Ivor-Lewis oesophagectomy: A standardized operative technique in 11 steps

Frederike Franke | Thorben Moeller | Anne-Sophie Mehdorn | Jan Henrik Beckmann | Thomas Becker | Jan-Hendrik Egberts

Department for General, Visceral-, Thoracic-, Transplantation-, and Pediatric Surgery, University Hospital Schleswig-Holstein, Kiel, Germany

Correspondence
Jan Hendrik Egberts, Department for General, Visceral-, Thoracic-, Transplantation-, and Pediatric Surgery, Kurt-Semm Center for Minimal Invasive and Robotic Surgery, University Hospital Schleswig Holstein, Arnold Heller Str 3, Kiel 24105, Germany, Email: Jan-Hendrik.Egberts@uksh.de

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Abstract
Synopsis: Standardization of robotic oesophagectomy can benefit both patients and surgeons by decreasing complications, shortening the learning curve and improving surgical training.

Background: Thoraco-abdominal oesophagectomy with lymphadenectomy is the cornerstone of curative therapy for oesophageal carcinoma. To reduce post-operative morbidity, minimally invasive technology has become increasingly established. Conventional thoraco-laparoscopic procedures, however, are limited by their technical feasibility. These limitations can be overcome using robot-assisted technology.

Methods: Robotic Ivor-Lewis oesophageal resection has gradually been implemented in our clinic from 2013. We have performed over 250 robot-assisted minimally invasive oesophagectomies and more than 2000 robotic procedures overall. This experience allowed us to establish a standardized operative technique.

Results: We identified 11 operative steps as key elements for oesophageal resection, which should help implementation of this technique and allow surgeons to approach this complex procedure with greater confidence.

Conclusion: Standardization is fundamental to the establishment of a new surgical technique and is a key element in the learning curve of Ivor-Lewis oesophageal resection. Standardization can lead to better reproducibility of results, and thus to improved quality.

KEYWORDS
Ivor-Lewis procedure, oesophagectomy, robotic esophagectomy
Abdominal phase

1. Trocar placement, robot docking and liver retraction
2. Opening of the gastro-hepatic ligament and DII-lymphadenectomy
3. Gastric and distal oesophagus mobilization
4. Gastric tube construction
5. Feeding jejunostomy

Thoracic phase

6. Trocar placement, robot docking and transection of the azygos vein and thoracic duct
7. En-bloc resection of the oesophagus and lymphadenectomy
8. Insertion of the stapler anvil and purse-string suture
9. Gastric tube pull-up
10. Circular stapled intrathoracic anastomosis
11. Finishing the gastric tube

| TABLE 1 Operative steps of the Ivor-Lewis oesophagectomy |
|----------------------------------------------------------|

1 | BACKGROUND

Oesophageal resection with en-bloc lymphadenectomy is the cornerstone of multimodal therapy of locally advanced oesophageal carcinoma. The use of minimally invasive techniques (MIE) has become increasingly important because it has been shown that MIE reduces surgical trauma and postoperative morbidity with the same surgical radicality. However, conventional thoraco-laparoscopic procedures are limited by two-dimensional vision and limited freedom of movement. These technical limitations can impair the feasibility of MIE and its further establishment and lead to a long learning curve and greater risks for the patient.

In recent years, robot-assisted technology has been increasingly used in oesophageal surgery. Limitations of conventional MIE techniques can be overcome by the greater mobility of the instruments, the guided, high-resolution camera and the surgeon's ability to work with a total of four arms. Numerous reports have been published on the technique for robot-assisted MIE (RAMIE) and early postoperative outcomes. However, there is inconsistent use of the term 'robotic-assisted technique', and some centres actually report a hybrid technique involving conventional laparoscopic or thoracoscopic techniques. Furthermore, reported techniques for the anastomosis differ greatly, and there are many different options regarding the positioning of the trocars and the incision for specimen removal. Therefore, the procedure is anything but standardized.

Our centre was the first German centre to perform a completely robot-assisted Ivor-Lewis oesophagectomy. Since then, we have gradually adapted and standardized our technique. We also played a leading role in a joint project with seven German robotic centres, where we drafted a proposal for a standard version of the operation. One way to adjust the learning curve step by step, and to ensure the safety of the patients, is modular division of the operative procedure into individual surgical steps. This has been successfully demonstrated in colorectal surgery and pancreatic surgery. Based on our experience with over 250 RAMIE procedures and more than 2000 robotic procedures overall, we have divided this operation into 11 steps (see Table 1). The surgeons train using these steps in modules, until the entire robotic procedure can be performed. The aim of our study is to present these steps individually, and to demonstrate the helpful tips and tricks that in our experience lead to a rapid increase in the learning curve.

