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HOW I DO IT

Robot-Assisted Oesophagectomy: Recommendations Towards a Standardised Ivor Lewis Procedure

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Abstract
A considerable number of reports have been published on the feasibility, techniques, and early postoperative results of robotic-assisted oesophageal surgery. However, these are mostly smaller case series, suggesting that the robot-assisted Ivor Lewis procedure is still in the implementation phase and far from being standardised. Oesophageal surgeons from seven robotic university centres in Germany, experienced in both minimally invasive and robot-assisted minimally invasive surgery, took part in a workshop on robot-assisted surgery. An intensive exchange of opinions and experiences, followed by a step-by-step re-enactment of the operation in a cadaver lab, enabled us to develop a standardised robot-assisted Ivor Lewis surgical workflow, which is presented here. Systematic and objective comparison of experiences and results using a robot-assisted Ivor Lewis procedure has made it possible to develop a standardised surgical workflow that is now clinically applied in our centres. It is hoped that standardisation of this procedure will help to maintain patient safety, prevent medical errors, and facilitate the learning curve, while introducing robotic surgery into a centre.

Keywords Oesophagectomy · Ivor Lewis procedure · RAMIE · Robotic oesophagectomy

Introduction

The use of robot-assisted technology in oesophageal surgery has gained considerably in importance in recent years.[1] On one hand, this is due to the increasing distribution of robotic systems and the associated experience of surgeons using them. On the other, especially in the last few years, the technical development of systems with advanced instrumentation has favoured their use in complex visceral and thoracic surgical procedures.

In the recent past, a considerable number of reports were published on the techniques and early postoperative results of robotic oesophageal surgery. However, these were mostly smaller case series with a description of feasibility and initial results. In particular, the reported techniques for oesophagogastrostomy were varied. Some surgeons used a

This paper is not based on a previous communication to a society or meeting.

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robot-assisted manual hand-sewn technique or a linear-stapled, side-to-side oesophagogastrostomy. Furthermore, end-to-end or end-to-lateral anastomoses were performed using a circular stapling device. Concerning the positioning of the trocars and the incision for specimen removal, many different options have been documented. Another problem is that the term "robot-assisted technique" is used very inconsistently, as some centres report a hybrid technique that involves a laparoscopic abdominal and robot-assisted thoracic approach, while other surgeons revert back to the conventional video-assisted thoracic surgery technique for establishing the oesophagogastrostomy.[2–6] Until now, only one prospective trial has been published, comparing the open and robotic technique. However, in this study, only cervical anastomoses were performed.[7]

These diverse reports suggest that the Ivor Lewis procedure is still in the implementation phase and far from being standardised. Based on our experience in seven robotic university centres in Germany, with several years of expertise in minimally invasive and especially robot-assisted oesophageal surgery, we conducted an intensive exchange of opinions and experiences in an oesophageal focus group setting. During a workshop lasting 3 days, we first evaluated our experiences and results using robot-assisted surgery. Then we re-enacted the robot-assisted operation step-by-step in a cadaver lab, to optimise trocar positioning, surgical steps, and the technique of the intrathoracic oesophagogastrostomy. The aim was to improve and define the individual steps in a practice-oriented setting and in particular through personal exchanges while "in" the operating theatre (i.e. the cadaver lab). The outcome of this workshop was the definition of a "standardised" Ivor Lewis procedure that is now clinically applied in our centres. The purpose of this paper is to present this standardised robotic-assisted Ivor Lewis surgical workflow.

Methods

Oesophageal surgeons from seven university hospitals in Germany (University Hospitals of Berlin (Charité), Cologne, Dresden, Hamburg, Heidelberg, Kiel, Mainz), with extensive and long-standing expertise in both minimally invasive (MIE) and robot-assisted minimally invasive oesophageal surgery (RAMIE), convened for a workshop on robot-assisted oesophageal surgery. The experience of the seven centres is based on a total of 351 MIE and 369 RAMIE procedures. Some centres started their RAMIE surgeries on a da Vinci Si™ system (Intuitive Surgical, Sunnyvale, CA, USA), but all have now switched to the da Vinci Xi™ system (Intuitive Surgical, Sunnyvale, CA, USA), the focus during the workshop. The surgeons met in a medical training centre (Medizin im Grünen, Wendisch-Rietz, Germany) for an exchange of experiences regarding robot-assisted surgery lasting 3 days. The da Vinci Xi™ system, with dual console, instruments, and staplers, was utilised during this time.

