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ORIGINAL ARTICLE

Transcervical Heller Myotomy Using Flexible Endoscopy

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Abstract

Introduction Esophageal achalasia is most commonly treated by laparoscopic myotomy. Transesophageal approaches using flexible endoscopy have recently been described. We hypothesized that using techniques and flexible instruments from our NOTES experience through a small cervical incision would be a safer and less traumatic route for esophageal myotomy. The purpose of this study was to evaluate the feasibility, safety, and success rate of using flexible endoscopes to perform anterior or posterior Heller myotomy via a transcervical approach.

Methods This animal (porcine) and human cadaver study was conducted at the Legacy Research and Technology Center. Mediastinal operations on ten live, anesthetized pigs and two human cadavers were performed using standard flexible endoscopes through a small incision at the supra-sternal notch. The esophagus was dissected to the phreno-esophageal junction using balloon dilatation in the peri-esophageal space followed by either anterior or posterior distal esophageal myotomy. Success rate was recorded of esophageal dissection to the diaphragm and proximal stomach, anterior and posterior myotomy, perforation, and complication rates.

Results Dissection of the esophagus to the diaphragm and performing esophageal myotomy was achieved in 100% of attempts. Posterior Heller myotomy was always extendable onto the gastric wall, while anterior gastric extension of the myotomy was found to be more difficult (4/4 and 2/8, respectively; $P=0.061$).

Conclusion Heller myotomy through a small cervical incision using flexible endoscopes is feasible. A complete Heller myotomy was performed with a higher success rate posteriorly possibly due to less anatomic interference.

Keywords NOTES · Flexible endoscopy · Achalasia · Heller myotomy · Mediastinoscopy

Introduction

The last several years has seen a rapidly increasing interest in the use of flexible endoscopy outside of the confines of the GI tract. While the initial focus of the “NOTES” (Natural Orifice Translumenal Endoscopic Surgery) approach was the replication of laparoscopic operations, more recently, investigators have been exploring other areas such as the thorax, retroperitoneum, and mediastinum.[1–6] Mediastinoscopy using variations of rigid endoscopes has existed for over 60 years.[7] Access to the esophagus and distal mediastinum was, however, difficult if not impossible with rigid scopes. Several researchers have recently experimented with translumenal, flexible endoscopic approaches to mediastinal surgery.[5,8,9] In particular, there has been an interest in the possibility of performing esophageal myotomy (Heller myotomy) for achalasia. Transesophageal myotomy, first described by Pasricha et al., has in fact, already found its way into the clinical setting.[6,10] There remains great concern however regarding possible catastrophic complications from the esophagotomy needed for transesophageal approaches.

As it is well established that the cervical approach for mediastinoscopy is safe and well tolerated[11] and based on

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our own experience with flexible endoscopic surgery (endoluminal, translumenal, and via single port access), we considered that accessing the distal esophagus for a Heller myotomy would be feasible by using a combination of endoluminal endoscopy and flexible endoscopes inserted through a single small, cosmetically advantaged incision in the low neck.[12] While such an approach to a myotomy would be slightly more (visibly) invasive than the transesophageal approach, it is still less invasive than the typical five-incision laparoscopic approach and avoids the potential risks associated with perforating the esophagus. It also presents the opportunity to preserve the suspensory structures of the lower esophageal sphincter, which are necessarily disrupted with the laparoscopic approach, and thereby may reduce the need for an anti-reflux surgery.[10] Experience achieved with flexible endoscopic surgery in the mediastinum using this safe approach may eventually be adapted to a translumenal, "incisionless" protocol, when esophageal closure methods have improved.

We hypothesized that a transcervical flexible approach to the inferior visceral mediastinum to perform Heller myotomy would be feasible and that either an anterior or posterior Heller myotomy could be safely performed.