2 | INITIAL STEPS

2.1 | Patient selection

At the beginning of a robotic program, attention should be paid to patient selection. We recommend selecting patients with few comorbidities, a BMI <30, and small tumours without infiltration of other structures. As approximately 80% of patients with oesophageal cancer are treated with neoadjuvant chemotherapy or combined radio-chemotherapy, the majority of patients in our cohort has received neoadjuvant treatment. When implementing this technique, we would advise selecting patients that have not received any neoadjuvant treatment as this can increase technical difficulty. With increasing surgical experience, restrictions can be lifted.

2.2 | Operating room configuration

We use the DaVinci Xi System (Intuitive) for the Ivor-Lewis procedures. Besides standardization of the procedure itself, it is essential to standardize the operating room setup. The recommended configuration of the operating room is as shown by Egberts et al.

2.3 | Patient positioning

The patient is placed in a supine position and intubated with a double-lumen endotracheal tube. After completion of the abdominal
phase, the patient will be repositioned to a modified prone position. Detailed positioning of the patient for both parts of the operation can be read in older publications by Egberts et al.\textsuperscript{17}

2.4 | Trocar position

2.4.1 | Abdominal phase

Using the DaVinci Xi System, we recommend port placement as follows: 8-mm da Vinci port (initial endoscope port [R2]) placed in the midline slightly above or at the umbilicus. A diagnostic laparoscopy is performed, before inserting the remaining ports and docking. Another da Vinci 8-mm port (R3) is positioned on the left midclavicular line (MCL) on a straight line, followed by the fourth arm (da Vinci 8 mm, R4) as far left lateral from R3 as possible. Particular attention should be paid to the left colon flexure. Arm 1 (da Vinci 8 mm, R1) is placed on the right MCL. If the EndoWrist\textsuperscript{®} stapler is used, a da Vinci 13-mm port should be inserted instead of the standard da Vinci 8-mm port. Depending on the stapling technique, a 12-mm assistant port (A) is placed midway inferior between R3 and R4. For liver retraction (LR), a 5-mm port is placed sub-costally on the right MCL (retraction with a laparoscopic grasper) (Figure 1).

\textbf{FIGURE 2} Trocar positioning in the thoracic phase. 1: Arm 1 (tip-up fenestrated grasper), 2: Arm 2 (fenestrated bipolar forceps), 3: Arm 3 (30°-Endoscope), 4: Arm 4 (monopolar curved scissors) and A: assistant trocar (Alexis port)

\textbf{2.4.2} | Thoracic phase

The ports for the thoracic phase are placed as follows: R4 (da Vinci 8-mm port) in the 4th intercostal space (ICS), 1 cm medial to the scapula; R3 (da Vinci 8-mm port) in the sixth ICS, slightly more medial than Port 4 and closer to the posterior axillary line. During anastomosis, the camera can be changed to either R2 or R3. Another da Vinci 8-mm port (R2) is positioned in the eighth ICS at the same level as Port 4. Arm 1 (da Vinci 13-mm port, R1) is positioned on the scapular line or slightly posterior in the 10th ICS. R1 is used for the EndoWrist\textsuperscript{®} Stapler. If the use of a laparoscopic stapler is preferred, place a da Vinci 8-mm port instead. The assistant port (12 mm [A\textsuperscript{2}]) is placed in the ninth ICS, triangulated between R1 and R2. The assistant port might be enlarged to a mini-thoracotomy (~3–5 cm) with a size ‘small’ or ‘x-small’ Alexis Wound Retractor (Applied Medical). This would be the site for specimen removal and entrance of the circular stapler. Alternatively, a 12-mm assistant port (A\textsuperscript{2}) can be triangulated between R3 and R4 in the 5th ICS (Figure 2).