In an intensive exchange, the previous experiences and results of the centres were presented and analysed. The individual techniques were demonstrated, the existing difficulties were addressed, and attempts were made to define solutions. Based on these experiences, the individual surgical steps were then simulated in four cadaveric models and optimised step-by-step and documented. In cases where individual preferences should not be abandoned, alternative options were defined.

Results

Operating Room Setup

To standardise the operating room (OR) setup, the patient cart is kept opposite to the anaesthesia and repositioned as needed for the procedure. The surgeon console is positioned so that effective communication with the patient-side team can be established. Direct eye contact is ideal. The bedside assistant is on the patient's side that facilitates easy access to the placed assistant ports. The scrub nurse is at the patient's feet. At least one video monitor showing the endoscopic view is located opposite the assistant. Figure 1 shows an overhead view of the recommended OR configuration for the da Vinci RAMIE, with the da Vinci Xi for the abdominal and thoracic phase of the operation. Table 1 indicates the instrumentation that is recommended for the robotic procedure.

Patient Positioning

All monitoring cabling and tubing should be sufficiently long to allow for subsequent repositioning of the patient without lead disconnection. To avoid any patient motions or increased stress on the patient due to low levels of anaesthesia during the procedure, the intensity of the anaesthesia and relaxation can be monitored using the bispectral index (BIS) as described previously.[2,8]

Abdominal Phase

The patient is placed in a supine position under general anaesthesia. Alternatively, the patient can be placed in a "French" position for assistant access between the legs if preferred. The patient's arms are placed alongside the body to lessen the possibility of shoulder injury. The table is then placed in a reverse Trendelenburg position (~ 20°–25°) with a ~ 10° rotation to the right (Fig. 2a).

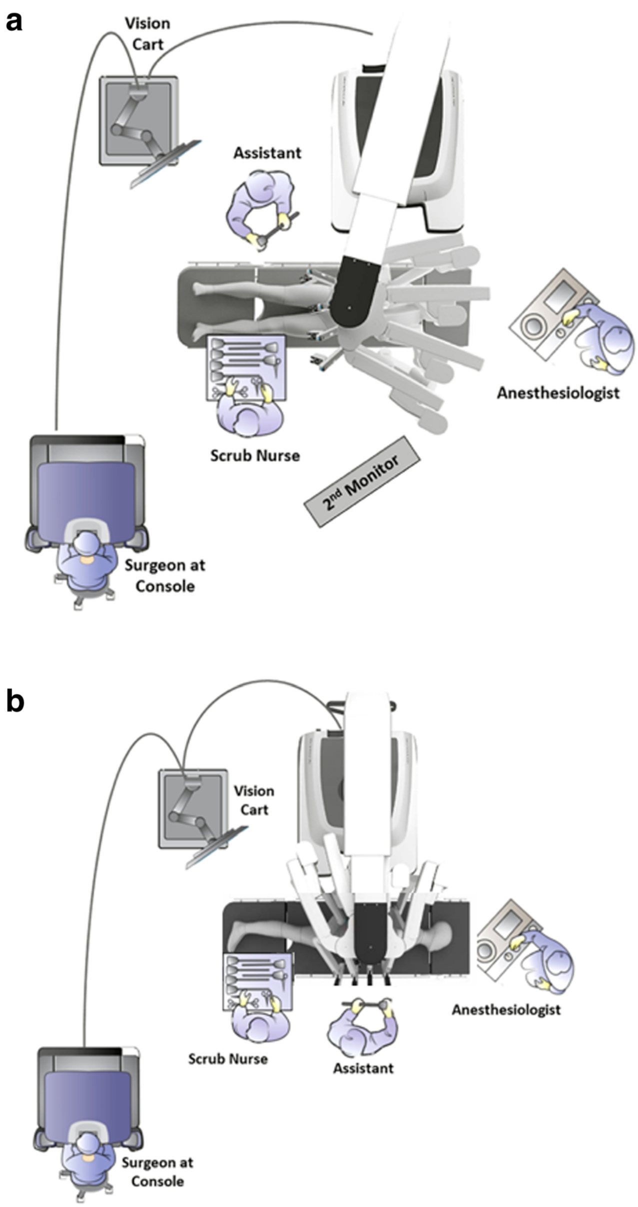

Fig. 1 Operating room setup for robot-assisted minimally invasive oesophageal (RAMIE) surgery with the da Vinci Xi system. **a** Abdominal phase. **b** Thoracic phase

