Peroral esophageal segmentectomy and anastomosis with single transthoracic trocar: a step forward in thoracic NOTES

Background and study aims: A transesophageal natural orifice transluminal endoscopic surgery (NOTES) approach has been proposed for thoracic and mediastinal access. Similarly to transgastric surgery, serious limitations remain related to creating an esophagotomy and its safe closure. A hybrid approach in thoracic NOTES could work as an intermediate step before pure transesophageal NOTES. We assessed the benefit of hybrid thoracic NOTES for peroral segmental esophagectomy and subsequent complete esophageal anastomosis with a single transthoracic port.

Methods: Two protocols were used to attempt esophago-esophageal anastomosis: ex vivo using a phantom model (n = 5), and in vivo after esophageal mobilization, and segmental esophagectomy achieved using either a gastroscopy (flexible) (n = 5) or thoracoscopy (rigid) instruments (n = 5). A forward-viewing double-channel endoscope and a transthoracic operative thoracoscope with a working channel were coordinated in order to create a complete single-layer, end-to-end esophageal anastomosis ex vivo as well as in vivo. Feasibility and anastomosis quality were evaluated by inside and outside assessment of: patency, the incorporation of mucosa in all stitches, and a leak test.

Results: Anastomosis was achieved in all ex vivo experiments and thoracoscopically-led in vivo procedures. All anastomoses were patent, allowing distal passage of the endoscope, with mucosa incorporation. In in vivo experiments, a leak was detected in three animals and corrected with additional stitching.

Conclusions: Peroral esophageal anastomosis with a single transthoracic trocar is feasible, which may represent a step forward in thoracic NOTES.
tional step for humans in reducing the number of transabdominal ports and enabling a natural orifice approach without losing safety [18, 19], we hypothesized that the use of a peroral approach in a hybrid mode can significantly reduce the number of transthoracic ports.

Aiming to eliminate some of the current limitations of transesophageal NOTES, we designed this study to carry out peroral esophageal mobilization, segmental esophagectomy and esophageo-esophageal anastomosis with a single trocar, to assess the reliability of this strategy for opening, resection and suturing of the esophagus.

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Materials and methods

Study design

This study was approved by ethical review boards of Minho University (Braga, Portugal).

The study was divided in two main branches: ex vivo studies in which esophago-esophageal anastomoses were carried out in a phantom model (five porcine esophagus), and in vivo studies in anesthetized pigs. The in vivo studies involved esophageal mobilization and segmental esophagectomy using either a flexible gastroscope (five animals) or rigid instruments introduced through the working channel of an operative thoracoscope (five animals). Esophago-esophageal anastomoses were then carried out in the subset group in which esophagectomy had been carried out using rigid instruments introduced through the working channel of an operative thoracoscope. In all conditions, we used a forward-viewing double-channel gastroscope (G28/34; Karl Storz, Tuttingen, Germany) and a transthoracic 10-mm operative thoracoscope with a 5-mm working channel (26036AA; Karl Storz).

Ex vivo studies

Phantom model A three-dimensional structure consisting of synthetic polyurethane foam with an attached PVC container was mounted to simulate the thoracic cavity, and a tube 20 cm long was used to reproduce the oropharynx. Esophagus harvested from adult pigs were positioned, fixed and sectioned in the middle segment, creating a gap 4 cm long between the ends (Fig. 1a). The model had a black, non-transparent removable cover with an opening on the right side to position the trocar (Fig. 1b).

Surgical technique The operative thoracoscope was inserted into the phantom model through a 12-mm trocar (Excel port; Ethicon Endo-Surgery, Cincinnati, USA), whereas the gastroscope was introduced through the proximal esophagus; both instruments were coordinated to carry out an esophago-esophageal anastomosis (Fig. 2). First, a suturing needle with a 3–0 absorbable PDS stitch (Polydioxanone; Ethicon Endo-Surgery) was mounted on a needle-holder (26178KPL; Karl Storz), previously passed through the operative thoracoscope working channel and introduced into the phantom model. Then the gastroscope was moved towards the free lower extremity of the esophagus to grasp it on its posterior wall, including always muscle and mucosa, making proximal traction for the first stitch passage (inside to outside). The needle was then repositioned by the needle-holder for approaching the esophageal upper extremity, and the gastroscope was used to promote esophageal stump alignment and esophageal wall traction for outside-to-in proximal puncture. The knot-tying was achieved by extracorporeal knot techniques using a knot-pusher (26596D; Karl Storz) under gastroscope vision. Then scissors (34410MW; Karl Storz) were introduced through the operative thoracoscopic working channel and the excess suture lengths were cut. This procedure was repeated until 10 single-layer interrupted sutures had been completed, the posterior stitches with internal knotting and the later ones with external knotting. The duration of the procedure was recorded.

