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Lung Resection Using Transumbilical Incision: An Animal Survival Study

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ABSTRACT

Introduction: Transumbilical single-port surgery is a potentially less invasive approach to many types of abdominal surgeries and offers better cosmetic outcomes than conventional 3-port laparoscopic surgery. It avoids the complication of intercostal neuralgia and may reduce the risk of pulmonary complications after video-assisted thoracic surgery. This study evaluated the feasibility of transumbilical lung wedge resection.

Methods: Lung resection was performed in 11 beagle dogs weighing 5.9 to 8.5 kg. A 3-cm umbilical incision and one diaphragmatic incision were made, and an endoscopic stapler was used. The diaphragmatic incisions were repaired under video guidance using a V-Loc knotless suturing device (Covidien, Mansfield, Massachusetts). Animals were monitored daily for signs of postoperative infection. White blood cell count, C-reactive protein level, and IL-6 level were measured in all animals. Animals were euthanized 14 days after surgery and underwent necropsy evaluation.

Results: Accurate lung resection was achieved in 10 of 11 animals during a median operative time of 98 minutes (range 60–165). In 1 animal, transumbilical lung resection was not possible and was converted to thoracotomy. All animals survived without major postoperative complications. At necropsy, evidence of uneventful healing of the stapled resection margin and diaphragmatic wound were found. There was no evidence of vital organ injury or intrathoracic infection.

Conclusion: A transumbilical approach to thoracic cavity exploration and stapled lung resection is technically feasible. Primary suturing of the diaphragmatic incision is a simple and effective means of diaphragmatic wound closure. This may be an alternative to video-assisted thoracic surgery for the management of simple thoracic disease.

Key Words: Transumbilical, Thoracoscopy, Lung wedge resection.

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INTRODUCTION

Since its introduction into clinical practice in the early 1990s, video-assisted thoracic surgery (VATS) has become widely accepted as the standard diagnostic and therapeutic platform for a variety of thoracic procedures including lung biopsy, lobectomy, bullectomy, and pneumonectomy. However, VATS via transthoracic incision carries the risk of well-known postoperative sequelae: intercostal neuralgia and chronic thoracotomy pain. Avoiding this kind of thoracic incision would obviate such complications.[1–3]

Advancements in endoscopic equipment and instruments led to the development of single-port transumbilical laparoscopic surgery in 1997. Many researchers have further described the cosmetic benefits of single-port laparoscopy and claimed that it is an alternative to the conventional 3-port laparoscopic approach to cholecystectomy, salpingo-oophorectomy, and breast augmentation.[4–6] Further, acute postoperative pain is significantly less with the single-port technique than with the conventional 3-port technique.[7,8]

The present study aimed to investigate the feasibility of single transumbilical incision combined with transdiaphragmatic incision for thoracic exploration and lung resection using an endostapler. The main purpose of the study was to establish a new surgical platform for the exploration of the thoracic cavity for lung resection as an alternative to the current transthoracic thoracoscopic approach.

METHODS

The animal studies were approved by the Chang Gung Memorial Hospital Animal Care Institutional Review

Board. Preanesthetic medication, consisting of ketamine (5 mg/kg) and xylazine hydrochloride (10 mg/kg), was intramuscularly administered to 11 beagle dogs (BioVet Beagle Farm, Pingtung, Taiwan) weighing 5.9 to 8.5 kg. The experiments were performed with 2% isoflurane general anesthesia, and 5.0-mm endotracheal intubation of the contralateral mainstem bronchus provided one-lung ventilation during transumbilical thoracoscopy (**Figures 1 to 3**).

With the animal in the supine position, we accessed the thoracic cavity through one 3-cm umbilical incision and one diaphragmatic incision. Initially the bronchoscope was introduced into the abdominal cavity via the umbilical incision. The diaphragmatic incision site was carefully selected by finger palpation over the subxiphoid process. A needle knife inserted through the working channel of the bronchoscope was used to make a 1-cm incision just below the junction of the diaphragm and the xiphoid process. Once the incision was completed, a 10-mm metallic tube was introduced through the incision into the thoracic cavity for thoracic cavity exploration under direct bronchoscopic guidance. The diaphragmatic incision was then sequentially dilated to 2.5 cm using a metallic tube, as previously described.[9] Two metallic tubes (10 mm and 15 mm) were then inserted into the thoracic cavity via the diaphragmatic incision and used as a working port for stapled lung wedge resection. After adequate exploration of the thoracic cavity with the bronchoscope via the 10-mm port, the stapler was gently applied to the targeted lung lobe (left upper lobe, n = 3; right upper lobe n = 3; right middle lobe, n = 3; right lower lobe, n = 2) via the 15-mm port. Alligator forceps were inserted via the

