

Comparison of the amounts of air leakage into the thoracic cavity associated with four thoracostomy tube placement techniques in canine cadavers

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Objective—To compare the amount of air leakage into the thoracic cavity associated with each of 4 thoracostomy tube placement techniques in canine cadavers.

Sample Population—28 canine cadavers.

Procedures—Thoracostomy tube placement techniques (7 cadavers/technique) included subcutaneous tunneling with a silicone tube by use of Carmalt forceps or with a polyvinyl chloride tube by use of a trocar (SC-CARM and SC-TRO, respectively) and tunneling under the latissimus dorsi muscle with similar tube-instrument techniques (LD-CARM and LD-TRO, respectively). Differences in intrapleural pressures (IPPs) measured before and after tube placement and before and after tube removal were calculated; duration of air leakage around the tubes was assessed by use of a 3-chamber thoracic drainage system.

Results—Tunneling method and depth had no interaction effect on the difference in IPP measured before and after tube placement; the IPP difference for both forceps technique groups was significantly greater than findings for both trocar technique groups. Tunneling method and depth had an interaction effect on the difference in IPP measured before and after tube removal; compared with SC-TRO and LD-CARM group differences, the SC-CARM group difference was significantly greater, but the LD-TRO group difference was similar. More intermittent air leakage was associated with the 2 forceps techniques than with the 2 trocar techniques.

Conclusions and Clinical Relevance—Trocar-implemented thoracostomy tube placement in canine cadavers resulted in less air leakage than the forceps method. Air leakage upon tube removal was less pronounced for the LD-CARM technique than the SC-CARM technique. The LD-TRO technique is recommended to prevent iatrogenic pneumothorax in dogs. (*Am J Vet Res* 2009;70:1161–1167)

Thoracostomy tube placement is indicated for the management of severe pleural effusion that necessitates repeated pleural drainage and for the treatment of pneumothorax if air continues to accumulate despite evacuation of the thoracic cavity via needle thoracocentesis.^{1–4} Tube-associated pneumothorax can be a fatal complication of thoracostomy tube use.^{5,6} Pneumothorax may develop after thoracostomy tube placement as a result of tube mutilation by the patient, loosening of tube connections and adapters, or inadvertent extraction of the tube.^{5,7} Also, prevention of chronic leakage of air into the thoracic cavity along the tube tunnel and avoidance

ABBREVIATIONS

IPP	Intrapleural pressure
LD-CARM	Tunneling under the latissimus dorsi muscle with a silicone tube by use of Carmalt forceps
LD-TRO	Tunneling under the latissimus dorsi muscle with a polyvinyl chloride tube by use of a trocar
SC-CARM	Subcutaneous tunneling with a silicone tube by use of Carmalt forceps
SC-TRO	Subcutaneous tunneling with a polyvinyl chloride tube by use of a trocar

of iatrogenic pneumothorax during tube placement and removal are essential goals for successful usage of thoracostomy tubes.^{8,9}

Hemostatic forceps–assisted thoracostomy tube placement via a subcutaneous tunnel for the management of dogs and cats with pleural effusion or pneumothorax has been described.^{10–12} After incision of the skin in the dorsal third of the lateral thoracic wall at the level of the 11th intercostal space, a large curved forceps is used to create a tunnel through the subcutaneous tis-

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sues approximately 2 intercostal spaces in length; the forceps is clamped on the tip of a tube, passed through the subcutaneous tunnel, and thrust through underlying musculature into the pleural space.¹⁰⁻¹² An alternative technique for creating a subcutaneous tunnel has been reported.^{9,13} After incision of the skin, an assistant draws the skin of the thoracic region cranially to pull the skin opening forward over the intercostal space to be entered, which is typically 2 rib spaces cranial to the skin incision.^{9,13} With either of the aforementioned subcutaneous tunneling techniques, a specifically designed trocar thoracostomy tube is typically easier to manipulate than tubing attached to hemostatic forceps and is easily directed into the thoracic cavity once it has been inserted through the skin and thoracic cavity wall.¹⁴⁻¹⁶