Methods

This study was conducted under a protocol approved by Legacy Institutional Animal Care and Use Committee (IACUC). Ten pigs (35–60 kg) were included in the study as well as two male human cadavers. Standard dual and single channel endoscopes (GIF 2T160 and GIF 140, respectively; Olympus, Tokyo, Japan) were used through a small cervical incision to perform mediastinal operations on the animals and the human cadavers. The endoscopes were connected to two CV-180 video processors and CLV-180 Xenon light sources (both Olympus) and displayed on two monitors (PVM-20M2MDU, Sony, Tokyo, Japan).

The animals were set on liquid diet for 24 h prior to the procedure. General anesthesia was induced with Telazole (6–8 mg/kg) and Atropine (0.06 mg/kg). The animals were then placed in supine position on the operating table, on a warm water circulating blanket, and endotracheal intubation was performed. An isoflurane (1.5%–3%) inhalation anesthesia was maintained throughout surgery; cardiac monitoring, pulse oximetry, end tidal CO_2, and blood pressure monitoring ensured a normal physiologic response to the anesthetic agent and CO_2 insufflation. If there were hemodynamic or respiratory problems, the mediastinum was deinsufflated, and if breath sounds were diminished, a needle was introduced into the pleural space to check for a pneumothorax. If there was one, chest tubes were placed. After the procedure, the animal was euthanized with sodium pentobarbital (80 mg/kg).

Surgical Technique

A small, transverse skin incision was made two-finger breadths above the supra-sternal notch in the human

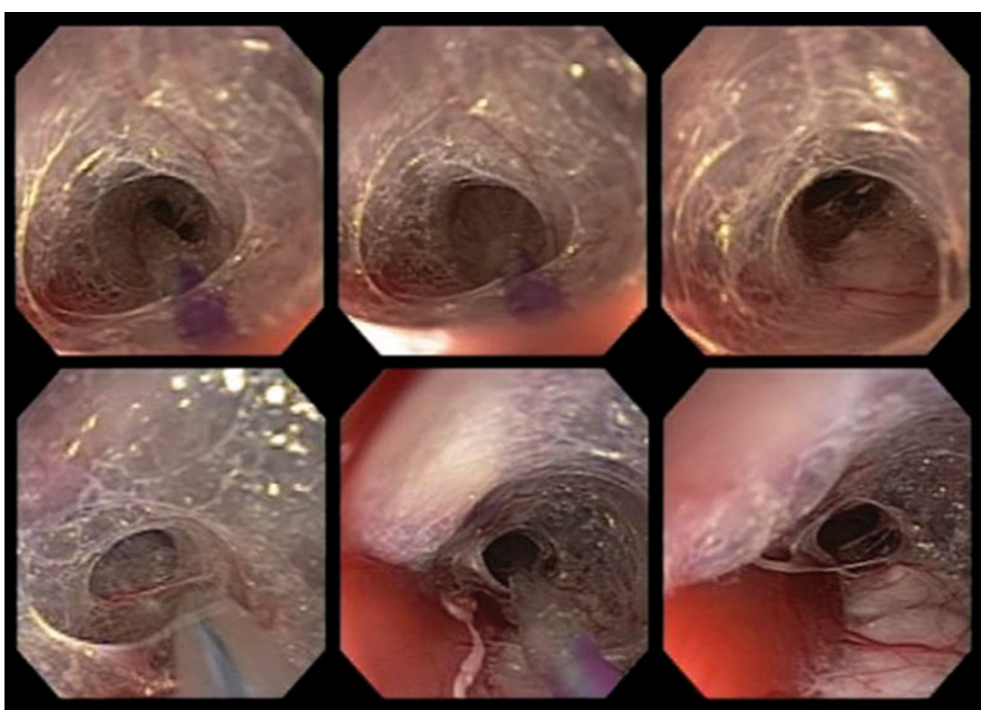

Fig. 1 A standard endoscopic dilatation balloon is used to create a connective tissue tunnel in which the endoscope can follow the esophagus (visible between 6 and 8 o'clock) safely