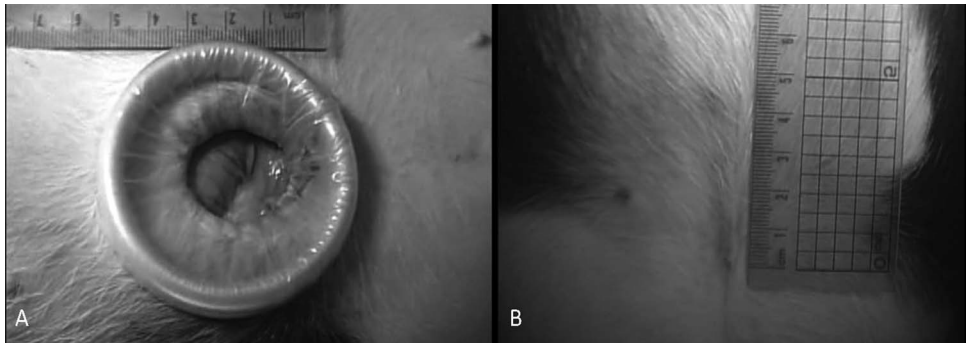

Figure 1. A, The incision at the umbilicus. B, Complete healing of the umbilical incision at necropsy.

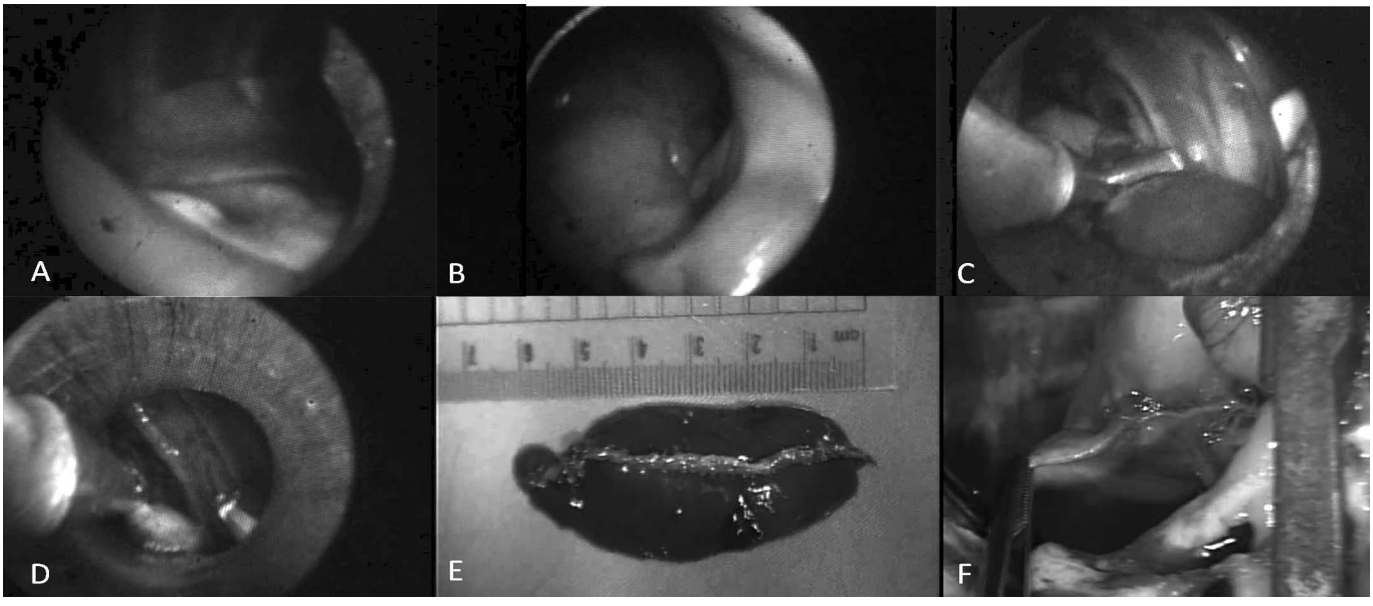

Figure 2. The incision at the diaphragm. A, Endoscopic diaphragmatic incision creation by using a needle knife. B, The diaphragmatic incision was dilated with a homemade metal tube. C, The diaphragmatic incision after dilation. D and E, Closure of the diaphragmatic incision by suture after lung resection. F, Complete healing of the region of diaphragmatic incision at necropsy (arrow).

