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CLINICAL RESEARCH

Perioperative outcomes of 65 dogs and 15 cats undergoing lung lobectomies with a hilar circumferential ligature

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Abstract

Objective: To report perioperative morbidity and mortality in dogs and cats undergoing total lung lobectomy using a hilar circumferential ligature (HCL).

Study design: Retrospective clinical study.

Sample population: Client owned dogs ($n = 65$) and cats ($n = 15$).

Methods: Medical records were searched for dogs and cats undergoing surgery for total lung lobectomy using a HCL, consisting of either a commercial pre-tied ligature loop (CPLL) or handtied circumferential ligature (HTCL). Cases were collected between 2017 and 2022 from six different hospitals and included signalment and perioperative data.

Results: A total of 94 lung lobes were removed, 59 with CPLL and 35 with HTCL, in 80 dogs and cats. The HTCL group comprised seven sliding, 25 modified Miller's and three Roeder knots. Intraoperative hemorrhage occurred in 4/94 (4.3%) lung lobectomies using 2/59 (3.4%) CPLL and 2/7 (28.6%) sliding knots. There was no association between hemorrhage and use of CPLL versus HTCL ($p > .99$), knot type ($p = .09$), or number of sutures per pedicle ($p = .30$). One dog died intraoperatively from tumor extrusion into the bronchus. One dog required revision surgery for pneumothorax eight days postoperatively.

Conclusion: The overall incidence of intraoperative complications was low. Our findings support the use of CPPLs, handtied Roeder and modified Miller's knots for total lung lobectomy in dogs and cats with clinical disease. Sliding knots should be used with caution.

The preliminary data for this study was presneted in the Short Communications at the 2021 online ECVS Annual Meeting, July 8–10, 2021.

Clinical significance: The low complication rate, together with the ease of use and cost efficiency of HCL, makes this technique a promising option for total lung lobectomy.

1 | INTRODUCTION

Total lung lobectomy is most commonly performed in dogs and cats with pulmonary neoplasia, cysts, bullae, blebs, atelectasis, abscesses, lacerations, bronchiectasis, bronchoesophageal fistula, lung lobe torsion, and pulmonary emphysema.[1–4] Most stapling devices are designed and manufactured for human patients and so they are not optimized for veterinary applications in dogs and cats. Consequently, some may find that these devices can sometimes be cumbersome or challenging to place correctly during surgery, especially in smaller animals.[5,6]

Commercial pre-tied ligature loops (CPLL) are designed to facilitate ligation of vascular pedicles in human surgery, particularly for minimal invasive surgery.[7,8] The Endoloop (Ethicon, Sommerville, New Jersey) is a ready-made, 45 cm suture loop that is passed through a long, thin plastic tube, tapered at the loop end, and circumferentially scored at the other end where the suture attaches. When the loop has been positioned, the scored end is snapped and pulled towards the surgeon while the tube is pushed along the material, thus pushing and securing the knot. In human surgery, CPLL are used for partial lung resection in patients with bullous disease,[9,10] and in laparoscopic procedures such as appendectomies and salpingo-oophorectomy.[7,8] Their simple construction makes the CPLL a cost-effective option, considerably less expensive than a linear stapling device. Their use has been described for complete or partial liver lobectomy,[11–14] lung biopsy,[15] and total lung lobectomy in dogs and cats.[6,16,17]

An ex vivo study on cadaveric canine lung tissue tested CPLL for total lung lobectomy, followed by successful clinical use in five client owned dogs with clinical disease without any reported complications.[16] This study showed that the larger diameter hilar bronchi, with theoretically increased cartilaginous support compared to peripheral airways,[15] could be safely occluded with an encircling ligature.[16] A more recent study compared thoracoabdominal stapling devices and CPLL, with the CPLL used in 18 dogs and cats, none of which developed complications.[17] To date, only 25 cases in total have been reported in which a CPLL has been used to perform total lung lobectomy in dogs and cats.[6,16,17] There have been no reports of a requirement to oversew the bronchus, or of development of an arteriovenous fistula, as a consequence of bulk ligation of the hilus.

