Received: 10 February 2019 | Revised: 15 July 2019 | Accepted: 12 August 2019

DOI: 10.1111/vec.13059

ORIGINAL STUDY

Journal of Veterinary Emergency and Critical Care WILEY

Comparison of left fourth and fifth intercostal space thoracotomy for open-chest cardiopulmonary resuscitation in dogs

Anushri M. Warang BVSc & AH, MS[1] | F. A. Mann DVM, MS, DACVS, DACVECC[1] | John R. Middleton DVM, PhD, DACVIM[1] | Colette Wagner-Mann DVM, PhD[2] | Keith Branson DVM, MS, DACVAA[1]

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

[2] Department of Biomedical Sciences, University of Missouri, Columbia, Missouri

Correspondence
F. A. Mann, MU Veterinary Health Center, 900 East Campus Drive, Columbia, MO, 65211
Email: MannF@missouri.edu

Funding: Phi Zeta Veterinary Honor Society – University of Missouri

The authors declare no conflicts of interest.

Presented in part at the 23rd International Veterinary Emergency and Critical Care Symposium, Nashville, TN, 2017.

Abstract

Objective: To determine whether ease of access to thoracic structures for performing open-chest cardiopulmonary resuscitation (OC-CPR) differed between fourth and fifth intercostal space (ICS) left lateral thoracotomies in dogs, and to determine if "shingling" improved access for OC-CPR manipulations.

Design: Prospective single-blinded study.

Setting: Laboratory.

Animals: Twelve mixed breed canine cadavers weighing approximately 20 kg.

Interventions: Left lateral thoracotomies were performed at the 4th ICS (n = 6) or 5th ICS (n = 6). Shingling at the 4th or 5th ICS, as applicable, was performed after initial data collection and outcomes were reassessed.

Measurements and main results: Three evaluators blinded to the surgical approach scored the following parameters on a 0 to 10 scale (0 = easiest, 10 = most difficult): ease of access of the phrenicopericardial ligament, ease of pericardial incision, ease of appropriate hand position, ease of aortic access, ease of Rumel tourniquet application, and ease of proper placement of defibrillation paddles. Objective measurements (time to completion or number of attempts) were made for all but ease of pericardial incision and ease of appropriate hand position. Outcomes were reassessed after shingling.

The 5th ICS was superior for ease of aortic access ($P = 0.042$), time to visualization of aorta ($P = 0.009$), and ease of application of a Rumel tourniquet ($P = 0.019$). When comparing scores pre- and post-shingling, shingling improved time to visualization of the aorta ($P < 0.001$), time to placement of Rumel tourniquet ($P < 0.001$), ease of paddle placement ($P = 0.017$), and time to paddle placement ($P < 0.001$).

Conclusions: Either 4th or 5th ICS thoracotomy may provide adequate access to intrathoracic structures pertinent to performing OC-CPR in dogs weighing

Abbreviations: ICS, intercostal space; OC-CPR, open chest cardiopulmonary resuscitation

approximately 20 kg, but 5th ICS was preferred for most manipulations, and shingling improved access for most of the measured parameters.

KEYWORDS
canine, resuscitation, shingling, tourniquet

1 | INTRODUCTION

Open-chest cardiopulmonary resuscitation (OC-CPR) is indicated in certain cardiopulmonary arrest situations. Despite laboratory research and clinical studies in human medicine having established the superiority of OC-CPR compared to closed-chest cardiopulmonary resuscitation with regard to cardiac output, aortic blood pressure, blood flow, and perfusion,[1–3] the technique for OC-CPR has not been described in detail in the veterinary literature. The most commonly used incision location for emergent lateral or bilateral anterior thoracotomy in human patients is the fourth or fifth intercostal space (ICS),[4,5] with second and third ICS approaches being considered obsolete.[6] Likewise, the veterinary literature describes fourth or fifth ICS thoracotomies for performing OC-CPR,[7,8] without preference for a specific ICS.

