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CLINICAL RESEARCH

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Evaluation of a knotless barbed suture for canine total lung lobectomy: An ex vivo study

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Abstract

Objective: To compare leakage pressure and ligation time of bronchial sealing using barbed sutures, stapling devices, or traditional sutures during total lung lobectomy in dogs.

Study design: Experimental ex vivo study with randomized order of procedures.

Sample population: A total of 30 lung lobes from five canine cadavers weighing 10–13 kg.

Methods: The lobe samples were randomly allocated to the stapling device (ST), traditional suture ligation (TR), or barbed suture ligation (BA) group ($n = 10$ each). Bronchial ligation time was recorded for each procedure. Each bronchial stump was tested for air leakage for pressures up to 80 cmH_2O.

Results: The median air leakage pressure was 45.0 cmH_2O (range: 30.0–80.0) for the ST, 47.5 cmH_2O (range: 36.0–80.0) for the TR, and 57.5 cmH_2O (range: 25.0–80.0) for the BA ($p = .36$). No group showed leakage at physiological airway pressures (< 20 cmH_2O). At pressures up to 80 cmH_2O, leakage was observed in nine of 10 bronchial stumps in the ST, eight of 10 in the TR, and six of 10 in the BA ($p = .43$). The mean bronchial ligation time was 2.4 ± 0.5 min for the ST, 14.1 ± 3.4 min for the TR and 10.7 ± 1.6 min for the BA ($p < .01$).

Conclusion: Barbed sutures for bronchial closure provided comparable leakage pressure to stapling devices and traditional sutures and reduced suturing time compared to traditional sutures.

Clinical significance: Barbed suture ligation might be a viable alternative for canine total lung lobectomy.

1 | INTRODUCTION

In veterinary medicine, total lung lobectomy is primarily performed for treating conditions such as neoplasia, blebs, bullae, abscesses, trauma, lobe torsion, and bronchoesophageal fistula.[1,2] It is typically achieved through open thoracotomy or minimally invasive surgery, such as thoracoscopy or video-assisted thoracic surgery (VATS).[3]

Linear staplers, commonly used for en bloc ligation of the lung hilum, reduce surgery duration and facilitate rapid skill acquisition relative to suture ligation of the pulmonary bronchus and vessels separately.[1,4] However, as they are designed for human use, staplers are occasionally inadequate for veterinary patients or VATS due to the relatively smaller size of the thoracic cavity.[2,5–7] Additionally, conditions such as tumor invasion, bronchial wall calcification, or hilar lymphadenopathy at the lobectomy site may necessitate manual suturing instead of stapling.[6,8]

Knotless barbed sutures, designed to enhance tissue apposition and evenly distribute tension along the suture line, have demonstrated significant advantages in minimally invasive procedures.[9–16] Numerous studies have investigated the applications of barbed sutures in veterinary practice, including for skin wound closure, tracheal anastomosis, gastrointestinal surgery, cystotomy, and diaphragmatic herniorrhaphy.[10,17–22]

When manual suturing is required, barbed sutures, which self-anchor within tissues and eliminate the need for knots, reduce the need for assistance and decrease the technical demands in confined thoracic spaces. These benefits are particularly relevant in minimally invasive procedures and in cases where staplers are impractical due to high cost or anatomical constraints. Nevertheless, the effectiveness of barbed sutures for bronchial ligation during total lung lobectomy has not previously been studied. Thus, the current study aimed to assess the leakage pressure and ligation time of bronchial sealing with knotless barbed sutures in comparison with stapling devices and traditional sutures in canine cadavers. We hypothesized that knotless barbed sutures would achieve a leakage pressure comparable to that of stapling devices and traditional sutures while reducing the time required for bronchial closure compared to traditional sutures.