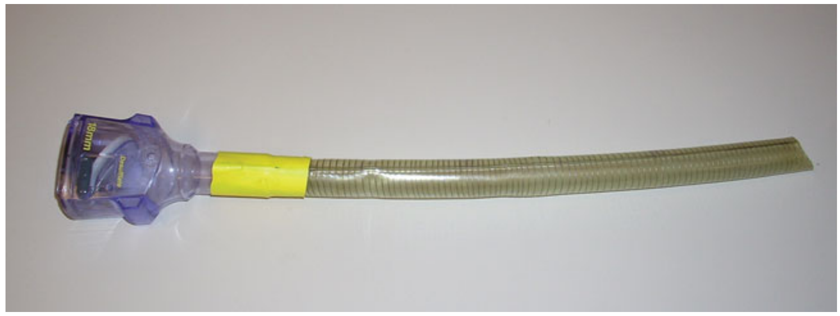

Fig. 2 The modified overtube is used to protect the cervical anatomy and facilitates endoscope insertion and removal. The endoscopic port was used with open insufflation valve to avoid mediastinal over-pressure. CO_2 insufflation was provided over the scope (minimal flow)

cadavers. When operating on pigs, we performed a longitudinal incision. Platysma and superficial cervical fascia were dissected using electrocautery, and the pretracheal muscles were separated vertically to expose the trachea. Dissection was performed on the left side of trachea and esophagus, and the left recurrent laryngeal nerve was routinely visualized. The pre- or post-esophageal plain was entered using both blunt and sharp dissection, and the esophagus was followed distally for 2 cm. The light of a second endoscope in the esophagus was useful to easily identify the esophagus from the outside through the small cervical incision.

The sternocleidomastoid muscle and carotid sheath were retracted laterally, the trachea to the opposite side, and the thyroid gland cranially. The endoscope was then inserted in the pre- or post-esophageal plane and blunt dissection with a grasper, or by sequentially advancing an endoscopic balloon (CRE 5842 and 5843, 12–15 and 15–18 mm, Boston Scientific, Natic, MA, USA), inflating it, and then advancing the scope along the resulting tract; it was used to follow the esophagus in a distal direction (Fig. 1). A modified flexible 18-mm overtube (NOTES toolbox, Ethicon Endo-Surgery, Cincinnati, OH, USA; Fig. 2) was used to protect the cervical anatomy, allowing atraumatic changes of the endoscope during the surgery and evacuation of insufflated gas.

CO_2 insufflation was provided through the overtube using laparoscopic insufflators with a maximal pressure of 8 mmHg for the first three animals; for the following seven animals, CO_2 insufflation was achieved using the endoscope but with a special insufflation flow reducer to avoid over-insufflating the mediastinum (Water bottle, MAJ-902, Olympus; pressure reduction valve, M1-940-12FM Western Medica, Wastlake, OH, USA).

The esophagus was followed to the diaphragm, and a Heller myotomy was performed in a manner similar to laparoscopic myotomies, starting proximally and extending well onto the gastric wall (Fig. 3). The full thickness of the muscle layers was divided and spread using a variety of flexible endoscopic instruments, both currently available and new prototype ones designed for NOTES (Table 1), such as articulating hook (Fig. 4) or needle knife, articulating graspers, and flexible Maryland Graspers (all NOTES toolbox, Ethicon Endo-Surgery); standard endoscopic instrumentation like snares and hook knifes (SD-221L-25 and KD-620LR, respectively; both Olympus), transparent caps (Fig. 3; cap of Speedband SuperView Super 7 Multiple Band Ligators; Boston Scientific Microvasive; or D-402-13212; Olympus), and balloon dilator (10–12 mm, CRE 5841; Boston Scientific Microvasive). We incidentally found that it was easier to perform the myotomy posteriorly. There seemed to be less dense connective tissues in the plane of dissection, and there was less risk of entering the peritoneal cavity with subsequent pneumoperitoneum.

A second endoscope in the esophagus facilitated orientation and was used to check for perforations and completeness of the myotomy.