Open-chest CPR can be a life-saving measure to achieve a return of spontaneous circulation. It has been proposed that OC-CPR be performed immediately in human patients arriving in extremis with loss of signs of life associated with conditions such as pleural space compromise (ie, pneumothorax, pleural effusion, diaphragmatic hernia) and cardiac tamponade.[9] The Reassessment Campaign on Veterinary Resuscitation also suggests the employment of OC-CPR for patients with significant intrathoracic disease that are in cardiopulmonary arrest.[10] Time is of the essence for resuscitative thoracotomy; hence, it is imperative that the optimal OC-CPR technique be determined for rapid intrathoracic access in veterinary patients.

In addition to being expeditious, the surgical approach must achieve sufficient access to intrathoracic structures, allowing resuscitative maneuvers. Shingling is a procedure that may be performed to enhance exposure during a unilateral lateral thoracotomy.[*] Shingling is described as the complete transection of the rib caudal (or cranial) to the thoracotomy incision at the costochondral junction followed by tucking the transected rib under the next caudal (or cranial) rib. Shingling can be used with the intercostal thoracotomy incision to improve access to intrathoracic organs. If further exposure is required, the next caudal (or cranial) rib may also be shingled.

The goal of this study was to compare 4th and 5th ICS left lateral thoracotomies to determine whether the ease of access to the thoracic cavity for performing OC-CPR manipulations in dogs differed by ICS. Secondarily, this study aimed to determine if shingling improved access for OC-CPR manipulations. It was hypothesized that OC-CPR manipulations would be more easily achieved through the 5th ICS than the 4th ICS. Second, we hypothesized that shingling would improve the ease of performing the manipulations for OC-CPR.

2 | MATERIALS AND METHODS

2.1 | Sample population

Twelve adult canine cadavers weighing approximately 20 kg each with body condition scores[†] ranging from 3 to 6 were used for this study (Table 1). These animals were procured from an animal shelter and were euthanized for shelter management reasons. The institutional animal care and use committee did not require approval for research performed on cadavers. The shelter was not informed about the study or study requirements. The cadavers were chosen by visual assessment of the size and approximate body weight as determined by physically lifting the frozen cadavers while they were still in body bags. The animal shelter does not undertake euthanasia decisions based on the requirements of the institute. Brachycephalic breeds and barrel-chested breeds were excluded. Approximate breed, gender, and body weight were recorded for each cadaver. Cadavers were assigned to 1 of 2 groups, such that group 1 (n = 6) cadavers had a 4th ICS thoracotomy and group 2 (n = 6) cadavers had a 5th ICS thoracotomy performed. All thoracotomies were performed by the same investigator (FAM).

2.2 | Preparation of cadavers

Cadavers were procured frozen and stored at 5°C for 1 week. To accelerate thawing, cadavers were placed outside the cooler at room temperature (~22°C) for a few hours each day. Immediately prior to performing the procedures, the cadavers were left at room temperature overnight. The temperature of each cadaver was measured at the time of data collection by placing a thermometer[‡] in the center of the thoracic cavity at the caudal aspect of the heart. Cadavers with a temperature ≥16°C were considered adequately thawed based on the authors' experience with the use of similar frozen/thawed cadavers for teaching. Prior to performing the thoracotomies, the cadavers were circumferentially shaved of hair around the thoracic region, from approximately the level of the first rib to the last rib on both sides to facilitate measuring the circumference of the thorax of each cadaver.

