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Assessment of How Practical a Transdiaphragmatic Route Is for Performing Lung Lobectomy in Canine Patients

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ABSTRACT

Treatment of certain pulmonary conditions may require removal of part or all of a lung lobe. This study investigated two approaches for caudal lung lobectomy in dogs: the standard lateral thoracotomy (LT) and an alternative transdiaphragmatic (TD) method. The TD and LT techniques were performed on 18 canine cadavers, with the order of procedures and the operating surgeon randomized. To evaluate both methods, data were collected on operative duration, proportion of lobe resected, incision size, and any procedure-related tissue damage. Surgical time for the TD approach averaged 1155 ± 232.8 seconds, which did not differ significantly from the LT approach (1126.8 ± 180.6 seconds; p = 0.6131). The TD approach allowed removal of 25.83 ± 8.95% of the caudal lobe (range: 10.55–40.72%), while the LT approach achieved complete (100%) lobe excision. No notable differences were found in terms of iatrogenic injury between the two approaches. As an ex vivo study with three surgeons involved, results may not fully reflect in vivo conditions, and no leak testing was performed after lobectomy. The TD route offers a feasible alternative for partial caudal lung lobectomy in dogs, achieving comparable safety and operative time to the conventional LT method.

Keywords: Transdiaphragmatic lung lobectomy, Surgery, Canine, Lung, surgery

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Introduction

Pulmonary lobectomy, involving either the complete or partial removal of a lung lobe, is a key surgical intervention for managing various lung diseases in dogs [1, 2]. In veterinary surgery, several thoracic approaches have been developed to perform this procedure. Among these, intercostal thoracotomy is commonly employed, providing direct access to the hemithorax and mediastinum [3, 4]. However, this approach is frequently associated with postoperative discomfort, largely due to potential compression of intercostal nerves from closure sutures [5, 6].

An alternative is median sternotomy, which permits visualization of both thoracic cavities through a single incision [4, 7]. Despite this advantage, its use is limited because of a higher complication rate (17–78%) relative to intercostal thoracotomy [7]. Minimally invasive techniques, including thoracoscopy and video-assisted thoracoscopic surgery (VATS), are increasingly utilized in human medicine to reduce surgical trauma and enhance recovery [8], with similar benefits reported in veterinary practice [9–11].

The transdiaphragmatic (TD) approach, first reported by Fingeroth and Birchard [12], has shown potential for reduced morbidity and improved access to the caudal thorax [13]. In canine models, this approach has been applied in diverse procedures, such as cardiopulmonary resuscitation [14], pacemaker implantation [12, 15, 16], pericardectomy [13], porto-azygous shunt attenuation [17], thoracic duct ligation [18], and retrieval of foreign bodies migrating from the stomach or duodenum [19]. The ventral midline route may also be technically less demanding due to broader clinical familiarity [14].

This study aimed to investigate whether a TD approach via celiotomy could serve as a feasible alternative to conventional intercostal thoracotomy for performing partial caudal lobectomies in dogs. We hypothesized that this approach would enable successful lobectomy without increasing operative time or causing additional trauma to surrounding tissues.

Materials And Methods

Eighteen fresh canine cadavers weighing 15.3–39.2 kg, euthanized for unrelated reasons, were used. Three veterinarians participated: a board-certified surgeon and two surgical residents. Each cadaver was randomly assigned to a surgeon, and the sequence of TD and LT procedures as well as the targeted caudal lobe was determined randomly using https://www.random.org. Each surgeon performed six TD and six LT procedures.

To measure the proportion of the lobe resected with the TD method, a complete caudal lobectomy was subsequently performed using an intercostal approach. All lobectomies were carried out with a thoracoabdominal linear stapler (Linear Stapler LS6035, Aesculap) using a blue cartridge (60 mm × 3.5 mm; Linear Staple Cartridge LSC6035). Operative time and incision length were recorded using a stopwatch and metric ruler, and a cross-stitched plastic template was used to determine the area of resected lung tissue. Three intervals were noted: T1, from skin incision to lobectomy completion; T2, from first suture placement to skin closure; and Tt, the sum of T1 and T2.