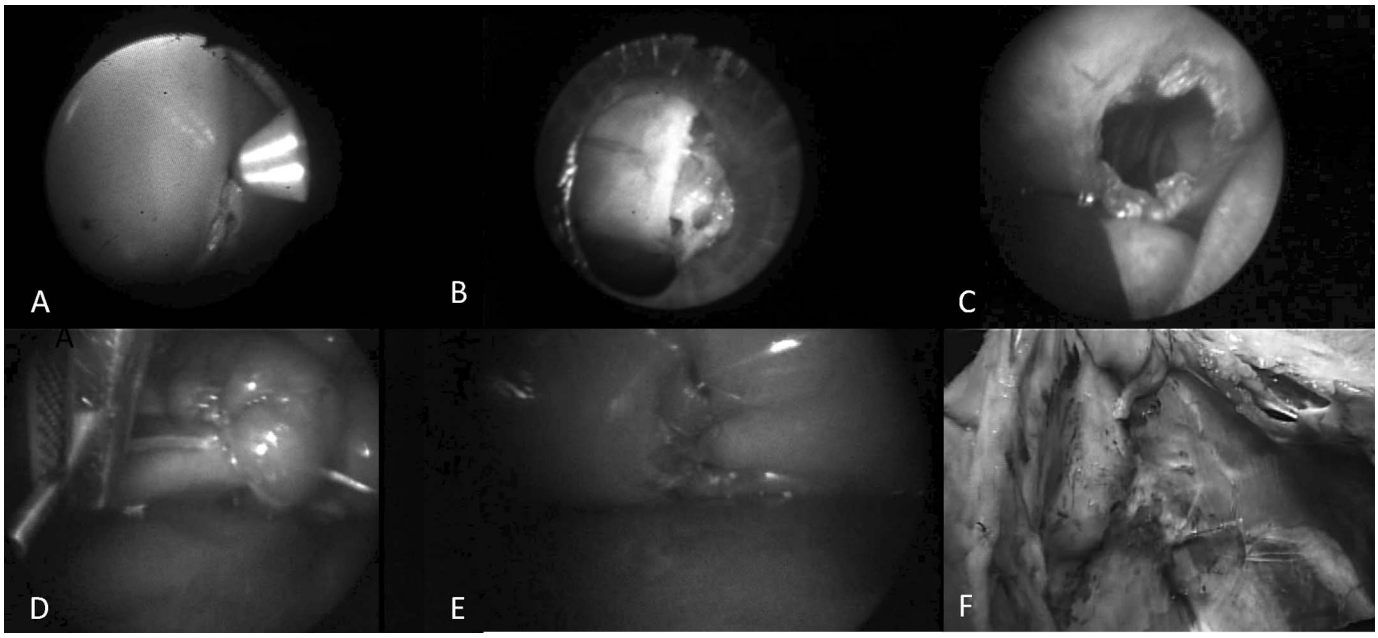

Figure 3. Transumbilical thoracoscopic lung resection. A and B, Exploration of the thoracic cavity, lung (L), and pulmonary hilum (H). C and D, Lung wedge resection by using endoscopic forceps (F) and an endostapler (S). E, Lung specimen. F, Necropsy showing good healing of the lung resection margin (M) pleural cavity without infection.

10-mm port adjacent to the bronchoscope to position the targeted segment between the two arms of the linear stapler. The stapler was then fired to complete the stapled lung resection. A second and sometimes third stapler was used when indicated. Once the lung wedge resection was complete, the resection margin was immersed in warm saline to check for leaks under positive ventilation. Effusion in the thoracic cavity was evacuated after the air leak test verified the integrity of the resected lung margin. The diaphragmatic incision site was closed with a V-Loc suturing device (Covidien, Mansfield, Massachusetts). To reduce acute postoperative pain, chest tube drainage was not used in the current transumbilical approach (**Table 1**).