A latissimus dorsi muscle tunneling technique can be used to provide an additional sealing layer for prevention of air leakage into the thoracic cavity when tubes are placed with large hemostatic forceps. The latissimus dorsi muscle tunneling technique can also be used for trocar-implemented thoracostomy tube placement.¹⁷ The thoracostomy tube placement technique that most effectively prevents air leakage around the tube or through the tunnel following extraction of the tube would provide the safest protection from tube-associated pneumothorax. To the authors' knowledge, there are no published data that indicate which of the commonly employed thoracostomy tube placement techniques is the most advantageous for use in dogs.

The purpose of the study reported here was to compare the amount of air leakage into the thoracic cavity associated with each of 4 thoracostomy tube placement techniques in canine cadavers. Our intent was to evaluate the amount of air leakage around tubes immediately after tube placement, during the period that the tube remained in the thoracic cavity, and along the thoracostomy tunnel immediately after tube removal for each of 4 thoracostomy tube placement techniques: the SC-CARM, SC-TRO, LD-CARM, and LD-TRO methods. We hypothesized that there would be no significant difference in air leakage among the 4 thoracostomy tube placement techniques.

Materials and Methods

Cadavers—Twenty-eight humane society-source cadavers (weight range, 15.0 to 25.0 kg) of dogs that were euthanized for reasons unrelated to the study were used. For each cadaver, sex was recorded and breed was estimated. No respiratory tract problems were evident in any of the dogs prior to euthanasia. Physical examination was performed on the cadavers to rule out evidence of blunt trauma; thus, no cadaver with thoracic injury was included in the study. Cadavers were preserved in a freezer^a at -20°C immediately after euthanasia, thawed at room temperature (24°C) for 72 hours, and kept in a cooler (4°C) for 24 hours. All cadavers were randomly assigned to 1 of the 4 technique groups.

Study procedures—Experiments were performed in 3 separate sessions; 8 cadavers were used in each of 2 experimental sessions, and 12 cadavers were used in 1 experimental session. Four thoracostomy tube place-

ment techniques were performed in each session (2 or 3 cadavers/technique). The techniques involved the use of 1 of 2 tube types. A commercially available polyvinyl chloride trocar thoracostomy tube^b (outer diameter, 8.0 mm) was used in 14 cadavers; this type of tube was placed via subcutaneous tunneling ($n = 7$) or tunneling under the latissimus dorsi muscle (7). A silicone tube^c (outer diameter, 7.95 mm) was used in the other 14 cadavers; this type of tube was placed via subcutaneous tunneling ($n = 7$) or tunneling under the latissimus dorsi muscle (7). In each silicone tube, 2 additional side holes were made, similar to holes present in the polyvinyl chloride trocar tube; these holes were no greater than a third of the diameter of the tube. All thoracostomy tubes were placed in the left thoracic wall entering the pleural cavity at the eighth intercostal space. The same surgeon (HY) placed all thoracostomy tubes in all cadavers. By use of 2 tube types and 2 tunneling techniques, 4 experimental groups (7 cadavers/group) were created—the SC-CARM, SC-TRO, LD-CARM, and LD-TRO technique groups.

SC-CARM and LD-CARM techniques—A stab incision was made by use of a No. 11 scalpel blade through the skin (SC-CARM technique) or through the skin and the latissimus dorsi muscle (LD-CARM technique) over the 11th rib in the region of the dorsal third of the left lateral thoracic wall. A curved Carmalt forceps was used to create a tunnel as wide as the width of the forceps through the subcutaneous tissues (SC-CARM technique) or under the latissimus dorsi muscle (LD-CARM technique) from the 11th rib to the 8th intercostal space in the middle third portion of the thoracic wall, and the Carmalt forceps was removed. The tip of a thoracostomy tube was grasped in the tip of the forceps with the tube parallel to the body of the instrument. The forceps bearing the thoracostomy tube was then passed through the subcutaneous tunnel (SC-CARM technique) or the tunnel under the latissimus dorsi muscle (LD-CARM technique) from the 11th rib to the 8th intercostal space. Once the tip of the forceps reached the eighth intercostal space, the forceps was raised perpendicular to the thoracic wall. The forceps bearing the thoracostomy tube was then firmly grasped at a distance of 1 to 2 cm from the body wall with one hand, while the other hand was used to push the forceps tip and thoracostomy tube through the thoracic wall musculature into the pleural space. Following entry of the thoracostomy tube into the pleural space, the Carmalt forceps was removed and the tube advanced in a cranioventral direction without resistance until the predetermined length of the tube to be inserted from the skin incision to the thoracic inlet was in place.