To replicate conditions similar to live surgery, cadavers were intubated via tracheostomy, and lungs were inflated manually to maintain a mean pulmonary pressure of 10–20 cm H_2O, measured with a digital manometer (TL100 Digital Manometer Handheld, SEAFRONT) **(Figure 1)** [14].

Figure 1. Manual Pump Device for Maintaining Pulmonary Pressure

Transdiaphragmatic (TD) surgical technique

In accordance with the method described by Jack *et al.* [14], cadavers were placed on their backs. A ventral midline incision was initiated approximately 2 cm above the xiphoid process and extended caudally to reach at least half the midline length, using a number 23 scalpel. The xiphoid and underlying linea alba were exposed, and the cranial linea alba was lifted to allow entry into the abdominal cavity with a reversed scalpel blade, mimicking a standard celiotomy. The abdominal wall incision was then carefully lengthened caudally with Mayo scissors to correspond with the skin incision.

The cranial portion of the incision was further extended along the right side of the xiphoid toward the ventral aspect of the ninth right rib. The falciform ligament was excised to improve access, and a Balfour retractor was positioned cranially to enhance visualization of the cavity. A diaphragmatic incision was made near the sternum using a number 11 scalpel to minimize risk to the lungs and heart, then extended circumferentially with scissors toward the side of the intended lobectomy.

An assistant provided gentle retraction to expose the caudal lung lobe. Using a surgical stapling device, the maximal portion of the lobe accessible through this approach was excised **(Figure 2)**. The diaphragm was repaired using a continuous simple suture, and the abdominal wall was closed in three layers according to standard surgical practice.

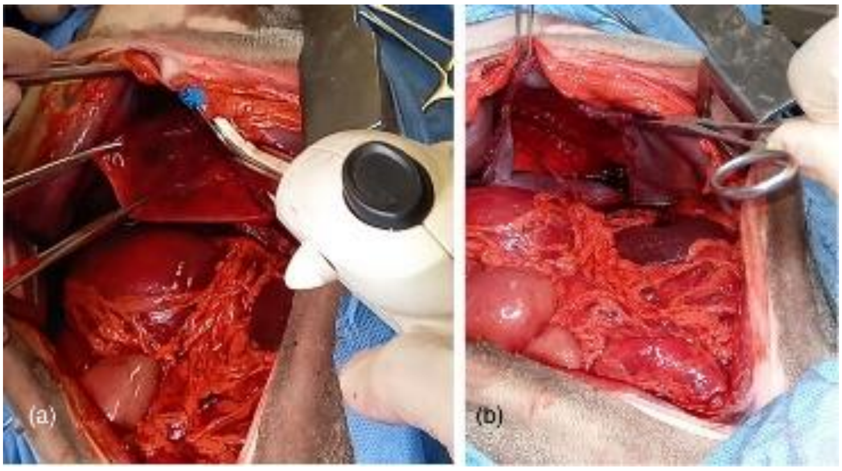

Figure 2. (a) Thoracoabdominal linear stapler for partial lung lobectomy via the transdiaphragmatic approach. (b) Residual left caudal lobe following lobectomy

Lateral Thoracotomy (LT) procedure

For the LT approach, cadavers were placed in lateral recumbency. The sixth intercostal space was chosen as the standard access site, determined by palpating cranially from the 12th intercostal space [1, 20]. A skin incision over the target rib space was made using a number 23 scalpel, followed by careful dissection through the latissimus dorsi and serratus ventralis muscles with Metzenbaum scissors.

The external and internal intercostal muscles of the sixth space, together with the pleura, were then incised. To facilitate access, a Farabeuf retractor provided proximal traction, while a Finochietto retractor expanded the space cranially and caudally. The caudal lung lobe was freed by dividing its pulmonary ligament along the medial edge, from the hilum to the mediastinal pleura.

A total caudal lobectomy was completed using a linear stapling device following Monnet's method [4] **(Figure 3)**. The thoracic wall was reconstructed with circumcostal sutures, and closure of the muscle layers, subcutaneous tissue, and skin was completed in a simple continuous pattern.

