrathoracic mass that appeared to involve the left caudal and accessory lung lobes and nodules throughout the mediastinum and pleural wall. Enlarged lymph nodes were reported in 4 dogs at the following locations: cranial mediastinum (3), sternal (1) cranial abdominal (1), and superficial cervical (1). Other CT findings were similar to thoracic radiographs and included: pleural effusion (6), pneumothorax (3), and abdominal effusion (1). Echocardiograms were performed in 15 dogs with the following findings reported: pericardial effusion (7), mass (4), mitral valve regurgitation secondary myxomatous mitral valve disease (4), possible constrictive physiology (2), subaortic stenosis (1). A concurrent electrocardiogram identified hemodynamically insignificant ventricular premature complexes in a single dog. The locations of the masses included right auricle (3) and pericardium (1). Right auricular masses ranged from (2-2.5 cm) in diameter; the pericardial mass measured 10.8 cm in diameter.

Pericardiocentesis had been performed prior to presentation for surgery in 9 dogs; of these 9 dogs, 5 had undergone a single pericardiocentesis and 4 had undergone 2 pericardiocentesis procedures. The median volume of fluid removed from the pericardial sac was 150 mL (range 115-1400 mL). Pericardial fluid analysis was performed on 3 dogs and was consistent with hemorrhagic effusion; neoplastic epithelial cells suggestive of a glandular origin such as ectopic thyroid tissue was also documented in 1 dog. One dog had a fine needle aspirate performed on a pericardial mass, which was consistent with pyogranulomatous inflammation. Of the 7 dogs diagnosed with chylothorax, 4 had triglyceride levels measured at the referral institution: median serum and pleural effusion triglycerides was 56.5 (range 33-57 mg/dL) and 1441 (431-1816 mg/dL), respectively. In all 4 dogs, pleural effusion triglyceride levels were markedly higher than serum triglycerides, prompting a diagnosis of chylothorax. The other 3 dogs had a diagnosis of chylothorax established by a local veterinarian for the which confirmatory diagnostic test results were not available. One of these 7 dogs with chylothorax was included in a previous report on the outcomes of chylothorax in a cohort of 39 dogs.[19]

3.4 | Anesthesia and surgery

One-lung ventilation was not utilized during surgery in any dog. Dogs were anesthetized using a protocol approved by the attending anesthesia staff. Days from diagnosis to surgery ranged from 1 to 1936 days. Surgical approaches included thoracoscopy (12/16 dogs), right fifth intercostal thoracotomy (2/16 dogs), right tenth intercostal thoracotomy (1/16 dogs), and median sternotomy (1/16 dogs). In 13/16 procedures, dogs were positioned in dorsal recumbency; the remaining 3 were positioned in left lateral recumbency. Of the 13 thoracoscopic procedures, 12 utilized a 3-port technique, 1 utilized a 2-port technique.

The following abnormalities were reported at the time of surgery: pleural and pericardial thickening and fibrosis (5), a right auricular mass (3; estimated size at surgery 2-3.5 cm), pleural effusion (2), pericardial effusion (1) and a pericardial mass (1). Initiation of the pericardiectomy (in 14 dogs in which it was documented) occurred at the following locations: apex (12), subphrenic (1), and immediately ventral to the great vessels (1). Pericardiectomy was initiated with scissors in 9/16 dogs and with an electrosurgical device in 7/16 dogs. Electrosurgical units were used to perform at least part of the pericardiectomy procedure in 15 of 16 dogs (Table 1). The Ligasure/Forcetriad (Medtronic, Minneapolis, Minnesota) generators were used in 12 dogs and the Enseal GEN 11 generator (Ethicon Endosurgery, Cincinnati, Ohio) was used in 2 dogs. When the Ligasure/Forcetriad was used, the generator type/generation used was not documented. The following handpiece types were used in conjunction with the Ligasure/Forcetriad units: Dolphin ($n = 6$), Small jaw (2), Atlas (1), V (1) and Precise (1). Enseal Trio handpieces were used in conjunction with the Enseal generator. Both new and previously used electrosurgical devices were employed but the number of times an electrosurgical handpiece had been used was not recorded reliably. Procedures performed prior to pericardiectomy under the same anesthetic episode included thoracic duct ligation (7), granulomatous mass resection that was associated with the pericardium (1), and cranial mediastinal lymph-node extirpation (1).