Thoracic Phase

The patient is positioned in a left lateral decubitus position, with the right side of the chest up and the arms in a swimmer's position to display the axilla. The best position is when the lateral chest is slightly upwards in a mild reverse Trendelenburg position (Fig. 2b). The table is then further rotated ventrally so that a modified prone position (~45° rotation of the lateral chest) is reached. The goal is to position the right posterior axillary line as the highest part parallel to the floor. The body position is carefully secured and a strap applied across the patient's thighs to avoid any shifting of the reverse Trendelenburg position.

Table 1 Recommended Da Vinci instrumentation

	Surgical step	Robotic arm 1 (R1)	Robotic arm 2 (R2)	Robotic arm 3 (R3)	Robotic arm 4 (R4)
Abdominal phase	Gastric and distal esophagus mobilisation	Fenestrated bipolar forceps	Endoscope 30° down	Monopolar curved scissors (might be temporarily exchanged with Harmonic ACE, EndoWrist® Vessel Sealer, Large or Medium-Large Clip Applier)	Tip-up fenestrated grasper
	Gastric tube construction	EndoWrist® Stapler Alternatively, if laparoscopic stapler device is used: large needle driver	Endoscope 30° down	Fenestrated bipolar forceps	Tip-up fenestrated grasper
Thoracic phase	Dissection of oesophagus	Tip-up fenestrated grasper	Fenestrated bipolar forceps	Endoscope 30° down	Monopolar curved scissors or vessel sealer
	Insertion of anvil/pursuring suture	Fenestrated bipolar forceps	Endoscope 30° down	Large needle driver	Tip-up fenestrated grasper
	Anastomosis/oversewing	Fenestrated bipolar forceps		Endoscope 30° down	Large needle driver

Fig. 2 Patient positioning and docked da Vinci Xi system. **a** Abdominal phase. **b** Thoracic phase

Port Placement

Abdominal Phase

An 8-mm da Vinci port (which serves as arm 2 (R2)) is placed in the midline slightly above or at the umbilicus. Arm 3 (da Vinci 8 mm, R3) is positioned on the left mid-clavicular line (MCL) at least 8 cm away from R2 on a straight line, followed by the fourth arm (da Vinci 8 mm, R4) as far left lateral from R3 as possible. Arm 1 (da Vinci 8 mm, R1) is placed on right MCL at least 8 cm away from R2. Depending on the use of the EndoWrist® stapler, either a da Vinci 13-mm port or a standard da Vinci 8-mm port is used (if laparoscopic stapling is through a 12-mm assistant port). A 12-mm assistant port is triangulated midway inferior between R3 and R4. If a laparoscopic stapler is used, R1 (da Vinci 8 mm) is placed as lateral as possible on the right, 2–3 cm superior to the arm 2 port and at least 8 cm away from a 12-mm assistant port (A) used for the laparoscopic stapling. The assistant port (A) is then moved to the location of R1 (Fig. 3a). For liver retraction (LR), a 5-mm port is placed either subcostally on the right MCL (retraction with a laparoscopic grasper) or subxiphiodal for a Nathanson retractor (Cook Medical, Limerick, Ireland).

Thoracic Phase

Single lung ventilation is induced and moderate CO_2 insufflation of ~ 8 mmHg is applied, creating the surgical workspace in the thorax. The ports 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 6th ICS, slightly more medial than port 4; R2 (da Vinci 8 mm port) in the 8th ICS at the same level as port 4; R1 (da Vinci 13 mm port) on the scapular line or slightly posterior in the 10th ICS. A 6–10-cm spacing is maintained between ports. This port is used for the EndoWrist® Stapler (if a laparoscopic stapler is used, a da Vinci 8-mm port is adequate). There are two recommended options for the assistant port (12 mm (A)) location, depending on surgeon's preference for the introduction of the circular