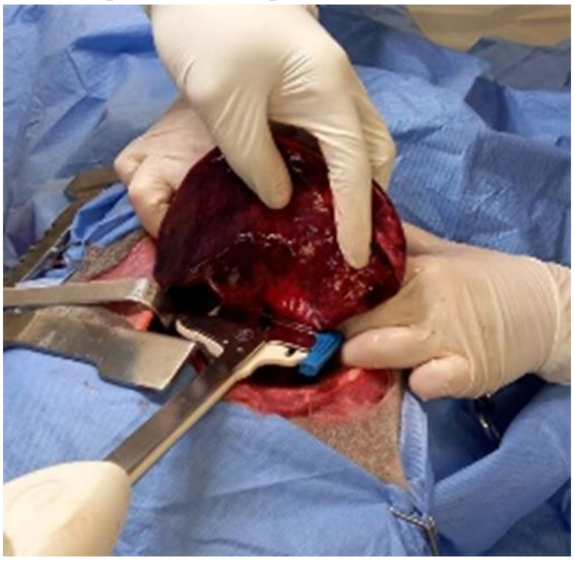

Figure 3. Complete caudal left lung lobectomy via lateral thoracotomy

During all procedures, research assistants closely observed each cadaver and recorded key parameters for both techniques. These included the duration from skin incision to completion of the pulmonary lobectomy, the interval from the first suture placement to final skin closure, and the total operative time. Additionally, incision length, the proportion of the lobe resected **(Figures 4 and 5)**, and any iatrogenic injuries were documented. Although formal lung leak testing was not performed, potential tissue damage was assessed visually, including lacerations on the lungs or liver, injury to major blood vessels, and any other surgical trauma.

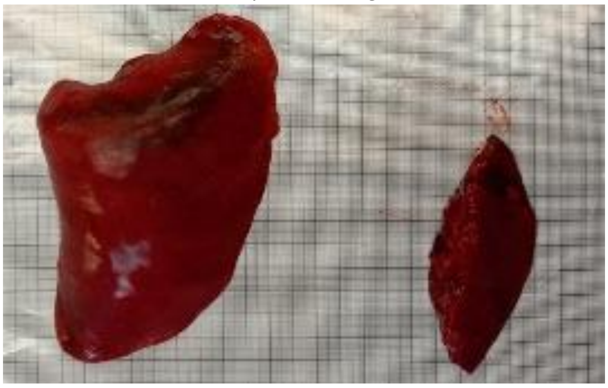

Figure 4. Comparison of the resected caudal lung lobe area in canine cadavers using lateral thoracotomy (left) versus the transdiaphragmatic approach (right)

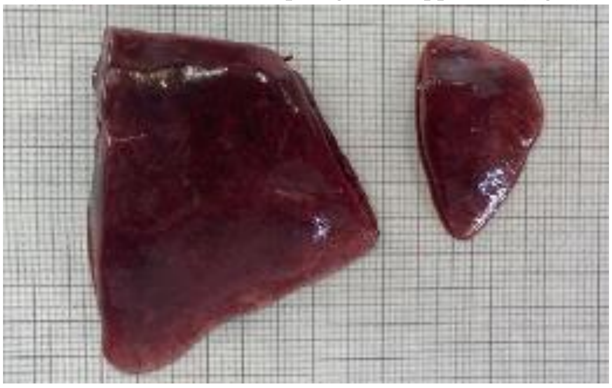

Figure 5. Surface area of the lung lobe removed via the transdiaphragmatic approach (right) compared with the remaining lobe tissue (left)

Statistical analysis

To evaluate whether the TD approach was non-inferior to LT in terms of mean operative time, a non-inferiority margin of 60 seconds was set, based on the study by Jack *et al.* [14]. An initial power analysis for the first six procedures (two per surgeon) using this margin, with α = 0.05 and 80% power, indicated that at least 17 cadavers were necessary to demonstrate statistical non-inferiority.