When the sutures were complete, the gastroscope was used to verify the immediate endoluminal reliability of the anastomosis, confirming that mucosa from both tips were touching each other, and identifying possible sites for supplementary stitches.

In vivo studies

Pig preparation Male 40–50 kg pigs (Sus scrofus domesticus) were fed liquids for 1 day and not allowed food and water for 8 hours before the surgery. All procedures were performed under general anesthesia with endotracheal intubation and mechanical ventilation, according to previous descriptions [20, 21]. Before the procedure, 1 mg of intravenous atropine was administered.

Surgical technique The pig was placed in the prone position (Fig. 3). A 12-mm trocar was positioned around the eighth intercostal space in the right posterior axillary line, through which the operative thoracoscope was introduced; CO2 insufflation was maintained with a pressure up to 6 mmHg. The gastroscope was advanced through an oropharyngeal overte (US Endoscopy, Mentor, Ohio, USA) into the esophagus. Esophageal mobilization and segmental esophagectomy were carried out in the proximal third using either rigid instruments through an operative thoracoscope (five animals) or flexible instruments through a gastroscope (five animals), as detailed schematically in Fig. 4.
In those animals where esophagectomy was performed using flexible instruments, the proximal section was carried out with an endoscopic submucosal dissection (ESD) knife. This procedure was enhanced by clamping the esophageal lumen with an external grasper introduced through the working channel of the operative thoracoscope, which helped also in mobilizing the esophagus and providing traction while the gastroscope knife sectioned the esophagus circumferentially with cautery. Subsequently, the gastroscope was introduced into the mediastinum, and the esophagus was released from its vessels and attachments using a flexible hemostatic grasper. Finally, the esophagectomy was completed using an endoscopic snare.

In both approaches, approximately 4 cm of esophagus was sectioned and removed perorally.

In those animals where the esophagectomy was accomplished with the rigid instruments, the gastroscope was reintroduced into the thoracic cavity providing traction and alignment of both esophageal stumps for suturing. The creation of the anastomosis followed the same steps as described in the ex vivo studies (Fig. 2). At the end of the procedure, the gastroscope con-
firmed the patency of the anastomosis and the incorporation of mucosa in all stitches; the thoracoscopic view was used to check the reliability of the anastomosis by looking for bubbles released under saline when the gastroscope was insufflating air inside the esophagus (air leak test).

Results

Ex vivo studies
The phantom model was easy to operate and simulated reasonably well the steps of the in vivo anastomosis, although the lung, other thoracic structures, and the cardio-respiratory movements were not present.

After some initial difficulties, we verified progressive coordination, making possible the construction of a complete single-layer end-to-end esophageal anastomosis in all experiments, with at least 10 interrupted sutures having five knots each. The crucial step was always the first stitch. Gastroscopic grasping of the muscular and mucosal layers of the distal stump was easily achieved and useful as it provided positioning and traction for the needle passage (Fig. 5a).

Similarly, the gastroscope was useful in exposing the proximal extremity and for countertraction. Once the needle had crossed both extremities, the gastroscope view was also effective in monitoring the knotting. The subsequent stitches were progressively easier to apply (Fig. 5b). The entrance of the knot-pusher in the thorax was well monitored by the gastroscope image, allowing the operator to recommend pressure adjustment or even knot removal when the knot was not correctly applied (Fig. 5c). The knots’ edges were easily cut with the scissors (Fig. 5d). As the anastomosis evolved, the benefit of the image provided by the gastroscope was gradually reduced, but the need for support and exposure was also less as the anastomosis was reaching completion. Although the aim was single-layer sutures involving both mucosa and muscle, we found that mucosa easily dislodged from the muscle layer and could be involuntarily missed by the needle; the gastroscope was very useful in monitoring the correct transmural involvement and in providing better exposure whenever necessary. The mean (standard deviation [SD]) time to perform complete anastomoses was 65.5 (10.9) minutes. The anastomoses were finally checked by their endoluminal aspect for lumen patency, intersuturing space and stitch mucosal misplacement. It was found in a few sutures that some stitches did not include the mucosal layer.

In vivo studies
The prone approach and the CO₂ insufflation provided good exposure of the intrathoracic esophagus without the need for additional retraction instruments. This and the endoluminal transillumination of the esophagus allowed rapid access of the operative thoracoscope to select the esophageal segment of interest.

In this study, we tested esophageal mobilization and esophagectomy using either a flexible gastroscope (Video 1) or rigid instruments (Video 2), and both approaches were feasible. How-
ever, the margin of the proximal esophageal stump was left more irregular when esophagectomy was performed using a flexible instrument (the gastroscope) than using a rigid instrument (the operative thoracoscope).

With both strategies, segmental esophagectomy was done and the specimen was removed perorally without complications (\textbullet\ Fig. 6a and b).