SC-TRO and LD-TRO techniques—A stab incision was made by use of a No. 11 scalpel blade through the skin (SC-TRO technique) or through the skin and latissimus dorsi muscle (LD-CARM technique) over the 11th rib in the region of the dorsal third of the left lateral thoracic wall. The trocar tube was then tunneled subcutaneously (SC-TRO technique) or under the latissimus dorsi muscle (LD-CARM technique) from the 11th rib to the 8th intercostal space in the middle third portion of the thoracic wall. Once the tip reached the

eighth intercostal space, the trocar tube was raised perpendicular to the thoracic wall. The trocar tube was firmly grasped 1 to 2 cm from the body wall with one hand, while the other hand was used to push the trocar tube through the thoracic wall musculature with 1 rapid motion. Following entry of the trocar tube into the pleural space, the trocar was withdrawn 1 cm to protect pleural cavity contents from trocar tip trauma, and the tube was advanced in a cranioventral direction without resistance until the predetermined length of the tube to be inserted from the skin incision to the thoracic inlet was in place. The trocar was removed when the tube reached the sternum to allow advancement to the thoracic inlet.

Completion of tube placement—For each placement technique, the length of the tube to be inserted was predetermined from the distance between the skin incision and the thoracic inlet; the tube was marked with an indelible marker to indicate the insertion length. After tube placement, a horizontal mattress suture of size-1 monofilament polybutester^d suture material was placed around the skin incision but left loose and untied (to be used later as a Rumel tourniquet after injection of air into the pleural cavity), and the tube was sutured to the skin and underlying fascia with 4 friction sutures of the same suture material.

Measurement of IPP—Cadavers were placed in right lateral recumbency. Before the thoracostomy tube was placed, a thoracocentesis catheter^e was inserted into the pleural cavity in the dorsal third portion of the left lateral thoracic wall through a small stab skin incision over the sixth intercostal space to measure IPP. A transducer^f was connected to a monitor^g and the thoracocentesis catheter by use of a 3-way stopcock^h to measure and record IPP. The transducer was positioned at the level of the table and zeroed with the 3-way stopcock opened to air and closed to the cadaver. Then the 3-way stopcock was opened to the cadaver, and the pressure value was recorded after the pressure on the monitor was stabilized (1 minute after manipulation). Intrapleural pressure was measured 5 times: before placement of the thoracostomy tube, after placement of the thoracostomy tube and its connection with a thoracic drainage unit, after injection of air through the thoracostomy tube into the pleural space, after manual evacuation of all air via the thoracostomy tube (all residual air was manually evacuated via the thoracostomy tube after bubbling stopped in the thoracic drainage system), and after removal of the thoracostomy tube.

Measurement of the duration of air leakage around tubes—Following placement, the thoracostomy tube was attached to a large Y-connectorⁱ; 1 part was connected to a 3-way stopcock to inject air, and the other part was connected to a commercial thoracic drainage system^j that was comprised of 3 chambers. The capillary tube of the water seal chamber was submerged 2 cm below the surface of the water level in the bottle. The capillary tube of the suction chamber was submerged 10 cm below the surface of the water level in the bottle and attached to a vacuum line via a regulator.^k A clamp^l placed on the line connected to the collection chamber was closed, and the Rumel-style mattress suture placed

around the skin incision was secured. Air was injected into the pleural cavity through the thoracostomy tube via the 3-way stopcock to mimic a pneumothorax. On the basis of data provided in a previous study,¹⁸ the volume of air injected into the pleural space was $1.75 \times 0.032 \times \text{body weight (in kg)}^{1.05}$ L.