3 | OPERATIVE STEPS

3.1 | Abdominal phase

3.1.1 | Step 1: Trocar placement, robot docking and LR

The patient is positioned as described above and the ports are placed as shown in Figure 1. The da Vinci Xi patient cart is then docked from the right side of the patient. The endoscope is inserted via R2. After docking, targeting is performed with the oesophageal hiatus as
TABLE 2  Recommended instrumentation

|                         | R1 (Arm 1)                        | R2 (Arm 2)                               | R3 (Arm 3)                                                | R4 (Arm 4)                                                                 |
|-------------------------|-----------------------------------|------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------|
| Gastrolysis, lymphadenectomy | Fenestrated bipolar forceps       | Endoscope 30° down                       | Harmonic® ACE, monopolar curved scissors or EndoWrist® vessel sealer, temporarily exchanged to medium-large clip applier | Tip-up fenestrated grasper                                              |
| Gastric tube construction | EndoWrist® stapler alternatively, if laparoscopic stapler is used: large needle driver | Endoscope 30° down                       | Fenestrated bipolar forceps                               | Tip-up fenestrated grasper                                              |
| Oesophageal dissection, Lymphadenectomy | Tip-up fenestrated grasper                         | Endoscope 30° down                       | Monopolar curved scissors                                  | Tip-up fenestrated grasper                                              |
| Anvil insertion         | Fenestrated bipolar forceps       | Endoscope 30° down                       | Large needle driver                                       | Tip-up fenestrated grasper                                              |
| Anastomosis             | Fenestrated bipolar forceps       | -                                        | Endoscope 30° down                                       | Large needle driver                                                     |

the target. Via R1, we use the fenestrated bipolar forceps and via R4 the tip-up fenestrated grasper, which will be used for static traction of the stomach to the lateral left. For gastric and distal oesophagus mobilization, an energy device is inserted via R3. For ligation of vascular structures, we also use a medium-large clip applier via R3 (see Table 2).

For clear visualization of the operative field, it is essential to retract the liver. We use a method for static retraction that allows all da Vinci instrument arms to be free for dynamic use and localized static retraction where necessary. A liver retractor (e.g., Reveel Endoscopic Retractor; Retraction Limited) or laparoscopic grasper is placed through a 5-mm port in the right flank (LR). The liver is usually sufficiently elevated when this hook is fixed to the lateral drape with a clamp.

3.1.2  Step 2: Opening of the gastro-hepatic ligament and DII-lymphadenectomy

Dissection begins by opening the gastro-hepatic ligament close to the liver and up to the right crus of the diaphragm, after evaluation of an aberrant left hepatic artery. To do this, Arm 4 (tip-up grasper) is used to hold the stomach to the lateral left, and arms 1 and 3 are used to open the omentum minus. This is followed by preparation of the common hepatic artery and lymph node dissection along its upper margin to the celiac axis. It is helpful to now press down the pancreas with Arm 4 and a swab, so that the table assistant has the hand free to assist or suck. The right gastric artery is preserved and the ligamentum hepatoduodenal is freed from the medial left until the portal vein becomes visible. The left gastric artery and atrial coronary vein are then ligated with Hem-o-lok® clips using a large or medium-large clip applier via Arm 3. The DII-lymphadenectomy is then completed from the lesser curvature along the splenic artery.

3.1.3  Step 3: Gastric and distal oesophagus mobilization

For gastric mobilization, we follow a medial to lateral approach (Figures 3 and 4). The gastric fundus is lifted up with the tip-up grasper, using Arm 4 (R4) to expose a good view of the oesophageal hiatus, right and left crura, and the lesser sac. By lifting the gastric fundus with Arm 4, these structures are displayed vertically and can be safely dissected with the energy device. In particular, this adjustment eliminates traction on the spleen and prevents potential bleeding. Afterwards, the hiatus is widened by transecting the right crus of the diaphragm. The oesophagus and surrounding tissue with lymph nodes can now be released circumferentially and mobilized high into the mediastinal cavity (Figure 4B). It should be noted that
the parietal pleura might be breached while mobilizing the distal oesophagus. In this case, it can help to reduce the intra-abdominal pressure to 8 mmHg.

