COMPARISON OF LEFT 4TH AND 5TH INTERCOSTAL SPACE THORACOTOMY FOR OPEN-CHEST CARDIOPULMONARY RESUSCITATION IN DOGS

A Thesis

presented to

the Faculty of the Graduate School

at the University of Missouri-Columbia

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

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JULY 2018

The undersigned, appointed by the dean of the Graduate School,

have examined the thesis entitled

COMPARISON OF LEFT 4TH AND 5TH INTERCOSTAL SPACE THORACOTOMY FOR OPEN-CHEST CARDIOPULMONARY RESUSCITATION IN DOGS

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a candidate for the degree of

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DEDICATION

I dedicate this work to my family and friends, in India and in the United States.

Mom, thank you for sending me warm good morning wishes every single day. They brighten up my whole day and work better than my morning gallon of coffee. Dad, thank you for sending me photos of family gatherings and holiday decorations. And thanks for sending me photos of those beautiful hibiscus flowers on the window sills as they bloom throughout the year. They make me nostalgic even more than the family photos! I explicitly do not want to thank my brother who has never shown any interest in anything I've done in the entirety of my life; but who keeps sending me cat videos, that he shot himself, every week like clockwork. (Seriously bro, stop stalking cats!) I would also like to thank all my cousins for discussing everything under the sun in group chats. I absolutely needed to know about all those dinner plans (without me!) and everybody's ETA! Finally, I thank all my friends for never forgetting my birthday, offering a listening ear when I needed it and tolerating me when I would ramble on about my master's program; especially those here in Columbia. Much love!

Being away from loved ones has been difficult, but all of you have made it so much easier, one good morning wish, one photo, one cat video and one text message at a time. I wish you all the health and happiness in the world.

ACKNOWLEDGEMENTS

I would like to acknowledge my mentor Dr. Tony Mann, for all his support and encouragement throughout my graduate program. Dr. Mann was instrumental in my decision to come to the United States to improve my knowledge and skills and broaden my horizons. His patience and motivation was the foundation over which rested the whole of my program.

I would like to acknowledge Dr. John Middleton for his help with the statistics for my research. He was extremely patient in explaining complicated statistical concepts to me and was always available for discussions whenever needed.

I would also like to acknowledge Dr. Colette Wagner-Mann for advising me during the planning stage of my research. Dr. Wagner-Mann was extremely generous to allow me to use her laboratory for data collection and I couldn’t have finished it smoothly without her help and guidance.

I would like to acknowledge Dr. Keith Branson for suggestions and ideas for my research. His input helped a lot and it was insightful and helped me fine tune my project.

Finally, I would like to thank Dr. Kimberly Aeschlimann, Dr. Heather Honious, Dr. Nicole Trenholme, and Dr. Kaoru Tsuruta for helping me through the data collection process for my research.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CC-CPR	Closed-chest cardiopulmonary resuscitation
CI	Clamshell incision
ICS	Intercostal space
LAT	Left anterolateral thoracotomy
OC-CPR	Open-chest cardiopulmonary resuscitation
RAT	Right anterolateral thoracotomy
RT	Resuscitative thoracotomy

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ABSTRACT

Open-chest cardiopulmonary resuscitation (OC-CPR) is indicated in certain cardiopulmonary arrest situations such as thoracic trauma. Laboratory research and clinical studies in human medicine have established the superiority of OC-CPR compared to closed-chest cardiopulmonary resuscitation (CC-CPR) with regard to cardiac output, aortic blood pressure, blood flow, and perfusion. Despite this demonstrated superiority, the technique for OC-CPR has not been described in detail in the veterinary clinical literature. The most convenient incision for performing OC-CPR is a left intercostal thoracotomy. Literature most commonly describes a 4th or 5th intercostal space (ICS) thoracotomy for performing OC-CPR in dogs. No studies to date have been performed to compare the two approaches. The goal of this study was to evaluate whether lateral thoracotomies through the 5th ICS should be recommended over those performed through the 4th ICS for canine OC-CPR. We hypothesized that access to the heart would be more convenient through the 5th ICS, and the 4th ICS would not provide appropriate access for all the procedures involved in performing OC-CPR.

Left lateral thoracotomies were performed on twelve canine cadavers, six through the 4th ICS and six through the 5th ICS. Six parameters (ease of grasping

phrenicopericardial ligament, ease of pericardial incision, ease of aortic access, ease of achieving appropriate hand position, ease of application of Rumel tourniquet, and ease of proper placement of defibrillator paddles) involved in performing OC-CPR were assessed by three evaluators. The results indicated that either 4th or 5th ICS thoracotomy may provide adequate access to intrathoracic structures pertinent for performing OC-CPR in dogs weighing approximating 20 kg, but the 5th ICS was found to be better for most manipulations.

Chapter 1

Introduction

Open-Chest Cardiopulmonary Resuscitation

Open-chest cardiopulmonary resuscitation (OC-CPR) is called 'resuscitative thoracotomy' (RT) , emergency room thoracotomy, or emergent thoracotomy in human medicine.[1,2] Emergent thoracotomy is described as a way of exposing some or all of the contents of the thorax for rapid repair and control in a patient presenting in extremis (acutely dying victim of trauma).[3] More than half of all cases of thoracic trauma in human medicine can be managed conservatively, thus less than half require surgery.[4] However, RT can be lifesaving in the select cases where it is indicated. Outcome depends on the mechanism and location of the injury and the physiological status of the patient.[5] Definitive indications for OC-CPR are not established for veterinary patients, but experimental evidence indicates that when OC-CPR is used it improves outcomes, return of spontaneous circulation, neurological function, and survival.[6] However, the optimal time at which OC-CPR should be applied needs to be determined.[7]

In human beings, OC-CPR is indicated in certain cardiopulmonary arrest situations such as thoracic trauma.[8] Laboratory research and clinical studies in human medicine have established the superiority, of OC-CPR compared to closed-chest cardiopulmonary resuscitation (CC-CPR) with regard to cardiac output, aortic blood pressure, blood flow, and perfusion.[9,10] Despite this superiority the technique for OC-CPR is not well-described in the veterinary literature. Open-chest cardiopulmonary resuscitation can be performed by different incisions or approaches. The standard incision for human patients is considered to be the left anterolateral thoracotomy (LAT), since LAT provides rapid access to the heart and the descending aorta.[11] Furthermore, if the lesion is eventually out of reach of the LAT incision, the incision may be extended to a clamshell incision (CI) across the sternum. A CI is made in the 4th or 5th intercostal space (ICS), with 2nd and 3rd ICS approaches being obsolete.[12] Although several other incisions have been described for use in RT, the clamshell incision is the superior incision for human patients arriving at the hospital in extremis. While the LAT and right anterolateral thoracotomy (RAT) have utility in specific injury patterns (RAT: penetrating injuries to the right side of the chest, accessing the trachea, carina, and mid-esophagus; LAT: heart, aorta, left subclavian vessels, and distal esophagus),[13] they remain a feasible option only because of ease of conversion to clamshell incision if further control of specific injuries is mandated.[14] It has been shown that LAT access time is no different than CI access time with inexperienced surgeons; this is a counter-intuitive observation since the CI incision line is demonstrably larger than the LAT incision line.[4] However, it is inconvenient to perform CI in canine patients as described below, in spite of CI providing access to both sides of the thoracic cavity.

Technique for clamshell approach[15] and impracticality for canine patients

For performing a CI, a 4 cm 4th or 5th intercostal space thoracotomy is performed bilaterally at the level of the mid-axillary line, incising the intercostal muscles and parietal pleura. Skin and subcutaneous fat are incised from one ICS thoracotomy across the sternum to the other. Two fingers are inserted in the incision to hold the lungs away and the sternum is cut with heavy scissors. If the sternum cannot be cut with heavy scissors, Gigli wire may be used to cut the sternum.[16] A Finochietto retractor is placed with the bar on the right side. The clamshell incision provides rapid access to the heart, great vessels, and both hemithoraces, thus injuries to these organs may be repaired. A CI incision can be performed in a prehospital setting and the patient may be transported to a trauma center if return of spontaneous circulation is achieved.[17]

For performing the CI, the patient must be positioned in dorsal recumbence. Using a CI for dogs would be challenging due to the laterally flattened anatomical shape of the canine thorax. The most appropriate position for performing OC-CPR in most dogs is right lateral recumbence. In the case of barrel chested dogs, a dorsally recumbent position may be used for performing CC-CPR.[18] With barrel chested dogs additional personnel are required for positioning, and dorsal recumbence is not suitable for most other breeds. Hence, it is challenging to extrapolate data obtained from human studies using the CI approach to OC-CPR in canine patients due to the unsuitably of the CI approach for the majority of dogs.

Historic background of OC-CPR

One of the pioneers of OC-CPR in human medicine was Moritz Schiff, a distinguished physician of the latter half of the nineteenth century.[19] Schiff investigated the effects of chloroform and ether anesthesia on dogs and performed OC-CPR on those dogs when their hearts stopped.[20] The results of those studies were extrapolated to human subjects by Dr. Paul Neihans, who first attempted OC-CPR on a 40-year-old man who had a cardiac arrest prior to undergoing surgery. Dr. Neihans' efforts were, however, unsuccessful.[21] Kristian Ingelsrud, in 1901, was the first physician to achieve a successful outcome after OC-CPR as an emergency treatment for cardiac arrest.[20] While the procedure gained popularity in the decades to come, a study by Kouwenhoven, Jude, and Knickerbocker showed that the rate of success of closed-chest cardiac compression was higher than OC-CPR, after which the use of the open-chest procedure declined.[22]

The techniques for thoracotomy in dogs and cats were described by D. D. Lawson in 1968, in the *Journal of Small Animal Practice.*[23] That article stated that thoracotomy was considered unsafe for animals in the years preceding its publication, as anesthesia techniques for animals lacked refinement. Advances in the field of anesthesia made thoracic surgery safe for the veterinary patient. Open-chest cardiopulmonary resuscitation for dogs became popular at about the same time as the publication of Lawson's paper. Lawson stated that emergency thoracotomy in the treatment of cardiac collapse, by direct cardiac massage, may be needed during any operative procedure.[23] Yet, survival with intact neurological function eluded animal and human patients. In 1961 and the following years, Beall and colleagues advocated the use of resuscitative thoracotomy for trauma patients.[24] Since 1990, the development of specific, evidence-based clinical guidelines for human CPR, from extensive surveys of the literature by the International Liaison Committee on Resuscitation, has allowed consistent training for human healthcare professionals, leading to improved outcomes. Yet, only recently has there been the only comparable evidence-based veterinary guidelines, which are those described in *the Reassessment Campaign on Veterinary Resuscitation* initiative published in the *Journal of Veterinary Emergency and Critical Care*.[25]

<u>Approaches for performing thoracotomy in veterinary patients</u>

LATERAL THORACOTOMY

Five approaches for OC-CPR via lateral thoracotomy are: (a) intercostal incision, (b) rib resection, (c) partial stripping of the rib, (d) rib pivot thoracotomy, and (e) rib osteotomy thoracotomy. The most commonly used approach is the intercostal incision,[26] which was used for data collection in this study. The other approaches, rib resection and semi-stripping of rib,[23] have been described in the literature, but have not been specifically indicated for performing OC-CPR. Rib pivot thoracotomy is more conservative than a rib resection thoracotomy. A rib osteotomy thoracotomy provides limited access to the thoracic cavity for specific indications.