The animals were allowed to recover and resumed a normal diet almost immediately after the surgery. They were monitored daily for clinical performance, and signs of pain (decreased food intake, weight reduction, or inappropriate social behavior) and infection. Rectal body temperature and respiratory rate were assessed before surgery and at 1, 2, 3, 7, and 14 days after the procedure. Complete blood cell count, C-reactive protein (CRP), and IL-6 levels were measured before the surgery and on postoperative days 1, 3, 7, and 14. On postoperative day 14, the animals were euthanized and necropsy was performed to evaluate the outcome of transumbilical lung resection, including organ injury, intrathoracic infection, thoracic adhesion, and pathological findings near the diaphragmatic incision.

RESULTS

Transumbilical lung resection was successfully performed in 10 of 11 animals. The median procedure time was 98 minutes (range 60–165). In 1 animal, the lung resection had to be performed via a transthoracic approach. All animals survived the surgery and no signs of postoperative infection were observed during the 14-day follow-up period. The median weight gain over the next 2 weeks was 0.7 kg, representing a 10% increase (**Figures 4 to 6**).

In the 10 animals that successfully underwent transumbilical thoracoscopy, resection of the predetermined lung lobe was performed using alligator forceps and endoscopic staplers. The mean number of staplers used for lung resection was 2 (range 1–3), and the mean length of the lung specimen was 4.5 cm (range 3.5–6). After completion of lung resection, an air leak test under positive ventilation confirmed secure closure of the lung resection margin in all animals.

All 10 animals showed an increase in the respiratory rate, which gradually returned to the preoperative rate in 8 animals 14 days after surgery. Rectal temperature rose above the normal level in 3 animals and returned to normal 3 days after the surgery. White blood cell (WBC) count revealed leukocytosis 1 day after the surgery in all animals, but the WBC count gradually recovered to base-

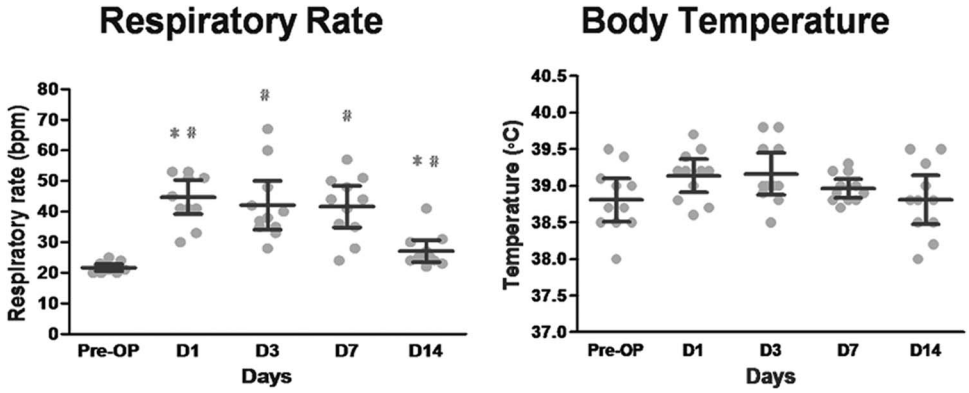

Figure 4. Changes in respiratory rate and rectal temperatures of the 11 animals. Mean and 95% confidence intervals: $^*P < .05$ compared with the previous time point, $\#P < .05$ compared with the preoperative level.

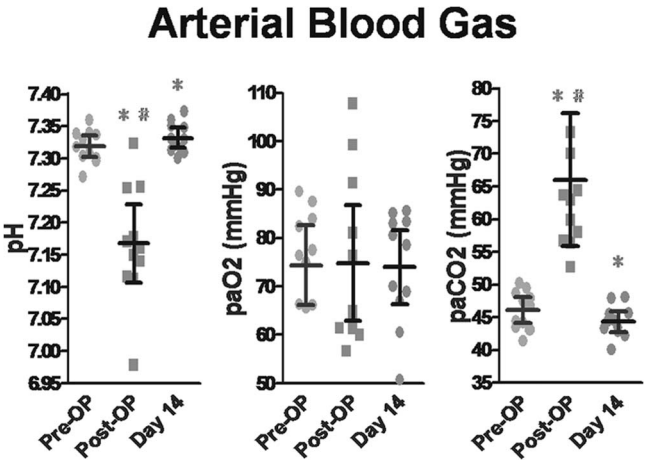

Figure 5. Changes in the arterial blood gases (pH, pCO_2, and PaO_2) of the 11 animals. Mean and 95% confidence intervals: $^*P < .05$ compared with the previous time point, $\#P < .05$ compared with the preoperative level.