3.5 | Ventricular fibrillation events and treatment

The initiation of VF relative to electrosurgical device use is summarized in Table 1. In 1 of the 5 dogs where electrosurgery did not appear to be associated with the development of VF, the arrhythmia appeared to be initiated by manipulation of a right auricular mass. In 7/16 dogs, cardiac arrhythmias were noted prior to the development of VF; these included ventricular premature complexes (3), ventricular tachycardia (2), and sinus bradycardia (1).

Rescue medications administered after VF had been diagnosed included vasopressor, antiarrhythmic, and reversal agents aimed at improving hemodynamic status and therapies aimed at improving oncotic pressure, including colloidal support. Cardiac compressions were initiated in 15/16 dogs; time frame from initiation of VF to commencing compressions ranged from 0-5 min. Defibrillation was attempted in 13/16 dogs with the number of attempts ranging from 1-13. Three dogs were successfully converted to a sinus rhythm following defibrillation. Conversion to an open approach was performed in 9 of 13 thoracoscopic procedures. Median anesthesia time was 203 min (range 50-395 min) and median surgical time was 73 min (range 30-273 min). Histopathology of the pericardium was available for 2 of the cases and was reported as follows: (1) severe, chronic, lymphoplasmacytic and fibrinous pericarditis with chronic hemorrhage; and (2) proliferative serositis with lymphosuppurative inflammation. Histopathology was available for 1 of the 4 masses identified intraoperatively and was consistent with a chemodectoma. Notably, this was not the dog where VF occurred when the mass was being manipulated.

3.6 | Incidence of ventricular fibrillation during pericardiectomy

During the study period, the number of pericardiectomy procedures that were performed at 9 of the 11 contributing institutions was available for review. For 2 institutions, medical records databases were not able to be searched and so data was not available. In total 456 pericardiectomies were performed at institutions from which 14 cases were submitted. Estimated incidence of VF during pericardiectomy can therefore be estimated to have occurred in 14/456 (3%) pericardiectomy procedures.

3.7 | Outcome

Fourteen of 16 dogs died from intraoperative VF. One of the surviving dogs developed postoperative hypoxemia, was supported in an intensive care unit, was discharged, and made a full recovery. This dog remains clinically normal 5 months postoperatively. The other dog was taken back to surgery approximately 3 h postoperatively to address ongoing hemorrhage. A median sternotomy was performed and extensive parietal hemorrhage was noted at the level of the left internal thoracic artery/vein. Both structures were ligated, a thoracic drain was placed, and the patient was recovered from anesthesia. Postoperative pleural effusion and hypoalbuminemia was reported in this case but no further surgical intervention was performed and this dog is clinically normal 24 months postoperatively.

4 | DISCUSSION

Ventricular fibrillation (VF) was found to be a rare and most often fatal complication of pericardiectomy. It might be possible that the use of electrosurgical devices and cardiac manipulation during this procedure could act as a trigger for VF although a causal link could not be established from the data in this study.