Intercostal incision

Described in Materials and Methods (Page 17)

Rib resection[23,27]

Rib resection thoracotomy was described by D. D. Lawson.[23] The initial approach for rib resection may be made down to the level of the rib similar to the intercostal method as succinctly described here. A number 10 scalpel blade is used to make a skin incision (ICS determined as per indication) from just ventral to the vertebral bodies dorsally to the sternum ventrally. The incision is deepened with the scalpel blade to incise the subcutaneous tissue and cutaneous trunci muscle. The latissimus dorsi muscle is incised with Mayo scissors, and closed Mayo scissors are used to enter the intercostal space bluntly. Then, the lateral periosteum of the selected rib is cut from the curvature of the rib to the costal cartilage making sure that the incision is placed at the cranio-caudal mid-point of the rib throughout the length of the cut. The periosteum is then stripped from the underlying rib using a moderately sharp dissector. When the periosteal tissue has been removed from the rib on the lateral aspect, it can be carefully stripped from either the cranial or caudal face of the rib at one point on the rib. When the periosteal tissue has been removed, a dissector can be introduced around the curvature of the rib and the whole of the periosteum stripped by simple longitudinal movements of the dissector. The periosteum then forms a complete hose separated from the rib, which is cut dorsally and ventrally by bone cutting forceps and the section of rib removed **(Figure 1).** The periosteal hose which has been exposed in this way is cut along its length to maintain a good strip of periosteum attached to the intercostal muscles both cranially and caudally.

Closure of the rib resection thoracotomy can be achieved by simple continuous sutures around the periosteal hose. One method of achieving closure is using two short lengths of continuous suture, one at the dorsal end of the incision from just dorsal to the cut end of the rib to nearly halfway down the incision, and the second from ventral to the ventral end of the incision to a point approximately 0.5 cm from the end of the upper continuous suture. Both of these lines of suture are tied firmly and a mattress suture is inserted where the two suture lines meet. Although it was previously recommended that the lungs be rapidly inflated when the mattress suture was placed, and the suture tied after inflating the lungs, inflating the lungs is no longer recommended as it could cause re-expansion pulmonary edema.

Semi-stripping of the rib[23]

The technique for semi-stripping of the rib, as described by D.D. Lawson,[23] employs the stripping of the periosteum and perichondrium from the caudal or cranial half of the selected rib from just above the curvature of the rib well down onto the costal cartilage distally. The technique is similar to that used for the rib resection procedure. The first step is cutting the lateral periosteum and perichondrium by a single incision placed at the mid-point of the rib and costal cartilage. Next, a dissector is used to strip the periosteum from the edge of the rib and to displace it from the medial face of the rib and of the costal cartilage. The periosteal hose so formed is now cut along its length and rib retractors are inserted. Because of the length of the incision and the ability of the rib cranial to the section to rotate on its head, the exposure obtained is very wide and the whole of the appropriate region of the hemithorax is accessible **(Figure 2a).**

Closure of the incision is performed by applying a continuous suture that is used to close both layers of the incision in the thoracic wall. This suture replaces the periosteal hose around its original site on the rib (**Figure 2b**). The suture is inserted just above the upper end of the cut in the latissimus dorsi muscle and the end of the suture is tied. The suture is then taken through the latissimus dorsi muscle to carry out closure of the defect of the thoracic wall proper. The closure of the defect is achieved by passing the continuous suture through the chest wall via the intercostal muscle which is adjacent to the rib that has been half stripped. The suture is then taken through the pleural cavity and brought back to the lateral surface of the thoracic wall through the intercostal muscle which has on its edge the strip of periosteum. Before this step is repeated, the suture is taken through the very outer edge of the periosteal hose. This positioning of the suture causes the periosteal hose to flap back into its original position around the rib and produces a very effective seal of the pleural cavity. This continuous suture is carried along the length of the incision and, as the lower end of the section is being sutured, the dog is rolled to a 45 degree angle with its sternum uppermost to allow appropriate closure of the incision. It was previously recommended that the suture line be tightened throughout approximately three-quarters of its length and the last three or four sutures left untightened until the lungs were inflated as the whole suture line was drawn tight. Such inflation of lungs is no longer recommended due to the possibility of re-expansion pulmonary edema. The long end of the suture material is then used to run a simple continuous suture line in the incised external abdominal oblique muscle and part of the serratus ventralis. The suture is then taken into the cut latissimus dorsi and the suture line continued up to the original knot and the two ends secured.

Rib Pivot Thoracotomy[28]

A rib pivot thoracotomy provides comparable access to thoracic structures as a rib resection thoracotomy, with the preservation of the rib. For performing a rib pivot thoracotomy, an incision is made on the lateral periosteum of the rib. A transverse osteotomy is performed at the level of the costo-chondral junction. The rib is rotated cranially by grasping the rib proximal to the osteotomy site, with the costovertebral articulation being used as a hinge on which the rib is pivoted. The incision is completed through the costal pleura. A rib retractor is inserted to expose the indicated thoracic structures.

To close a rib pivot thoracotomy, the parietal pleura, the intercostal musculature, and the rib periosteum are apposed. The rib is pivoted back to its normal position. A hole is drilled through the near cortex of the rib slightly distal to the osteotomy site. An orthopedic wire is passed through the defect. The procedure is repeated proximal to the osteotomy site. The orthopedic wire is tightened in a hemicerclage fashion to stabilize the rib.

Rib osteotomy thoracotomy[29]

A rib osteotomy thoracotomy provides access to the thoracic cavity through a small incision. It may be used to increase exposure of an intercostal thoracotomy by approximately 33% by performing two osteotomies, one dorsal and one ventral, on the ribs cranial or caudal to the intercostal incision site. In human medicine, rib osteotomy is described as a minithoractomy technique for cardiac and thoracic procedures to reduce post-thoracotomy pain.[30]

MEDIAN STERNOTOMY[31] or sternum splitting incision

Median sternotomy may be used when access is needed simultaneously to both sides of the thorax. A lateral thoracotomy provides access to one side of the thorax and is hence inadequate if access is needed to both hemithoraces. Median sternotomy is the equivalent of midline celiotomy applied to the thorax.[23]

A median sternotomy is usually chosen when exploration of the thorax is necessary (e.g., pneumothorax of unknown origin, or pyothorax), or for wide exposure of mediastinal masses, and bilateral access to the heart.[32,33] The patient is positioned in dorsal recumbence; the front limbs are extended cranially.[34] The skin and subcutaneous tissue are incised midline over the sternum from the manubrium to the xiphoid. The pectoral muscles are incised through the midline, then elevated to expose the sternum.[35] Dissection is kept to a minimum to avoid hemorrhage from perforating vessels and postoperative pain. Electrosurgery is useful to control bleeding from perforating vessels. The sternebrae are transected on midline using an oscillating bone saw. Bone cutters (or even heavy scissors) may be adequate for small dogs; however, using a saw avoids crushing the bone.[36] Delineating the incision line in advance with a scalpel or electrosurgery helps in keeping the saw on the midline, making closure easier. Having an assistant peer down the longitudinal axis of the patient can also help staying on the midline. Lavage with warm saline can help prevent thermal injury to the sternum.[37] Depending on the exposure needed, either the manubrium or the xiphoid cartilage maybe left intact. Leaving the manubrium or xiphoid cartilage intact increases sternotomy closure stability, with consequent faster/uncomplicated healing and reduction in postoperative pain.[31] [Note: The thesis supervisor (Mann) routinely incises both the manubrium and xiphoid cartilage without any observed untoward effects.] In small dogs, it is not uncommon for the incision to move from the midline in places, resulting in a parasternal approach (separation of the costal cartilages from the sternum). The incision moving away from the midline does not result in any particular difficulties. For exposure of the heart or lung, the sternotomy extends from the xiphoid cartilage cranially to the second or third sternebrae.[36] Median sternotomy can be combined with a ventral midline celiotomy and diaphragmatic incision when access to the abdominal cavity is also necessary. When exposure of the cranial mediastinum is required, the sternum is incised from the manubrium caudally to the 6^{th} or 7^{th} sternebra. Extending the incision cranially into the cervical area allows exposure of the thoracic inlet structures.[35]

Once sternotomy is completed, moistened laparotomy sponges are placed to protect the edges of the incision, and self-retaining retractors[a] are inserted. The internal thoracic vessels are identified in the cranial thorax, and the mediastinum is freed from the dorsal aspect of the sternum to obtain bilateral exposure.

Before closure, a thoracostomy tube is inserted between the ribs, lateral to midline. The sternum is apposed using preplaced sutures in a figure-of-eight pattern around each costosternal junction. Alternating the orientation of the figure-of-eight suture every other sternebra (passing the suture first obliquely or perpendicularly across the sternotomy to apply a cruciate suture) avoids distraction of the sternotomy during suture tightening and maximizes bone contact.[35] An assistant places traction on the central sutures while the surgeon ties those at either end. Alternatively, reduction forceps can be used to appose the sternotomy as the sutures are tightened. Sternotomy closure in medium-to-large dogs may be achieved with orthopedic stainless steel wire or suture. The stainless steel wire should be cut leaving three unbent twists in the patient; this may not be possible if there is poor soft tissue coverage. To avoid wire exposure, the knot may be bent, although this will reduce its strength. In patients of small size (up to 10 kg) heavy monofilament suture (0 to1 polypropylene or polydioxanone) can be used, but wire closure is recommended for larger dogs (i.e., 30 kg).[38] The pectoral muscles are closed with a simple continuous suture using 3-0 to 0 polydioxanone; subcutaneous tissue and skin are closed routinely, in separate layers. Incisional analgesia can be achieved by injecting bupivacaine as a local block at the base of each costal cartilage at this stage. Alternatively, insertion of bupivacaine through the thoracostomy tube,[39] can be used after residual air is removed from the thoracic cavity.

BILATERAL THORACOTOMY

Trans-sternal thoracotomy or sternum transecting incision[23]

This procedure is the equivalent of the ‘clamshell incision’ used in human medicine. Trans-sternal thoracotomy, as was described by D. D. Lawson, is indicated primarily for experimental surgery in animals.[23]

This method gives excellent exposure to both sides of the thorax and may be made at different ICSs for different purposes. Trans-sternal thoracotomy at the 7^{th} ICS can be used for management of diaphragmatic lesions and at the 4^{th} ICS for approach to the heart. The dog is placed in a dorsally recumbent position for a trans-sternal thoracotomy. The skin and subcutaneous muscle are incised at the appropriate level. Hemorrhage from the highly irregular subcutaneous venous network can be controlled by two methods. The first involves ligating the vessels as they get incised. The second method achieves control of hemorrhage by lifting the layer of fat in this region and identifying and preemptively ligating the arteries and veins before the subcutaneous muscles are incised. Electrosurgery may also be used to control hemorrhage. The caudodorsal edge of the deep pectoral muscle is separated from its fascial attachments and from the sternum as far cranially as is necessary. The vessels supplying this muscle, which are penetrating the thoracic wall, require ligation. If the pectoral muscles are separated far cranial to the branches of the internal thoracic artery, which supply the pectorals from their deep face, the branches must be carefully identified and ligated. There are usually two branches of the internal thoracic artery to each intercostal space, a large vessel caudally and a smaller one cranially close to the sternum.

After the pectoral edge has been reflected cranially, the tendon of the rectus abdominis muscle is severed on the selected intercostal line. The lower edge of the insertion of the scalenus dorsalis and serratus ventralis thoracis muscles may also need to be incised, and the vessels supplying the scalenus dorsalis and serratus ventralis thoracis muscles ligated.

The intercostal muscles are then cut and the internal thoracic arteries and veins identified and ligated both cranially and caudally. Finally, the sternum is cut through one of the sternal cartilages. The defect produced will tend to remain widely opened because of the directional pull of the rectus abdominis muscles caudally and the pectoral mass cranially.

Closure of trans-sternal thoracotomy incision is accomplished by applying a stainless steel mattress suture to the sternum and two stainless steel mattress sutures around the adjacent pairs of ribs at the level of the intercostal section. All of these sutures should be in position before any attempt is made to close the defect. Assistance is required to hold the thoracic wall together while the sutures are tied. The degree of tension applied must be accurately judged to prevent displacement of the cut ends of the sternum from their correct median position. The defect in the rectus tendon is sutured and finally the intercostal incision is covered by the large flap of pectoral muscle. The skin is sutured in normal fashion.