For preparation of the gastroepiploic arcade, the gastro-colic ligament is dissected to reach the omental bursa, which has already been dissected from medial. When this window is created, Arm 4 holds the colon transversum caudally and the bedside assistant pulls the stomach cranially. This traction and counter-traction causes the tissue to expand and prevents injury to the gastroepiploic arcade. Holding the colon away also prevents its injury. For dissection, the Harmonic® ACE or EndoWrist® Vessel Sealer is used on R1. We leave a part of the omentum attached for the later omentum-wrap covering the anastomosis. Mobilization of the stomach is completed by freeing the pyloric antrum and enabling tension-free displacement of the gastric conduit from the pylorus up to the right crus of the diaphragm. In cases where the anatomical situation is not immediately apparent (e.g., obesity), it may be useful at this stage to visualize the vascular arcade using intravenous indocyanine green (ICG).

3.1.4 Step 4: Gastric tube construction

The bedside assistant retracts the gastric fundus towards the left upper quadrant with a laparoscopic grasper. The construction of the gastric tube starts at the pyloric antrum. A gastric tube (approximately 5 cm diameter) is formed on the site of the greater curvature. To estimate the diameter of the gastric tube, it is helpful to hold the tip-up fenestrated grasper (grasping tip length 32 mm) against the stomach (Figure 5). The stomach is carefully elongated with the EndoWrist® instruments. The tip-up fenestrated grasper on the secondary right (R4) lifts and stretches the fundus, while the fenestrated bipolar forceps (R3) puts gentle tension on the developing gastric tube. The stomach is stapled using the 45 or 60 mm EndoWrist® Stapler (SureForm; Intuitive Surgical) via the left arm. Alternatively, the gastric tube construction can be performed with a laparoscopic linear stapler introduced through the 12-mm assistant port. We staple 3–5 times to create the initial part of the tube, with the residual stomach left to subsequently introduce the circular stapler for the intrathoracic anastomosis.
3.1.5 | Step 5: Feeding jejunostomy

We regularly perform a percutaneous jejunostomy at the end of the abdominal phase, to ensure enteral feeding and optimal nutrition during the post-operative course. The transverse colon is elevated and the first jejunal loop is identified at the Treitz ligament. Now the endoscope is rotated 30° upwards to allow visualization of the ventral abdominal wall. The location of the feeding catheter is a few centimetres caudal to the left subcostal margin on the MCL. The jejunum is presented tension-free to the needle insertion point. Then a purse-string suture is placed with a barbed suture (i.e., Stratafix®; Ethicon) to secure the jejunum to the abdominal wall. The jejunum is penetrated with the catheter introducer needle. After catheter placement, the distal limb of the jejunostomy is clamped off and saline injected to assure for correct placement. After confirmation of correct placement, the jejunum is secured tightly to the abdominal wall by pulling the purse-string suture line snug with a self-locking suture (Figure 6).

3.2 | Thoracic phase

3.2.1 | Step 6: Trocar placement, robot docking, and transection of the azygos vein and thoracic duct

Single-lung ventilation is introduced, and the port placement is executed as shown in Figure 4. The da Vinci Xi® patient cart is also docked from the right side of the patient. Once docked, targeting is performed using the azygos vein as the target. The endoscope is inserted via Arm 3 and will later be switched to Arm 2 for anastomosis. Moderate carbon dioxide insufflation of 8 mmHg is applied to maximize workspace in the thorax. The tip-up fenestrated grasper is inserted via R1, and the fenestrated bipolar forceps via R2. Monopolar curved scissors are inserted via R4 for dissection of the oesophagus.

After division of pulmonary adhesions, the right pulmonary ligament is dissected. Mobilization of the oesophagus starts with incision of the parietal pleura immediately below the azygos vein (Figure 7A), from the diaphragm to the azygos arch. The azygos vein should then be ligated at its origin. The thoracic duct is identified and should be ligated at the level of the hiatus with a Hem-o-lok® clip to prevent chylous leakage.

3.2.2 | Step 7: En-bloc resection of the oesophagus and lymphadenectomy

Depending on the location of the tumour, dissection removes all tissues superiority along the pericardium from the level of the hiatus and inferior vena cava to the carina, lower trachea, and right main bronchus, posteriorly along the length of the thoracic aorta, and laterally along the pleural surfaces. Therefore, the dissection plane is according to the described meso-oesophagus—defined by the adventitia of the aorta, mediastinal pleura with view of the ventilated left lung, and the pericardium.22

En-bloc resection of the oesophagus and its surrounding tissue starts with incision of the pleura along the azygos vein to the hiatus as described above. Mediastinal incision is followed by dissection of the parietal pleura along the right lung, the right main bronchus and the right vagal nerve from slightly above the azygos vein to the hiatus (Figure 7). On the left paratracheal side, the left recurrent laryngeal nerve is identified and preserved. Cranial mobilization of the oesophagus is dependent on the tumour location and usually stops at the level above the azygos arch. To complete resection of the oesophagus and meso-oesophagus retract the oesophagus to the right and complete dissection between the thoracic aorta and the oesophagus.