A number of factors have been associated with the development of cardiac arrhythmias in humans.[20] These include electrolyte/acid base derangements, fluid imbalances, certain medications, physical manipulation of cardiac tissue, the use of electrosurgical devices, the severity of underlying pericardial disease and structural cardiac disease, conduction disturbances, hypertension, and pulmonary or endocrine disease.[20] Interestingly, no dogs in this study had been diagnosed with pre-existing hypertension, pulmonary or endocrine disease although not all dogs had blood pressure recorded preoperatively. Preoperative examinations did not detect alterations in volume status; laboratory evaluation and diagnostic imaging findings did not identify any previously unknown systemic conditions that could contribute to the development of arrhythmias. One dog had been previously diagnosed with structural heart disease and 4 dogs were diagnosed via preoperative echocardiogram with mild mitral valve disease, one of whom also had subaortic stenosis. Two dogs demonstrated evidence of constrictive physiology and 1 dog had rare ventricular premature complexes. Although these findings were considered mild and were not accompanied by clinically significant conduction disturbances, the presence of preexisting cardiac disease still cannot be excluded as a potential contributor to the subsequent development of intraoperative VF. It is of course possible that primary or secondary heart disease went underdiagnosed due to inadequate preoperative diagnostic evaluation in this cohort of dogs. It is also possible that in some cases, even when a standard of care cardiac diagnostic evaluation was performed, occult or undetected cardiac pathologies might predispose a patient to VF. Examples of these documented in human patients that have suffered VF include long Q-T syndrome and Takotsubo cardiomyopathy.[21] Myocarditis and myocardial ischemic injury are also plausible.

The arrhythmogenic stimulus that led to VF in these dogs most likely varied from case to case and may have been multifactorial in some. It is important to state that data from this study cannot establish a causal link between these factors and the development of VF in the study cohort. Evidence for this stems from the fact that in 5 dogs, the initiation of VF did not seem to be directly associated with the use of electrosurgical energy. Conversely, in 8 dogs the discharge of electrosurgical energy did appear to occur concurrently with the development of VF. Physical handling of pericardial and cardiac tissues during dissection might have been a potential cause for development of intraoperative arrhythmias. Surgical manipulation of parasympathetic and sympathetic cardiac innervation through structures including the vagal nerve and sympathetic ganglia may alter vagal tone and subsequent autonomic imbalance, predisposing the patient to the development of arrhythmias.[22] Similarly, dissection may result in inadvertent triggering of pressure receptors present in the aortic arch or cardiac chambers, which in turn, may alter the complex pressure-volume relationship that governs electrical conduction and cardiac function.[22,23] Although no current veterinary studies have directly explored this relationship, previous human publications have supported a link by demonstrating that specific surgical approaches and more extensive procedures can impact the likelihood of arrhythmia development.[22,23]

Electrosurgical units are commonly used for dissection and hemostasis in both open and thoracoscopic canine pericardiectomy. In human case descriptions, an association between the use of electrosurgery and the development of intraoperative ventricular fibrillation has been suggested during pericardectomy[24] but also a plethora of other procedures including bilateral mastectomy,[21] resection of liver and lung masses,[25,26] hemorrhage following a previous esophagectomy,[27] and during a gastric banding procedure.[28] Monopolar electrosurgery was implicated in all of the human cases, whereas both bipolar and monopolar devices were employed in the dogs that developed VF during veterinary procedures.[16,17] A thoracoscopic approach was used in 75% of dogs and the procedure was aided by the use of electrosurgical devices in most cases; these findings reflect broader trends in veterinary surgery including the application of minimally invasive surgical approaches and the use of modern electrosurgical devices to achieve hemostasis and efficient dissection.[11–16]

Three distinct mechanisms for electrosurgical induction of VF have been established.[29] These can be separated on the basis of magnitude and duration of the current applied in each. The first example involves a single high current stimulus that occurs during the T wave of a cardiac cycle and immediately induces VF.[29,30] This phenomenon is a result of the relative and absolute refractory nature of cardiac myocytes to electrical stimulation during the repolarization period represented by the T wave. A shock during this vulnerable period can alter the rhythm and result in VF.