line values after 14 days in 7 animals. The CRP level increased significantly in 9 animals 1 day after surgery and returned to the preoperative level in 7 animals at 2 weeks. The IL-6 level increased significantly in 8 animals after surgery and returned to the preoperative level in 5 animals at 2 weeks. Mild postoperative pain occurred in 2 animals.

One transumbilical resection of the right lower lobe was converted to a mini-thoracotomy because of accidental injury to the lung parenchyma during stapler application. The main factor contributing to lung injury was the difficulty in approaching the lower lung region via a transumbilical approach. Two animals experienced a minor lung laceration (right middle lobe, n = 1; left lower lobe, n = 1) during the resection of the left upper lobe, and these were repaired with endostaples. Both animals had uneventful postoperative periods. Another animal had a bleeding complication during surgery caused by accidental liver injury by the tip of a metallic tube, and the bleeding was controlled with gauze compression. This animal had lethargy and poor peroral intake in the first 4 postoperative days. The animals were managed conservatively and were euthanized 2 weeks (14 days) after surgery.

Necropsies of the 11 animals confirmed accurate lung resection and revealed healthy staple lines. The diaphragmatic incision had completely healed in all animals. There was no gross evidence of infection or hemorrhage. During necropsy, 9 of 11 animals were noted to have a mediastinal adhesion around the staple line, 7 of 11 animals had adhesions between the parietal pleura and the lung, 5 of 11 animals had lung adhesions over the diaphragmatic access region, and all 11 animals had liver adhesions over the diaphragmatic incision site.

DISCUSSION

The combination of transumbilical access and transdiaphragmatic incision in the present study allowed exploration of the thoracic cavity and lung wedge resection. The transumbilical approach is a reasonable alternative to thoracic intervention. It obviates the need for thoracic incision and avoids complications associated with a transthoracic approach (eg, pulmonary complications, intercostal neuralgia). Direct repair of the diaphragmatic incision allowed complete wound healing and averted visceral herniation. However, because the surgical field is obstructed by the liver and heart when a transumbilical approach is used, this technique should be reserved for resection of lesions in the upper and middle lung and for early phases of clinical research.