2 | MATERIALS AND METHODS

2.1 | Cadaver preparation

Five adult mongrel-breed canine cadavers were acquired from a local animal shelter. All dogs were euthanized according to the shelter's standard protocol for reasons unrelated to the study. The euthanasia was conducted in accordance with the humane methods recommended by the American Veterinary Medical Association (AVMA). No live animals were used in this study; therefore, Institutional Animal Care and Use Committee (IACUC) approval was not required. The shelter had legal custody of the animals, and no owner consent was needed for the use of the cadavers in this research. After euthanasia, the cadavers were transported to our facility and stored at −70°C in a deep freezer for a maximum duration of 2 weeks. The cadavers were thawed at room temperature for 24–48 h prior to the experiment. All experimental trials were conducted within 5 h.

Intact respiratory tracts, extending from the tongue, larynx, and trachea to the lungs were harvested from the cadavers. Six lung lobes per cadaver were used: left cranial, left caudal, right cranial, right medial, right caudal, and accessory lung lobes. Specimens with gross lesions in the respiratory tracts were excluded.

2.2 | Total lung lobectomy

A total lung lobectomy was performed in each lung lobe, and three different bronchial sealing methods—the stapling device (ST), traditional suture ligation (TR), and barbed suture ligation (BA)—were randomly assigned to two lobes per cadaver ($n = 10$ per group; Figure 1). The order of the lung lobes undergoing lobectomy was randomized. All experiments were conducted by a single operator.

2.2.1 | Stapling device

For the ST group, thoracoabdominal (TA) staplers (TA30 V3 2.5 mm stapler; Medtronic), which are commercially available linear stapling devices, were used for total lung lobectomy following the method described by Dunning[1] and guidelines stipulated by the manufacturer. After clamping the hilum with non-crushing forceps distal to the lobectomy site, both the pulmonary vessels and bronchus entering the targeted lobe were stapled together using a TA stapler without prior isolation of the vessels and bronchus. After firing the staples, the lobe was transected distal to the staple lines. The jaws of the stapler were then opened to release the tissue. In the ST group, all stapling devices were placed 3 mm away from the pulmonary hilum.

2.2.2 | Traditional suture ligation

In the TR group, traditional suture ligation was performed following the procedure described by MacPhail and Fossum.[3] The pulmonary vasculature and bronchi from the hilum were subjected to blunt dissection, ligation, and transection. The pulmonary artery and vein were individually ligated with three circumferential ligatures using 2–0 silk sutures and transected between the two distal ligatures. The lobar bronchus was clamped using two non-crushing forceps and transected between the forceps. A simple continuous horizontal mattress suture pattern was used to suture the bronchus proximal to the remaining forceps, employing 3–0 monofilament polydioxanone sutures (PDS II suture; Ethicon) on a swaged SH 26 mm 1/2 circle taper needle. After removing the clamping, the distal margin of the bronchial stump was oversewn using a simple continuous pattern with the same suture material. All knots were tied using a surgeon's knot (4 throws). All suture bites were placed 2–3 mm apart.