The main objectives of this study were to report the intra- and postoperative adverse events and mortality associated with the use of CPLL or handtied circumferential ligatures (HTCL) for total lung lobectomy in a large group of dogs and cats treated at several different hospitals. We hypothesized that a hilar circumferential ligature would have a low complication rate and that HTCL would perform similarly to CPLL.

2 | MATERIALS AND METHODS

2.1 | Case identification

Medical records of dogs and cats that underwent total lung lobectomy from 2017 to 2022 from six hospitals were reviewed. Dogs and cats were included in the study if they had undergone total lung lobectomy using CPLL or HTCL. Cases with multiple lung lobectomies and surgeries were included. Ethical approval was granted by the Department of Veterinary Medicine, University of Cambridge Ethics and Welfare Committee (study no. CR422).

2.2 | Data retrieved

Data retrieved from medical records included: signalment, bodyweight, surgical approach, lung lobe(s) resected, suture material, if CPLL or HTCL was used, knot type in HTCL, number of ligatures placed, result of leak testing, intraoperative complications, postoperative complications, survival to discharge and histopathologic diagnosis. Intraoperative complications were reported using the Classification of Intraoperative Complications (CLASSIC) grading scheme (Table 1)[18] and any postoperative complications were reported using the Accordion severity grading system (Table 2).[19,20]

2.3 | Statistical analysis

Data was assessed for normality using the Shapiro–Wilk test and quantile-quantile plots. Descriptive statistics are presented as median values with interquartile ranges (IQR), minima and maxima. Intraoperative complications were reported per surgical procedure. Postoperative complications were reported per animal. Dichotomous

TABLE 1 Classification of Intraoperative Complications (CLASSIC) grading scheme.[a]

Grade	Definition
0	No deviation from the ideal operative course
I	Any deviation from the ideal operative course • Without the need for any additional treatment or intervention
II	Any deviation from the ideal operative course • With the need for any additional treatment or intervention
III	Any deviation from the ideal operative course • With the need for any additional treatment or intervention • Life-threatening and/or leading to permanent disability
IV	Any deviation from the ideal operative course • With death of the patient

[a]Sequelae, failure of cure, events related to the underlying disease, wrong-site or wrong-patient surgery, or errors in indication are not defined as intraoperative complications.

TABLE 2 Accordion severity classification for postoperative complications: contracted classification.

Level	Definition
1	Mild complication Requires only minor invasive procedures that can be done at the bedside such as insertion of intravenous lines, urinary catheters, and nasogastric tubes, and drainage of wound infections. Physiotherapy and the following drugs are allowed: antiemetics, antipyretics, analgesics, diuretics, electrolytes
2	Moderate complication Requires pharmacological treatment with drugs other than such allowed for minor complications, for instance antibiotics. Blood transfusions and total parenteral nutrition are also included
3	Severe complications All complications requiring endoscopic or interventional radiologic procedures or reoperation as well as complications resulting in failure of one or more organ systems
4	Death Postoperative death

outcomes were compared using chi-squared tests with exact two-sided significances. Effect sizes were estimated using Cramér's V and interpreted as small, medium or large at cutoffs of 0.1, 0.3, and 0.5 (for 1 degree of freedom).[21] Statistical significance was set at .05.

3 | RESULTS

A total of 94 total lung lobectomies ($n = 76$ in dogs and $n = 18$ in cats) were carried out in 80 client-owned dogs and cats ($n = 65$ dogs and $n = 15$ cats). Of the 65 dogs included in the study, there were 23/65 (35.4%) neutered males, 15/65 (23.1%) entire males, 22/65 (33.8%) neutered females and 5/65 (7.7%) entire females. Breeds included 20 cross-breed dogs, six cocker spaniels, five springer spaniels, five Labradors, five pugs, two greyhounds, two Border collies, two Staffordshire bull terriers, two West Highland white terriers, two miniature schnauzers, two Weimaraners and one each of Tibetan terrier, Jack Russell terrier, Cavalier King Charles spaniel, German shorthaired pointer, boxer, Havanese, Boston terrier, papillon, Irish Setter, Broholmer, French Bulldog and Bernese Mountain dog. Median age was 7 years (IQR: 2 years 10 months; 10 years 4 months: range: 4 months–13 years) and median body mass was 15.0 kg (IQR: 9.9 kg; 20.3 kg: range: 3.3–58.0 kg). Of the 15 cats, 10/15 (66.7%) were neutered males, 4/15 (26.7%) neutered females and 1/15 (6.7%) entire females. Breeds included 11 domestic shorthair cats, two Persians, one domestic long hair cat and one Maine Coon. Median age was 7 years (IQR: 3 years 11 months; 9 years 3 months: range: 1–13 year 2 months) and median body mass was 4.1 kg (IQR: 3.5 kg; 4.9 kg: range: 2.9–8.1 kg).