The second mechanism is a result of multiple electrical pulses of a lower current applied over 1-5 s to epicardial cells. These cells demonstrate variability in their repolarization capabilities and refractory properties. The inherent heterogeneity within this cell population leads to a discordant response to electrical signaling, inducing a brief period of profound tachycardia (>450 BPM) and potentially VF. The final mechanism involves an even lower current applied over 90-300 s, which also causes an increase in heart rate. Values greater than 220 BPM decrease the diastolic filling time, which may induce myocardial ischemia due to reduced cardiac output. The resulting ischemia directly lowers the intrinsic VF threshold thereby increasing the likelihood for arrhythmia development.[29] It is difficult to hypothesize which of these mechanisms, if any, could have played a role in the initiation of VF in the 8 of 15 dogs where electrosurgical energy was used and its use appeared subjectively to concur with the onset of VF. The frequency of most electrosurgical units ranges from 200 kHz-3.3 MHz, which is substantially greater than the 50-60 Hz range to which cardiac myocytes respond.[31] This considerable difference typically protects the heart from inadvertent stimulation as the current flows through the tissues to the return electrode. However, in rare exceptions, low-frequency stray current can result from the use of electrosurgery and cause pathologic excitation of cardiac cells. This phenomenon can occur with the use of both monopolar and bipolar devices, although the frequency varies depending upon the type and mode of use, and its relationship with surrounding tissues. The monopolar cut function is characterized by use of continuous current, which allows for lower voltage requirements to achieve a given amount of power (watts). Reductions in voltage decrease the size of the surrounding area susceptible to inadvertent low level stray currents, thereby mitigating the potential for unexpected, pathologic cellular excitation. Similarly, bipolar technology decreases the risk for causing low frequency stray currents to travel through the regional tissues; however this is due to the location of the return electrode. Specifically, the orientation of the 2 electrodes relative to the tissues of interest restricts the current to that region. This reduces the risk of adverse sequelae caused by low frequency stray current as the electrical pathway does not travel through the patient. These 2 functions can be contrasted with the monopolar coagulation mode, which employs an interrupted current at higher voltages. These parameters predispose the surrounding tissues to more collateral damage, including transmission of low-level stray current. The results of this study do not necessarily support the premise that monopolar coagulation function is the most likely type of electrosurgical current to initiate VF as in 6 of 7 dogs the initiation of VF appeared to be associated with a bipolar vessel-sealing device. That said, this is likely a reflection of more widespread use of bipolar vessel-sealing devices for this procedure, especially when pericardiectomy is performed thoracoscopically, as opposed to a true increase in the incidence relative to monopolar devices. There is very little information in the literature regarding the release of stray current from bipolar vessel sealers although a case of VF during pericardiectomy associated with a bipolar vessel-sealing device has been reported.[16]

The overall survival rate in this study was poor (2/16), which is consistent with the general prognosis associated with VF in veterinary patients. Interestingly, the human literature has demonstrated a better prognosis for fibrillation events that are presumed to be electrically induced as opposed to naturally occurring,[32] suggesting this population may have an improved possibility for recovery. Important factors that have been associated with successful conversion to a sinus rhythm include the duration of time between diagnosis of VF and implementation of cardiac contractions as well as the location of cardiac compressions and defibrillator paddle placement.[32] Decreased time, internal compression (cardiac massage technique), and application of the defibrillator leads directly onto the heart are associated with improved rates of survival.[33,34] In the current study, compressions were instituted in 5 min or less for all cases and defibrillation was performed on 13/16 patients. These steps must be anticipated and addressed in preparation for this surgery so that intervention can proceed efficiently should VF occur. Despite these points, the high rate of mortality associated with intraoperative fibrillatory events underscores the importance of preventative measures prior to surgical intervention.