The 3-way stopcock was locked after air injection, and the Rumel-style mattress suture placed around the skin incision and the clamp placed on the line connected to the collection chamber were released. The suction chamber was maintained at 10 cm H₂O to provide consistent suction, and the regulator was turned on. The interval from the onset of bubbling in the water seal chamber until the continuous bubbling in the water seal chamber stopped was measured by use of a stopwatch. If bubbling in the water seal chamber stopped, the chamber was observed for 2 minutes to detect whether bubbling recurred.

Statistical analysis—All data are expressed as mean \pm SD. A 1-way ANOVA was used to compare mean values of cadaver weights, the amounts of air injected, and the amounts of residual air among the 4 technique groups. Comparisons of IPP differences and durations of water seal chamber bubbling were performed by use of a 2-way ANOVA. For the dependent variables of IPP difference and duration of bubbling, tunneling method (a silicone tube positioned by use of Carmalt forceps or a polyvinyl chloride tube positioned by use of a trocar) and tunneling depth (subcutaneous or under the latissimus dorsi muscle) were evaluated for an interaction effect by use of a 2-way ANOVA. A Fisher exact test was performed to determine whether technique was independent of the presence of water seal chamber bubbling. Data analysis was performed by use of computer software.^m A value of $P \leq 0.05$ was considered significant for all comparisons.

Results

Cadavers—Fifteen male and 13 female canine cadavers were used in the study. Breeds represented within each technique group were as follows: SC-CARM, 6 mixed-breed dogs and 1 Australian Cattle Dog; SC-TRO, 6 mixed-breed dogs and 1 Pointer; LD-CARM, 5 mixed-breed dogs and 2 American Pit Bull Terriers; and LD-TRO, 6 mixed-breed dogs and 1 American Pit Bull Terrier. Mean \pm SD weight of the cadavers was 18.9 ± 3.1 kg, 19.6 ± 3.7 kg, 18.6 ± 2.6 kg, and 19.4 ± 3.5 kg in the SC-CARM, SC-TRO, LD-CARM, and LD-TRO technique groups, respectively. There was no significant ($P = 0.939$) difference in cadaver weight among the 4 groups.

Manipulation of thoracostomy tube—Compared with the use of a trocar, tubes that were grasped by Carmalt forceps were more difficult to manipulate to achieve introduction into the thoracic cavity. The resistance against introduction of a thoracostomy tube through the subcutaneous tunnel or under the latissimus dorsi muscle by use of forceps was greater than that encountered by use of the trocar, and comparatively more force was required to pop the forceps bearing the thoracostomy tube through the thoracic wall musculature into the pleural space.

Amount of air injected—Mean \pm SD amounts of air injected into the pleural space and mean amounts of residual air in the pleural space after evacuation of air via the thoracostomy tubes in the 4 technique groups were recorded (Table 1). Among the 4 groups, the amounts of air injected into the pleural space and amounts of residual air in the pleural space after evacuation of air via the thoracostomy tubes did not differ significantly ($P = 0.938$ and $P = 0.958$, respectively).

IPP data—Mean \pm SD IPPs for each technique group were determined before placement of the thoracostomy tube, after placement of the thoracostomy tube and its connection with a thoracic drainage unit, after injection of air through the thoracostomy tube into the pleural space, after manual evacuation of all air via the thoracostomy tube (all residual air was manually evacuated via the thoracostomy tube after bubbling stopped in the thoracic drainage system), and after removal of the thoracostomy tube (Table 2). Mean \pm SD differences between IPP values recorded before and after tube placement and before and after tube removal

were calculated for the 4 technique groups. Tunneling method and tunneling depth had no interaction effect ($P = 1.000$) on the difference between IPP values before and after thoracostomy tube placement. The differences in IPP values before and after thoracostomy tube placement in both the SC-CARM and SC-TRO technique groups did not differ significantly ($P = 0.249$) from differences in both the LD-CARM and LD-TRO technique groups. The differences in IPP values before and after thoracostomy tube placement were significantly ($P < 0.001$) greater in both the SC-CARM and LD-CARM technique groups, compared with differences in both the SC-TRO and LD-TRO technique groups.