TRANSDIAPHRAGMATIC APPROACH[37]

A transdiaphragmatic approach may be used for performing OC-CPR when a celiotomy has been performed and there is cardiac arrest. The transdiaphragmatic approach provides access to the caudal thoracic duct, the caudal vena cava, the caudal portion of the esophagus, and the heart. A standard midline celiotomy is performed. Self-retaining retractors placed, and the falciform ligament is removed. The diaphragmatic incision may be right-side, left-side, or central, depending on the indication. Centrally located incisions are made through the central tendinous portion of the diaphragm. Right- or left-sided approaches made by splitting the muscular fibers in a radial direction.

For closure of the diaphragmatic incision, a simple continuous suture line is begun from the most dorsal position of the incision working ventrally and laterally. An absorbable, monofilament suture (e.g., 0, 2-0, or 3-0 polydioxanone or similar) is used for closure of the diaphragm. Once diaphragmatic closure is complete, trans-diaphragmatic thoracocentesis is used to restore the sub-atmospheric pressure differential within the pleural space. Return of the concave appearance of the diaphragm indicates appropriate evacuation. The celiotomy is closed in a standard fashion.

PARASTERNAL APPROACH[40]

A parasternal approach to thoracotomy involves incising the costal cartilage to access the thoracic cavity. This technique is used in human pediatric thoracic surgery, or for young patients. The patient (dog) is placed in dorsal recumbence for a parasternal thoracotomy, and a scalpel blade is used to make a skin incision on the ventral midline or close to the ventral midline. Mayo scissors are used to separate the chondrosternal joints and soft tissues, starting at the manubrium and extending caudally for 4 to 5 sternebrae. Tips of the Mayo scissors are kept as ventral as possible to prevent injury to the brachiocephalic veins and other great vessels. It is necessary to sever the internal thoracic vein and artery on one side, which require ligation later. Parasternal closure is performed with orthopedic wire, nylon or polypropylene. The suture material is brought around the sternum and then to each side of the rib. A chest tube is placed prior to closure.

Shingling

Shingling may be performed to enhance exposure during unilateral lateral thoracotomy, Shingling is described as transverse incision of the rib caudal (or cranial) to the thoracotomy incision completely at the costo-chondral junction and tucking the rib under the next caudal (or cranial) rib. Shingling is performed to provide more exposure to the thoracic cavity and can be used with the intercostal thoracotomy incision. If further exposure is required, the next caudal (or cranial) rib may also be shingled.

Rationale behind study design

To the author's knowledge, no studies have been performed comparing the ease of access to the heart of different ICS thoracotomies. The objective of the present study was to compare the ease of access to the organs in the thoracic cavity for performing OC-CPR when using either a 4th or 5th ICS left lateral thoracotomy in dogs. Canine closed-chest compressions and OC-CPR are usually performed in lateral recumbence for non-brachycephalic dogs, and hence a lateral thoracotomy was used for this study.[41]

Objective and hypothesis of study

The goal of this study was to evaluate whether left lateral thoracotomy through the 5th ICS space should be recommended over the same approach performed through the 4th ICS for canine OC-CPR. To achieve this goal, we performed left 4th and 5th ICS thoracotomies in canine cadavers and determined ease of OC-CPR manipulations. The parameters used to determine the aforementioned outcomes are described under the subheading "Observations" (pages 18-19). We hypothesized that access to the heart would be more convenient through the 5th ICS, and the 4th ICS would not provide appropriate access for all the procedures involved in performing OC-CPR. We tested this hypothesis based on the scores ascribed by three evaluators for the six parameters assessed. The null hypothesis was that there would be no significant differences between the 4th and 5th ICS for each of the six parameters.

Chapter 2

Materials and Methods

Sample Population

Twelve approximately 20 kg adult canine cadavers with body condition scores[b] ranging from 3 to 6 that were euthanized for reasons other than the purpose of this study were studied (**Table 1**). Brachycephalic breeds and barrel chested breeds were excluded from this study. Approximate breed, gender, and body mass were recorded for each cadaver. Cadavers were assigned to one of two groups such that Group 1 (n = 6) cadavers had a 4^{th} ICS thoracotomy and Group 2 (n = 6) cadavers had a 5^{th} ICS thoracotomy performed. All thoracotomies were performed by the same surgeon (Mann).

Procedure

Left lateral thoracotomies were performed in all cases. Using a number 10 scalpel blade, the skin was incised 1 to 2 cm caudal to the caudal border of the scapula and extended from just below the vertebral bodies dorsally to the sternum ventrally. The incision was deepened with the scalpel to incise subcutaneous tissue and the cutaneous trunci muscle. Using Mayo scissors to clear loose fascia, the ventral border of the latissimus dorsi muscle was identified. Then the latissimus dorsi muscle was incised with Mayo scissors from ventral to dorsal. After completion of the latissimus dorsi incision, the surgeon's left index finger was inserted under the latissimus dorsi muscle cranially to palpate the first rib and count caudally to identify the 4^{th} or 5^{th} ICS. The convergence of the scalenus dorsalis and external abdominal oblique muscles was visualized at the 5^{th} rib to help verify intercostal location. Once the ICS was located, closed Mayo scissors were used to bluntly enter the ICS, puncture the pleura, and allow the lungs to collapse. The incision was extended dorsally and ventrally with Mayo scissors as needed so that all specimens had incisions of equivalent length. A Balfour retractor without the sternal blade was used for separating the ribs. The Balfour retractor was opened maximally and the width of the incision was measured at the midpoint of the thoracotomy. The skin where the jaws of the Balfour blades rested on the cranial and caudal ribs was marked with India ink and the distance between the two markings was measured with a centimeter tape measure to record the cranial-caudal distance. **Table 2** contains the widths of thoracotomy incision in all cadavers when the Balfour retractor was extended maximally. Measuring this width immediately prior to the manipulations by each evaluator allowed assurance of the same width for each evaluator's performance for the same cadaver. Finally, drapes were placed around the thoracotomy so that the evaluators could not ascertain which ICS was being evaluated based on appearance. The only way to assess the location of the incision was to count the ribs, and the evaluators were instructed not to attempt to determine the ICS.

Observations

Parameters were assessed by three evaluators, who each had a recorder record their assessment. The surgeon performing the incision (Mann) was a recorder and not one of the three evaluators. Evaluators assessed the six parameters outlined below. For each parameter assessment, a scale of 0 to 10, 0 being easiest and 10 being most difficult, was utilized:

i. Ease of access of the phrenicopericardial ligament (Note: the number of sweeps needed to grasp the ligament was recorded by the recorder and this parameter could be assessed only once per cadaver);

ii. Ease of access to pericardial incision (Note: this parameter could be assessed only once per cadaver);

iii. Ease of appropriate hand position (Note: this parameter could be assessed only once per cadaver);

iv. Ease of aortic access (Note: time [in seconds] from lung retraction to visualization of the aorta was recorded by the recorder)

v. Ease of application of a Rumel tourniquet (Note: time [in seconds] from lung retraction to clamping of umbilical tape was recorded by the recorder)

vi. Ease of proper placement of defibrillator paddles (Note: time [in seconds] from handing paddles to proper placement was recorded).

Training of evaluators

All evaluators practiced evaluating parameters on a separate cadaver immediately prior to data collection.

i. The phrenicopericardial ligament was grasped with the index finger of the left hand. All evaluators were right-handed.

ii. The pericardial incision was performed with Mayo scissors. A small incision was made in the phrenicopericardial ligament at the apex of the heart. Then, one of the blades of the Mayo scissors was inserted to extend the pericardial incision taking care to avoid the phrenic nerve.

iii. To achieve appropriate hand position, the evaluators were shown to place one hand on the right lateral aspect (underside) of the heart and the other hand on the left lateral aspect (upper side) of the heart. They were instructed to pump from the apex of the heart to the base.

iv. Each evaluator was instructed to retract the left cranial lung lobe ventrally with the left hand to visualize the heart and to point to the aorta with a right angle forceps held in the right hand. They were handed the right angle forceps by their recorders, at which time a stopwatch was started. When the evaluators located the aorta and pointed to the aorta with the forceps the stopwatch was stopped.

v. The Rumel tourniquet was premade with a piece of silastic tubing inserted into mosquito hemostatic forceps with umbilical tape grasped in the jaws of the forceps (**Figure 3**). The evaluators were instructed to penetrate the connective tissue around the descending aorta immediately dorsal to the heart with a right angle forceps and grasp the umbilical tape with the jaws of the right angle forceps. After passing the umbilical tape around the aorta, both ends of the umbilical tape were then grasped with the jaws of the mosquito forceps, and the silastic tubing was slid down both ends of the umbilical tape toward the aorta. The mosquito forceps were then re-set onto the umbilical tape strands against the silastic tubing to tighten the umbilical tape around the aorta, maintaining the aorta in collapsed position (**Figure 4**). To record the time for application of the Rumel tourniquet, the stopwatch was started when the evaluators were handed the mosquito forceps. The stopwatch was stopped when the evaluators finished re-setting the mosquito forceps.

vi. The evaluators were instructed to place the defibrillator paddles around the widest diameter of the heart. The time to proper placement of paddles was started when the evaluators were handed the defibrillator paddles by the recorder and stopped when the evaluator vocally indicated that they had achieved appropriate paddle position.

All the evaluators were assessed for surgical glove size on the day of training. All their glove sizes were 6.5. Two of the evaluators (B and C, both 2nd year small animal emergency and critical care residents) had performed OC-CPR at least once. One of the evaluators (A, surgical intern) had reported to not have performed the procedure in the past. Thus, all evaluators had limited experience performing OC-CPR. The evaluators were instructed to not count ribs to determine the ICS of the thoracotomy incision, and the cadavers were draped in such a way that the evaluators could only see the thoracotomy incision. (**Figure 5)**

Preparation of Rumel tourniquet

The Rumel tourniquets were made with umbilical tape, silastic tubing and mosquito hemostatic forceps, and right angled forceps. The umbilical tape was cut into lengths of 38 cm and the silastic tubing into 2.5 cm lengths. The jaws of the mosquito forceps were inserted through the silastic tubing and one end of the umbilical was grasped by the mosquito forceps **(Figure 3).** Each evaluator had new umbilical tape and silastic tubing to use for each cadaver.

Preparation of cadavers

As the cadavers were procured in a frozen state and stored in a cooled room (5 degrees C), they were thawed (by leaving them in room temperature conditions for a few hours per day) on the week prior to the data collection. They were transferred back to the cooled room after being kept at room temperature. The cadavers were left at room temperature overnight on the day prior to data collection and their temperature (degrees C) was measured on the day of data collection with a thermometer[c] to ensure that they were adequately thawed (**Figure 6**). The thermometer was placed in the center of the thoracic cavity at the caudal aspect of the heart. The cadavers were also shaved of hair around the thoracic region, from approximately the level of the first rib to the last rib, on the left lateral and right lateral side. They were shaved on both sides to facilitate measuring the circumference of the thorax for each cadaver.

Shingling

After the first round of data collection, all the cadavers were “shingled” by the same investigator (Mann). The 5^{th} rib was shingled for all cadavers having a 4^{th} ICS thoracotomy and the 6^{th} rib was shingled for all cadavers having a 5^{th} ICS thoracotomy. Shingling involved transversely cutting the rib caudal to the thoracotomy incision. The rib was cut completely at the costo-chondral junction and then the rib was tucked under the next caudal rib, the caudal rib thus being "shingled."

Data collection

Cadavers were placed on tables numbered 1 to 12 without the use of a random number generator. Tables were taken to the cooled room and cadavers were placed on them as per accessibility. Then, the tables were arranged in the testing room. Odd numbered tables had a 4th ICS thoracotomy and even numbered tables had a 5th ICS thoracotomy. Evaluators were blinded to thoracotomy site. Evaluator A began at table 1, evaluator B began at table 5 and evaluator C began at table 9. Each evaluator had a recorder alongside them, noting their assessments and times.