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

Cadaver number	Body weight (kg)	Apparent breed	Sex (male, male neutered, female)	Age classification (juvenile, adult, mature)*	Body condition score (1 to 9)[§]	Circumference of chest (cm)	Temperature of cadaver at time of evaluation (°C)
1	21.15	Pit Bull mix	M	Adult	5	59.00	16.50
2	25.50	Pit Bull mix	M	Adult	5	64.00	18.00
3	18.20	Pit Bull mix	F	Mature	3	56.00	18.50
4	21.50	Pointer/Dalmatian	MC	Mature	4	66.00	17.50
5	24.50	Pit Bull mix	F	Adult	6	72.00	17.00
6	18.25	Retriever mix	M	Mature	4	62.00	16.00
7	23.75	Retriever mix	F	Adult	5	68.00	16.50
8	26.45	Pit Bull mix	F	Adult	5	64.00	18.00
9	18.85	Pointer mix	F	Mature	4	59.00	19.00
10	19.05	Pit Bull mix	M	Adult	4	55.00	19.00
11	17.05	Pit Bull mix	F	Mature	3	56.00	18.50
12	21.60	Pit Bull mix	F	Adult	4	60.00	18.00

*Based on dentition, cadavers classified as mature if missing teeth or appearing mature.
[§]Nestle Purina Body Condition Score (www.purina.com).

2.3 | Thoracotomy procedure

Left lateral thoracotomies were performed in all cases. The skin was incised with a #10 scalpel blade 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 and this muscle was incised with Mayo scissors from ventral to dorsal. The surgeon's left index finger was then inserted under the latissimus dorsi muscle cranially to palpate the first rib and count caudally to identify the 4th or 5th ICS, as appropriate. The convergence of the scalenus dorsalis and external abdominal oblique muscles was visualized at the 5th rib to help verify the 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 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 to standardize the width of the thoracotomy incision to approximately 8 cm. This was accomplished by marking the skin where the jaws of the Balfour blades rested on the cranial and caudal ribs with India ink and the measuring distance between the 2 markings with a tape. Finally, drapes were placed over the chest surrounding the thoracotomy site so that the evaluators could not determine which ICS was being evaluated. 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.

2.4 | Data collection

Outcome measures were assessed by 3 evaluators, who each had another person record their assessments. The investigator performing the surgical approaches (FAM) served as one of the recorders, but was not one of the 3 evaluators. Evaluators assessed all 6 outcomes (Table 2). For each outcome, results were subjectively assessed using a 0 to 10 scale, with 0 being easiest and 10 being most difficult. In addition, objective measurements were made using the time to complete or the number of attempts needed to complete a given outcome measure (Table 2).

All evaluators practiced performing and scoring each of the measured outcomes on a separate cadaver not enrolled in the data collection immediately prior to data collection. The procedures are outlined below and numbered according to the outcome measures identified in Table 2.

1. The phrenicopericardial ligament was grasped with the index finger of the left hand. All evaluators were right-handed.
2. The pericardial incision was performed with Mayo scissors. A small incision was made in the phrenicopericardial ligament at the apex of

TABLE 2 Outcome measures and number of cadavers evaluated for comparison of 4th and 5th intercostal space thoracotomies

Outcome measure	Subjective score	Objective measure	Number of cadavers evaluated by each evaluator
1. Ease of access of the phrenicopericardial ligament	0-10	Number of sweeps	4
2. Ease of access to pericardial incision	0-10	Not applicable	4
3. Ease of appropriate hand position	0-10	Not applicable	12
4. Ease of aortic access	0-10	Time (s)	12
5. Ease of application of a Rumel tourniquet	0-10	Time (s)	12
6. Ease of proper placement of defibrillator paddles	0-10	Time (s)	12

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.

3. To achieve an appropriate hand position, the evaluators were shown to place the right 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 towards the base.
4. 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.
5. 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 1). 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 reset onto the umbilical tape strands against the silastic tubing to tighten the umbilical tape around the aorta, maintaining the aorta in a collapsed position (Figure 2). 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.
6. The evaluators were instructed to place 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 verbally indicated that they had achieved appropriate paddle position.