In contrast, tunneling method and tunneling depth had an interaction effect ($P = 0.021$) on the difference between IPP values before and after thoracostomy tube removal. The difference in IPP values measured after manual evacuation of all air via the thoracostomy tube and after removal of the thoracostomy tube was greater in the SC-CARM technique group, compared with differences in the SC-TRO and LD-CARM technique groups ($P = 0.001$ and $P = 0.005$, respectively); how-

Table 1—Mean \pm SD amounts of air injected into the pleural space prior to thoracic drainage and amounts of residual air in the pleural space after completion of thoracic drainage in 28 canine cadavers that were each treated with 1 of 4 thoracostomy tube placement techniques (SC-CARM, SC-TRO, LD-CARM, or LD-TRO).

Variable	Technique				Total amount of air
	SC-CARM (n = 7)	SC-TRO (n = 7)	LD-CARM (n = 7)	LD-TRO (n = 7)	
Amount of injected air (mL)	1,231 \pm 215	1,276 \pm 255	1,209 \pm 179	1,267 \pm 241	1,246 \pm 213
Amount of residual air* (mL)	50 \pm 70	60 \pm 58	51 \pm 47	64 \pm 50	56 \pm 54

For either variable, there were no significant ($P > 0.05$) differences among technique groups.
*The thoracic cavity was manually evacuated via the thoracostomy tube after bubbling in the water seal chamber of the thoracic drainage system ceased.

Table 2—Mean \pm SD values of IPP (mm Hg) measured before and after tube placement, after injection of air into the thoracic cavity, and before and after tube removal in 28 canine cadavers that were each treated with 1 of 4 thoracostomy tube placement techniques (SC-CARM, SC-TRO, LD-CARM, and LD-TRO).

Variable	Technique				Mean
	SC-CARM (n = 7)	SC-TRO (n = 7)	LD-CARM (n = 7)	LD-TRO (n = 7)	
IPP value before placement of the thoracostomy tube	-5.7 \pm 0.7	-5.4 \pm 1.2	-4.8 \pm 1.3	-5.4 \pm 1.2	-5.4 \pm 1.1
IPP value after placement of the thoracostomy tube and connection of tube with a thoracic drainage unit	-2.8 \pm 1.0	-4.7 \pm 1.7	-1.4 \pm 1.3	-4.1 \pm 1.5	-3.2 \pm 1.8
Difference in IPP before and after tube placement*	-2.8 \pm 1.2	-0.7 \pm 0.9	-3.4 \pm 1.2	-1.2 \pm 1.6	-2.0 \pm 1.6
IPP value after injection of air through the thoracostomy tube into the pleural space	6.5 \pm 2.2	4.5 \pm 2.2	7.7 \pm 1.8	5.0 \pm 2.0	6.4 \pm 2.3
IPP value after manual evacuation of air via the thoracostomy tube	-5.2 \pm 2.4	-5.5 \pm 1.8	-5.0 \pm 1.8	-6.0 \pm 1.2	-5.4 \pm 1.8
IPP value after removal of the thoracostomy tube	-2.7 \pm 1.7	-5.1 \pm 1.3	-4.2 \pm 1.3	-5.7 \pm 0.9	-4.4 \pm 1.7
Difference in IPP values measured after manual evacuation of air via the thoracostomy tube and after tube removal†	-2.5 \pm 1.2	-0.4 \pm 0.7	-0.7 \pm 0.7	-0.2 \pm 0.7	-1.0 \pm 1.2

For each technique group, differences in IPPs measured before and after tube placement and before and after tube removal were calculated.
*For this variable, findings in both the SC-CARM and LD-CARM technique groups differ significantly ($P < 0.001$) from the findings in the SC-TRO and LD-TRO technique groups. †For this variable, value for the SC-CARM technique group differs significantly from the value for the SC-TRO and LD-CARM technique groups ($P = 0.001$ and $P = 0.005$, respectively).

ever, the IPP difference in the LD-TRO technique group did not differ significantly from the differences in the LD-CARM and SC-TRO technique groups ($P = 0.819$ and $P = 0.991$, respectively).