The first five parameters (ease of access of phrenicopericardial ligament, ease of pericardial incision, ease of appropriate hand position, ease of aortic access, and ease of application of Rumel tourniquet) were assessed by each evaluator on the first four cadavers assessed by them. Thus, evaluator A assessed the first five parameters on cadaver numbers 1, 2, 3, 4; evaluator B assessed the first five parameters on cadaver numbers 5, 6, 7, 8; evaluator C assessed the first five parameters on cadaver numbers 9, 10, 11, 12. Once the respective first four cadavers were assessed by each evaluator, evaluators assessed parameters iii to v (ease of appropriate hand position, ease of aortic access, and ease of application of Rumel tourniquet) on all of the remaining cadavers that they had not yet examined. As the evaluators had one pair of defibrillator paddles, parameter vi (ease of proper placement of defibrillator paddles) was evaluated one by one by each of the evaluators after evaluating parameters i to v (ease of access of phrenico-pericardial ligament, ease of access of pericardial incision, ease of appropriate hand position, ease of aortic access, and ease of application of Rumel tourniquet) on all cadavers.

After shingling, evaluator A started at cadaver number 1, evaluator B started at cadaver number 5 and evaluator C started at cadaver number 9. All evaluators reassessed parameters iii to v (ease of achieving appropriate hand position, ease of aortic access, and ease of application of Rumel tourniquet) on all the cadavers in sequential order. Parameters i and ii (ease of access of phrenicopericardial ligament and ease of access of pericardial incision) could not be performed again, as the phrenicopericardial ligament and the pericardium were incised during the first round of data collection. Parameter vi (ease of proper placement of defibrillator paddles) was reassessed by all evaluators one by one after reassessing parameters iii to v (ease of achieving appropriate hand position, ease of aortic access, and ease of application of Rumel tourniquet) on all cadavers.

Data Analysis

Due to the variability in scores and the limited amount of data recorded (n = 2 per evaluator by rib space) for ease of grasping the phrenicopericardial ligament, number of sweeps, and ease of pericardial incision, these data were not statistically analyzed.

For the remaining parameters, scores and times were combined into a single value by taking the geometric mean value of the three evaluators' scores or times. A repeated measures analysis of variance (ANOVA) was used to compare outcomes pre- and post-shingling between 4^{th} and 5^{th} ICS (main effects). Ease of hand position, time to visualization of aorta (in seconds), ease of aortic access, time to application of Rumel tourniquet by clamping with umbilical tape (in seconds), ease of application of Rumel tourniquet, time to placement of paddles (in seconds), and ease of paddle placement were the dependent variables. The dependent variables included group (4^{th} or 5^{th} ICS), shingling (pre- and post-) as the repeated measure, interaction of group and shingling. Normality of the data was checked using Shapiro-Wilk method and equality of variances was checked using the Brown-Forsythe method. Post-hoc pairwise comparisons were made using the Holm-Sidak method. All analyses were considered significant at $P < 0.05$. All data were analyzed using commercial software.[d]

Chapter 3

Results

The scores for three evaluators before shingling are presented in **Tables 3 to 10**. The scores for three evaluators after shingling are presented in **Tables 11 to 17. Table 18** summarizes the results before and after shingling.

i) Ease of access of phrenicopericardial ligament

Due to the limited number of data points, ease of access of phrenicopericardial ligament was not statistically analyzed. The mean ± SD score for all evaluators was 4.5 +/- 2.6 and 3.3 +/- 1.5 for ICS 4 and 5, respectively. The mean ± SD number of sweeps needed to grasp the phrenicopericardial ligament was 3.3 +/- 2.4 for the 4^{th} ICS thoracotomy and 2.0 +/- 0.89 for the 5^{th} ICS thoracotomy.

ii) Ease of pericardial incision

Due to the limited number of data points, ease of pericardial incision was not analyzed statistically. The mean ± SD for all evaluators was 6.0 +/- 1.9 and 4.6 +/- 2.3 for ICS 4 and 5, respectively.

iii) Ease of hand position

The difference in the mean score for ease of hand position was not statistically significant between the 4^{th} and 5^{th} ICS (P = 0.138), but was different before and after shingling (P = 0.024) (mean ± SD before shingling 2.9 ± 0.9 and 2.5 ± 0.9 after shingling irrespective of ICS), and there was an interaction of ICS and shingling (P = 0.001).

Post-hoc pairwise comparisons revealed that the mean ± SD ease of ease hand position score was lower for the 5th ICS (2.3 ± 0.6) than the 4th ICS (3.6 ± 0.5) before shingling (P = 0.011); however, after shingling there was no difference between the 4th ICS (2.6 ± 0.8) and 5th ICS (2.5 ± 1.0) (P = 0.937). Furthermore, shingling improved ease of hand position at the 4th ICS (3.6 ± 0.5 before versus 2.6 ± 0.8 after; P < 0.001), but not at the 5th ICS (2.3 ± 0.7 before versus 2.5 ± 1.0 after; P = 0.262)

iv) Ease of aortic access

Mean ± SD ease of aortic access score was lower for the 5th ICS (1.4 ± 0.2) than the 4th ICS (2.1 ± 0.2) (P = 0.042); however, there was no significant difference in ease of aortic access before and after shingling (P = 0.165), and there was no significant interaction between ICS and shingling (P = 0.077). Hence, in the model, the difference detected between the 4th and 5th ICS was not dependent on shingling. Mean time to visualization of the aorta differed between groups (P = 0.009) where the mean time for the 5th ICS was shorter as compared to the 4th ICS, and there was a statistically significant difference in mean time to visualization of the aorta pre- versus post-shingling where the mean time post-shingling was shorter as compared to pre-shingling; however, there was not a significant interaction between group and shingling (P = 0.105). Hence, in the model, the differences in mean time to visualization of the aorta between the 4th and 5th ICS and before and after shingling were not dependent on each other. Post-hoc pairwise comparisons showed that the mean ± SD time to visualization of the aorta was shorter for the 5th ICS (2.4 ± 0.5 seconds) than the 4th ICS (3.2 ± 1.0 seconds) irrespective of shingling (P = 0.009). Similarly, the mean ± SD time to visualization of the aorta was shorter after shingling (2.3 ± 0.5 seconds) than before shingling (3.3 ± 0.8 seconds) ($P < 0.001$), irrespective of ICS.

v) Ease of application of Rumel tourniquet

Mean ± SD score for ease of application of the Rumel tourniquet was lower for the 5th ICS (1.8 ± 0.4) than the 4th ICS (2.9 ± 1.1) ($P = 0.019$); however, there was not a significant difference between pre- and post-shingling ($P = 0.050$), and the interaction of ICS and shingling was not significant ($P = 0.208$). Hence, in the model, the difference in mean ease of application of the Rumel tourniquet score between the 4th and 5th ICS was not dependent on shingling. There was not a statistically significant difference in mean time to placing the Rumel tourniquet by clamping with umbilical tape between the 4th and 5th ICS ($P = 0.067$), but there was a statistically significant difference in mean time to clamping with umbilical tape pre- and post-shingling ($P < 0.001$), where the mean time post-shingling was shorter as compared to pre-shingling. However, the interaction of ICS and shingling was not significant ($P = 0.500$). Hence, the differences detected between pre- and post-shingling were not dependent on ICS. Post-hoc pairwise comparisons showed that mean ± SD time to clamping with umbilical tape was shorter post-shingling (20.4 ± 5.0 seconds) than pre-shingling (26.7 ± 2.9 seconds) ($P < 0.001$), irrespective of ICS.

vi) Ease of paddle placement

There was not a statistically significant difference in mean score for ease of paddle placement between ICSs ($P = 0.356$), but there was a statistically significant difference in mean score for ease of paddle placement pre- and post-shingling (P = 0.017). However, there was not a significant interaction between ICS and shingling (P = 0.050). Hence, in the model, the differences detected pre- and post-shingling were not dependent on ICS. Post-hoc pairwise comparisons showed that, irrespective of ICS, the mean ± SD ease of paddle placement score was lower after shingling than before (1.9 ± 0.8 versus 2.3 ± 0.6, respectively; P = 0.017). There was not a statistically significant difference in mean time to placement of paddles between the 4^{th} and 5^{th} ICS (P = 0.683), but there was a difference between pre- and post-shingling (P < 0.001), where the mean time post-shingling was shorter as compared to pre-shingling. However, there was not a significant interaction between ICS and shingling (P = 0.093). Hence, in the model, the differences detected between pre- and post-shingling were not dependent on ICS. Mean ± SD time to placement of paddles was 4.6 ± 0.8 seconds before and 3.4 ± 0.8 seconds after shingling (P < 0.001), irrespective of ICS.

Chapter 4

Discussion

The model of OC-CPR surgical approach used in this study provided acceptable exposure (as determined by the subjective scale and objective times recorded for the assessed parameters) to intrathoracic structures via 4^{th} and 5^{th} ICS thoracotomies, but the 5^{th} ICS was easier for most manipulations. The 5^{th} ICS was superior for ease of hand position, ease of aortic access, time to visualization of aorta, and ease of application of a Rumel tourniquet. The limited number of cadavers prevented useful statistical analysis of some parameters (ease of grasping phrenicopericardial ligament and ease of pericardial incision), but preliminary evidence is provided to aid in the design of future studies to determine the best surgical approach for OC-CPR. Although the ease of access to the phrenicopericardial ligament was not statistically analyzed, access of the phrenicopericardial ligament appeared to be easier through the 5^{th} ICS thoracotomy. In addition, the mean ± SD number of sweeps needed to grasp the phrenicopericardial ligament was 3.3 +/- 2.4 for the 4^{th} ICS thoracotomy and 2.0 +/- 0.89 for the 5^{th} ICS thoracotomy. Thus, on average fewer sweeps were needed to grasp the phrenicopericardial through the 5^{th} ICS thoracotomy. The ease of pericardial incision was not statistically analyzed, but incising the pericardium appeared to be easier through the 5^{th} ICS thoracotomy. All of the statistically analyzed parameters except for time to placement of Rumel tourniquet, ease of placement of defibrillator paddles, and time to placement of defibrillator paddles were improved when performed through the 5^{th} ICS. Some variability was expected among the three evaluators, but this variability was minimized by calculating the geometric mean score or time for each parameter before statistical analyses were performed.

Open-chest CPR is performed when other non-invasive techniques have been exhausted or are inappropriate and, as such, must be emergently performed.[25,42,43] Thoracic surgery is a relatively common procedure performed in referral veterinary practice.[44] Thus, it is likely that referral veterinary practices would not only encounter canine patients where OC-CPR is indicated, but members of the practice would have the requisite training to perform the procedures detailed herein. Given the paucity of evidence in the literature with regard to OC-CPR in the canine patient, it was deemed important to study best practices for performing canine OC-CPR. Knowing which ICS provides the best exposure to intrathoracic organs can help reduce the time necessary to perform OC-CPR. The parameters evaluated in this study were chosen because they were considered important components of OC-CPR that could cause crucial time wastage if impeded by the surgical approach. Proper hand position is necessary to perform manual cardiac massage efficiently and effectively. Locating the aorta and applying a tourniquet is important to direct blood flow towards the brain and myocardium. Internal defibrillator paddles may be used when manual cardiac massage fails to achieve return of spontaneous circulation in cases of ventricular fibrillation. Results of the present study suggest that the 5th ICS thoracotomy provides better access to the heart and aorta for the above mentioned manipulations and provide preliminary evidence that the 5th ICS should be used in future investigations to further determine the best surgical technique for OC-CPR. A well-defined technique will be useful to facilitate successful outcomes with OC-CPR.