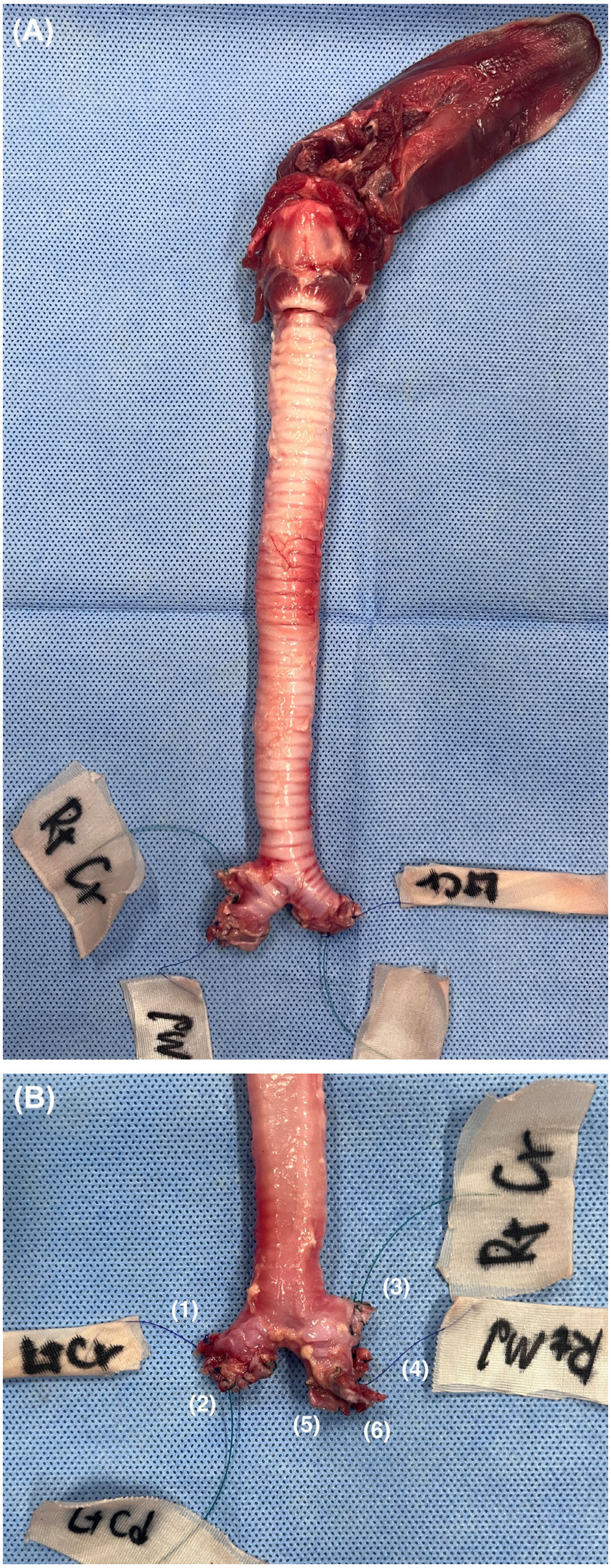

FIGURE 1 Images of bronchial stumps undergoing total lung lobectomies, with three different bronchial sealing methods. (A) Each lung lobe underwent lobectomy using one of three different bronchial sealing methods randomly assigned to two lobes per cadaver. (B) The lobes and assigned groups were as follows: (1) left cranial lobe, TR; (2) left caudal lobe, BA; (3) right cranial lobe, BA; (4) right middle lobe, TR; (5) right caudal lobe, ST; and (6) the accessory lobe, BA. BA, barbed suture ligation; ST, stapling device; TR, traditional suture ligation.

2.2.3 | Barbed suture ligation

In the BA group, the lobar bronchus was ligated using 3–0 unidirectional polyglyconate barbed sutures (V-Loc 180 wound closure device; Medtronic) on a swaged V-20 26 mm 1/2 circle taper needle. The same suture patterns were used in both the BA and TR groups, with the distinction of employing barbed sutures per the guidelines of the manufacturer (Figure 2). The needle of the barbed suture was passed through the loop end effector at the initial suture stitch to anchor the bronchial tissue. Two additional bites were placed beyond the end of the suture line to secure anchoring and prevent pullback. All suture bites were placed 2–3 mm apart.

2.3 | Bronchial ligation time

The time taken to complete the bronchial ligation was recorded. For the ST group, time measurement began when the TA stapler cartridge was loaded after clamping distal to the ligation site and ended when the stapler was released after transecting distal to the staple lines. For the TR and BA groups, suture ligation time began when the needle first entered the bronchial tissue and ended after the completion of two suture layers.