The results of this study suggest that the incidence of VF is uncommon during pericardiectomy with approximately 3% of dogs undergoing pericardiectomy developing VF based on the estimated incidence from the institutions where data was available. From these and other data, various strategies should be considered to mitigate the risk of VF during pericardiectomy. A thorough history and diagnostic plan related to underlying cardiac and/or respiratory conditions is imperative, as appropriate management will minimize the intraoperative impact. Alterations in the patient's hemodynamic status or electrolytes should be corrected prior to anesthesia, and protocols should avoid arrhythmogenic medications. Preoperative and perioperative antifibrillatory medication (eg, amiodarone, sotalol) might also be considered for some cases. Theoretical surgical considerations include the use of bipolar as opposed to monopolar devices (especially coagulation mode), or alternatively, the use of a harmonic scalpel as it avoids the electrosurgical technology entirely. If a monopolar device is used, periods of application should be limited to short durations (<5 s) with the cut as opposed to the coagulation function employed whenever possible.[25] All devices should be employed at the lowest power (watts) setting regardless of the mode of use.[26] Collectively, these steps will reduce the likelihood of stray current developing during application of electrosurgery. Increased focus should be placed on intraoperative ECG monitoring as the development of any type of arrhythmias should be interpreted as a warning sign and subsequent steps should be performed with heightened caution. In this study in 7 dogs, ECG rhythm disturbances were documented prior to the development of VF, including ventricular premature complexes, ventricular tachycardia and sinus bradycardia. A preoperative discussion, as part of a surgery safety checklist, reviewing the anticipated steps and roles of all relevant members of the surgical team including the surgeon(s), anesthesiologist(s), criticalist(s) and support staff should take place. Acknowledgement of these risk factors and the possible strategies that can be employed to combat them will help reduce the incidence of, and mortality resulting from, intraoperative VF.

Limitations of this study included the small case numbers, variable preoperative diagnostic evaluation and the variable nature of multiple contributors from different clinics contributing case data. Detailed electrocardiographic information from each case was not available for review to evaluate more carefully the electrical activity of the heart in the period immediately preceding VF initiation. It is imperative to state that the suggested association between intraoperative events and the development of VF can only be hypothesized for each case. Observations in this study do, however, provide useful data to consider the factors that may have initiated VF and can allow us to make recommendations for the future to try and minimize the incidence of this potentially lethal complication.

In conclusion, the current study has provided data on an uncommon, life-threatening complication of pericardiectomy in dogs. Ventricular fibrillation should be discussed with the owners and additional members of the surgical team to promote proper understanding and preparation. The findings underscore the considerable limitations in our current understanding of the development of intraoperative VF in veterinary patients and the importance of further research in the field.

ACKNOWLEDGMENTS

Author Contributions: Raleigh JS, DVM: Study design, acquisition of data, manuscript preparation. Mayhew PD, BVM&S, DACVS: Study conception, study design, acquisition of data, and manuscript preparation. Visser LC, DVM, MS, DACVIM (Cardiology): Study design, manuscript preparation. Milovancev ML: study design, manuscript preparation, Kuntz CA: study design, manuscript preparation Formaggini L: study design, manuscript preparation Chiu HC: study design, manuscript preparation Skinner OT: study design, manuscript preparation Naiman JH: study design, manuscript preparation Oblak ML: study design, manuscript preparation McAnulty JF: study design, manuscript preparation Hoffman CL: study design, manuscript preparation Brückner M: study design, manuscript preparation Singh A: study design, manuscript preparation.

CONFLICT OF INTEREST

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

ORCID

Milan Milovancev https://orcid.org/0000-0002-0556-4409
Owen T. Skinner https://orcid.org/0000-0002-3765-429X
Michelle L. Oblak https://orcid.org/0000-0001-8489-4643
Michael Brückner https://orcid.org/0000-0003-3498-9294
Ameet Singh https://orcid.org/0000-0002-8095-9339