Shingling is performed to improve exposure to the thoracic cavity. If further exposure is required then the next caudal (or cranial) rib is shingled (i.e., transected at the costo-chondral junction) and when placing a retractor, such as a Finochetto or Balfour, and the rib is tucked under the next caudal (or cranial) rib. The results of the present study should be interpreted after taking into account that the same cadavers were used for post-shingling analysis as were used for the first round of data collection. However, the statistical model used for analyzing the results took into account the repeated usage of cadavers. Shingling improved access for ease of hand position, time to visualization of aorta, time to application of Rumel tourniquet, ease of paddle placement, and time to paddle placement. These results are not unexpected as shingling increases maneuverability, providing improved access to intrathoracic structures. Further, ease of hand positioning was improved after shingling at the 4th ICS, but not at the 5th ICS, suggesting that, at least for this parameter, shingling should be performed when a 4th ICS incision is chosen.

Care should be taken in translating the results to small and giant breed dogs and dogs with different body conformations. We chose dogs of similar body weight and conformation to reduce variability and thus reduce sample size. While a narrow range of cadavers may not necessarily reflect all patients encountered in small animal clinical practice, the results provide initial guidance for future studies of OC-CPR, especially because studies of human OC-CPR patients are difficult to extrapolate to veterinary use.

In addition to scoring parameters on a subjective scale from 0 to 10, the time for visualization of the aorta, the time to application of a Rumel tourniquet, and time to proper placement of defibrillator paddles were also recorded. Recording time provided an objective proxy for ease of access to intrathoracic structures and ease of performing intrathoracic manipulations. For ease of aortic access, the time to visualization of aorta reflected the subjective scores for the main effect of ICS (4^{th} versus 5^{th} ICS), with the 5^{th} ICS being easier than the 4^{th} ICS. For main effect pre- and post-shingling, shingling was seen to improve access as per time to visualization of aorta. For ease of application of Rumel tourniquet, subjective scores showed that the 5^{th} ICS was easier than the 4^{th} ICS. However, time to proper placement of the Rumel tourniquet was not found to differ between the 4^{th} and 5^{th} ICS, but shingling did improve time to proper placement of the Rumel tourniquet irrespective of ICS. Hence, subjective scoring somewhat disagreed with time to result for placement of the Rumel tourniquet. For ease of paddle placement, subjective scores reflected objective time to paddle placement scores, with no statistically significant difference being seen between the 4^{th} and 5^{th} ICS. For main effect pre- and post-shingling, shingling improved ease of paddle placement subjectively and objectively. The improvements with shingling could have occurred because the evaluators became more adept over the course of the experiment. Overall, ease of performance generally correlated with time to result.

The glove size (6.5) was the same for all evaluators. Since hand size can play a role in access to the thoracic cavity, the results should be interpreted in the context of operators with reasonably small hands. We chose evaluators with the same glove size to reduce variability among evaluators. We suspect that individuals with larger hands would prefer a 5^{th} ICS thoracotomy based on the results. Further studies are necessary to evaluate the correlation between glove size and access to intrathoracic organs to see if there should be alteration of technique to accommodate larger hands. Similarly, right handed evaluators were chosen for this study. This was done intentionally to reduce variability among evaluators. Further studies are necessary to evaluate if the results hold true for left handed individuals.

All the evaluators chosen for this study had relatively limited experience with OC-CPR. Evaluators with limited experience were chosen so that they were adequately familiar with OC-CPR to provide useful results, but did not have a predetermined preference for one ICS over another. Furthermore, the evaluators were trained in advance of data collection to ensure that they used the same method to evaluate each parameter. A board-certified critical care specialist or surgeon may not always be available to perform OC-CPR in clinical practice and, hence, the results obtained herein may be applied to clinicians and technicians with a limited range of experience with OC-CPR.

This study had certain limitations. Due to the limited number of available cadavers, some parameters (ease of grasping the phrenico-pericardial ligament and ease of pericardial incision) could only be performed once, resulting in too few data points to be statistically analyzed. Furthermore, to allow all evaluators to perform four pericardial incisions, it was essential for them to follow a fixed sequence of evaluation. Thus, it was difficult to randomize evaluators and cadavers and we did not randomize evaluators to cadavers for performing manipulations on the phrenicopericardial ligament and the pericardium. This fixed sequence could possibly have introduced some bias. Finally, outcomes (survival to discharge) could not be evaluated in this study due to this being a cadaveric study.

In conclusion, this study showed that either 4th or 5th ICS thoracotomy may provide adequate access to intrathoracic structures pertinent to performing OC-CPR in dogs weighing approximating 20 kg, but the 5th ICS was preferred for most manipulations, and shingling improved access for some of the measured parameters.

Chapter 5

Future Directives

This study indicated that the 5th ICS thoracotomy provided better exposure to the thoracic cavity than the 4th ICS for most of the parameters assessed. Statistics could not be performed for certain parameters (ease of grasping phrenicopericardial ligament and ease of pericardial incision) due to the limited number of cadavers. Further studies are needed with a larger sample size to obtain statistical comparisons for these parameters. A larger sample would also allow for statistical comparisons of those parameters after shingling. This study was performed on cadavers with a narrow weight range and body condition score. Studies with larger and smaller dogs would determine if the same results hold true for a larger range of sizes. Ease of access to thoracic organs can be considered relative to glove size. Studies with evaluators of larger and smaller glove sizes, relative to dogs of larger and smaller body size would help to identify any relationship between glove size and size of the patient. This study excluded barrel chested and brachycephalic dogs to reduce variability. Studies with these breeds are warranted to investigate whether the results of this study hold true for a larger range of breeds. With barrel chested dogs, the preferred position for performing OC-CPR and CC-CPR may be dorsal recumbence. Hence, the results of this study, which was performed in lateral recumbence, may or may not hold true for barrel-chested dogs. The experience of the clinician or technician can also play a role in ease of performing OC-CPR. Studies using evaluators with a range of experience would help define the relationship between evaluator experience and ease of performing OC-CPR. Finally, studies with cadavers of other species (such as cats) are warranted to establish the technique for OC-CPR for a larger range of veterinary patients.

TABLES

Table 1: Signalment of cadavers (n=12) used to compare left 4th and 5th intercostal spaces for open-chest cardiopulmonary resuscitation techniques.

Cadaver Number	**Mass (kg)**	**Apparent Breed**	**Sex (Male, Male Castrated, Female)**	**Age Classification (Juvenile, Adult, Mature)***	**Body Condition Score[1] (1 to 9)**	**Circumference of chest (cm)**	**Temperature of cadaver at time of evaluation (C)**
1	21.15	Pitbull mix	M	Adult	5	59	16.5
2	25.5	Pitbull mix	M	Adult	5	64	18
3	18.2	Pitbull mix	F	Mature	3	56	18.5
4	21.5	Pointer/ Dalmatian	MC	Mature	4	66	17.5
5	24.5	Pitbull mix	F	Adult	6	72	17
6	18.25	Retriever mix	M	Mature	4	62	16
7	23.75	Retriever mix	F	Adult	5	68	16.5
8	26.45	Pitbull mix	F	Adult	5	64	18
9	18.85	Pointer mix	F	Mature	4	59	19
10	19.05	Pitbull mix	M	Adult	4	55	19
11	17.05	Pitbull mix	F	Mature	3	56	18.5
12	21.6	Pitbull mix	F	Adult	4	60	18

*Based on dentition, cadavers classified as mature if missing teeth and/or appearing mature

1: Nestle Purina Body Condition Score (www.purina.com)

Table 2: Width of thoracotomy incision for open-chest cardiopulmonary resuscitation on canine cadavers (n=6 for 4th intercostal space, n=6 for 5th intercostal space), measured from cranial to caudal in the center (widest part of the incision, measured between the blades of Balfour retractors) of the intercostal space incision with Balfour retractors extended maximally.

Cadaver Number	**Intercostal Space**	**Width of thoracotomy incision (cm)**	**Mean values +/- SD**
1	4th	9.1	4th ICS: 9.4 +/- 1.0 5th ICS: 8.2 +/- 1.1 P = 0.06
3	4th	8.8	
5	4th	8.1	
7	4th	7.7	
9	4th	7.9	
11	4th	7.5	
2	5th	10	
4	5th	10.9	
6	5th	9.6	
8	5th	10.3	
10	5th	7.7	
12	5th	8	

Table 3: Ease of grasping the phrenicopericardial ligament, number of sweeps needed to grasp the phrenicopericardial ligament, and ease of pericardial incision via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by each evaluator (A, B, C) using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Site of Thoracotomy ICS	**Cadaver #**	**Ease of grasping the phrenicopericardial ligament**			**Number of sweeps**			**Ease of pericardial incision**		
		A	B	C	A	B	C	A	B	C
4th	1	6			7			6		
	3	5			5			6		
	5		8			4			9	
	7		5			2			7	
	9			2			1			4
	11			1			1			4
Mean +/- SD for all evaluators		4.5 +/- 2.6			3.3 +/- 2.4			6 +/- 1.9		
5th	2	4			3			6		
	4	2			1			7		
	6		3			2			3	
	8		3			2			3	
	10			6			3			7
	12			2			1			2
Mean +/- SD for all evaluators		3.3 +/- 1.5			2 +/- 0.89			4.6 +/- 2.3		

Table 4: Ease of achieving appropriate hand position to perform cardiac massage via a left 4th or 5th intercostal space (ICS) thoracotomy on canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	3	5	5	4.2
3	4th	3	4	5	3.9
5	4th	4	4	3	3.6
7	4th	4	6	1	2.9
9	4th	3	4	4	3.6
11	4th	3	4	3	3.3
2	5th	3	7	2	3.5
4	5th	2	4	1	2.0
6	5th	2	2	1	1.6
8	5th	2	3	1	1.8
10	5th	4	5	1	2.7
12	5th	3	3	1	2.1

Table 5: Ease of aortic access via a left 4th or 5th intercostal space (ICS) thoracotomy on canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	2	2	2	2.0
3	4th	1	2	1	1.3
5	4th	3	3	3	3.0
7	4th	4	6	2	3.6
9	4th	1	2	1	1.3
11	4th	2	2	4	2.5
2	5th	2	2	1	1.6
4	5th	1	2	1	1.3
6	5th	1	2	1	1.3
8	5th	1	2	1	1.3
10	5th	2	2	1	1.3
12	5th	1	2	1	1.6

Table 6: Time from handing right angle forceps to visualization of aorta (seconds) via a left 4th or 5th intercostal space (ICS) thoracotomy on canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	3.7	3.5	3.3	3.5
3	4th	3.3	3.3	2.3	2.9
5	4th	4	13.9	2.5	5.2
7	4th	4.8	6.3	2	3.9
9	4th	3.3	3.8	6.6	4.4
11	4th	2.6	3.1	5.4	3.5
2	5th	3.1	2.9	2.9	3.0
4	5th	2.5	2.9	1.8	2.4
6	5th	3	5.2	1.5	2.9
8	5th	2.7	3.9	1.6	2.6
10	5th	3	3.8	3.6	3.4
12	5th	2.6	2.4	2.3	2.4

Table 7: Ease of application of Rumel tourniquet via a left 4th or 5th intercostal space (ICS) thoracotomy on canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	4	3	2	2.9
3	4th	2	3	1	1.8
5	4th	4	4	3	3.6
7	4th	5	8	4	5.4
9	4th	3	3	3	3.0
11	4th	2	3	4	2.9
2	5th	2	2	1	1.6
4	5th	2	2	2	2.0
6	5th	2	4	1	2.0
8	5th	2	2	1	1.6
10	5th	2	4	2	2.5
12	5th	2	2	1	1.6