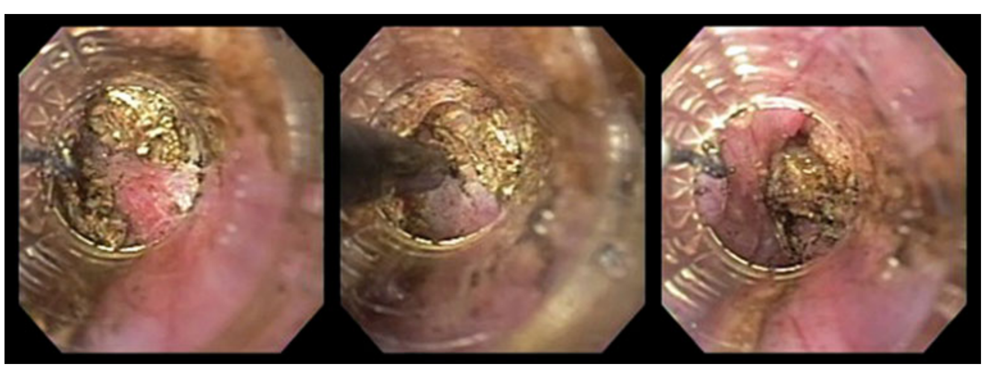

Fig. 3 Heller myotomy was performed using mostly standard endoscopic instruments like hook knife and transparent cap. The submucosal layer is visible between 3 and 6 o'clock (esophago-gastric junction). The prominent muscularis propria (already divided) of the stomach is visible in the upper quadrant of the cap between 10 and 3 o'clock

Table 1 Endoscopic instrumentation used with the standard endoscopes

Endoscopic instrument	Currently available	NOTES prototype	Manufacturer
Dissecting cap	+		Boston Scientific, Olympus
Balloon dilator (10–18 mm)	+		Boston Scientific
Polypectomy snare	+	+	Olympus, Boston Scientific, Ethicon
Hook knife	+	+	Olympus, Ethicon
Articulating hook knife		+	Ethicon
Articulating needle knife		+	Ethicon
Flexible Maryland dissector		+	Ethicon

Commercially available instrumentation and NOTES prototypes used for the endoscopic dissection and myotomy

Analysis

Necropsy was performed after the procedures in animals and human cadavers to assess the quality of the dissection. Operation time for the different steps of the procedure was recorded. Quality control called for a minimum length of 4 cm for the myotomy and 2 cm extension of the myotomy onto the gastric wall (Fig. 5). Failure to extend the myotomy onto the gastric muscularis propria was noted. Critical errors (death of the animal, injury of blood vessels, intraoperative laceration of the pleura, intraoperative laceration of the main bronchus, esophageal injury, injury of other vital organs, thoracic duct leak, injury of recurrent or vagal nerve, and blood loss >200 ml in animal studies) were documented. Comparisons were made between anterior and posterior myotomy performed on animals and cadavers on the critical errors, operative complications, operative times, and length. Categorical variables are compared using Fisher's exact test, and continuous variables have been compared with the unpaired Student *t* test (two sided, two tailed). *P* value <0.05 was considered statistically significant.

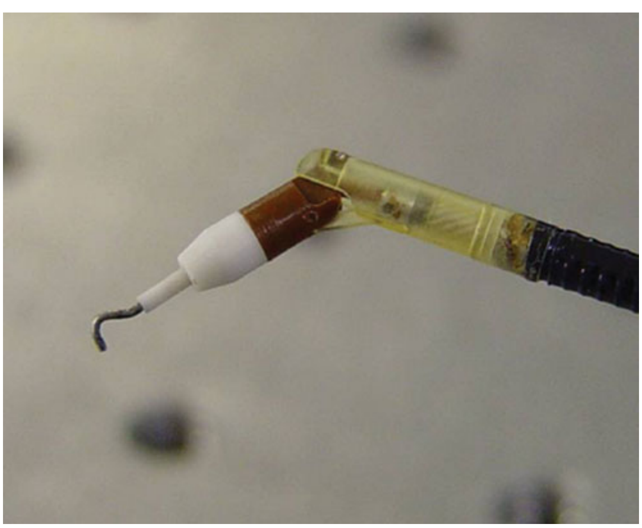

Fig. 4 A flexible articulating hook knife (prototype from a NOTES toolbox) has been used to create the first opening in the muscularis safely