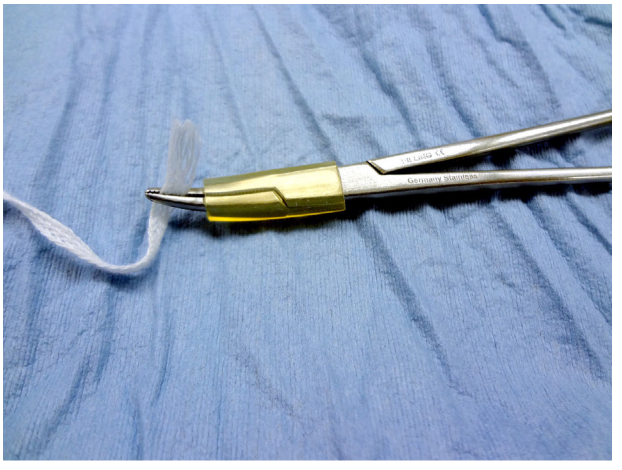

FIGURE 1 Close-up view of custom-made Rumel tourniquet used for descending aorta occlusion in comparing 4th vs 5th intercostal space left lateral thoracotomy for open-chest cardiopulmonary resuscitation, showing relationship of the hemostatic forceps, silastic tubing, and umbilical tape prior to application to the cadaver

All the evaluators wore the same size gloves (6.5). All evaluators had limited experience with OC-CPR. Two of the evaluators (B and C) were second-year small animal emergency and critical care residents and had previously performed OC-CPR at least once. One of the evaluators (A) was a surgical intern and had not previously performed OC-CPR, other than during the practice session denoted above.

On the day before data collection, cadavers were placed on tables numbered 1 to 12 in a single room at approximately 22°C. Cadavers on odd-numbered tables had a 4th ICS thoracotomy, and cadavers on even-numbered tables had a 5th ICS thoracotomy. Evaluators were blinded to thoracotomy site. Evaluator A began at table 1, evaluator B

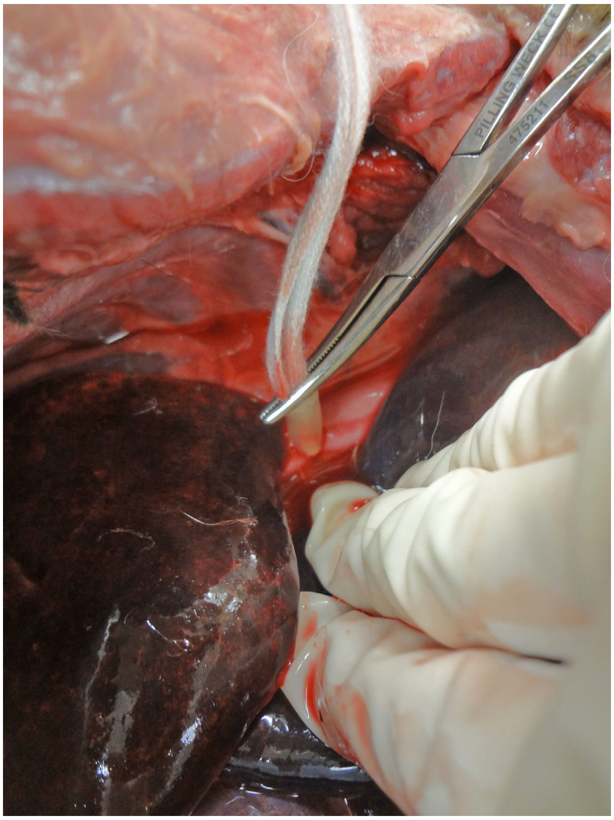

FIGURE 2 Application of a custom-made Rumel tourniquet occluding the descending aorta of a cadaver. Cranial is to the left and dorsal is at the top of the photo

began at table 5, and evaluator C began at table 9. Each evaluator had a person recording data alongside them.