Table 8: Time (seconds) from handing mosquito forceps to application of a Rumel tourniquet via a left 4th or 5th intercostal space (ICS) thoracotomy on canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	35.5	30.2	19	27.3
3	4th	29.2	33.8	14.8	24.4
5	4th	24.6	45	16.8	26.5
7	4th	27.3	110	20.7	39.6
9	4th	25.7	29.5	32.7	29.2
11	4th	19.9	35.2	26.9	26.6
2	5th	30.7	23.9	19	24.1
4	5th	26.1	25.2	18.1	22.8
6	5th	25	42.8	14.4	24.9
8	5th	24	37.2	12.1	22.1
10	5th	20	46.6	33.8	31.6
12	5th	16.8	28.9	20	21.3

Table 9: Ease of defibrillator paddle placement around the heart via a left 4th or 5th intercostal space (ICS) thoracotomy on canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	3	3	2	2.6
3	4th	2	3	2	2.3
5	4th	3	3	3	3.0
7	4th	2	2	2	2.0
9	4th	2	3	2	2.3
11	4th	1	2	2	1.6
2	5th	3	5	3	3.6
4	5th	2	2	1	1.6
6	5th	2	2	1	1.6
8	5th	1	4	5	2.7
10	5th	2	5	1	2.2
12	5th	1	4	3	2.3

Table 10: Time (seconds) from handing paddles to appropriate paddle placement (seconds) via a left 4th or 5th intercostal space (ICS) thoracotomy on canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	6.6	4.3	6.7	6.4
3	4th	5.5	4.8	3.5	4.7
5	4th	8.6	3.2	3	4.8
7	4th	3.9	2.6	3.7	3.8
9	4th	4.3	3	3.5	3.9
11	4th	4.1	3.9	3.3	4.1
2	5th	4	4.5	4.5	5.3
4	5th	5.3	2.8	2.7	3.9
6	5th	4.3	3.5	3	3.5
8	5th	7.5	5.8	4.7	5.5
10	5th	5	3.8	3.8	4.9
12	5th	4.4	3.2	2.8	4.1

Table 11: Post shingling ease of achieving appropriate hand position to perform cardiac massage via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	2	6	5	3.9
3	4th	1	6	3	2.6
5	4th	2	4	3	2.9
7	4th	2	4	1	2.0
9	4th	2	4	2	2.5
11	4th	1	3	1	1.4
2	5th	2	7	4	3.8
4	5th	1	3	1	1.4
6	5th	1	2	2	1.6
8	5th	1	5	3	2.5
10	5th	3	5	3	3.6
12	5th	1	3	4	2.3

Table 12: Post shingling ease of aortic access via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	1	2	3	1.8
3	4th	1	2	1	1.3
5	4th	2	2	2	2.0
7	4th	2	3	3	2.6
9	4th	2	2	1	1.6
11	4th	2	2	2	2.0
2	5th	1	2	2	1.6
4	5th	1	2	1	1.3
6	5th	1	2	1	1.3
8	5th	1	2	1	1.3
10	5th	2	2	1	1.6
12	5th	2	2	1	1.6

Table 13: Post shingling time (seconds) from handing right angle forceps to visualization of aorta via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	2.4	2.3	2.4	2.4
3	4th	2.5	1.7	1.8	2.0
5	4th	2.8	3.1	2	2.6
7	4th	5.1	3.4	2.7	3.6
9	4th	2.3	2.6	2.1	2.3
11	4th	2.9	2.6	2.1	2.5
2	5th	2.7	2	2.4	2.3
4	5th	1.8	1.5	1.8	1.7
6	5th	3.6	2.4	1	2.1
8	5th	2.1	2.8	2.1	2.3
10	5th	2.4	1.8	2.3	2.1
12	5th	2.2	2.2	1.5	1.9

Table 14: Post shingling ease of application of Rumel tourniquet via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	2	4	5	3.4
3	4th	1	3	1	1.4
5	4th	2	3	3	2.6
7	4th	3	3	5	3.6
9	4th	2	2	3	2.3
11	4th	2	2	2	2.0
2	5th	2	3	2	2.3
4	5th	1	2	1	1.3
6	5th	1	2	1	1.3
8	5th	1	3	2	1.8
10	5th	2	2	2	2.0
12	5th	1	2	2	1.6

Table 15: Post shingling time (seconds) from handing mosquito forceps to application of a Rumel tourniquet via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	23.2	37.3	21.2	26.4
3	4th	19.8	30.8	12.4	19.6
5	4th	20.9	22.9	12.9	18.3
7	4th	21	29.5	20.3	23.3
9	4th	19.7	33.8	18.7	23.2
11	4th	19.5	25.8	13.9	19.1
2	5th	21.5	24.4	17	20.7
4	5th	15.3	21.7	16.3	17.6
6	5th	16.4	24.5	11	16.4
8	5th	21.1	31.7	16.5	22.3
10	5th	16.7	24.3	17.9	19.4
12	5th	15.1	31	13.1	18.3

Table 16: Post shingling ease of paddle placement around the heart via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators using a scale of 0 to 10, where 0 was easiest and 10 was most difficult.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	1	2	3	1.8
3	4th	2	2	1	1.6
5	4th	1	2	3	1.8
7	4th	1	1	1	1.0
9	4th	1	2	1	1.3
11	4th	1	2	2	1.6
2	5th	2	4	5	3.4
4	5th	1	2	2	1.6
6	5th	1	2	2	1.6
8	5th	3	4	4	3.6
10	5th	2	3	1	1.8
12	5th	1	2	1	1.3

Table 17: Post shingling time (seconds) from handing paddles to appropriate paddle placement via a left 4th or 5th intercostal space (ICS) thoracotomy in canine cadavers (n=6 for 4th ICS, n=6 for 5th ICS) as performed by three evaluators.

Cadaver Number	**Intercostal Space**	**Evaluator A**	**Evaluator B**	**Evaluator C**	**Geometric mean within each cadaver**
1	4th	4.3	4.2	3.1	3.8
3	4th	4.8	4.2	1.6	3.2
5	4th	3.2	3.7	3.4	3.4
7	4th	2.6	3.5	1.6	2.4
9	4th	3	3.1	2.3	2.8
11	4th	3.9	3.3	3.1	3.4
2	5th	4.5	3.6	6.2	4.6
4	5th	2.8	3.1	2.9	2.9
6	5th	3.5	3.1	1.8	2.7
8	5th	5.8	5.4	4.9	5.4
10	5th	3.8	4.3	2.4	3.4
12	5th	3.2	3.7	2.2	3.0

Table 18: Summary of results comparing pre and post shingling of left 4th (n=6 cadavers) and 5th (n=6 cadavers) intercostal space (ICS) thoracotomies for open-chest cardiopulmonary resuscitation in canine cadavers. Ease of assessment was scored on a scale from 0 to 10, where 0 was easiest and 10 was most difficult.

Parameter	**Mean 4th ICS pre shingling**	**Mean 4th ICS post shingling**	**Mean 5th ICS pre shingling**	**Mean 5th ICS post shingling**	**P-value 4th vs. 5th ICS pre shingling[1]**	**P-value 4th ICS pre vs. post shingling [1]**	**P-value 5th ICS pre vs. post shingling [1]**	**P-value 4th vs. 5th ICS post shingling [1]**
Ease of appropriate hand position Model: ICS (4 versus 5), P = 0.138. Shingling (Pre versus Post), P = 0.024; Pre = 2.9 ± 0.9; Post = 2.5 ± 0.9 Interaction (ICS x Shingling), P = 0.001.	3.6 ± 0.5	2.6 ± 0.8	2.3 ± 0.6	2.5 ± 1.0	0.011	<0.001	0.262	0.937

Table 18 continued.

Parameter	Mean 4th ICS pre shingling	Mean 4th ICS post shingling	Mean 5th ICS pre shingling	Mean 5th ICS post shingling	P-value 4th vs. 5th ICS pre shingling[1]	P-value 4th ICS pre vs. post shingling [1]	P-value 5th ICS pre vs. post shingling [1]	P-value 4th vs. 5th ICS post shingling [1]
Ease of aortic access Model: ICS (4 versus 5), P = 0.042; ICS 4 = 2.1 ± 0.7; ICS 5 = 1.4 ± 0.2. Shingling (Pre versus Post), P = 0.165. Interaction (ICS x Shingling), P = 0.077.	2.3 ± 1.0	1.9 ± 0.5	1.4 ± 0.2	1.4 ± 0.2	0.013*	0.034*	0.743*	0.169*
Time to visualization of aorta (seconds). Model: ICS (4 versus 5), P = 0.009; ICS 4 = 3.2 ± 1.0; ICS 5 = 2.4 ± 0.5. Shingling (Pre versus Post), P < 0.001; Pre = 3.3 ± 0.8; Post = 2.3 ± 0.5. Interaction (ICS x Shingling), P = 0.105.	3.9 ± 0.8 s	2.6 ± 0.6	2.8 ± 0.4	2.1 ± 0.2	0.002*	<0.001*	0.024*	0.140*

Table 18 continued.

Parameter	Mean 4th ICS pre shingling	Mean 4th ICS post shingling	Mean 5th ICS pre shingling	Mean 5th ICS post shingling	P-value 4th vs. 5th ICS pre shingling[1]	P-value 4th ICS pre vs. post shingling [1]	P-value 5th ICS pre vs. post shingling [1]	P-value 4th vs. 5th ICS post shingling [1]
Ease of application of Rumel Tourniquet. Model: ICS (4 versus 5), P = 0.019; ICS 4 = 2.9 ± 1.1; ICS 5 = 1.8 ± 0.4. Shingling (Pre vs. Post), P = 0.050. Interaction (ICS x Shingling), P = 0.208.	3.3 ± 1.2	2.6 ± 0.8	1.9 ± 0.4	1.7 ± 0.4	0.008*	0.030*	0.545*	0.078*
Time to application of Rumel Tourniquet (seconds). Model: ICS (4 versus. 5), P = 0.067. Shingling (Pre versus. Post), P < 0.001; Pre = 26.7 ± 2.9; Post = 20.4 ± 5.0. Interaction (ICS x Shingling), P = 0.500.	28.9 ± 5.4	21.7 ± 3.1	24.5 ± 3.7	19.1 ± 2.1	0.056*	0.004*	0.020*	0.261*

Table 18 continued.

Parameter	**Mean 4th ICS pre shingling**	**Mean 4th ICS post shingling**	**Mean 5th ICS pre shingling**	**Mean 5th ICS post shingling**	**P-value 4th vs. 5th ICS pre shingling[1]**	**P-value 4th ICS pre vs. post shingling [1]**	**P-value 5th ICS pre vs. post shingling [1]**	**P-value 4th vs. 5th ICS post shingling [1]**
Ease of paddle placement. Model: ICS (4 versus 5), P = 0.356. Shingling (Pre versus Post), P = 0.017; Pre = 2.3 ± 0.6; Post = 1.9 ± 0.8. Interaction (ICS x Shingling), P = 0.050.	2.3 ± 0.5	1.5 ± 0.3	2.3 ± 0.7	2.2 ± 1.0	0.967*	0.017*	0.666*	0.104*
Time to paddle placement (seconds) Model: ICS (4 versus 5), P = 0.683. Shingling (Pre versus Post), P < 0.001; Pre = 4.6 ± 0.8; Post = 3.4 ± 0.8. Interaction (ICS x Shingling), P = 0.093.	4.6 ± 0.9	3.2 ± 0.5	4.5 ± 0.8	3.7 ± 1.1	0.867*	<0.001*	0.003*	0.350*

1: All pairwise comparisons (Holm-Sidak method).

* Indicates that P-values were based on all pairwise comparisons regardless of main effect P-values. Main effects and interaction P-values are detailed in the left hand column

FIGURES

Figure 1. Left lateral thoracotomy in a human being by rib resection (complete) after dissecting periosteal tissue with a moderately sharp dissector and the periosteal hose thus formed.