Median sternotomy was used for 13 dogs and two cats, whereas intercostal thoracotomy was performed in 52 dogs and 13 cats. Of the 76 canine lung lobectomies, 49/76 (64.5%) were performed with CPLL (Endoloop, Ethicon) made from either polydioxanone or polyglactin 910 size 2-0 or 0 USP. The remaining 27/76 (35.5%) were performed with HTCL, comprising 21/27 (77.8%) modified Miller's knots, 3/27 (11.1%) Roeder knots and 3/27 (11.1%) sliding knots (Table 3) made from either polydioxanone or polypropylene size 2-0 or 0 USP. Of the 18 feline lung lobectomies, 10/18 (55.6%) were performed with CPLL (Endoloop, Ethicon) made from either polydioxanone or polyglactin 910 size 2-0 or 0 USP. The remaining 8/18 (44.4%) were performed with HTCL, comprising of 4/8 (50.0%) modified Miller's knot and 4/8 (50.0%) sliding knot (Table 3) made from either polydioxanone or polypropylene size 3-0 or 2-0 USP. A single circumferential hilar ligature was placed in 65/94 (69.2%) lung lobectomies and two circumferential hilar ligatures were placed in 29/94 (30.8%) lung lobectomies prior to resection. In the CPLL group 50/59 (84.7%) lung lobectomies were performed with a single ligature and 9/59 (15.3%) with two ligatures prior to resection. In the HTCL group 15/35 (42.9%) lung lobectomies were performed with a single ligature and 20/35 (57.1%) with two ligatures prior to resection.

TABLE 3 Distribution of the numbers of total lung lobectomies in dogs and cats performed with CPLL or HTCL.

		Canine	Feline	Total
CPLL	Endoloop	49	10	59
HTCL	Modified Miller's knot	21	4	25
	Roeder knot	3	0	3
	Sliding knot	3	4	7

Abbreviations: CPLL, commercially pre-tied ligature loops; HTCL, handtied circumferential ligatures.

TABLE 4 Distribution of lung lobectomy location in dogs and cats.

Lung lobectomy location	Canine	Feline	Total
Left cranial	13	6	17
Left caudal	21	4	25
Right cranial	8	1	11
Right middle	14	3	17
Right caudal	13	2	15
Accessory	7	2	9
Total	76	18	94

The distribution of lung lobes undergoing lung lobectomy is outlined in Table 4. Overall polydioxanone was used in 43/80 (53.8%) patients, polypropylene in 23/80 (28.8%) and polyglactin in the remaining 14/80 (17.5%).

Histological analysis of the resected lung lobes was available for 87/94 (92.6%) lobectomies. Diagnoses included pulmonary neoplasia (40/87; 46.0%), pleuritis/pneumonia (12/87; 13.8%), pulmonary torsion (12/87; 13.8%), lobar laceration (7/87; 8.0%), pulmonary abscess (6/87; 6.9%), pulmonary foreign bodies (2/87; 2.3%), pulmonary bulla (1/87; 1.2%), and congenital pulmonary emphysema (1/87, 1.2%).