Results

Dissection of the esophagus to the diaphragm and performing an esophageal myotomy was achieved in 100% of attempts. The esophagus was easily followed to the gastro-esophageal junction. The blood supply to the esophagus from the inferior thyroid arteries, the branches from the bronchial arteries, and aortic perforators could be partially visualized and avoided by creating connective tissue tunnels using blunt dissection. The small confines of the connective tissue tunnels provided excellent stability for the endoscope and allowed safe advancement and manipulation. Dissection through the phreno-esophageal ligament was more difficult. Table 2 provides a summary of procedure times and details about the performed myotomies.

Myotomy of the esophagus was successful 100% (12/12) of the time. Extension of the myotomy 2 cm onto the gastric wall was successful in 50% (6/12) of attempts (Fig. 5). Anterior myotomy was performed in seven pigs and one human cadaver, and posterior myotomy was performed in three pigs and a human cadaver. Posterior Heller myotomy was more often extendable onto the gastric wall for 2 cm than anterior myotomy. A 25% success rate (2/8) was recorded when the myotomy was performed anteriorly, and a 100% success rate (4/4) when performed posteriorly. However, due to the small numbers used in our feasibility study, the difference was not found to be statistically significant ($P=0.061$). Differences between anterior and posterior myotomy regarding esophageal dissection time, time for myotomy, length of myotomy, number of perforations, and blood loss were not found significant (Table 3).

One 20-mm-long esophageal perforation occurred in a human cadaver in the mid-portion of the esophagus during

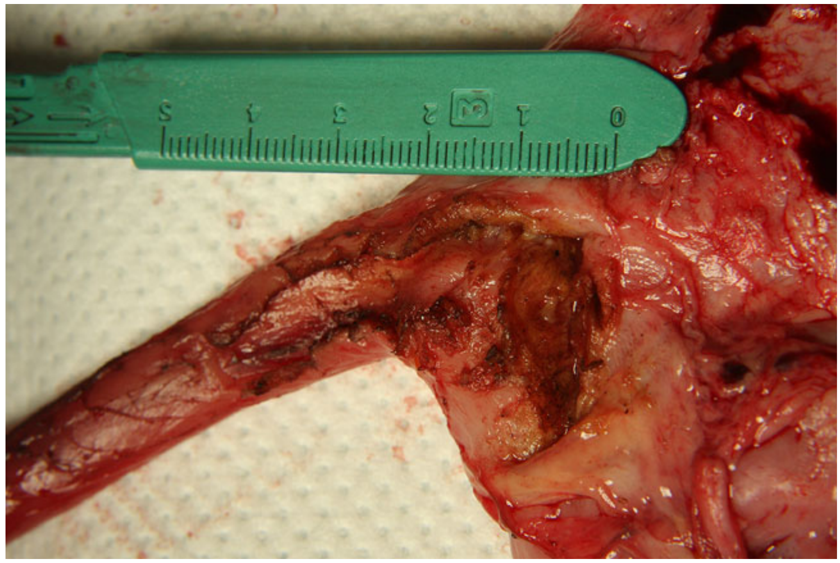

Fig. 5 Result of a successful posterior myotomy with extension onto the gastric wall

blind advancement of an overtube over the inserted endoscope. Unfortunately, the patient had had previous thoracic radiation and chemotherapy with an angled fixation of the esophagus to the right side, which facilitated the perforation to a high degree. The esophageal perforation could be closed endolumenally with T-anchors (Tissue Apposition System, NOTES toolbox, Ethicon Endo-Surgery). Three small (2 mm) perforations occurred during myotomy; all were closed by endoscopic clipping (Fig. 6; Resolution Clips, Boston Scientific Microvasive) and were well sealed by air leak testing. Minor bleeding (<10 ml) occurred in four myotomies, which were easily treated with electrocautery. Chest tubes were not used in the pig model during the myotomies. No death or severe complication occurred during the myotomies or related dissection in the pig model.