For those steps we use the monopolar curved scissors and the bipolar fenestrated forceps. After complete en-bloc resection of the oesophagus, with peri-oesophageal and infraracrical lymph tissue, the oesophagus is transected slightly above the level of the azygos vein. This can either be done with a stapling device or simply with monopolar curved scissors.

3.2.3 | Step 8: Insertion of the stapler anvil and purse-string suture

Different options for intra-thoracic oesophagogastrotomy have been described in literature. We will describe the circular stapled anastomosis, as we find this to be the best option. We recommend using a minimum diameter of 28 mm, so that enough tissue can be grabbed to avoid the ‘doughnut’ reaching into the staple line. During this part of the procedure, it is helpful to optimize the view by switching the endoscope to R1 or R2.
A small thoracotomy is created at the assistant port side (Figure 2). The circular stapler anvil (Model CDH29A; Ethicon EndoSurgery) is inserted through the Alexis port into the oesophageal stump. The intra-oesophageal bougie that has already been placed prevents oesophageal spasm and facilitates placement of the stapler anvil. The anvil is positioned using the large needle driver, with support of the oesophageal wall at three points. The tip-up fenestrated grasper (Arm 1) gently pulls to the upper right at 11 o’clock and the fenestrated bipolar forceps to the lower left (7 o’clock), while the bedside assistant pulls to the lower right (Figure 8A). The anvil is secured with a purse-string suture using a Stratafix® Spiral® (Ethicon). This makes it possible to control and precisely dose the tension after each stitch. The stapler anvil is then secured with a second suture using a Roeder-Loop (Ethicon) (Figure 8B).

### 3.2.4 | Step 9: Gastric tube pull-up

The gastric tube is pulled up into the thoracic cavity through the hiatus. This manoeuvre should be done extremely carefully because of the risk of damaging the fragile gastric tube. We recommend performing the pull-up with laparoscopic graspers via the assistant port because of the lack of haptic feedback from the robot. Special attention should be given not to twist the gastric tube, by keeping the lesser curvature toward the lateral chest wall. The conduit should be carefully grasped without damaging the right gastroepiploic arcade. Sometimes, it is necessary to pull up the omentum majus step-by-step in obese patients because it can be blocked at the hiatus. The stomach is pulled into the thoracic cavity through the extended hiatus up to the Vicryl marker stitch, which ensures that the maximum available length of the stomach tube is utilized.

### 3.2.5 | Step 10: Circular stapled intrathoracic anastomosis

Now the intact minor gastric curvature of the transected specimen is brought out of the chest, through the previously created mini thoracotomy. The perfusion of the gastric conduit and oesophageal

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**FIGURE 7** En-bloc resection of the oesophagus. (A) Begin with incision along the azygos vein. (B) Mediastinal incision along the azygos vein and along the parietal pleura of the right lung

**FIGURE 8** (A) Insertion of the stapler anvil. (B) Placement of Roeder Loop after securing the stapler anvil with a purse string suture
stump is checked with ICG using the FireFly technology of the DaVinci system (Figure 9A). For insertion of the circular stapler handle, the stomach conduit is opened by incising the stapler line previously created at the antrum in the minor curvature. The best position for the anastomosis near the greater curvature of the conduit is then chosen, and the trocar of the circular stapler is extended (Figure 9B). Ensure that a tension-free, non-twisted gastric tube with adequate perfusion is created. The gastric conduit is then straightened by the assistant, the stapler anvil is carefully grabbed with the large needle driver via Arm 4, and the anvil shaft slid over the trocar to perform the anastomosis (Figure 9C).

3.2.6 | Step 11: Finishing the gastric tube

After removal of the circular stapler, the bougie is gently pushed past the anastomosis into the gastric conduit, to prevent narrowing of the proximal conduit during the subsequent specimen transection. The remaining gastric part with the oesophageal specimen attached is transected using either an EndoWrist® Stapler in Arm 1 or a laparoscopic linear stapler introduced via the assistant port and removed through the mini thoracotomy.