Ease of access of phrenicopericardial ligament, number of sweeps needed to grasp phrenicopericardial ligament, ease of pericardial incision, ease of appropriate hand position, ease of aortic access, time to visualization of the aorta, ease of application of Rumel tourniquet, and time for application of Rumel tourniquet were sequentially assessed by each evaluator on the first 4 cadavers they evaluated such that evaluator A assessed cadavers 1 to 4, evaluator B assessed cadavers 5 to 8, and evaluator C assessed cadavers 9 to 12. Following these assessments, evaluators assessed the ease of appropriate hand position, ease of aortic access, time to visualization of the aorta, ease of application of Rumel tourniquet, and time for application of Rumel tourniquet on all of the remaining cadavers that they had not yet examined. As the evaluators had 1 pair of defibrillator paddles, ease of proper placement of defibrillator paddles and time to paddle placement were evaluated one by one by each of the evaluators after evaluating outcomes 1 to 5 on all cadavers.

Once all evaluations were complete, the 3 evaluators left the testing room, and shingling was performed on all specimens by the same investigator who performed the original thoracotomy incisions. Shingling was achieved by transversely cutting the rib caudal to the thoracotomy incision. The rib was cut completely at the costochondral junction, and then the rib was tucked under the next caudal rib, the caudal rib thus being "shingled." 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 ease of appropriate hand position, ease of aortic access, time to visualization of the aorta, ease of application of Rumel tourniquet, and time for application of Rumel tourniquet on all the cadavers following the same sequence used before shingling. Ease of access of phrenicopericardial ligament, number of sweeps to grasp the phrenicopericardial ligament, and ease of pericardial incision could not be assessed again, as the phrenicopericardial ligament and the pericardium were incised during the first round of data collection. Again, the ease of proper placement of defibrillator paddles was reassessed by all evaluators one by one after reassessing the aforementioned outcomes on all cadavers.

2.5 | Data analysis

Due to the variability in scores and the limited amount of data recorded (n = 2 cadavers per evaluator at each ICS) for ease of grasping the phrenicopericardial ligament, the number of sweeps, and ease of pericardial incision, these data were not statistically analyzed. The scores reported by the evaluators for these outcome measures are reported in Table 3.

Thoracotomy incisional width, body weight, body condition score, chest circumference, and cadaver temperature were compared between groups (4th vs 5th ICS) using the *t*-test to assess homogeneity among the experimental groups. For all other outcomes, scores or times reported by the 3 evaluators were combined into a single value by taking the geometric mean value of the 3 evaluators' scores or times. A repeated measures ANOVA was used to compare outcomes pre- and post-shingling between 4th and 5th ICS. 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 independent variables included group (4th or 5th ICS), shingling (pre- and post-) as the repeated measure, and the 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.[§]

3 | RESULTS

All measurements were completed as planned. Overall, mean ± SD incisional width (4th ICS = 8.2 ± 0.6 cm and 5th ICS = 9.4 ± 1.3 cm, $P = 0.06$), body weight (4th ICS = 20.6 ± 3.1 kg and 5th ICS = 22.1 ± 3.3 kg, $P = 0.44$), body condition score (4th ICS = 4.3 ± 1.2 and 5th ICS = 4.3 ± 0.5, $P = 1$), chest circumference (4th ICS = 61.6 ± 6.7 cm and 5th ICS = 61.8 ± 3.9 cm, $P = 0.95$), and cadaver temperature (4th

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 (n = 6) or 5th (n = 6) intercostal space (ICS) thoracotomy on canine cadavers as performed by each of 3 evaluators (A, B, or C) using a scale of 0 to 10, where 0 was easiest and 10 was most difficult

Site of thoracotomy ICS	Cadaver number	Ease of grasping the phrenicopericardial ligament			Number of sweeps to grasp the phrenicopericardial ligament			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
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

ICS = 17.6 ± 1.1°C and 5th ICS = 17.7 ± 1.0°C, $P = 0.89$) did not differ between the 4th and 5th ICS.