REFERENCES

1. Berg RJ, Wingfield WE. Pericardial effusion in the dog: a review of 42 cases. *J Am Anim Hosp Assoc*. 1984;20:721-730.
2. Kerstetter KK, Krahwinkel DJ, Millis DL, Hahn K. Pericardiectomy in dogs: 22 cases (1978-1994). *J Am Vet Med Assoc*. 1997;211:736-740.
3. Aronsohn MG, Carpenter JL. Surgical treatment of idiopathic pericardial effusion in the dog: 25 cases (1978–1993). *J Am Anim Hosp Assoc*. 1999;35:521-525.
4. Jackson J, Richter KP, Launer DP. Thoracoscopic partial pericardiectomy in 13 dogs. *J Vet Intern Med*. 1999;13:529-533.
5. Mellanby RJ, Herrtage ME. Long-term survival of 23 dogs with pericardial effusions. *Vet Rec*. 2005;156:568-571.
6. Tobias AH, McNiel EA. Pericardial disorders and cardiac tumors. In: Smith FWK, Tilley LP, Oyama M, Sleeper MM, eds. *Manual of Canine and Feline Cardiology*. 5th ed. Elsevier; 2016: 198-216.
7. Shaw SP, Rush JE. Canine pericardial effusion: pathophysiology and cause. *Compend Contin Educ Vet*. 2007;29:400-403.
8. Fossum TW, Mertens MM, Miller MW, et al. Thoracic duct ligation and pericardectomy for treatment of idiopathic chylothorax. *J Vet Intern Med*. 2004;18:307-310.
9. Sumner-Smith G, Archibald J. Surgical approaches to the treatment of cardiac tamponade. *J Am Vet Med Assoc*. 1971;159(11): 1414.
10. Matthiesen DT, Lammerding J. Partial pericardiectomy for idiopathic hemorrhagic pericardial effusion in the dog. *J Am Anim Hosp Assoc*. 1984;185(9):988-992.
11. Walsh PJ, Remedios AM, Ferguson JF, Walker DD, Cantwell S, Duke T. Thoracoscopic versus open partial pericardectomy in dogs: comparison of postoperative pain and morbidity. *Vet Surg*. 1999;28:472-479.
12. Dupre GP, Corlouer JP, Bouvy B. Thoracoscopic pericardectomy performed without pulmonary exclusion in 9 dogs. *Vet Surg*. 2001;30:21-27.
13. Mayhew KN, Mayhew PD, Sorrell-Raschi L, Brown DC. Thoracoscopic subphrenic pericardiectomy using double-lumen endobronchial intubation for alternating one-lung ventilation. *Vet Surg*. 2009;38(8):961-996.
14. Atencia S, Doyle RS, Whitley NT. Thoracoscopic pericardial window for management of pericardial effusion in 15 dogs. *J Small Anim Pract*. 2013;54(11):564-569.
15. Case JB, Maxwell M, Aman A, Monnet EL. Outcome evaluation of a thoracoscopic pericardial window procedure or subtotal pericardiectomy via thoracotomy for the treatment of pericardial effusion in dogs. *J Am Vet Med Assoc*. 2013;242(4): 493-498.
16. Barbur LA, Rawlings CA, Radlinsky MAG. Epicardial exposure provided by a novel thoracoscopic pericardiectomy technique compared to standard pericardial window. *Vet Surg*. 2018;47(1): 146-152.
17. Jalife J. Ventricular fibrillation: mechanisms of initiation and maintenance. *Annu Rev Physiol*. 2000;62:25-50.
18. Studer N, Vizcaíno Revés N, Rytz U, Iff I. Suspected electrically induced ventricular fibrillation during thoracoscopic partial pericardectomy in two dogs. *Vet Rec Case Reports*. 2019;7: e000750.
19. Mayhew PD, Steffey MA, Fransson BA, et al. Long-term outcome of video-assisted thoracoscopic thoracic duct ligation and pericardiectomy in dogs with chylothorax: a multi-institutional study of 39 cases. *Vet Surg*. 2019;48:O112-O120.
20. Chung MK. Cardiac surgery: postoperative arrhythmias. *Crit Care Med*. 2000;28(10 Suppl):N136-N144.
21. Lieb M, Orr T, Gallagher C, Moten H, Tan JM. A case of intraoperative ventricular fibrillation: electro-cauterization, undiagnosed takotsubo cardiomyopathy or long QT syndrome? *Int J Surg Case Rep*. 2012;3:155-157.
22. Asamura H, Naruke T, Tsuchiya R, Goya T, Kondo H, Suemasu K. What are the risk factors for arryhthmias after thoracic operations? A retrospective multivariate analysis of