Discussion

Mediastinal surgery through a transcervical incision in the form of scalene lymph node biopsy originated over 60 years

Table 2 Procedural detail of the myotomies

	Heller myotomy	Cervical diss. (min)	Esoph. diss. (min)	Heller (min)	Myotomy length (cm)	2-cm gastric extension of myotomy	Perf.	Perf. diameter (mm)	Perf. management	Blood loss (ml)
Pig 1	Anterior	32	24	35	6	No	No			5
Pig 2	Anterior	11	6	8	4	No	No			0
Pig 3	Anterior	10	8	25	5	No	No			0
Pig 4	Anterior	9	8	20	5	No	No			0
Pig 5	Anterior	22	16	60	4	Yes	No			8
Pig 6	Posterior	31	11	55	6	Yes	No			0
Pig 7	Anterior	39	36	40	6	Yes	Yes	2	Endoscopic (clips)	5
Pig 8	Anterior	16	15	35	5	No	No			0
Pig 9	Posterior	28	23	51	5	Yes	Yes	2	Endoscopic (clips)	0
Pig10	Posterior	19	11	30	6	Yes	No			5
Cad.1	Anterior	35	30[a]	33	4	No	Yes	20[a]	T-anchors	n.a.
Cad.2	Posterior	15	26	55	5	Yes	Yes	2	Endoscopic (clips)	n.a.

Procedural details of Heller myotomies performed transcervically

Cad. human cadaver, *diss.* dissection, *Esoph.* esophagus, *Perf.* perforation

[a] Perforation of mid-portion of esophagus from outside (post radiation); time for esophageal closure (t-anchors) not calculated

Table 3 Detailed comparisons between anterior and posterior cardiomyotomy

Heller myotomy	Type of myotomy		Significance
	Anterior	Posterior	
Esophageal dissection (min)	17.9±11.1	17.8±7.9	n.s.
Heller myotomy (min)	32.0±15.3	47.8±12.0	n.s.
Myotomy length (cm)	4.9±0.8	5.5±0.6	n.s.
2-cm gastric extension of myotomy	25%	100%	n.s.
Perforation	25%	50%	n.s.
Blood loss (ml)	2.6±3.4	1.7±2.9	n.s.

Procedural details (average ± standard deviation) of the myotomies and significance level

n.s. not significant

ago.[7,13] Currently, mediastinoscopy with short rigid tools is an established, safe, and minimally invasive surgical procedure for diagnosis of anterior mediastinal lymph nodes or masses.[11] Since the early 1990s, the concept of expanding the use of mediastinoscopy to perform more advanced procedures through a cervical approach has been explored by different researchers using larger rigid platforms with the ability to perform simple bimanual tasks.[11,14–18] While generally adequate for superior mediastinal surgery, access beyond the tracheal bifurcation requires significant and difficult dissection to achieve sufficient working space for triangulation at the tip of the instruments. The other limitation with this type of rigid platform is the awkwardness of the extremely long rigid tools and the difficulty manipulating targets that are farther away.

We demonstrate that the use of flexible endoscopes allows advanced mediastinal dissection with little trauma because these instruments can operate in the small confines of connective tissue tunnels, which can be created by simple, atraumatic dilatation (Fig. 1). All blood vessels and nerves can be avoided, and these tissue tunnels collapse immediately after surgery with expected minimal scaring in uncomplicated procedures.