Measurement of the duration of air leakage around tubes—Mean \pm SD interval between onset of water seal chamber bubbling immediately after thoracostomy tube placement and injection of air and cessation of continuous bubbling were calculated for each technique group. The duration of bubbling in the SC-CARM, SC-TRO, LD-CARM, and LD-TRO technique groups was 41.0 ± 10.1 seconds, 27.2 ± 8.1 seconds, 37.2 ± 10.3 seconds, and 30.1 ± 8.6 seconds, respectively. The mean duration for all 4 technique groups was 33.9 ± 10.4 seconds. Tunneling method and tunneling depth had no interaction effect ($P = 0.363$) on duration of bubbling. Bubbling duration in both the SC-CARM and SC-TRO technique groups did not differ significantly ($P = 0.905$) from findings in both the LD-CARM and LD-TRO technique groups. However, bubbling duration in both the SC-CARM and LD-CARM technique groups was significantly ($P = 0.007$) longer than that in both the SC-TRO and LD-TRO technique groups.

In 3 cadaver experiments in the SC-CARM group and 1 cadaver experiment in the LD-CARM group, intermittent bubbling was detected at 7, 4, 5, and 4 seconds after the continuous bubbling endpoint respectively, and continued until the thoracic drainage unit was turned off in preparation for the next step in the experiment. No intermittent bubbling was detected in any cadaver experiment in the SC-TRO or LD-TRO technique groups. While the tube remained in the thoracic cavity, significantly ($P = 0.049$) more intermittent bubbling after the continuous bubbling endpoint occurred in both the SC-CARM and LD-CARM technique groups, compared with findings in both the SC-TRO and LD-TRO technique groups.

Discussion

On the basis of results of the present study to assess thoracostomy tube placement techniques in cadaveric dogs, the use of a trocar appears to be more effective than the use of Carmalt forceps in preventing air leakage around the thoracostomy tube during placement and during the period that the tube remains in the thoracic cavity and along the thoracostomy tunnel after tube removal. Additionally, with regard to prevention of air leakage when the tube is removed, the use of Carmalt forceps to tunnel under the latissimus dorsi muscle for tube placement was more effective than the use of that forceps to tunnel subcutaneously for tube placement. Of the 4 thoracostomy tube placement methods evaluated, the LD-TRO technique was the best technique with which to prevent iatrogenic pneumothorax.

Both the use of a trocar and the use of Carmalt forceps for thoracostomy tube placement have advantages and disadvantages. Compared with the techniques involving Carmalt forceps, the techniques involving the trocar were easier to perform and caused less tunneling trauma; it was easier to evaluate positioning of the trocar radiographically because of the presence of a radiopaque line on the polyvinyl chloride tube. However,

the sharp tip of the trocar could cause trauma to lung and cardiac structures if care is not exercised during placement. A Carmalt forceps method involves comparatively less expensive tubing, which may be more readily available to most practicing veterinarians, but causes more thoracic wall trauma during placement than does a trocar method.^{5-7,9}