3.1 | Access of phrenicopericardial ligament and pericardial incision

Due to ease of access of phrenicopericardial ligament, the number of sweeps to grasp the phrenicopericardial ligament, and ease of pericardial incision only being scored on 2 cadavers by each evaluator in each experimental group with no 2 evaluators scoring the same cadaver, statistical analyses were not performed for these outcomes, and only raw data are presented (Table 3).

3.2 | Hand position

The difference in the mean ± SD score for ease of hand position was not significantly different between the 4th (3.1 ± 0.8) and 5th ICS (2.4 ± 0.8) ($P = 0.138$) but was significantly higher before shingling (2.9 ± 0.9) than after shingling (2.5 ± 0.9; $P = 0.024$), irrespective of ICS, and there was a significant interaction of ICS and shingling ($P = 0.001$). Post-hoc pairwise comparisons revealed that the mean ± SD ease of 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 vs 2.6 ± 0.8 after; $P < 0.001$) but not at the 5th ICS (2.3 ± 0.7 before vs 2.5 ± 1.0 after; $P = 0.262$).

3.3 | 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 (1.8 ± 0.8) or after shingling (1.7 ± 0.4) ($P = 0.165$), and there was no significant interaction between ICS and shingling ($P = 0.077$). Hence, in the model, the difference in aortic access detected between the 4th and 5th ICS was not dependent on shingling.

Mean ± SD time to the visualization of the aorta was shorter for the 5th ICS (2.4 ± 0.5 s) compared to the 4th ICS (3.2 ± 1.0 s) ($P = 0.009$), and mean ± SD time to visualization of the aorta post-shingling (2.3 ± 0.5 s) was shorter compared to pre-shingling (3.3 ± 0.8 s) ($P < 0.001$); 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 were not dependent on shingling, and the differences detected before and after shingling were not dependent on ICS.

3.4 | 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-shingling (2.6 ± 1.1) and post-shingling (2.1 ± 0.8) ($P = 0.050$), 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 (25.3 ± 5.7 s) and 5th ICS (21.8 ± 4.0 s) ($P = 0.067$), but there was a statistically significant difference in mean time to placement between pre-shingling (26.7 ± 5.0 s) and post-shingling (20.4 ± 2.9 s) ($P < 0.001$). 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.

3.5 | Paddle placement

Mean ± SD score for ease of paddle placement did not differ between the 4th (1.9 ± 0.6) and 5th (2.3 ± 0.9) ICS ($P = 0.356$), but there was a difference in mean ± SD score for ease of paddle placement pre-shingling (2.3 ± 0.6) vs post-shingling (1.9 ± 0.8) ($P = 0.017$). 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.

Mean ± SD time to placement of paddles did not differ between the 4th (3.9 ± 1.0) and 5th (4.1 ± 1.0) ICS ($P = 0.683$), but there was a difference between pre-shingling (4.6 ± 0.8 s) and post-shingling (3.4 ± 0.8 s) ($P < 0.001$). 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.

4 | DISCUSSION

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.[11] A left-sided thoracotomy was used in this study as it provided access to all thoracic structures necessary for performing manipulations for OC-CPR. However, a right-sided thoracotomy might be more appropriate if access to the right side of the heart is needed. The results of this research might have been different if a right lateral approach had been used. The model of OC-CPR used in this study provided acceptable exposure, as determined by the subjective score and objective measurements recorded for the assessed parameters to intrathoracic structures via 4th and 5th ICS thoracotomies, but the 5th ICS was easier for most manipulations (aortic access, time to the visualization of aorta, and ease of application of a Rumel tourniquet). The limited number of cadavers prevented statistical analyses of some parameters (ease of grasping phrenicopericardial ligament, number of sweeps to grasp the phrenicopericardial ligament, and ease of pericardial incision), but preliminary data are provided (Table 3) to aid in the design of future studies. When comparing scores pre- and post-shingling, shingling improved access for ease of hand position, time to visualization of the aorta, time to placement of Rumel tourniquet, ease of paddle placement, and time to paddle placement. Some variability was expected among the 3 evaluators, but this variability was minimized by calculating the geometric mean score or time for each outcome measure before the final 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.[12–14] Given the paucity of evidence in the literature with regard to OC-CPR in dogs, 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 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 most of the above-mentioned manipulations, and these data provide preliminary evidence that the 5th ICS should be used in future investigations to determine the best surgical technique for OC-CPR.

