Original Articles

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SURGICAL ENDOSCOPY and Other Interventional Techniques

Transvesical thoracoscopy: A natural orifice translumenal endoscopic approach for thoracic surgery

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Abstract
Background: Recently there has been an increasing enthusiasm for using natural orifices translumenal endoscopic surgery (NOTES) to perform scarless abdominal procedures. We have previously reported the feasibility and safety of the transvesical endoscopic peritoneoscopy in a long-term survival porcine model as useful for those purposes. Herein, we report our successful experience performing transvesical and transdiaphragmatic endoscopic approach to the thoracic cavity in a long-term survival study in a porcine model.
Methods: Transvesical and transdiaphragmatic endoscopic thoracoscopy was performed in six anesthetized female pigs. A 5 mm transvesical port was created on the bladder wall and an ureteroscope was advanced into the peritoneal cavity. After diaphragm inspection, we introduced through the left diaphragmatic dome a ureteroscope into the left thoracic cavity. In all animals, we performed thoracoscopy as well as peripheral lung biopsy. Animals were sacrificed by day 15 postoperatively.
Results: We easily introduced a 9.8 Fr ureteroscope into the thoracic cavity that allowed us to visualize the pleural cavity and to perform simple surgical procedures such as lung biopsies without complications. There were neither respiratory distress episodes nor surgical complications to report. Postmortem examination revealed complete healing of vesical and diaphragmatic holes, whereas no signs of infection or adhesions were observed in the peritoneal or thoracic cavities.
Conclusion: This study demonstrates the feasibility of transvesical thoracoscopy in porcine model. However, although this study extends the potential applications of NOTES to the thoracic cavity, new instruments and further work are needed to provide evidence that this could be translated to humans and with advantages for patients.

Key words: Swine — Endoscopy — Laparoscopy — Peritoneal cavity — Thoracic cavity

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Background

Since the early 1990s, it has been proposed that thoracoscopy is less invasive than open procedures [6]. Whereas its use as a definitive therapeutic tool in many pulmonary diseases is still controversial, its use as a diagnostic tool in pleural and pulmonary diseases is already well established [2, 17]. Indeed many prospective, randomized studies confirmed that thoracoscopy reduces postoperative pain, minimizes pulmonary dysfunction and shortens hospital stay [1, 18, 21].

Recently, there is an increasing enthusiasm for using natural orifice approaches to perform abdominal scarless surgery. In fact, Reddy and Rao (N. Reddy, V. G. Rao, oral communications, May 15 and 19, 2005; N. Reddy, oral communication, May 2004) and Kalloo et al. [8] described a new port to the peritoneal cavity through a transgastric approach in humans and pigs, respectively. Subsequently, various authors described more-complex intra-abdominal procedures in porcine models, opening a new era in surgery that is being considered third generation surgery: the natural orifice translumenal endoscopic surgery (NOTES) [7, 9, 11–14, 19–20]. Building on these findings, our group described transvesical endoscopic peritoneoscopy as a complementary and safe approach to the abdominal cavity in a porcine model [10, 16].

The aim of this study was to assess the feasibility and the safety of transvesical endoscopic approach to

the thoracic cavity with lung biopsy in a porcine model.

Materials and methods

The ethical review board of Minho University (Braga, Portugal) approved this study. Survival studies of thoracoscopy by transvesical approach were performed in six consecutive 15–20 kg female pigs (*Sus scrofus domesticus*). Pigs were followed after surgery for 15 days before sacrifice and postmortem examination.

Pig preparation

The animals were restrained from food (24 hours) and water (6 hours) before the surgical procedure. All procedures were performed under general anesthesia, with 6.0-mm endo-tracheal intubation (Super Safety clear tracheal tube, Ruschelit®) and mechanical ventilation. Pre-anesthesia medication consisted of an intramuscular injection of 32 mg/ml azaperone (Stressnil®, Esteve Farma) reconstituted with 1 mg/ml midazolam (Dormicum®, Roche) at dose of 0.15–0.2 ml/kg.

Venous access was obtained through an IV line placed in the marginal ear vein. Anesthesia was induced with 3 μg/kg fentanyl (Fentanest®, Janssen-Cilag), 10 mg/kg thiopental sodium (Pentothal®, Abbott) and 1 mg/kg vecuronium (Norcuron®, Organon). For infection prophylaxis, all animals received intramuscular injection of 1 g ceftriaxone (Rocephin®, Roche) before endoscopy. Anesthesia was maintained with 1.5–2% sevoflurane (Sevorane®, Abbott) and a perfusion of 1 mg/kg/h vecuronium (Norcuron®, Organon).