3.1 | Intraoperative morbidity and mortality

Ligation-related intraoperative complications were observed in 5/94 (5.3%) lobectomies (Table 5). One of 94 (1.1%) was a result of tumor protrusion into the bronchus of a dog leading to airway obstruction and death: two HTCL (both modified Miller's knots made from polypropylene) were placed in this case. The remaining 4/94 (4.3%) were hemorrhage during transection of the hilus following single polydioxanone ligature placement in three dogs and one cat, using 2/59 (3.4%) CPLL and 2/7 (28.6%) sliding knots, with body mass ranging from 3.5 to 30 kg. Hemorrhage was immediately addressed either by placing an additional ligature ($n = 2$) or applying a vascular clip ($n = 2$), resolving the issue, and these complications were categorized as CLASSIC grade II. No blood transfusions were required. Incidence of intraoperative hemorrhage did not differ with number of suture loops applied per hilus ($X^2_{(1,n=80)} = 1.91$, $p = .30$, $V_{(df=1)} = 0.16$), use of CPLL versus HTCL ($X^2_{(1,n=80)} = 0.28$, $p > .99$, $V_{(df=1)} = 0.06$), nor type of knot ($X^2_{(3,n=80)} = 9.50$, $p = .09$, $V_{(df=1)} = 0.35$). Although 3/4 incidences of hemorrhage were associated with caudal lung lobe ligation, after reclassifying ligations into either caudal and accessory lobes, or cranial and middle lobes, no difference was observed ($X^2_{(1,n=80)} = 0.46$, $p = .64$, $V_{(df=1)} = 0.08$). Neither surgical approach (sternotomy vs. intercostal) nor suture material were associated with incidence of hemorrhage ($X^2_{(1,n=80)} = 0.11$, $p > .99$, $V_{(df=1)} = 0.04$ and $X^2_{(1,n=80)} = 1.41$, $p = .49$, $V_{(df=1)} = 0.13$). One additional dog suffered cardiopulmonary arrest during surgery and was not resuscitated.

Positive pressure leak testing was performed between 18 and 20 cmH_2O in all cases and no bronchial air leakage was reported.

3.2 | Postoperative morbidity and mortality

Of the 78 dogs and cats that survived surgery, one dog (1.3%) that had a single CPLL placed developed a major postoperative complication, categorized at Accordion classification level 3. Revision surgery was performed eight days after the first procedure to manage spontaneous pneumothorax, and a bronchial leak was identified at the hilus of the recent lung lobectomy. Histopathology of the pulmonary tissue was consistent with bronchopneumonia and multifocal abscess. A single additional CPPL was placed, and the dog was discharged three days later with no further complications. No other postoperative air leaks were reported. One mild postoperative complication (Accordion classification level 1) was reported in a dog undergoing right caudal and right middle lung lobectomies with one CPLL each, with a low volume hemothorax which spontaneously resolved within four days of surgery. This dog's histopathology results were consistent with pulmonary carcinoma.

Of the 78 dogs and cats surviving surgery, 4/78 (5.1%) did not survive to discharge. These were all cats that were euthanized due to rapid progression of the underlying pathology including pulmonary adenocarcinoma, necrotizing pleuropneumonia, and angiocentric lymphoma.

TABLE 5 Intraoperative compilations and treatment during total lung lobectomy in dogs and cats with CPLL or HTCL.

Intraoperative complication	Species	Body mass (kg)	Lung lobe	Approach	Loop	Suture material	Number of loops	Treatment
Hilar hemorrhage	Dog	30.0	Right caudal	Right 6th ICT	CPLL	Polydioxanone	1	Additional CPLL placed
Hilar hemorrhage	Dog	10.0	Left caudal	Left 5th ICT	CPLL	Polydioxanone	1	Additional CPLL placed
Hilar hemorrhage	Dog	11.5	Left caudal	Median sternotomy	HTCL-sliding	Polydioxanone	1	Vascular clip placement
Hilar hemorrhage	Cat	3.5	Left cranial	Left 4th ICT	HTCL – sliding	Polydioxanone	1	Vascular clip placement
Bronchial tumor plug – death	Dog	16.0	Right caudal	Right ICT	CPLL	Propylene	2	N/A – died

Abbreviations: CPLL, commercially pre-tied ligature loops; HTCL, handtied circumferential ligatures; ICT, intercostal thoracotomy.