2.4 | Air leakage test

The 30 bronchial stumps were evaluated for air leakage using the method previously outlined by Cronin et al.[5] and Yu et al.[7] The size of the endotracheal tube was selected based on the bodyweight, according to published

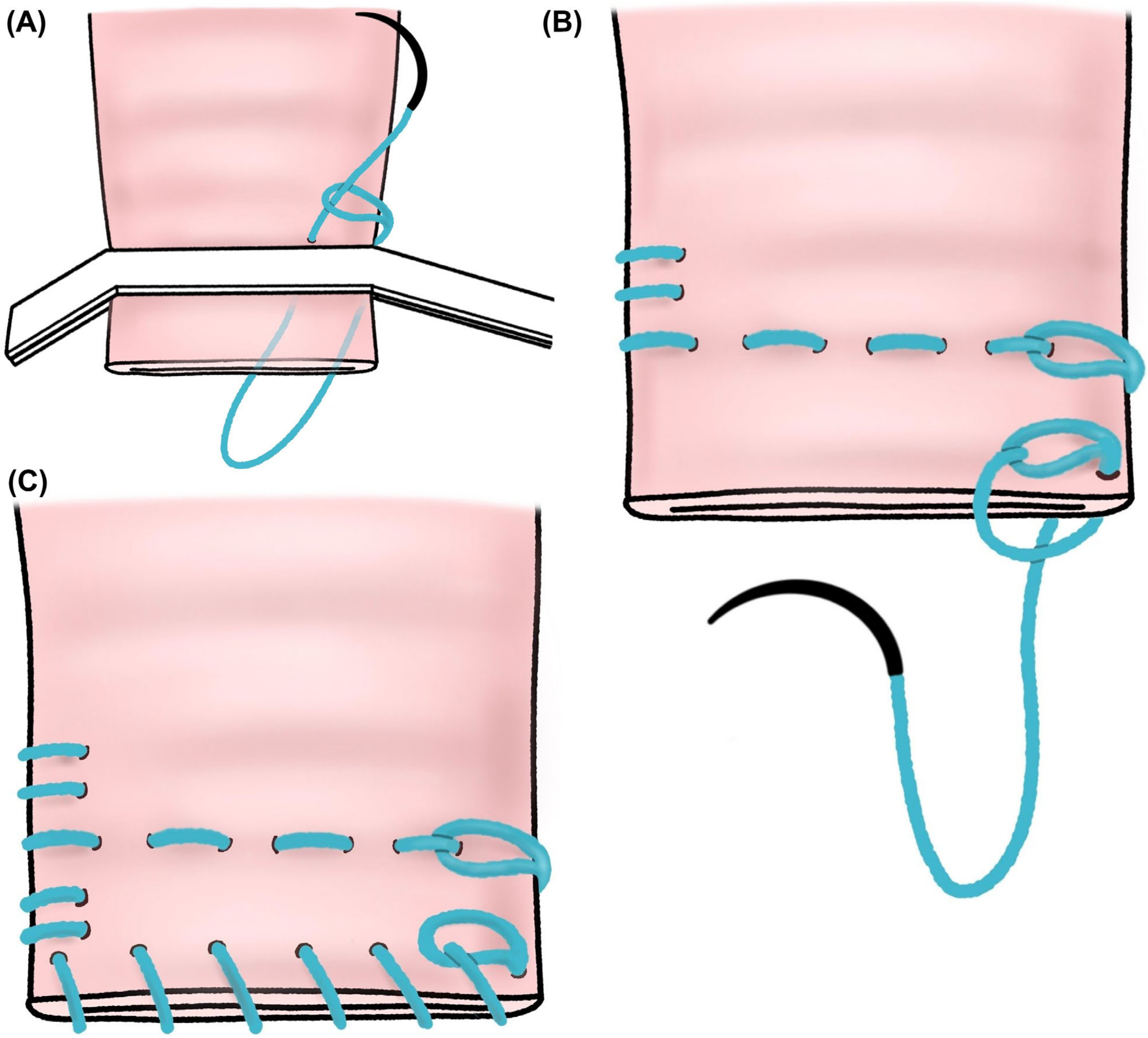

FIGURE 2 Illustrations of applying barbed sutures for bronchial ligation. The same suture patterns were used in both the BA and TR groups, with the distinction of employing barbed sutures according to the guidelines of the manufacturer. (A) The needle is passed through the loop end effector after taking initial bites for the proximal continuous horizontal mattress pattern. (B) Two additional bites are placed beyond the suture line, and the suture is cut flush. Oversewing is initiated at the distal margin of the bronchial stump by anchoring through the loop end effector. (C) Two additional bites are placed in the same manner after the oversewing pattern, and the suture is cut flush. BA, barbed suture ligation; TR, traditional suture ligation.