Surgical technique

An ureteroscope (Olympus A2942A) was introduced through the urogenital sinus and urethra into the bladder with hydro-distension. Before any further procedure, the bladder was emptied from urine and refilled with saline. The vesicotomy site was carefully selected on the bladder dome. A mucosal incision was made with scissors (Olympus A2576) introduced through the working channel of the ureteroscope. Subsequently, a 5 Fr open-ended ureteral catheter (Selectip, 62450200; Angiomed, Bard) was pushed forward through the incision into the peritoneal cavity. A 0.035-inch flexible-tip guide-wire (Terumo Corporation) was then inserted into the peritoneal cavity through the lumen of the ureteral catheter. Guided by the flexible-tip guide-wire, the vesical hole was enlarged with a dilator of an ureteroscope sheath (Microvasive, Boston Scientific Corporation) enveloped by a flexible over tube (equipment designed by the authors: 25 cm length, 5.5 mm internal diameter and 1 mm wall thickness). An ureteroscope was introduced into the peritoneal cavity through the over tube and allowed the creation of a pressure controlled CO_2 pneumoperitoneum up to 12 mmHg (Olympus Insufflator UHI-3 A90120A). Upper abdomen exploration and careful inspection of the diaphragm was performed using the ureteroscope.

The site of transdiaphragmatic approach was carefully chosen on the *muscular pars* of the left diaphragmatic dome. Peritoneal incision was made with a scissor (Olympus A2576) and the muscle fibers dissected until reaching the parietal pleura. Finally, we created a small hole in the parietal pleura and the ureteroscope was advanced into the thoracic cavity (Figure 1). In the thorax, CO_2 was insufflated up to 6 mmHg and the pleural cavity and lung surface were inspected. Under direct endoscopic control, lung biopsies were obtained from the lower left lung lobe using biopsy forceps (Olympus A2423). The ureteroscope was withdrawn from the thoracic cavity after CO_2 removal and expansion of the left lung. The peritoneal cavity was then decompressed through the over tube. At the end of the operation, a 14 Fr Foley catheter was inserted into the bladder and the balloon was inflated with 10 cm^3 of saline.

In this study, oral feeding was started within the following 24 hours. Pigs were evaluated daily and followed for 15 days. Bladder catheter was removed four days after surgery. Necropsy examination was then performed with particular attention to the site of vesical and diaphragmatic incision.

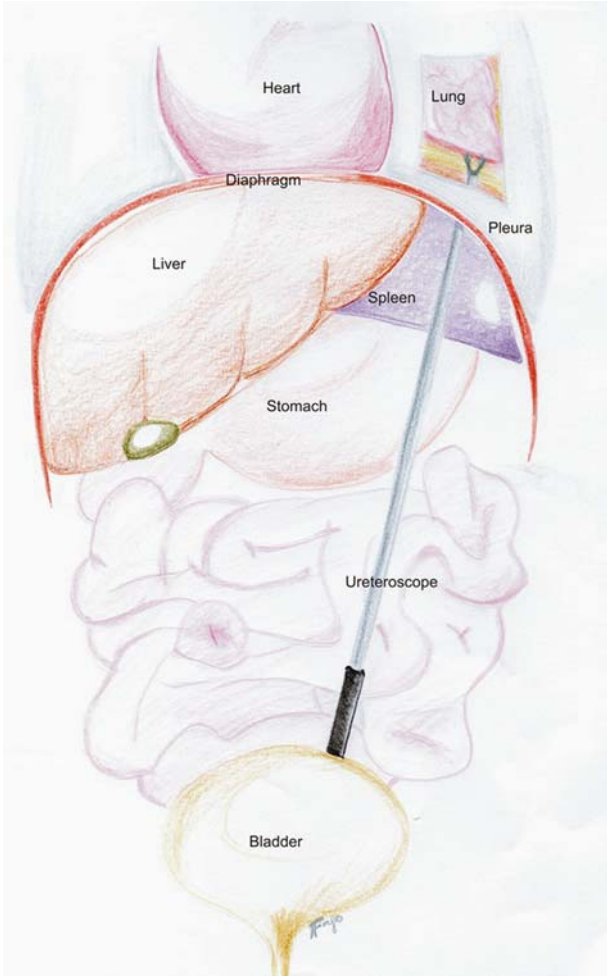

Fig. 1. Schematic drawing of transvesical and transdiaphragmatic approach.