The 4 techniques evaluated in the present study differed with regard to the number of layers that provided an airtight seal, the method of tunneling, and the equipment used for tunneling. Of the techniques, SC-CARM and LD-CARM were least able to prevent air leakage during tube placement. The use of Carmalt forceps created a tunnel larger than that created by use of the trocar tube because the diameter of the tunnel created by the trocar tube is the diameter of the tube itself, whereas the Carmalt forceps grasping a tube creates a tunnel that is wider than the diameter of the tube. Additionally, tubing attached to hemostatic forceps is more difficult to manipulate for introduction of the tube into the thoracic cavity, compared with placement of a trocar tube. A Carmalt forceps-tube combination has a dull tip and irregular shape (the tube protrudes out of the forceps), which necessitates more forceful introduction into the thoracic cavity than that associated with a trocar tube that has a sharp tip and regular tubular shape. The facts that the use of Carmalt forceps created a tunnel that was larger than the tube diameter and was associated with difficulty of tube manipulation likely contributed to the greater IPP differences for the SC-CARM and LD-CARM techniques, compared with the IPP differences for the SC-TRO and LD-TRO techniques.

Compared with the 2 trocar techniques, both Carmalt forceps techniques in the present study resulted in more air leakage during the period that the tube remained in the thoracic cavity. To assess air leakage, the duration of bubbling in the water seal chamber of a 3-chamber thoracic drainage device that was connected to the thoracostomy tube after placement was monitored, and the occurrence of intermittent bubbling after the study endpoint (ie, cessation of continuous bubbling) was recorded for each placement technique. The duration of bubbling was comparatively longer in the SC-CARM and LD-CARM technique groups, and intermittent bubbling was evident only in cadaver experiments in those groups. Baseline IPPs before evacuation of the thoracic cavity differed because the amounts of air introduced into the thoracic cavity in and around the tube, both during and after tube placement, were different among the 4 techniques. Greater volumes of air were introduced during tube placement with the Carmalt forceps techniques than with the trocar techniques. Thus, the interval before continuous bubbling ceased was longer with the Carmalt forceps techniques. The intermittent bubbling that occurred later in some of the SC-CARM and LD-CARM cadavers may have been caused by air trapped between lung lobes in the thoracic cavity; however, air leakage around tubes seems to be the most plausible explanation because intermittent bubbling continued until the thoracic drainage unit was turned off in preparation for the next stage in the cadaver experiments.

Ordinarily, a true intrapleural space does not exist in mammals, and the lungs occupy all parts of the thoracic cavity.¹⁹ In the present study, residual air was detected in the thoracic cavities of all 28 cadavers after evacuation of air via the thoracostomy tubes by use of a thoracic drainage system. This residual air in the cadavers might have been attributable to the absence of thoracic wall movement and the inability of lungs to inflate, and residual intrapleural air may not be present in live dogs that are capable of lung inflation and active thoracic wall movement. However, to evacuate residual air that may be present in live dogs that have undergone thoracostomy tube placement, manual evacuation or higher-pressure continuous suction at regular intervals should be considered after performing continuous suction with a thoracic drainage system.

During tube removal, less air leakage was associated with the SC-TRO and LD-CARM techniques, compared with that associated with the SC-CARM technique; however, air leakage associated with the LD-CARM and LD-TRO techniques did not differ. The technique involving tunneling under the latissimus dorsi muscle provides multiple layers (skin, subcutaneous tissue, and muscle) that act as a seal around the thoracostomy tube, whereas the technique of tunneling subcutaneously provides a 1-layer (skin) seal. The multiple sealing layers likely contributed to the smaller difference between IPP values before and after thoracostomy tube removal in the LD-CARM technique group, compared with the IPP difference in the SC-CARM technique group. It is possible that the multiple layers of the latissimus dorsi muscle tunneling method may provide a sufficiently airtight seal even when a large tunnel is made by use of Carmalt forceps.