All results are reported as mean ± standard deviation (SD) and range for the TD and LT procedures performed on canine cadavers. Comparisons among the three surgeons were made using ANOVA followed by the Duncan test. Surgical duration data were tested for normality with the Shapiro–Wilk test, and either Student's t-test or a rank-based test was applied to compare TD and LT. Descriptive analyses were conducted to compare operative time, incision length, and percentage of the lobe resected, including evaluation of differences between right- and left-sided TD procedures. Microsoft Excel 2016 (Office 16, Microsoft) was used for descriptive statistics, while all other analyses were performed using SAS 9.4 (SAS Institute).

Results

Eighteen fresh canine cadavers (mean weight 25.13 kg, SD 5.29, range 15.3–39.2 kg) were included, and both TD and LT procedures were completed on each cadaver without exclusions. At a 95% confidence level, no significant differences in any measured time intervals were observed among the three surgeons. Overall, operative times for TD (1155.0 ± 232.8 s; range 817.8–1755.0) and LT (1126.8 ± 180.6 s; range 753.6–1627.8) were not significantly different ($p = 0.6131$). The upper 95% confidence limit for the mean difference between TD and LT was 47 seconds, below the predefined 60-second non-inferiority threshold, indicating that the TD approach is non-inferior to LT **(Table 1)**.

Table 1. Comparison of variables for both of the pulmonary lobectomy techniques

Variable	TD			LT			p-Value
	Mean	SD	Range	Mean	SD	Range	
T1	390.0	92.4	259.8–567.0	465.6	129.0	303.0–820.0	0.0432
T2	765.0	168.6	459.0–1188.0	660.6	162.6	456.0–1203.0	0.0243
Tt	1155.0	232.8	817.8–1755.0	1126.8	180.6	756.3–1627.8	0.6131
Incision length	20.99	2.1	17.5–25.5	19.73	1.84	16.5–23.9	0.0170

Abbreviations: LT= lateral thoracotomy; SD= standard deviation; TD= transdiaphragmatic; Tt= total time spent; T1= time interval between skin incision and completion of pulmonary lobectomy; T2= time interval between the placement of the first suture and complete skin closure.

The interval from skin incision to completion of pulmonary lobectomy (T1) was significantly longer for the LT procedure (465.6 ± 129.0 s; range 303.0–820.0) compared with the TD approach (390 ± 92.4 s; range 259.8–567.0) (p = 0.0432) **(Table 1).** Conversely, the period from first suture placement to complete skin closure (T2) was longer for TD (765 ± 168.6 s; range 459.0–1188.0) than for LT (660.6 ± 162.6 s; range 456.0–1203.0) (p = 0.0243) **(Table 1)**. The average length of the skin incision was also greater for TD (20.99 ± 2.1 cm; range 17.5–25.5) compared to LT (19.73 ± 1.84 cm; range 16.5–23.9) (p = 0.0170) **(Table 1)**.

Through the TD approach, an average of 25.83% (± 8.95; range 10.55–40.72) of the caudal lung lobe was removed, whereas LT consistently allowed complete resection of the lobe. No significant differences were observed in the percentage of lobe removed during TD based on the side of the hemithorax approached (p = 0.7900). Diaphragmatic lacerations occurred in 2 of 18 cadavers (11.1%) during TD, both caused by the use of scissors to enlarge the diaphragmatic incision, and were repaired successfully. No iatrogenic injuries were noted during LT.

Discussion

To our knowledge, this study represents the first comparison of two thoracic approaches for pulmonary lobectomy in canine cadavers. Although the power analysis indicated that 17 cadavers would have been sufficient to detect meaningful differences, an additional cadaver was included so that each surgeon could perform six procedures of each type.

While statistically significant differences were observed for T1 and T2 between the two approaches, total operative time did not differ. A non-inferiority test was applied to confirm that TD was not inferior to LT, using a 60-second margin based on Jack *et al.* [14]. The original study had used 30 seconds for open-chest cardiopulmonary resuscitation; our margin was doubled to account for the longer and less urgent nature of lobectomy procedures. The upper 95% confidence limit for the mean difference was 47 seconds, confirming that TD is non-inferior to LT.