Results

Transvesical and transdiaphragmatic endoscopic thoracoscopy with lung biopsy was performed on six pigs. As we have previously described, all procedures involved in the creation of the vesical hole (cystoscopy, bladder mucosal incision, vesicotomy, transvesical overtube passage) were performed without complications. The ureteroscope was introduced into the peritoneal cavity and the diaphragm was easily identified. The length of the ureteroscope allowed us to cross through the diaphragm (small incision in the parietal peritoneum, dissection of muscle fibers and incision of the parietal pleura) in all animals without difficulty (Figure 2). The ureteroscope working-channel allowed creating a pressure-controlled CO_2-pneumothorax up to 6 mmHg. In the thorax, the visualization provided by the ureteroscope was limited to the lower half-cavity but allowed us easily to perform lower lobe lung biopsy (Figure 3). At the end of the procedure, it was easy to expand the lung and the ureteroscope showed signs of contraction of the small hole created in the diaphragm. The operative time from bladder-wall incision to completion of the surgery varied between 10 and 15 minutes.

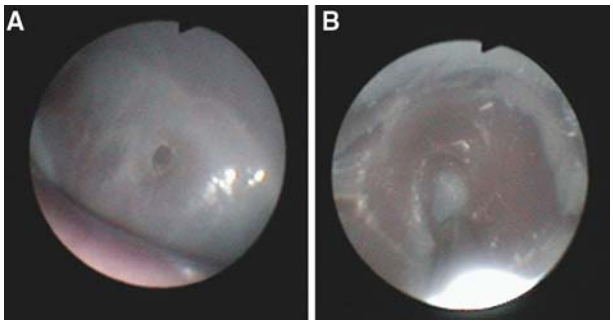

Fig. 2. Endoscopic views of a small hole on the *muscular pars* of left diaphragmatic dome. **A** Incision in diaphragmatic peritoneum. **B** Muscular hole being constructed in diaphragm *pars muscularis*.

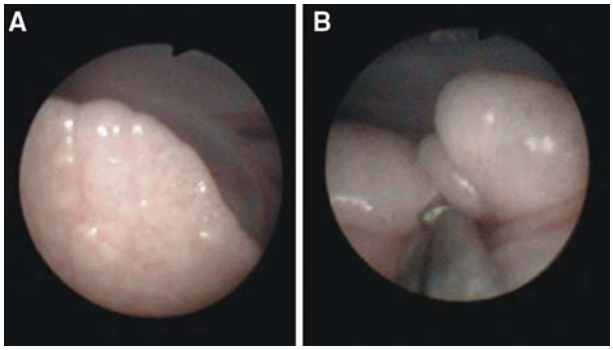

Fig. 3. Representative endoscopic views of lung biopsy. **A** Edge of left lower lung lobe; **B** lung biopsy being performed.

After recovery of anesthesia, the pigs tolerated a regular diet started the morning after surgery and they ambulated freely, exhibiting normal behavior. No adverse event occurred during the survival period. Until day 4 post-operative, pigs tolerated well the bladder catheter. After its removal, pigs began to void normally.

The postmortem examination 15 days after surgery revealed complete healing of the vesical and diaphragmatic incision (Figure 4). At necropsy, the lung biopsies were completely healed. There were no signs of infection or adhesions in both thoracic and peritoneal cavities.

Discussion

The widespread acceptance of minimally invasive techniques has revolutionized the practice of surgery including thoracic surgery. Within a short period of time, video-assisted thoracic surgery has become an acceptable approach with multiple studies confirming the advantages of thoracoscopy when compared to open procedure, which include shorter hospital stay, rapid recovery and return to physical activity, and excellent cosmetic results [1, 18, 21]. Recently, innovative natural orifices endoscopic techniques using per-oral transgastric surgery appear to further minimize surgical aggression in what has been designated as third generation surgery [10, 16]. In fact, several studies have confirmed the technical feasibility of transgastric diagnostic and therapeutic peritoneoscopy, including liver biopsy,

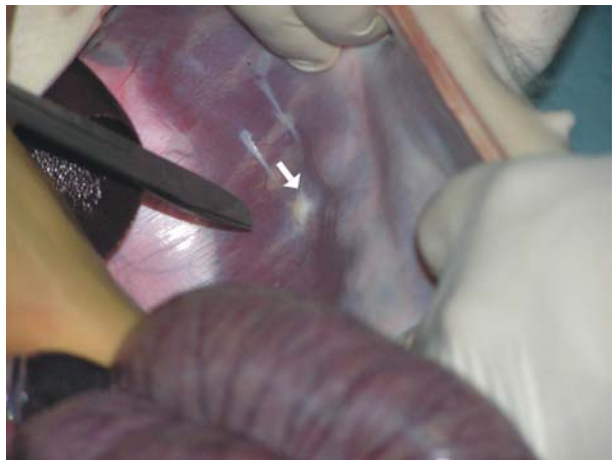

Fig. 4. Postmortem examination of diaphragm. Please note the small scar in the diaphragm *pars muscularis* (arrow).