Technically simple procedures like lymph node harvest or esophageal myotomy can be achieved using this technique with standard endoscopic instrumentation like snares, hook or needle knives, and transparent dissecting caps. The biggest challenge we encountered was crossing the phreno-esophageal ligament anteriorly using only linear moving instruments without adequate counter-traction to maneuver and due to the dense vascular tissues of this structure. We found this anterior dissection to be difficult enough that we could only complete it two times out of eight attempts. Newer flexible endoscopic multitasking platforms with superior bimanual coordination abilities may make this more feasible in the future, but currently, they are still in the prototype stage.[19,20] Conversely, a complete posterior gastric myotomy was able to be performed 100% of the time due to the less dense and more fixed posterior attachments of the gastro-esophageal junction. This may be a viable clinical approach as well. In the original 1913 publication of myotomy for achalasia, Ernst Heller described both an anterior myotomy (as originally suggested by Gottstein in 1901) and a posterior myotomy as his treatment of achalasia.[21] The open and later the laparoscopic approaches favored the anterior myotomy because of easier exposure, and a second cardiomyotomy was found to be redundant, but one could presume that the same could be true for a posterior myotomy alone as well.

The preservation of the suspensory structures of the lower esophageal sphincter may be beneficial in different ways. We expect a reduced need for an anti-reflux procedure and would propose performing an endoscopic anti-reflux procedure only for patients with documented reflux.[10] Inoue et al. transformed the formerly experimental

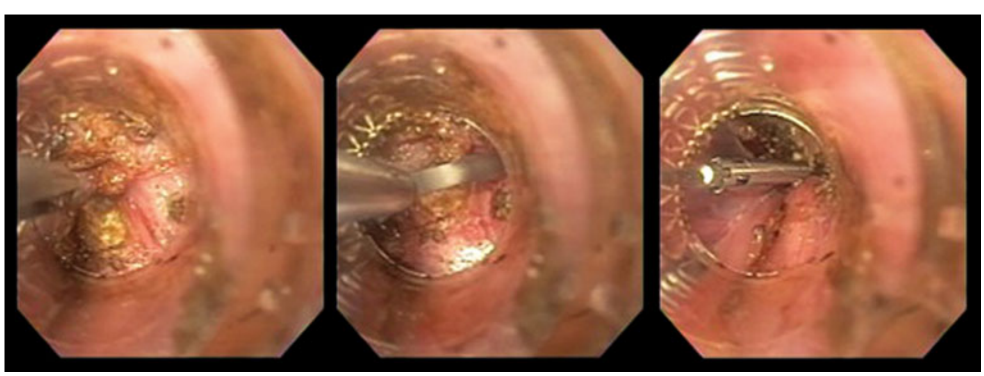

Fig. 6 A small perforation of the submucosal layer is closed using standard endoscopic clips

concept of transesophageal surgery into a clinical reality and performed the first endoscopic submucosal esophageal myotomy in 17 patients with achalasia.[6,10] Only one out of these 17 patients developed reflux esophagitis.

The transesophageal concept is very promising, but secure esophageal closure is still a matter of serious concern.[3,6,8,9,22,23] Experience in flexible endoscopic surgery achieved with a safe transcervical single port access may be helpful in establishing clinical translumenal mediastinal surgery in the future.

Maneuvering flexible endoscopes within the mediastinum relies upon anatomical landmarks for orientation. Following the esophagus anteriorly or posteriorly was found easy and safe using commercially available endoscopic instrumentation. The trachea and the main-stem bronchi, esophagus, heart, aorta, vagal branches, vertebrae, and diaphragm all provide reliable landmarks. The orientation in the animate model is easier than in the human cadaver because of the pulsations of heart and vascular system. The smaller amount of fatty tissue in the posterior mediastinum of the juvenile porcine model may also facilitate orientation compared to human anatomy. However, it was feasible to reproduce the dissection performed in the animals in the human cadaver as well. Virtual three-dimensional navigation systems would further enhance the applications of this approach.[24,25]

Conclusion

Heller myotomy through a cervical incision using flexible endoscopes is feasible and safe in an animal and human cadaver model. Posterior Heller myotomy was performed with a higher success rate than anterior myotomy and may be the preferred approach. With advancement in technology of flexible endoscopic multitasking platforms, the approach can be used for a multitude of mediastinal surgeries and interventions.

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