The shorter T1 observed with TD (390 ± 92.4 s) compared with LT (465 ± 129 s) may reflect the more complex thoracic dissection required in the intercostal approach, whereas surgeons may be more familiar with ventral abdominal access, even when combined with a diaphragmatic incision. The longer T2 for TD (765 ± 168.6 s vs. 660.6 ± 162.6 s) likely reflects the additional time required for diaphragmatic closure.

The TD technique permitted removal of only about a quarter of the caudal lobe, highlighting a major limitation compared with LT, which allows both partial and total lobectomy. TD may therefore be suitable primarily for lesions in the apical region or for conditions amenable to partial lobectomy, such as localized lung perforations, small foreign bodies, or bullae. Preoperative imaging is thus critical for selecting appropriate cases for this approach.

Although prior studies have suggested a higher risk of iatrogenic lung injury with LT due to proximity of the lung to the chest wall [14], no such injuries were observed in our study. This contrasts with previous human and veterinary reports, where iatrogenic lung damage occurred in 28.6–36% of cases [14, 21].

During the TD approach, potential complications include unintended injury to structures within both the thoracic and abdominal cavities. In the present study, only two minor diaphragmatic tears occurred, both resulting from cranial and paraxiphoid enlargement of the abdominal incision; these were successfully repaired without further issues. No lung injury was observed, consistent with the findings of Jack *et al.* [14]. Unlike their study, which reported liver damage in 21.4% of cases, no hepatic injury occurred in any of our procedures.

In contrast, LT has been associated with several complications, including postoperative pain, lameness, rib fractures, and pulmonary trauma [3, 14, 22]. Preservation of musculature during LT has been shown to reduce postoperative discomfort [5, 22], whereas circumcostal sutures used for thoracic closure can contribute to nerve entrapment and pain [6]. In this study, the latissimus dorsi was not preserved because postoperative pain was not evaluated and its impact on other outcomes was expected to be minimal.

Minimally invasive alternatives such as thoracoscopy and video-assisted thoracoscopic surgery (VATS) have been developed to reduce surgical trauma and facilitate recovery [11, 23–26], though they are technically more challenging and costlier [9–11].

The TD approach has previously been applied in both veterinary and human medicine for accessing intrathoracic structures. In animals, it has been successfully used for cardiopulmonary resuscitation [14], pacemaker implantation [12, 15, 16], pericardiectomy [13], lung biopsies in rabbits [27], porto-azygous shunt attenuation [17], chyle cisterna ablation [28], and thoracic duct ligation [18]. Calvo *et al.* [29] combined TD with caudal sternotomy to remove a foreign body migrating from the stomach to the heart.

Grass awn foreign bodies frequently migrate into the caudal lung lobes, with reported rates of 82.5% and 90.9% [30, 31]. In such cases, the TD approach may be advantageous for accessing apical lesions, allowing simultaneous exposure of the caudal thorax and abdomen through a single incision. This reduces the need for dual thoracic and abdominal procedures, thereby potentially decreasing morbidity, recovery time, hospitalization, costs, and postoperative pain [20, 32].

However, the TD approach has limitations, including restricted access to portions of the caudal lobe and potential cross-contamination between thoracic and abdominal cavities, which could theoretically increase the risk of surgical site infection [14]. To date, no clinical reports of these complications exist.

This study has inherent limitations associated with ex vivo models. Pulmonary leak testing was not performed, as the aim was to assess the feasibility of the TD approach rather than validate stapling efficacy. Additionally, the pulmonary ligament was left intact in the TD approach, unlike LT, where transection is required to mobilize the lobe [4]. Future research should explore whether ligament transection could increase the amount of lung tissue resected. Despite these constraints, all three surgeons successfully completed the TD procedure without major difficulties, even though they had no prior experience with this approach.

To our knowledge, this is the first study directly comparing TD with LT for caudal lung lobe access. Our findings support the non-inferiority of TD regarding operative time and show that partial caudal lobectomy can be performed safely in cadavers weighing 15.3–39.2 kg, with minimal risk of iatrogenic injury.

In conclusion, the TD approach appears to be a viable technique for performing partial right or left caudal pulmonary lobectomies in canine cadavers. Nevertheless, additional studies are required to assess its safety and efficacy in live animals before clinical implementation.

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Conflict of Interest: None

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