guidelines.[23] The endotracheal tube was intubated through the larynx, and an airtight seal was created using cable ties to prevent air leakage into the respiratory tract. To pressurize the intraluminal airway, a VBM Universal Cuff Pressure Manometer (VBM Medizintechnik GmbH, Einsteinstrasse, Sulz, Germany) was connected to the endotracheal tube. The bronchial stumps were submerged in saline, and the intraluminal airway pressure was increased to 80 cmH_2O at a rate of 1 cmH_2O/s (Figure 3). Air leakage was identified by observing air bubbles rising from a bronchial stump. To reach the maximum pressure, the leaking lobar bronchus was clamped, and the test was continued to evaluate other bronchial stumps that had not yet leaked. The pressure and location of air leakage were recorded and compared among the groups. The physiological airway pressure was set at 20 cmH_2O and the maximum pressure was set at 80 cmH_2O.[5,7,24]

2.5 | Statistical analysis

The lung lobes and surgical order were randomized using a commercially available randomization program (Microsoft

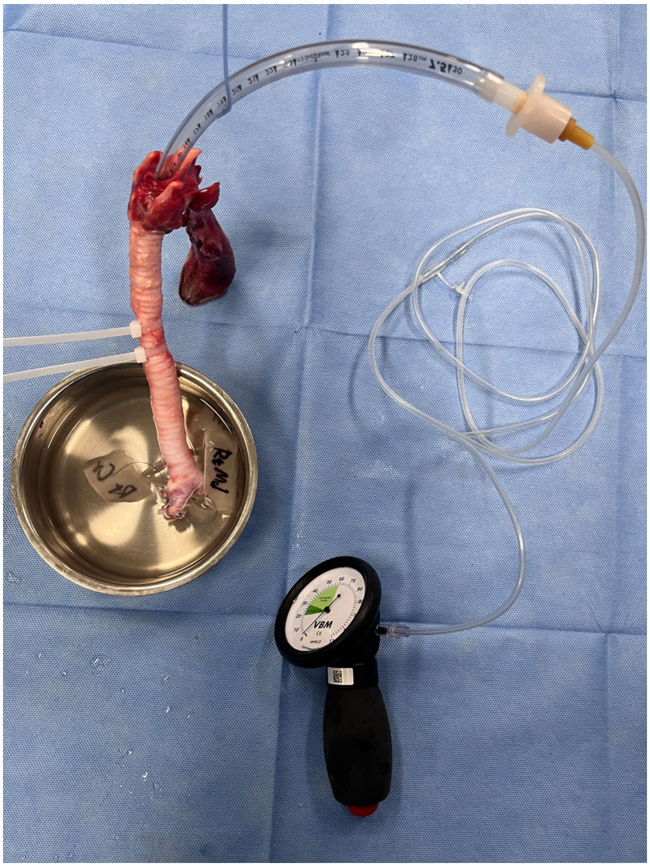

FIGURE 3 An air leakage test was performed to assess the bronchial sealing ability of the bronchial ligation technique. The bronchial stumps were submerged in a saline bowl. The intraluminal airway pressure was increased to 80 cmH_2O using a VBM Universal Cuff Pressure Manometer connected to the endotracheal tube, which was intubated in the trachea and secured with airtight cable ties.

Excel 2016; Microsoft, Redmond, Washington). Statistical analyses were performed using SPSS (SPSS version 28.0, IBM Corp., Armonk, New York). The Shapiro–Wilk test was used to evaluate data normality, and Levene's test was employed to examine the homogeneity of variance. The Kruskal–Wallis test was used to evaluate differences in air leakage pressure. Fisher's exact test was employed for leakage prevalence analysis. Bronchial ligation times were compared using a one-way analysis of variance followed by Tukey's test. Statistical significance was set at $p < .05$ for all tests.