267 consecutive thoracic operations. *J Thorac Cardiovasc Surg*. 1993;106(6):1104-1110.
23. Farsak B, Günaydin S, Tokmakoğlu H, Kandemir O, Yorgancioğlu C, Zorlutuna Y. Posterior pericardiotomy reduces the incidence of supra-ventricular arrhythmias and pericardial effusion after coronary artery bypass grafting. *Eur J Cardiothorac Surg*. 2002;22(2):278-281.
24. Cao X, Li Z, Friedman J, Cui Y. Ventricular fibrillation caused by electrocautery for pericardium hemostasis during thoracotomy. *J Clin Anesth*. 2017;42:95.
25. Yan CY, Cai XJ, Wang YF, Yu H. Ventricular fibrillation caused by electrocoagulation in monopolar mode during laparoscopic subphrenic mass resection. *Surg Endosc*. 2011;25:309-311.
26. Agarwal A, Tiwari RL, Jain S. Monopolar cautery: a rare, potential cause of perioperative cardiac arrhythmias. *J Anaesthesiol Clin Pharmacol*. 2015;31:418-419.
27. Fu Q, Cao P, Mi WD, Zhang H. Ventricular fibrillation caused by electrocoagulation during thoracic surgery. *Acta Anaesthesiol Scand*. 2010;54:256.
28. Klop WMC, Lohuis PJFM, Strating RP, Mulder W. Ventricular fibrillation caused by electrocoagulation during laparoscopic surgery. *Surg Endosc*. 2002;16:362.
29. Kroll MW, Panescu D, Hinz AF, Lakkireddy D. A novel mechanism for electrical currents inducing ventricular fibrillation: the three-fold way to fibrillation. *Ann Int Conf IEEE Eng Med Biol Soc*. 2010;1990-1996.
30. Mazer CD, Greene MB, Misale PS, Newman D, Dorian P. Transcutaneous T wave shock: a universal method for ventricular fibrillation induction. *Pacing Clin Electrophysiol*. 1997;20:2930-2935.
31. Massarweh NN, Cosgriff N, Slakey DP. Electrosurgery: history, principles, and current and future uses. *J Am Coll Surg*. 2006; 202(3):520-530.
32. Niemann JT, Rosborough JP, Youngquist S, Thomas J, Lewis RJ. Is all ventricular fibrillation the same? A comparison of ischemically induced with electrically induced ventricular fibrillation in a porcine cardiac arrest and resuscitation model. *Crit Care Med*. 2007;35:1356-1361.
33. Larsen MP, Eisenberg MS, Cummins RO, Hallstrom AP. Predicting survival from out-of-hospital cardiac arrest: a graphic model. *Ann Emerg Med*. 1993;22:1652-1658.
34. Rozanski EA, Rush JE, Buckley GJ, Fletcher DJ, Boller M, the RECOVER Advanced Life Support Domain Worksheet Authors. Recover evidence and knowledge gap analysis on veterinary CPR. Part 4: advanced life support. *J Vet Emerg Crit Care*. 2012;22(Suppl 1):S44-S64.

How to cite this article: Raleigh JS, Mayhew PD, Visser LC, et al. The development of ventricular fibrillation as a complication of pericardiectomy in 16 dogs. *Veterinary Surgery*. 2022;51(4):611-619. doi:10.1111/vsu.13795