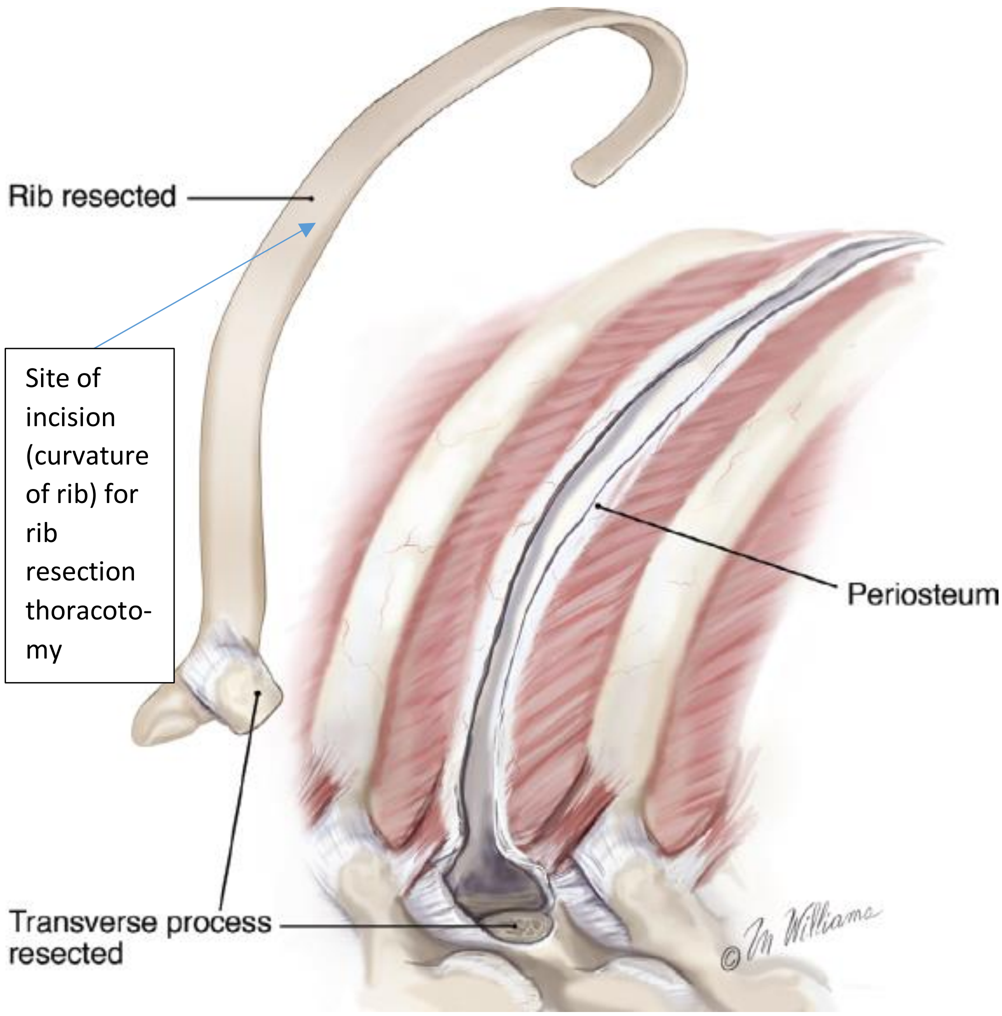

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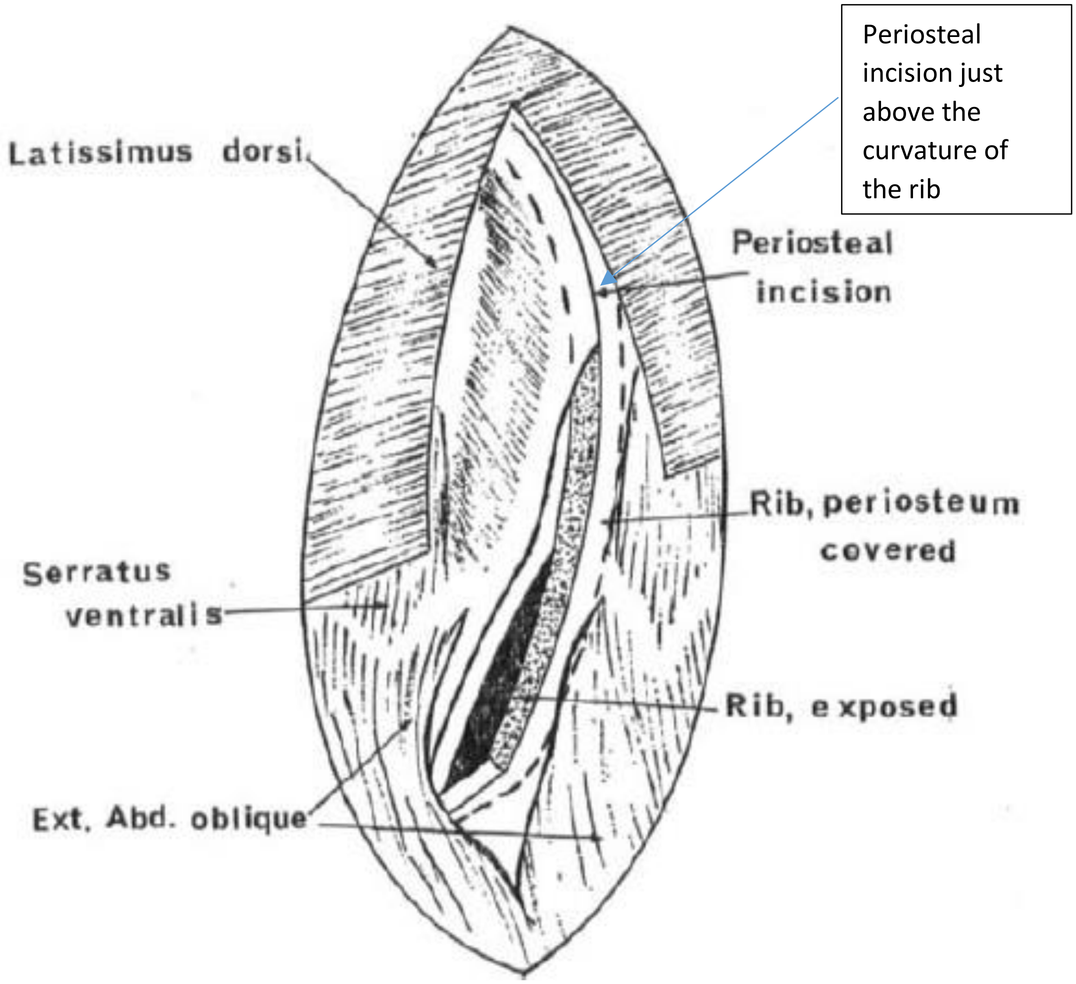
Figure 2: Right lateral thoracotomy by semi-stripping of a rib.

a) The initial incision and the incised periosteal hose. Left of the image is cranial, top is dorsal.



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b) Closure of thoracotomy by placing a continuous suture replacing the periosteal hose around its original site on the rib. Left of the image is cranial, top is dorsal

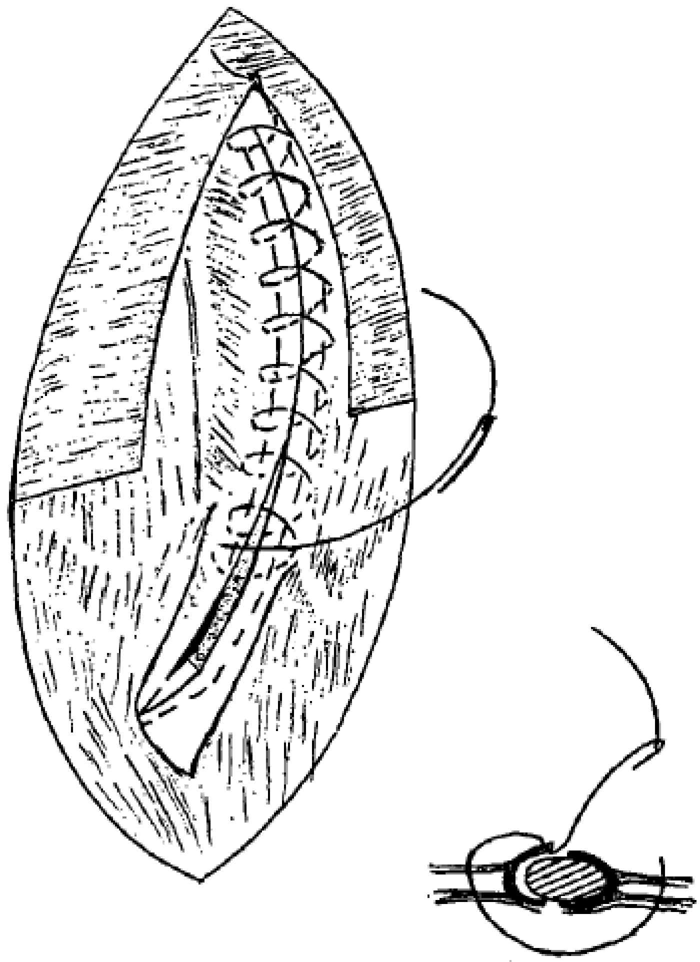

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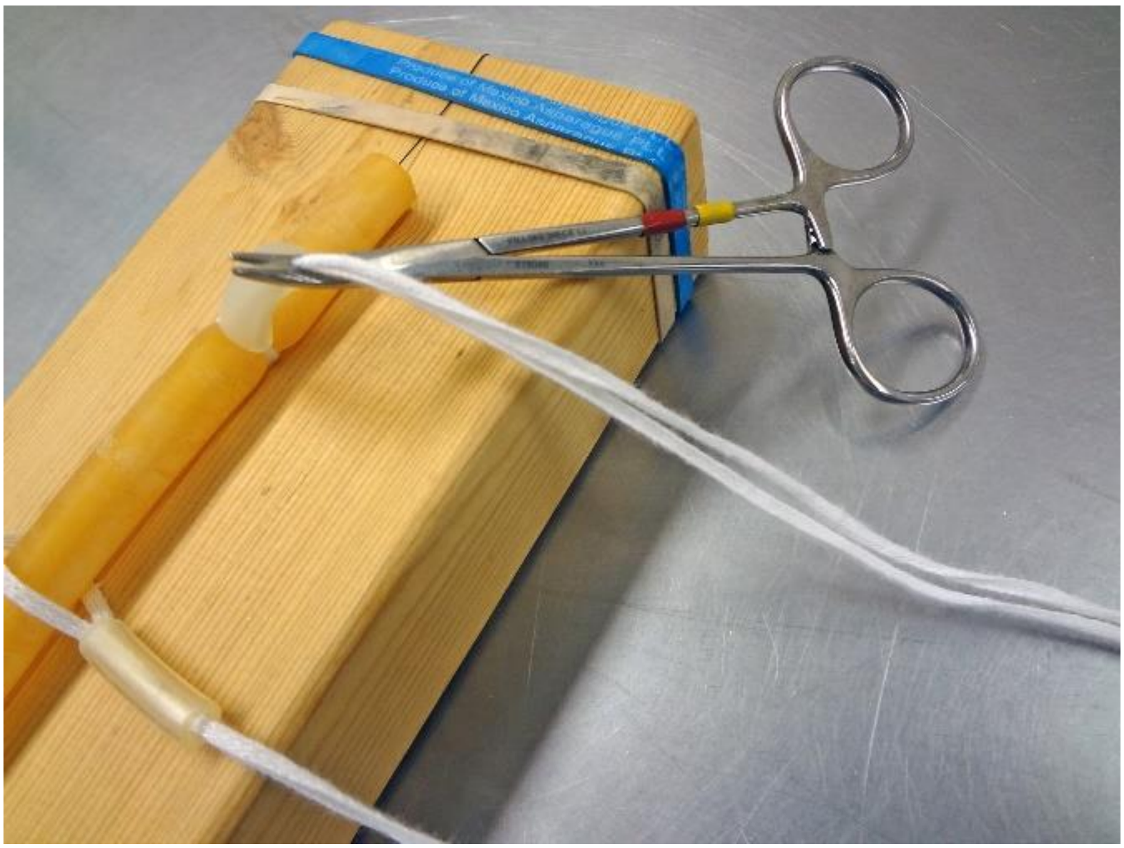
Figure 3. Rumel tourniquet used for descending aorta occlusion when comparing 4^{th} versus 5^{th} intercostal space thoracotomy for open-chest cardiopulmonary resuscitation.

a) Right angle forceps and mosquito hemostatic forceps with silastic tubing and umbilical tape.

b) Close up view of custom made Rumel tourniquet showing relationship of the hemostatic forceps, silastic tubing, and umbilical tape prior to application to the cadaver.