3 | RESULTS

The respiratory tracts, extending from the tongue to the lungs including the intact trachea, were successfully harvested from five adult mongrel-breed canine cadavers, weighing an average of 10.64 (range: 10–13) kg. No gross lesions were observed in any of the cadavers used in the study. The lung lobes were randomly assigned to one of the three examined bronchial ligation techniques (Table 1). Total lung lobectomies and air leakage tests to evaluate bronchial sealing ability were successfully performed for all 30 lung lobes. The details regarding leakage pressure and ligation time for individual lung lobes are listed in Table S1.

TABLE 1 Distribution of lung lobes in total lung lobectomy groups.

Lung lobe	Stapling device	Traditional suture ligation	Barbed suture ligation
Left cranial	2	1	2
Left caudal	1	1	3
Right cranial	1	2	2
Right middle	2	1	2
Right caudal	2	3	0
Accessory	2	2	1
Total	10	10	10

Note: Lobectomy groups were randomly assigned to two lobes per cadaver. All 30 lung lobes were included in the study.

The median air leakage pressure was 45.0 cmH_2O (range: 30.0–80.0) for the ST group, 47.5 cmH_2O (range: 36.0–80.0) for the TR group, and 57.5 cmH_2O (range: 25.0–80.0) for the BA group ($p = .36$). None of the bronchial ligation groups showed leakage at physiological airway pressures (<20 cmH_2O) (Table 2). At pressures up to the maximum tested, leakage was observed in nine of 10 bronchial stumps in the ST group, eight of 10 in the TR group, and six of 10 in the BA group. The prevalence of leakage did not significantly differ among the techniques ($p = .43$).

In the ST group, air bubbles were observed at either the first or last end of the staple lines in seven of nine bronchial stumps and from the stapled bronchial lumen in two of nine bronchial stumps. In both suture ligation groups, the air leakage site was identified at the suture hole. The location of the suture hole where the leakage occurred varied within the TR group. In the BA group, leakage was confirmed at the loop effector hole in one lobe. No incidents of knot rupture, suture breakage, or suture slippage were found in either suture ligation group.

The mean bronchial ligation time was 2.4 ± 0.5 min for the ST group, 14.1 ± 3.4 min for the TR group, and 10.7 ± 1.6 min for the BA group. The bronchial ligation time differed significantly among the three groups, with the BA group demonstrating a shorter mean ligation time compared to the TR group, and the ST group exhibiting

TABLE 2 Prevalence of air leakage of bronchial ligation groups.

Air leakage pressure (cmH_2O)	Stapling device ($n = 10$)	Traditional suture ligation ($n = 10$)	Barbed suture ligation ($n = 10$)
<20	0	0	0
20–80	9	8	6
>80	1	2	4

Note: Leakage at physiological airway pressure (< 20 cmH_2O) was not observed in any group. Fisher's exact test results revealed no differences in leakage prevalence across the groups ($p = .43$).

TABLE 3 Bronchial ligation time of bronchial ligation groups.

	Stapling device	Traditional suture ligation	Barbed suture ligation
Time (min)	2.4 ± 0.5^a	14.1 ± 3.4^b	10.7 ± 1.6^c

Note: Statistics are presented as mean value and SD. Values with different superscript letters differ significantly ($p < .01$).

the shortest mean ligation time overall ($p < .01$) (Table 3).

In both the TR and BA groups, 4–6 suture bites were placed per bronchial stump (excluding the final two additional sutures in the BA group).

4 | DISCUSSION

In this ex vivo study, barbed sutures provided secure bronchial closure. None of the bronchi leaked at physiological pressures. Barbed sutures reduced the suturing time. These results supported our hypothesis that the use of barbed sutures for bronchial sealing would achieve a leakage pressure comparable to that of stapling devices and traditional sutures while requiring less ligation time than traditional sutures. These findings suggested that barbed suture ligation may be considered a feasible technique for total lung lobectomy in dogs.