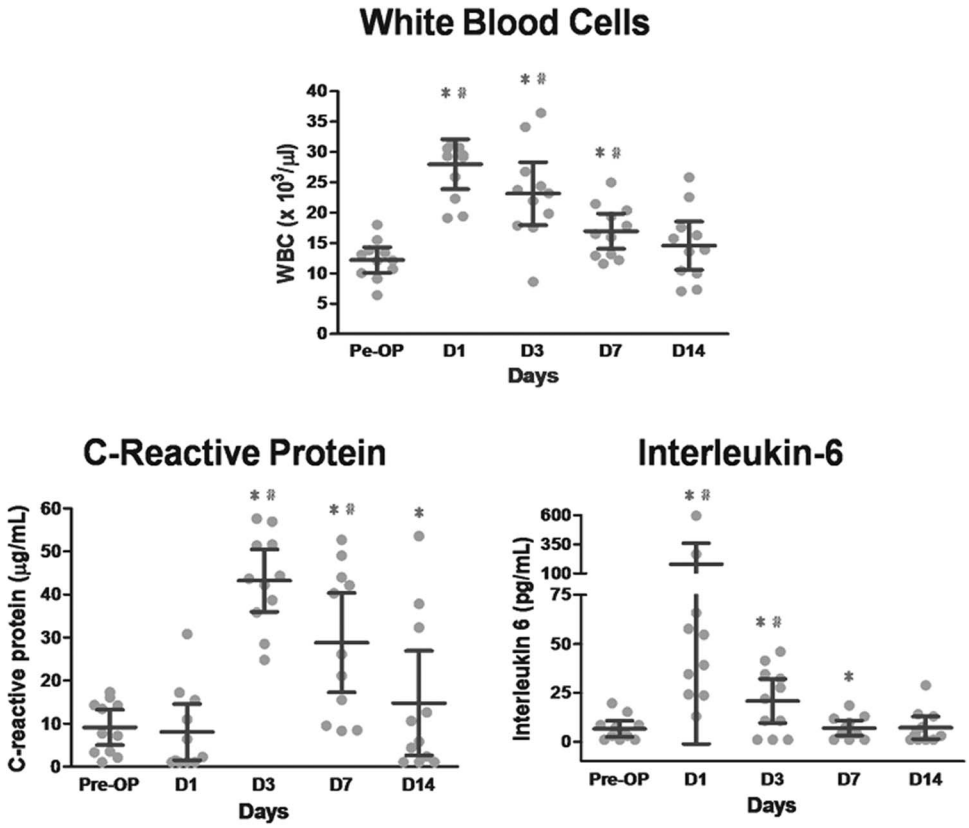

Figure 6. Changes in WBC count, serum CRP, and IL-6 in the 11 animals. Mean and 95% confidence intervals: $*P < .05$ compared with the previous time point, $\#P < .05$ compared with the preoperative level.

Three-port laparoscopic surgery is a well-established platform for abdominal and thoracic procedures. With advancements in endoscopic and surgical instruments, minimally invasive surgery through a single incision has become possible. Reduced postoperative pain and improved cosmetic results are the benefits of single-port surgery and have been shown in many abdominal and thoracic procedures.[7,8,10,11] Moreover, the safety and effectiveness of laparoscopy in the thoracic cavity has been confirmed in clinical practice. In this study, we were able to complete lung resection in 10 of the 11 targeted lobes.

Diaphragmatic rupture involves the risks of visceral herniation and strangulation. Many surgeons have reported that diaphragm injury can be successfully repaired with interrupted polypropylene suturing via laparoscopy. For example, Vallina et al reported their findings from a 10-year review of the literature and suggested that minimally invasive diaphragmatic rupture repair via laparoscopy is a reasonable alternative to open laparotomy or thoracotomy.[12] In 2003, Matthews et al reported successful repair of acute traumatic diaphragmatic lacerations and chronic traumatic diaphragmatic hernias in 13 patients.[13] In 2008, Groth et al reported successful laparoscopic repair of diaphragmatic hernias with polytetrafluoroethylene in patients who had undergone explantation of a left ventricular assist device.[14] To obviate the late complications of diaphragmatic hernia, the diaphragmatic incision was routinely closed with the V-Loc Absorbable Wound Closure Device (Covidien) in the present study. There was no evidence of diaphragmatic dehiscence or visceral herniation at 14 days after surgery. These preliminary results lead us to believe that diaphragmatic wounds can be repaired safely and without any sequelae via laparoscopy.

Potential postoperative complications of lung resection include air leakage and the development of pneumothorax. Many different types of endoscopic devices are used to treat air leakage after lung resection. These include monopolar and bipolar cautery instruments and endoscopic staplers. Numerous researchers have demonstrated significantly better prevention of air leakage with stapling than with other methods during lung resection.[15,16] In addition, the safety of thoracoscopic wedge lung resection

Table 1.
Procedure Characteristics and Animal Outcome

Animal	Duration (min)	Body Weight (kg)	Target Region of Wedge Lung Resection	Success of Procedures	Lung Specimen (cm)	Complication	Necropsy Findings (Diaphragm)	Necropsy Findings (Thorax)	Necropsy Findings (Abdomen)
Dog 1	145	6.9	LUL	Yes	4 cm	Bleeding	Complete healing	Mediastinal adhesion	Liver adhesion
Dog 2	80	7.5	LUL	Yes	5 cm	LLL injury	Complete healing	Pleural adhesion Mediastinal adhesion	Liver adhesion
Dog 3	115	5.9	LUL	Yes	4 cm	No	Complete healing	Pleural adhesion Diaphragmatic adhesion	Liver adhesion Mesentery adhesion
Dog 4	85	6.3	RUL	Yes	4.5 cm	No	Complete healing	Pleural adhesion Mediastinal adhesion	Liver adhesion Mesentery adhesion
Dog 5	65	6.8	RUL	Yes	4 cm	RML injury	Complete healing	Mediastinal adhesion Diaphragmatic adhesion	Liver adhesion Mesentery adhesion
Dog 6	85	7.4	RUL	Yes	3.5 cm	No	Complete healing	Pleural adhesion Mediastinal adhesion Diaphragmatic adhesion	Liver adhesion Mesentery adhesion
Dog 7	102	6.4	RML	Yes	6 cm	No	Complete healing	Lung adhesion	Liver adhesion Mesentery adhesion
Dog 8	90	7	RML	Yes	3.5 cm	No	Complete healing	Pleural adhesion Mediastinal adhesion	Liver adhesion Mesentery adhesion
Dog 9	60	7.6	RML	Yes	5 cm	No	Complete healing	Mediastinal adhesion	Liver adhesion
Dog 10	88	7.6	RLL	Yes	5 cm	No	Complete healing	Pleural adhesion Mediastinal adhesion Diaphragmatic adhesion	Liver adhesion
Dog 11	165	8.5	RLL	No	—	Thoracotomy	Complete healing	Pleural adhesion Mediastinal adhesion Diaphragmatic adhesion	Liver adhesion Mesentery adhesion