tubal ligation, gastrojejunostomy, cholecystectomy, splenectomy, oophorectomy and partial hysterectomy [7–9, 11–14, 19–20]. In this regard, we showed for the first time that transvesical endoscopic approach to the peritoneal cavity is also feasible and particularly useful to inspect diaphragm and upper abdominal organs [10, 16]. Moreover, this approach revealed particularly useful to complement transgastric port, becoming cholecystectomy by natural orifices a reliable procedure, at least in the porcine model [16]. The feasibility and usefulness of transvesical endoscopic peritoneoscopy for upper abdominal procedures raised the rationale to extend its application to the thoracic cavity.

The aim of this study was to determine the technical feasibility and the safety of the transvesical approach to the thoracic cavity with lung biopsy in a porcine model in a long-term survival study. These experiments demonstrate that a transdiaphragmatic hole can be performed safely without injuring the lung or pericardium. The transdiaphragmatic incision could be made using the rigid ureteroscope and the scissors introduced through the working-channel. Interestingly, with our approach, we could easily identify the whole diaphragm and select the precise site of the incision. We could not reach the entire thoracic cavity mainly due to limitations of current instruments (rigid and not long enough). Anyway, Lower lobe lung biopsies were also performed without any complications.

This study provides the first successful evidence that the thoracic cavity might also be reached through NOTES. We anticipate some theoretical advantages to a transvesical-diaphragmatic approach to the thoracic cavity such as less pain and certainly a better cosmetic effect than open or thoracoscopic procedures. We predict less pain because, according to pain physiology, visceral wall has much less nervous terminal endings than skin, fascia and muscles. Transbronchic procedures might also share from these advantages but they are available only for peri-hilar lesions. In fact, although our approach might have some limitations (the risk of abdominal infection or malignant cell spillage from the thoracic cavity), there is a vast number of interstitial pulmonary diseases where bronchoscopy with trans-

bronchic biopsy is unviable. For these conditions, we could predict that transvesical-diaphragmatic approach might have a potential role. Similarly, with the appropriate instruments, pleural interventions like thoracic sympathectomy for the treatment of palmar hyperhidrosis and Raynauds disease might also appear feasible with transvesical-diaphragmatic approach avoiding thoracic incisions [3]. Another potential application of transvesical approach to the thoracic cavity is the implantation of phrenic nerve pacing electrodes for diaphragm stimulation [4], or just diaphragm pacing as recently described by transgastric approach [12]. Recently, Fritscher-Ravens et al. reported the feasibility and safety of a variety of interventional trans-esophageal cardiac procedures using endoscopic ultrasound in live porcine model. In those experiments, the procedures studied included needle biopsies, contrast medium injections into atrium and coronary arteries, direct intracardiac recording of ECG, cardiac conductive tissue ablation and direct cardiac pacing [5]. However, the superb view of the pericardium and the proximity of cardiac structures by transvesical approach might allow a variety of transdiaphragmatic interventional procedures to be performed under direct control or under endoscopic ultrasound control without the risks of trans-esophageal approach such as infection or absence of direct control. Moreover, the transvesical approach could be useful in the treatment of pericardial effusion and tamponade, especially those with malignant effusions. In fact, in these cases, the creation of a pericardioperitoneal window seems to be the most effective method of drainage [15].

In our experiments, we did not place any pleural drain at the end of the examination and no complications were reported, namely pneumothorax. In fact, we avoid this complication because: (i) we created a pressure-controlled CO_2-pneumothorax only up to 6 mmHg; (ii) we promoted re-expansion of the lung during the withdrawing of the ureteroscope; (iii) of the small size of lung biopsy. The vesical 5 mm hole has been well tested in our previous survival porcine study and had also no problems of closure [10]. In fact, we did not observe any side effects or complications over a two-week follow-up period. All pigs thrived after surgery and postmortem examination did not reveal any signs of infection or adhesions in the thoracic cavity.

This preliminary study was only designed to assess the technical feasibility of transvesical and transdiaphragmatic thoracoscopy. The ultimate implications for humans can only be assessed with the development of endoscopes with some flexibility and length to reach overall thoracic cavity. However, our current study clearly demonstrates that the transvesical and transdiaphragmatic approach to the thoracic cavity is feasible and safe in a porcine model with long-term survival assessment.

Conclusions

This study demonstrates that endoscopic transvesical-diaphragmatic thoracoscopy with lung biopsies is technically feasible in a porcine model. However, although this study extends the potential applications of NOTES to the thoracic cavity, new instruments and much work are needed to provide evidence that this could be translated for humans with advantages for patients.

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