Air leakage within physiological pressure may lead to clinical symptoms such as pneumothorax, emphasizing the need for continuous postoperative monitoring.[1,3] Minor air leaks resolve spontaneously; however, massive air leaks necessitate reoperation.[1,3] Secure bronchial ligation technique is critical to minimizing complications that can impact postoperative outcomes, hospitalization duration, and costs. In this study, leakage failure did not occur at physiological pressure levels in any of the groups. No previous studies have examined air leakage related to bronchial ligation using barbed sutures. Nakagawa et al.[14] reported four cases of bronchoplasty with barbed sutures during sleeve lobectomy in humans, with no leaks detected during intraoperative tests. Agasthian[9] reported a minor air leak detected at 30 cmH_2O in an intracorporeal bronchial anastomosis using barbed sutures which was subsequently reinforced with non-barbed sutures. However, the current study focused on ligation rather than anastomosis, making direct comparisons difficult.

Under circumstances such as coughing, airway pressure can exceed physiological levels.[5,7,24] Persistent coughing has been reported in some patients even after lung tumor resection due to tumor-related or tumor-unrelated factors.[25] This highlights the importance of establishing a broad safety margin at supraphysiological levels, which can only be investigated using cadaveric models.[5,7] This study set the maximum pressure at 80 cmH_2O for the air leakage test, based on prior research.[5,7,24]

Barbed sutures, created by cutting barbs into monofilament sutures, have tensile strength equivalent to that of a non-barbed suture one size smaller.[10] V-Loc 180 devices account for the size difference in their product labeling.[10] Therefore, the same labeled size was used for comparison between V-Loc 180 devices and non-barbed sutures in this study. However, the suture hole size created by V-Loc 180 devices is equivalent to that of one size larger non-barbed sutures. Additionally, differences in suture hole size and effective diameter raised concerns about their potential impact on leakage pressure.[17] Despite these considerations, the leakage pressure of the BA group in this study was comparable to that of the TR group.

In the ST group, air leakage primarily occurred at either the first or the last end of the staple lines, consistent with previous findings.[5] The TA stapler uses B-shaped staples to maintain tissue perfusion and prevent necrosis.[5] However, these staples may not adequately compress tissue at the ends of the staple lines, thereby causing leakage. Leakage occurred in the suture holes in both suture groups. In the BA group, there were concerns that leakage might occur at the suture bites near the loop end effector, due to the lack of barbs. However, no significant differences were observed. The barbs and the absence of knots may have contributed to the ability to withstand airway pressure by anchoring the tissue and distributing tension evenly along the suture line.[10,11,16]

In this study, the BA group demonstrated a significant reduction of 3.7 min (mean) in bronchial closure time compared to the TR group. Factors contributing to the time reduction include the ability to omit tying four knots when using barbed sutures, as well as the elimination of the effort involved in retightening or maintaining tension to appose tissues during continuous suturing.[21] This degree of time reduction is expected to be more pronounced in clinical surgery situations. In prophylactic laparoscopic gastropexy in dogs, V-Loc barbed sutures saved 17.6 min in total surgical time compared to monofilament sutures, resulting in shorter anesthesia time, and the gastropexy was confirmed to remain successfully without any major complications.[21] Although barbed sutures have not yet been utilized for bronchial ligation in thoracoscopic procedures, their benefits have been demonstrated in intra- or extracorporeal suturing where knot tying is challenging during minimally invasive surgeries.[8,14,16] Barbed sutures can prevent potential risks related to knot tying in limited thoracic spaces. Additionally, the self-anchoring properties of barbed sutures reduce the need for assistance during the procedure.