In animals where esophagectomy was performed using rigid instruments (with a similar regularity of proximal and distal border), we performed esophageal anastomosis following the same principles as in the ex vivo training. Apart from some movement interference and some additional caution because of adjacent structures, the anastomoses were feasible and reproducible in all cases (\textbullet\ Video 3).

An interesting aspect of these experiments was that the thoracoscope view was sometimes not enough to see whether the needle position was the most appropriate for a specific suture orientation. However, combining the thoracoscope view with the gastroscope view, it was always possible to correct the needle-holder position. The total mean operative time was 101.8 (32.9) minutes, including dissection, segmentectomy and anastomosis.

At the end of the procedure, the internal and external appearance of the anastomoses was checked (\textbullet\ Video 4).

Externally, the thoracoscope was used to inspect the surface of the anastomosis by using endoluminal transillumination; the gastroscope was used to make small rotations of the anastomosis (\textbullet\ Fig. 6c). Inside, all anastomoses were patent allowing distal passage of the endoscope, and almost all sutures incorporated the mucosa (\textbullet\ Fig. 6d). Air leak (bubbling) was detected in three animals. This most commonly occurred when the mucosa was not included in the stitch or when the distance between two stitches was too long. In these cases, we were able to correct it with additional stitching.

**Discussion**

The esophagus is a fragile organ given its specific morphological characteristics and anatomical location, and it has been considered by surgeons something of a special zone [4]. This probably contributes to the slower dissemination of video-assisted surgery in the thorax when compared with laparoscopy [22, 23]. Similar-
Transesophageal NOTES endorses the possible absence of trans-thoracic incisions. Avoiding intercostal neuralgia, it brings the expectation of a potentially greater patient benefit in the thorax than in the abdomen [12]. Descriptions in a porcine model of transesophageal mediastinoscopy and thoracoscopy [9,13], lung and pleura biopsy [13], lymphadenectomy [12,13], pericardial fenestration [12], vagotomy and esophagomyotomy [14], Heller myotomy [15], esophageal wall resection [16], with or without the help of endoscopic ultrasound (EUS), can be found in the literature. Besides the possible benefits, the procedure’s main risks are always discussed: the ‘blind’ creation of the esophagotomy, the unpredictable thoracic side exit without EUS or fluoroscopic assistance, and finally the possible devastating consequences of leaking from an incomplete esophageal closure.

We hypothesized that a hybrid thoracic approach could achieve the benefits of reducing the number of transthoracic ports and simultaneously minimizing the limitations and risks of a pure transesophageal approach. This study explores the combination of the peroral route with a single transthoracic port for a complex intrathoracic procedure – segmental esophagectomy with esophageal anastomosis. The reduction of the usual four or five trocars used to a single transthoracic instrument was obtained as a result of three main factors: the use of an operative thoracoscope with a working channel for 5-mm instruments, the prone position instead of the regular left-lateral decubitus, and the coordinated beneficial use of the peroral gastroscopic instruments.

The prone position is being promoted because it allows gravity to provide exposure with minimal handling, giving good esophageal visualization, simplifying dissection and reducing the operative times, without sacrificing patient safety [1]. In our in vivo experiments, we also confirmed these benefits with no need of any accessory port for lung retraction, and the single transthoracic instrument was totally focused on esophageal surgery.

The great improvement explored in this study is the help provided by the peroral/transesophageal port. The benefits start with the endoscopic transillumination of the esophagus by the thoracoscope; this step may be particularly helpful for direct visualization of a possible lesion area, orienting a more precise resection [24]. In this study, esophageal dissection and mobilization were carried out through two distinct strategies led either by a flexible endoscope or by rigid thoracoscope instruments. Both strategies were successful in mobilizing, sectioning and dissecting the esophageal segment. When these processes were led by the gastroscopic instruments, esophageal dissection and distal section were quite reliable, but the proximal esophageal section often left the stump margin too irregular. In contrast, esophageal dissection and section carried out by the thoracoscope instruments was reliable and rapid, and both esophageal margins were similar and quite regular. This was our main reason for testing the feasibility of the esophageal anastomosis in those animals where esophageal dissection and sectioning were carried out by the operative thoracoscope. It should be emphasized that even in this strategy, coordinated movements of the endoscope and traction were important for the operative thoracoscope-oriented work. In minimally invasive esophagectomy, specimen retrieval is currently performed via a separated neck incision, but in our experiments the specimen was always removed perorally; depending on its size, we predict this can be done in humans too.

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transthoracic trocars, once there is secure endoscope sterility and the use of an oropharyngeal overture.

In conclusion, this study confirms the feasibility of a hybrid peroral transeosophageal approach with a single transthoracic trocar to carry out segmental esophagectomy with complete single-layer, end-to-end intrathoracic esophageal anastomosis in a porcine model. Moreover, this study reinforces the logic and pertinence of using a transeosophageal approach to the thoracic cavity.

**Competing interests**: Jorge Correia Pinto is a consultant to Karl Storz.

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**References**