Figure 4. Application of a custom made Rumel tourniquet to a model of an aorta (a) and a cadaveric aorta (b).

a) The umbilical tape is placed around a model of an aorta with both strands passing through the umbilical tape before (left) and after (right) securing the tape strands with a mosquito hemostatic forceps to occlude the aorta.



b) The Rumel tourniquet occluding the descending aortal of a cadaver. Cranial is to the left and dorsal is at the top of the photo.

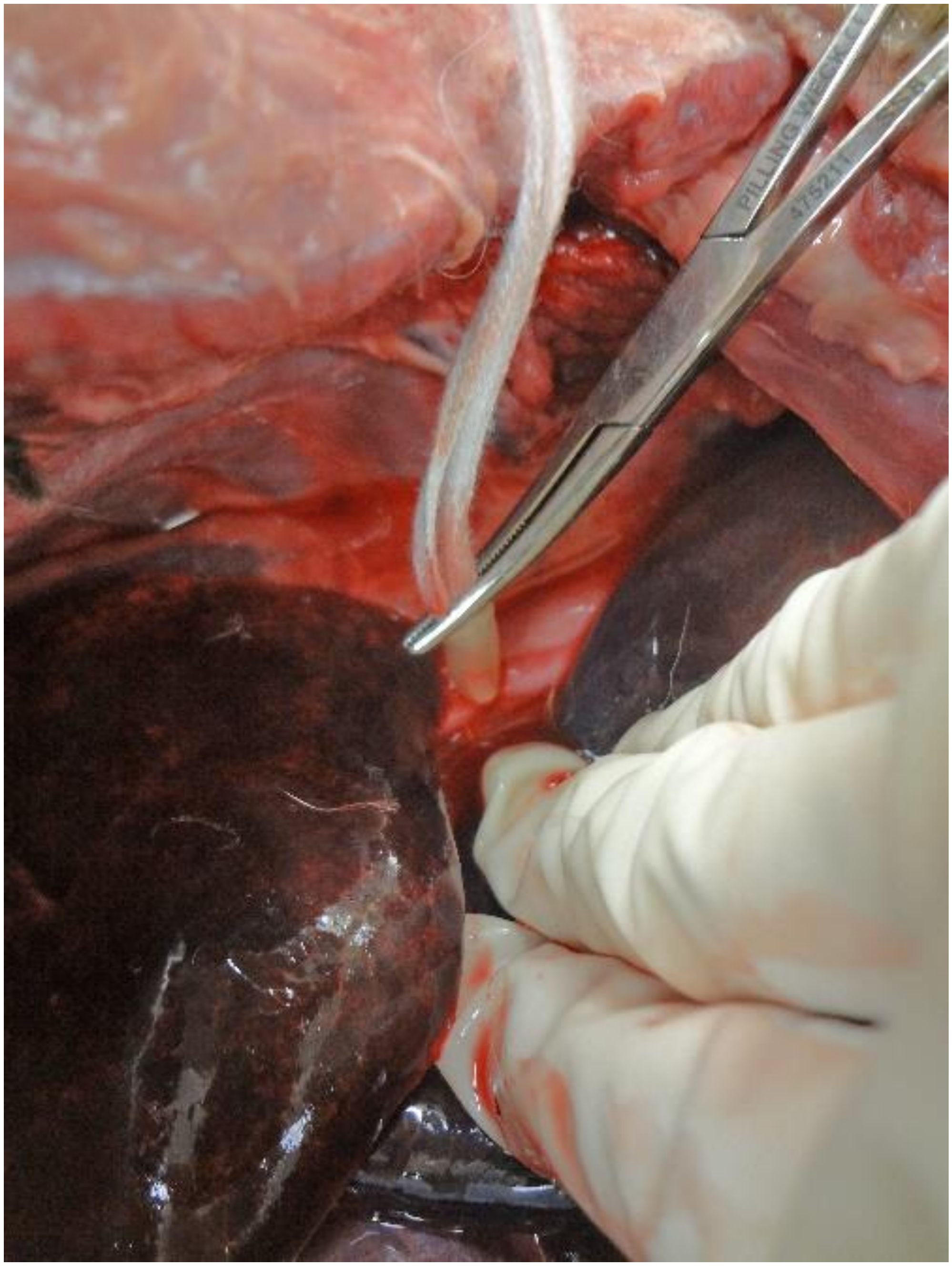


Figure 5. A prepared cadaver for evaluation of open-chest cardiopulmonary resuscitation techniques as seen by the evaluators. Left of the image is cranial, top is dorsal.

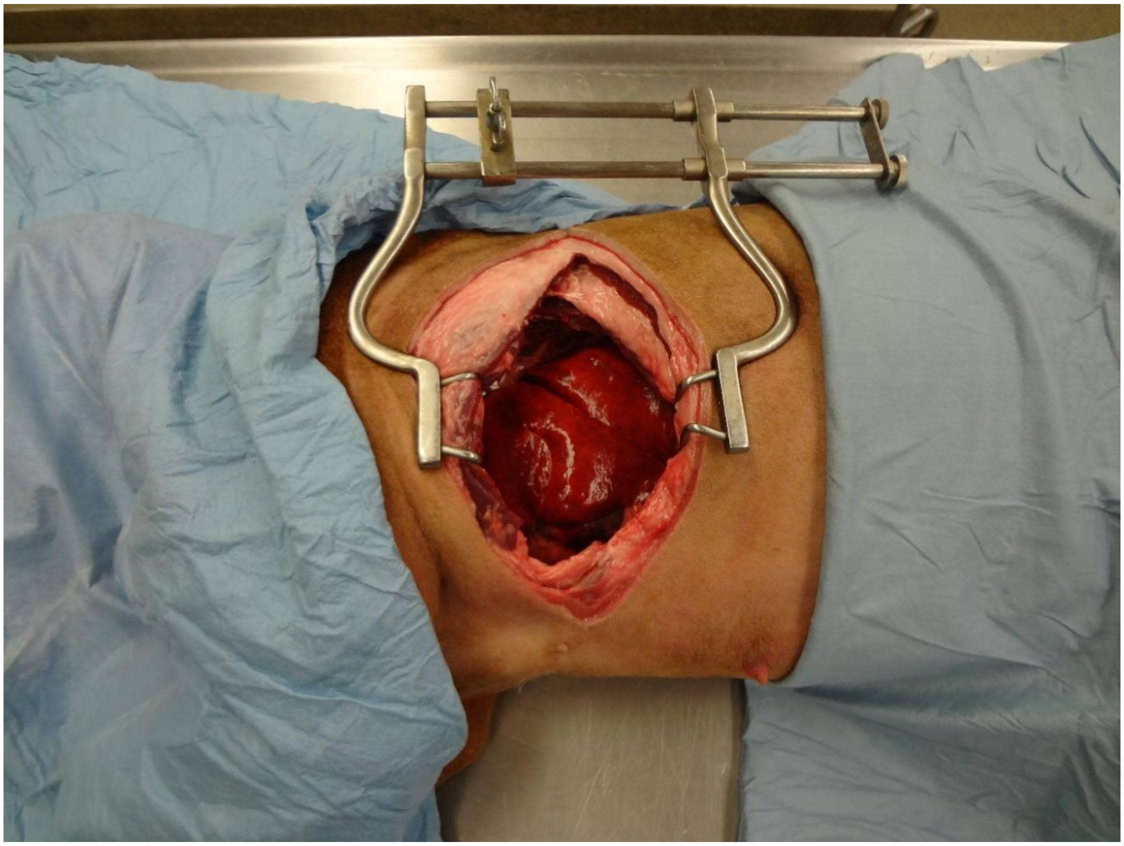
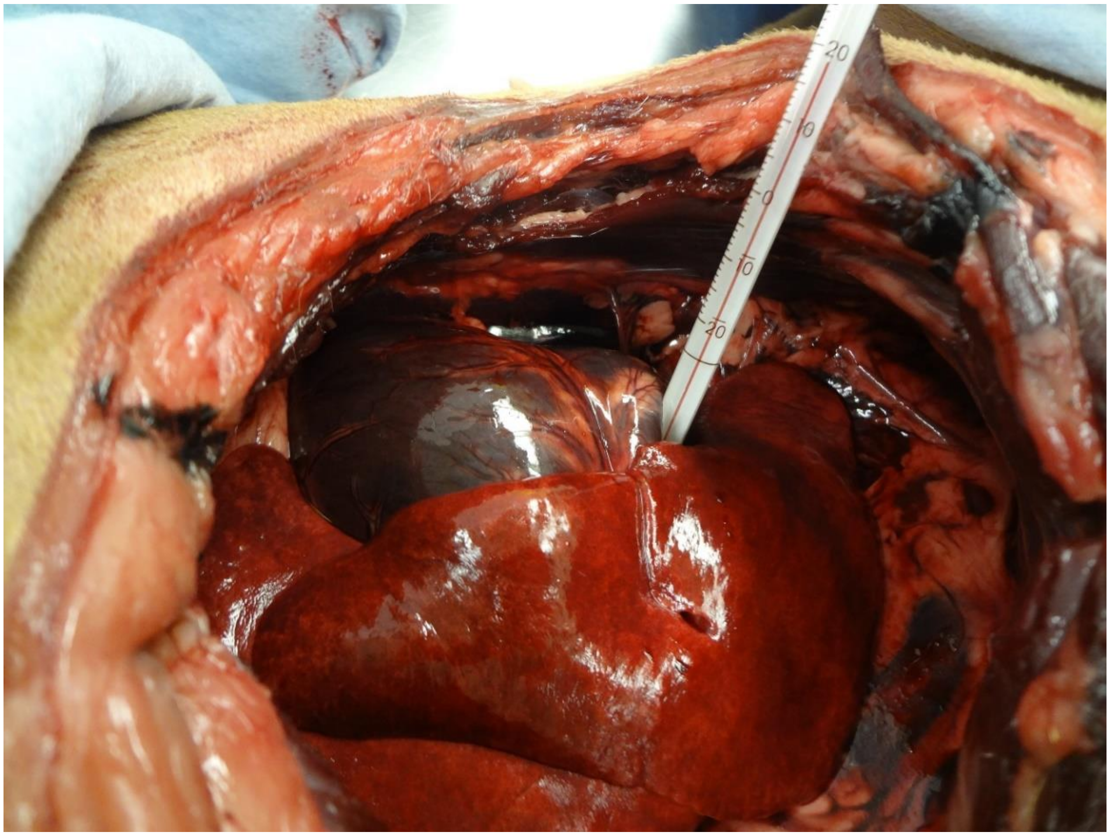


Figure 6. Measuring the temperature of cadavers used to evaluate the technique for open-chest cardiopulmonary resuscitation in dogs, to ensure the cadavers were adequately thawed (18 degrees C) prior to data collection.



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FOOTNOTES

a. Finochietto (Sklar Surgical Instruments, West Chester, PA)

b. Nestle Purina Body Condition Score (www.purina.com)

c. Welch Allyn Suretemp (www.welchallyn.com)

d. Sigmaplot 13.0, San Rafael, California