Linear staplers, which simultaneously ligate pulmonary vessels and the bronchus, are known to largely reduce the total surgical time compared to suturing techniques: 2.70 min (min–max: 1.55–4.57) versus 23.46 min (min–max: 17.65–43.3) in a previous study.[26] This study measured the time required for bronchial closure without including pulmonary vessel ligation, making it difficult to directly compare procedural times between the ST and BA groups. Despite their efficiency, alternative techniques to address the limitations of staplers have been explored for lung lobectomy.[5,7,26–30] Endoscopic staplers are easier to use in the limited thoracic space than TA staplers and offer improved sealing capabilities.[8,26] However, they are substantially more expensive than TA staplers and pose the same risk of stapling failure in cases of pathological changes in the hilum or bronchus.[6,8] Pretied loop ligatures and Liga-Tie, both en bloc methods for lung lobectomy, can be performed rapidly and are suitable for small patients or those undergoing VATS to provide adequate bronchial sealing.[5,7,27] However, there is a risk of ligation loop slippage, and a sufficient resection margin is required.[5,7,27]

The limitations of this study include the small sample size and the use of frozen cadavers, which may have influenced the air leakage assessment. As noted by Nylund et al.,[27] cadaver tissue likely exhibited lower airway leak pressures compared to clinical settings, likely due to the absence of physiological responses such as fibrin deposition to seal minor leaks. Although the freeze–thaw process may alter the structural integrity and elasticity of the bronchial tissue, its specific impact on leakage pressure remains uncertain. Further studies with in vivo tissues are needed to clarify this impact. Additionally, all procedures in this study were performed by a single operator, which may limit the generalizability of the findings. The bronchial diameter was not measured in this study, which may limit the evaluation of barbed sutures. In this study, the first 1–2 bites near the loop end effector lacked barbs, suggesting the importance of confirming the minimum tissue size or suture line when using barbed sutures. Moreover, although differences in bronchial size may have influenced the degree of compression applied by the stapler and the suture length required for ligation, their effects on the study results were likely minimized due to the relatively uniform cadaver size (10–13 kg) and the randomized allocation of lung lobes.

The advantages of barbed sutures may be more pronounced in larger dogs with increased bronchial diameters, as longer suture lines increase their time-saving benefits in comparison with traditional sutures. While manual bronchial suturing has been reported during VATS lobectomy in a dog weighing 25.3 kg,[31] this technique may be challenging in small-breed dogs due to size constraints or technical difficulties. However, stapling devices, primarily designed for human use, may also present challenges in small dogs, as the limited thoracic space can hinder proper positioning and application.[2,5–7] The selection of bronchial ligation techniques may ultimately depend on the surgeon's preference and experience, as well as the anatomical constraints of the patient. Further research is warranted to assess the applicability of barbed suture ligation in larger dogs, as well as in the 10–13 kg dogs included in this study.

Barbed sutures have been reported to reduce dehiscence, ischemia, and suture extrusion.[16,32] However, their effects on bronchial healing, including inflammatory response, vascularization, and long-term impacts, remain unexplored. Further research is required to investigate the impact of barbed sutures on normal and pathological bronchial tissues under varying respiratory conditions. V-Loc 180 and PDS are commonly used for bronchial surgery and are characterized by their prolonged tensile strength retention and slow absorption properties.[9,14,32,33] Although the composition of the sutures may have influenced the outcomes, its specific impact on air leakage assessment remains uncertain. Further research is warranted to compare barbed and non-barbed sutures with identical materials.

This ex vivo study suggested barbed sutures have the potential to provide comparable sealing and reduce suturing duration during total lung lobectomy, especially in cases when manual suturing is indicated, the use of staplers is cost-prohibitive, or in thoracic space-limited clinical settings. Large-scale in vivo studies are essential to comprehensively evaluate the clinical efficacy, safety, and long-term effects of barbed sutures.

AUTHOR CONTRIBUTIONS

You D, DVM, MS: Contributed to the study design, performed the research, interpreted data, and drafted and revised the manuscript. Kim HY, DVM, PhD: Contributed to the study design, interpreted data, and provided scientific in-line editing of the manuscript. All authors conducted a thorough review of the manuscript and endorsed the final version. All authors recognize their individual contributions and affirm the integrity of the coauthor's work.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest regarding this research.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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