4 | DISCUSSION

In this retrospective study on total lung lobectomies in dogs and cats performed with either CPLL or HTCL, we found an incidence of intraoperative hemorrhage of 4.3% (4/94). This compares with the previously reported 5.0%–11.8% when using linear stapling devices for total lung lobectomies.[17,22] No air leakage was identified during intraoperative leak testing compared to a reported rate of 2.0% (2/101) with linear stapling devices.[17] There were no deaths as a consequence of ligature failure.

All four incidences of intraoperative hemorrhage were promptly addressed by adding an additional HCL or a vascular clip. All cases experiencing intraoperative hemorrhage had a single polydioxanone ligature placed prior to resection however we could not demonstrate an association between number of ligatures applied per hilus and incidence of hemorrhage. Similarly, no significant associations were identified between hemorrhage and ligature technique or material, or surgical approach. Although 3/4 hemorrhagic events involved caudal lung lobes, we could not identify a significant difference in complications between caudal and accessory lobes and cranial and middle lobes. However, additional care may be warranted during ligation of the caudal lung lobes. Given the low number of complications, the study was likely underpowered to detect subtle associations, and further prospective investigation is warranted to elucidate potential risk factors for hilar ligation. Two instances of intraoperative hemorrhage occurred using sliding knots despite the small number of these used in the current study, and a moderately large effect size was observed despite lack of statistical significance. We speculate that it may be harder to ensure adequate ligature tightness with this knot type compared to modified Miller's knots, Roeder knots, or CPLLs. Larger numbers of each ligature type would need to be compared to draw confident conclusions. Due to the low complication rate, the wide range of bodyweight in the affected animals from 3.5 to 30 kg and the equal numbers of CPLL and HTCL involved, we are unable to definitively recommend any one ligation method or placement of two, rather than one, ligatures initially. Some of the authors prefer to place two ligatures prior to resection of the lobe. Intraoperative complications were classified by the CLASSIC scheme and the Accordion classification system for postoperative complications (Table 2) for more consistent complication reporting allowing more succinct comparison in future studies.[18–20] We must be mindful that these classification schemes are borrowed from human literature and do not allow for those dogs and cats who were euthanized. A validated veterinary alternative is not currently available.

The decision to perform total lung lobectomy with a HCL was based on individual surgeon preference. Institutions equipped with CPLL used this device exclusively in place of HTCL. In contrast, surgeons who used HTCL did not have access to CPLL and selected knot configurations based on personal familiarity and comfort. Although linear stapling devices were available at all participating institutions, HCL remained the preferred primary technique for total lung lobectomy.

The CPLL used by the authors in this study was the Endoloop (Ethicon). This pre-tied loop has a diameter of 8 cm which may be increased to 15 cm by shortening the plastic application device to allow the loop to pass over tumors and lung lobes larger than 8 cm in diameter, as described in a previous study.[13] A similar suture loop can be handtied by tying a self-locking knot such as the Roeder knot.[23] When used in confined spaces a knot pusher can be utilized to tighten down this knot.

A single dog in the current study developed postoperative pneumothorax requiring revision surgery. The air leak was assessed at the time of revision surgery and assumed to be associated with adhesions from the initial surgical procedure. An additional CPLL was applied, and the dog went on to recover without further complications. Postoperative pneumothorax has been reported in dogs and cats following stapled lung lobectomy.[22] One dog had minor, self-limiting hemothorax postoperatively. Postoperative hemothorax following lung lobectomy with stapling devices have been reported in the human and veterinary literature,[17,24,25] and so the authors find no evidence that linear stapling devices have a lower risk of postoperative pneumo- or hemothorax. A single case report in the human literature has reported hemothorax following bullectomy caused by a beveled cut suture tip from an Endoloop. In this case report they recommended cutting the Endoloop at a right angle to avoid this complication.[26] The authors of the current study also recommend leaving the end of the suture long when cutting it, especially when using a stiff monofilament suture or larger diameter suture material. Different materials will have different rigidity which influences the stiffness of the suture end. A quantitative study on suture stiffness showed that uncoated Vicryl (Ethicon, polyglactin 910) was the most flexible of the suture materials investigated, followed by PDS (Ethicon, polydioxanone), Prolene (Ethicon, polypropylene) and then coated Vicryl (Ethicon, polyglactin 910).[27] The optimal length for the different suture types used in this study has not yet been investigated.