LUL, left upper lobe; LLL, left lower lobe; RUL, right upper lobe; RML, right middle lobe; RLL, right lower lobe.

without a chest tube has been reported in the literature.[17–19] For these reasons, wedge lung resection was performed with endostaplers in all animals in the present study. This strategy allowed us to operate on the animals without chest tube placement, with an uneventful postoperative course; no air leakage occurred in any of the animals. Necropsy further demonstrated that there was no clinical evidence of a collapsed lung as a result of air leakage in the thoracic cavity. These findings suggest the safety of lung resection without chest tube placement via a transumbilical approach.

We accessed the thoracic cavity through 2.5-cm diaphragmatic incisions. We encountered some technical challenges during surgery. First, the endoscopic field of vision was restricted and triangulation was not possible through a single umbilical incision. Second, clashing of the endostapler and bronchoscope, which enter through a single port, can lead to iatrogenic lung contusion and laceration. Third, performing lung resection in a confined thoracic space via a single port may result in more stress and a greater workload compared with the conventional 3-port approach. Fourth, exploration and resection of the lower lobes was the most difficult aspect of these procedures because of the restricted working space and obstruction caused by the liver and heart. We believe that further studies using a larger and anatomically appropriate animal model will clarify the efficacy of transumbilical thoracoscopy for wedge resection of different lobes of the lung. We also believe that lung resection via a transumbilical approach can be successfully performed in human patients because the human thoracic cavity is larger.

This transumbilical approach has the following potential advantages. First, because it does not require a transthoracic incision, it reduces the risk of pulmonary complications compared with the conventional transthoracic technique. Second, omitting a transthoracic incision avoids injury to the intercostal vessel and the development of bleeding complications. Third, transumbilical thoracoscopy reduces the risk of iatrogenic injury of intercostal nerves and avoids the complications of intercostal neuralgia and thoracotomy pain syndrome. Fourth, a transumbilical approach results in a better cosmetic outcome because the incision in the umbilical region is almost invisible.

This study has several limitations. First, transumbilical thoracoscopy has been investigated only for lung resection procedures. More complex thoracic procedures, such as pulmonary lobectomy and lymph node dissection, could not be performed with transumbilical techniques and currently available instruments. Second, there is a potential for difficulty in controlling active bleeding or stopping air leakage from the staple line after transumbilical lung resection, because the visual field is restricted when the patient is supine. However, with the new version of endostaplers, hemorrhage and air leakage are less likely to occur. Moreover, the complications can be successfully managed with VATS. Third, only 11 animals were included in the present study. However, the results clearly demonstrated the feasibility of transumbilical evaluation of the pleural cavity and transumbilical wedge lung resection. Fourth, only clinical parameters and inflammatory reactions were evaluated after surgery. Future NOTES studies of thoracic diseases should focus on the effects on hemodynamic conditions.

The findings of the present study suggest that transumbilical thoracoscopy is a feasible approach for adequate removal of lung tissue in animal models. It is also apparent that the procedure would be suitable for operations on infants and children given the currently available instrumentation. Current projects pursued by our research group include (1) studies comparing the safety, efficacy, and physiologic and immunologic effects between the transumbilical and transthoracic anatomic lobectomy in a canine survival model; and (2) studies evaluating the safety and efficacy of transumbilical wedge lung resection in a cadaveric model. We believe that all of these studies are important to collect more evidence-based information before this technique can be widely used in clinical practice.

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