Shingling is performed to improve exposure to the thoracic cavity. With shingling, further exposure is facilitated by transecting the adjacent caudal or cranial rib at the costochondral junction, and when placing a retractor, such as a Finochetto or Balfour, the transected 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. Shingling improved access for ease of hand position, time to the visualization of aorta, time to application of Rumel tourniquet, ease of paddle placement, and time to paddle placement. These results were 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 may be required when a 4th ICS incision is chosen.

Care should be taken in translating these 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 optimize the interpretation of results with the limited 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, recording time for some parameters 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 the visualization of aorta reflected the subjective scores for the main effect of ICS (4th vs 5th ICS), with the 5th ICS being easier than the 4th ICS. For main effect pre- and post-shingling, shingling was seen to improve access based on time to the visualization of aorta. For ease of application of Rumel tourniquet, subjective scores showed that the 5th ICS was easier than the 4th ICS, but time to proper placement of the Rumel tourniquet was not found to differ between the 4th and 5th ICS. Shingling did, however, improve time to proper placement of the Rumel tourniquet irrespective of ICS. Hence, subjective scoring disagreed with time to result for placement of the Rumel tourniquet. For ease of paddle placement, subjective scores reflected time to paddle placement scores, with no statistically significant difference being noted between the 4th and 5th ICS. Although some outcomes were statistically significant (eg, timed events), these data need to be placed in a clinical context as small but statistically significant differences may not impact outcomes in clinical applications. For example, shorter times to perform individual manipulations would presumably correlate with better clinical outcomes when performing OC-CPR; however, survival and recovery could not be evaluated in the present study.

The glove size (6.5) was the same for all evaluators, and all evaluators were right handed. This helped minimize variation between evaluators. However, because 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. Based on the presented results, it is expected that individuals with larger hands would likely prefer a 5th ICS thoracotomy. Further studies are necessary to evaluate the correlation between hand size and access to intrathoracic organs to see if there should be an alteration of technique to accommodate larger hands or left-handed operators.

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 some other limitations. Due to the limited number of available cadavers, some parameters (ease of grasping the phrenicopericardial ligament and ease of pericardial incision) could only be performed once, resulting in insufficient data collection for statistical analyses. Furthermore, to allow all evaluators to perform four pericardial incisions, it was essential for them to follow a fixed sequence of evaluation. Further studies with a larger sample size are needed to overcome these limitations. The allocation of cadavers with 4th and 5th ICS incisions to odd- and even-numbered surgery tables, respectively, may have introduced some bias; however, the evaluators were blind to table assignment, and the thoracotomy site was masked by a drape. Further, the evaluators may have achieved better proficiency with the manipulations over the course of the study, thus impacting their assessment of outcomes including the effect of shingling; however, given the basal skill set of the evaluators it is expected that any influence of repeated assessment on proficiency would have been similar among the 3 evaluators. Thawed cadavers with no apparent underlying disease may have been easier to manipulate than live dogs with underlying diseases, such as pericardial effusion and hemothorax and, hence, these data need to be interpreted in context. Furthermore, the adequacy of OC-CPR to achieve return of spontaneous circulation and other outcomes such as survival to discharge could not be assessed as this was a cadaver study. Studies with dogs in cardiopulmonary arrest are necessary to assess if the findings hold true in clinical practice.