In clinical situations, it may not be important which technique is associated with a greater difference in IPP before and after placement of the thoracostomy tube if the IPP after placement of the thoracostomy tube is stable; likewise, it may not be clinically important which technique is associated with a longer interval from onset to cessation of bubbling if the bubbling eventually stops, because air that leaks into the thoracic cavity can be evacuated through the thoracostomy tube. However, it is important which technique is associated with a greater difference in IPP values measured after manual evacuation of all air via the thoracostomy tube and after removal of the thoracostomy tube because once a thoracostomy tube is removed, air that is introduced inadvertently into the thoracic cavity may need to be evacuated by other means.²⁰ Thus, prevention of inadvertent introduction of air is likely more important during thoracostomy tube removal than it is during thoracostomy tube placement and during the period that the tube remains in the thoracic cavity, as long as IPP after placement of the thoracostomy tube is stable and the water seal bubbling ceases. In humans, pneumothorax after thoracostomy tube removal has accounted for 27% of reported complications, and diagonal subcutaneous tunneling for tube insertion has been recommended to decrease the chance of air entry into the pleural space during tube removal.^{20,21}

A major anatomic consideration for the technique of tunneling under the latissimus dorsi muscle is that

one must ensure that the stab incision penetrates the latissimus dorsi muscle. Penetration of the latissimus dorsi muscle can be verified by observation of the cut edge of muscle. Thick subcutaneous fat may obscure the view, but gentle retraction of the fat with the edge of the scalpel or by grasping the cut edge of the latissimus dorsi muscle with a thumb forceps can facilitate verification.

Two limitations of the present study were the different tissue characteristics of frozen-thawed cadavers and live tissues and the possibility that a silicone tube guided into position with Carmalt forceps could have become kinked during placement. Under normal circumstances, there is a constant tendency for the lungs in cadavers to collapse because the lungs recoil inward from the thoracic wall even after death. The elastic recoil results in a vacuum, thereby creating negative pressure in the thoracic cavity after death regardless of whether oncotic and hydrostatic pressures still exist.^{19,22} In the present study, mean IPP measured in all canine cadavers before thoracostomy tube placement was -5.4 ± 1.1 mm Hg. Interestingly, this IPP value—presumably created by vacuum pressure that resulted from elastic recoil in the cadavers—was similar to the mean baseline IPP (-5 mm Hg) created by oncotic and hydrostatic pressures in anesthetized dogs.^{23,24} Freezing and thawing of cadavers might have resulted in more fragile lung parenchyma, which was more susceptible to minor trauma than fresh lung parenchyma; however, because there are no lung and thoracic wall movements in cadavers, the lung parenchyma was not likely a source of air that was evacuated from the thoracic cavity unless airways such as trachea, bronchi, or bronchioles were traumatized. The cadavers were fairly uniform in weight (15 to 25 kg), and all were frozen at the same temperature immediately after euthanasia; thawing of all cadavers occurred at the same temperature and for the same amount of time. The conditions of the cadavers had been patterned after those in a previous cadaveric study²⁵ and were consistent to minimize variability in the compliance of the thoracic cavity and diaphragm. It is possible that the nature of cadaveric subcutaneous tissues and muscles may have resulted in more air leakage than would have occurred in live dogs. We assumed that the tubes in the cadavers of the SC-CARM and LD-CARM technique groups were not kinked during tube placement because air was readily evacuated via all tubes upon application of the thoracic suction unit without pause in water seal chamber bubbling and because no tube was found to be kinked during its removal.

- a. Frigidaire, Electrolux Home Products, Augusta, Ga.
- b. Argyle trocar catheter, Covidien Animal Health and Dental Division, Mansfield, Mass.
- c. Bio-sil, Sil-med Corp, Taunton, Mass.
- d. Novafil, Covidien Animal Health and Dental Division, Mansfield, Mass.
- e. TURKEL safety thoracocentesis system, Covidien Animal Health and Dental Division, Mansfield, Mass.
- f. Argon, Argon Medical Devices Inc, Athens, Tex.
- g. MDE Escort, ACE Medical Equipment Inc, Clearwater, Fla.
- h. SolutionPlus 3-way stopcock, Covidien Animal Health and Dental Division, Mansfield, Mass.
- i. Nalgene Y-connector, Consolidated Plastic Co Inc, Twinsburg, Ohio.

- j. Thora-Seal III, Covidien Animal Health and Dental Division, Mansfield, Mass.
- k. Vacutron, Allied Healthcare Products, St Louis, Mo.
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