This retrospective study reports the use of HCL only for total lung lobectomies, our results are not applicable to partial lung lobectomies. The CPLL is reported to be safe in the human literature for management of bulla and blebs in children and adults.[9,28] However, these studies do not specify the amount of tissue removed or distance from the lung edge. A canine ex vivo cadaveric study showed that suture loop biopsies 3 cm from the edge of the lung were more consistently performed than with linear stapling devices.[15] Releve et al. reported the use of CPLL for lung biopsies in horses and their recommendation was to not use on resections $>3\ cm^3$.[29] The safety of partial lung lobectomy in dogs and cats over 3 cm from the edge of the lung with a CPLL has not yet been assessed in either an ex vivo cadaveric study or larger scale clinical study.

Other studies have evaluated the use of a resorbable self-locking ligation device for total lung lobectomy in 10 cadaveric ex vivo cat lung lobes, 10 cadaveric ex vivo dog lung lobes and 11 in vivo dogs, demonstrating that this alternative hilar encircling device has the potential to be used safely in small animals.[30–32] A custom handpiece is needed when using this device in confined spaces, such as during laparoscopic or thoracoscopic procedures, whereas the CPLL is readily available within its delivery system.[16] The resorbable self-locking ligation device is 4 mm wide and 0.65 mm thick, meaning there is the potential for more residual hilar tissue and foreign material compared with a suture.[30] There has been no study comparing residual hilar stump volume between the resorbable self-locking ligation device and CPLL to date. However, the hilus is cut at the same distance beyond the ligation for both the self-locking ligation device and the CPLL and so arguably the stump length is approximately 4 mm longer for the self-locking ligation device.

Limitations of the present study include its retrospective nature and multicenter data collection. While multicenter studies offer larger sample sizes, potentially more diverse populations for recruitment, and better generalizability than single center studies, quality assurance of data and uniformity of data collection is harder to ensure. This is particularly true when data is retrospective. In addition, the effect of surgeon bias or experience between centers cannot be discounted.

In conclusion, the overall incidence of intraoperative complications was low. The mortality reported in this cohort was not directly associated with the surgical technique. Our findings support the use of CPLLs, and hand-tied Roeder and modified Miller's knots for total lung lobectomy in dogs and cats with clinical pathology. Sliding knots should be used with caution. The ease of use and cost efficiency of this technique makes it an attractive alternative to using linear stapling devices.

AUTHOR CONTRIBUTIONS

Cronin AM, DVM, GPCert(SAS), AFHEA, DipECVS, MRCVS: Contributed 11 cases to the study. Substantial contribution to the conception and design of the study. Data collection and analysis. Drafting the study manuscript and revision of the final work. Final approval of the manuscript. Bird F, BVSc, CertSAS, DipECVS, MRCVS: Contributed 36 cases to the study. Substantial contribution to the acquisition of data, data interpretation, revision of work, manuscript editing, and final approval of manuscript. Vlasin M, DVM, PhD, DipECVS, MRCVS: Contributed 16 cases to the study. Substantial contribution to the acquisition of data, data interpretation, revision of work, manuscript editing, and final approval of manuscript. Miles JE, BSc, BVetMed, CertSAS, PhD: Contributed seven cases to the study. Substantial contribution to the acquisition of data, data interpretation, revision of work, manuscript editing, and final approval of manuscript. Kaczmarek J, DVM, DipECVS: Contributed seven cases to the study. Substantial

contribution to the acquisition of data, data interpretation, revision of work, manuscript editing, and final approval of manuscript. Hall JL, MA, VetMB, CertSAS, DipECVS, SFHEA, FRCVS: Contributed three cases to the study. Substantial contribution to the conception and design of the study. Data interpretation, revision of work, manuscript editing. Final approval of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest related to this report.

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