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

ORCID

Anushri M. Warang BVSc & AH, MS https://orcid.org/0000-0002-6321-7800

F. A. Mann DVM, MS, DACVS, DACVECC https://orcid.org/0000-0001-6181-0216

John R. Middleton DVM, PhD, DACVIM https://orcid.org/0000-0003-0791-6604

ENDNOTES

* Crowe DT, Trauma Director, Regional Institute for Veterinary Emergencies and Referrals, Chattanooga, TN: personal communication, April 12, 2016.

† Nestle Purina Body Condition Score, Nestlé Purina PetCare, St. Louis, MO.

‡ Suretemp Plus, Welch Allyn, Skaneateles Falls, NY.

§ Sigmaplot 13.0, San Rafael, CA.

REFERENCES

1. Benson DM, O'Neil B, Kakish E, et al. Open-chest CPR improves survival and neurologic outcome following cardiac arrest. *Resuscitation*. 2005;64:209-217.
2. Hachimi-Idrissi S, Leeman J, Hubloue Y, et al. Open chest cardiopulmonary resuscitation in out-of-hospital cardiac arrest. *Resuscitation*. 1997;35:151-156.
3. Pust GD, Namias N. Resuscitative thoracotomy. *Int J Surg*. 2016;33(Pt B):202-208.
4. Voiglio EJ, Simms ER, Flaris AN, et al. Bilateral anterior thoracotomy (clamshell incision) is the ideal emergency thoracotomy incision: an anatomical study: reply. *World J Surg*. 2014;38:1003-1005.
5. Flaris A, Reynard F, Caillot J, et al. Clamshell incision versus left anterolateral thoracotomy. Which one is faster when performing a resusci-

tative thoracotomy? The tortoise and the hare revisited. *World J Surg*. 2015;39:1306-1311.
6. Vassiliu P, Yilmaz T, Degiannis E. On the ideal emergency thoracotomy incision. *World J Surg*. 2014;38:1001-1002.
7. MacPhail C, Fossum TW. Surgery of the lower respiratory system: lungs and thoracic wall. In: Fossum TW, ed. *Small animal surgery*. 5th ed. St. Louis, MO: Elsevier; 2019:8 .
8. Lawson DD. Thoracic surgery in the dog and cat. I. Indications and technique for thoracotomy. *J Small Anim Pract*. 1968;9:389-398.
9. Ohrt-Nissen S, Colville-Ebeling B, Lehnert P, et al. Indication for resuscitative thoracotomy in thoracic injuries—adherence to the ATLS guidelines. A forensic autopsy based evaluation. *Injury*. 2016;47:1019-1024.
10. Fletcher D, Boller M, Smarick S, et al. RECOVER evidence and knowledge gap analysis on veterinary CPR. Part 7: clinical guidelines. *J Vet Emerg Crit Care*. 2012;22(Suppl 1):S102-131.
11. Crowe DT. Cardiopulmonary resuscitation in the dog: a review and proposed new guidelines (Part I). *Semin Vet Med Surg (Small Anim)*. 1988;3:321-327.
12. Pratschke KM. CPR: what are the current recommendations?. *Veterinary Ireland Journal*. 2014;4:582-587.
13. Massalis I, Efthymiou G, Gkanas P, et al. Resuscitative thoracotomy after stab heart injury. Two cases of tamponade, managed in a rural hospital. *Epistīmonika Chronika*. 2017;22:91-97.
14. Robinson R, Seymour C, Chang Y, Pelligand L. Predictors of outcome in dogs undergoing thoracic surgery (2002-2011). *Vet Anaesth Analg*. 2014;41:259-268.

How to cite this article: Warang AM; Mann FA; Middleton JR; Wagner-Mann C; Branson K. Comparison of left 4th and 5th intercostal space thoracotomy for open-chest cardiopulmonary resuscitation in dogs. *J Vet Emerg Crit Care*. 2021;31:331–339. https://doi.org/10.1111/vec.13059