The reconstruction is completed with a circular suture of the oesophagagastrostomy and suture of the linear staple line of the gastric tube with a barbed suture (i.e., Stratafix™ Spiral®; Ethicon) (Figure 9D).

3.3 | Procedure completion

After completed reconstruction, the bougie is replaced with a transnasal gastric tube. The previously inserted transtialt double Easy-Flow drain is placed directly at the anastomosis. A 24 French chest tube is also placed via R2 under direct vision. Local anaesthetic is injected in the thoracic ports for pain reduction. The right lung is re-insufflated and the chest closed using a standard technique.
MIE has gained importance throughout recent years. A number of studies have shown advantages in postoperative morbidity and mortality, particularly with regard to pulmonary complications. The oncological outcomes have been shown to be equivalent. Despite promising results, full implementation of MIE is hindered by the high variability in surgical techniques and the complexity of the procedure. The intrathoracic anastomosis is especially challenging. The robotic system can overcome the disadvantages of conventional MIE by offering better visualization and mobility and allowing the surgeon to work with four arms. Despite its reported advantages, RAMIE is still under evaluation and randomized controlled trials are lacking. We think this is mainly due to the inconsistent use of the term ‘robotic-assisted, minimally invasive oesophagectomy’ in the literature and the lack of a standardized procedure.

The advantages of the robotic system are particularly apparent during the thoracic phase, which is the most complex part of the procedure. Dissection of the sub-carinal, retro-tracheal and paratracheal tissues becomes less challenging, while dissection of lymph nodes along the vagal and recurrent nerves can be performed with a lower risk of damage. Extensive use of robotic systems or minimally invasive surgery in gastric and bariatric surgery has allowed standardization of the abdominal phase, with minor modifications. However, different techniques are described for the thoracic phase, starting with trocar placement up to the anastomosis technique. In addition, the advantages of the robot also apply to the abdominal part. Operative time is shorter in comparison to laparoscopic procedures, the increased intra-corporeal mobility of the instruments is helpful in obese patients and when performing the feeding jejunostomy. Also, the majority of patients has received neoadjuvant treatment in form of either preoperative chemotherapy or combined radiochemotherapy. In those cases, we believe the more precise dissection of the robotic system is beneficial. Furthermore, the abdominal part of Ivor-Lewis oesophagectomy serves as an ideal procedure for newly introducing surgeons to this technique in a structured proctoring program.

In 2018, a group of experienced robotic surgeons from seven university hospitals in Germany, including our clinic, took the first step towards creating a standardized surgical workflow for an Ivor-Lewis oesophagectomy. The open exchange of experiences with other centres enabled further improvements of the standardized technique implemented in our clinic. After experience in over 250 robotic oesophagectomies, we have found our technique to be the most feasible. The subdivision of the operation into 11 steps is arbitrary, but focuses on specific anatomical landmarks. In the future, our suggested standardization may be modified in accordance with the constant improvements in robotic platforms.

Use of a standardized technique with high-quality standards for robotic oesophagectomy is necessary to decrease the chances of related complications and to benefit from the advantages of minimally invasive surgery. A recent study has shown that the learning curve of RAMIE can be decreased from 70 to 24 cases when following a structured training program. Thus, our standardized approach could lead to a shorter learning curve, improved surgical training, and shorter operative times—benefitting patients and surgeons and easing implementation into other centres. Standardization could also result in a progressive reduction in morbidity, with possibly better oncological outcomes. As more centres use a standardized technique, results will become homogenous and reproducible, and will enable the much-needed multi-centre, randomized controlled trials that are necessary before this technique can become the gold standard for minimally invasive surgery in oesophageal cancer. Honest and intensive exchange with comparison of the results of specialized centres is essential. With standardization and use of the dual console DaVinci Xi, it is easily possible to use a stepwise approach to introduce this technique to other surgeons. Nevertheless, it is important that the entire surgical team is trained and has sufficient experience in robotic surgery.

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CONFLICTS OF INTEREST
TB received the da Vinci Xi robotic surgical system from Intuitive Surgical Sàrl for the purpose of clinical research. JHE and JHB are proctors for Intuitive Surgical.

ORCID
Frederike Franke  https://orcid.org/0000-0002-5219-8333
Jan-Hendrik Egberts  https://orcid.org/0000-0002-2540-7275

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