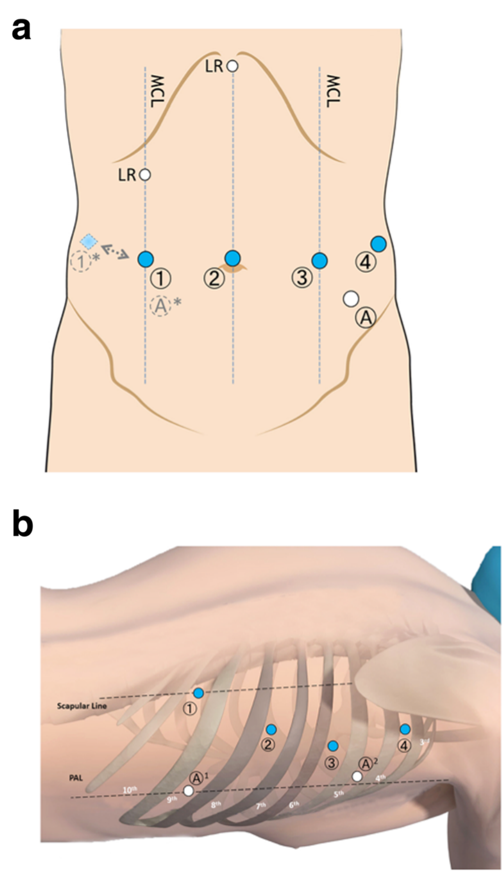

Fig. 3 **a** Abdominal phase port placement (asterisk means port positions if a laparoscopic stapler is used). **b** Thoracic phase port placement stapler to construct the oesophagogastrostomy. (A)1 is in the 9th ICS, triangulated between R1 and R2; this would be the site for specimen removal and entrance of circular stapler. Alternatively, (A)2 is triangulated between R3 and R4 in the 5th ICS. 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, Rancho Santa Margarita, CA, USA) placed here. This would be the site for specimen removal and entrance of the circular stapler (Fig. 3b).

Surgical Steps, Abdominal Phase

Liver Retraction

Utilising a method for static retraction allows all da Vinci instrument arms to be free for dynamic use and localised static retraction where necessary. There are two different options to retract the liver with a "static system": the placement of a long bariatric grasper through a 5-mm port in the right flank to lift up the right hepatic lobe (using locking bariatric grasper to "lock" grips on the right crus for static retraction of liver) or a Nathanson Liver Retractor (Cook Medical, Limerick, Ireland).

Gastric and Distal Oesophagus Mobilisation

The 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 gastric artery. The common hepatic artery is identified, followed by lymph node dissection of its upper margin up to the celiac axis. The right gastric artery is preserved. The DII lymphadenectomy is then completed to the area of the coelic trunk and splenic and left gastric artery. The left gastric artery and the atrial coronary vein are ligated using a Large or Medium-Large Clip in R3. The gastric mobilisation follows a medial to lateral approach. The gastric fundus is lifted up with the forceps in the secondary arm on the right (R4) to expose the oesophageal hiatus, right and left crura, and the lesser sac. Care should be taken if a posterior gastric artery is encountered. The retro-gastric adhesions, as well as the short gastric arteries, can be dissected and ligated safely with the EndoWrist Vessel Sealer or Harmonic ACE. The hiatus is dissected and, if necessary, widened by severing the right crus of the diaphragm. By doing so, the oesophagus can be released circumferentially and mobilised high into the mediastinal cavity, which leads to a less challenging dissection of the greater gastric curvature and conservation of the right gastroepiploic arcade by fully dissecting the gastrocolic ligament. The fundus of the stomach is elevated with R4, while the bedside assistant elevates the stomach by lifting the antrum. The large curvature of the stomach is mobilised by dissecting the gastrocolic ligament from caudal to cranial, preserving the right gastroepiploic vascular arcade.

Gastric Tube Construction

The construction of the gastric tube starts at the pyloric antrum. A stomach tube on the site of the greater curvature (5 cm diameter) is formed. To approximate the diameter of the gastric tube, either the Cadiere Forceps (grasping tip length 20 mm) or the Tip-Up Fenestrated Grasper (grasping tip length 32 mm) can be held up against the gastric conduit. The stomach is carefully elongated with the EndoWrist instruments. The stomach tube is only partially created in the abdominal cavity. For this, the stomach is stapled using only 3–5 45- or 60-mm stapler magazines to create the initial part of the tube, with a remnant stomach left to subsequently introduce the circular stapler (Fig. 4a).

Surgical Steps, Thoracic Phase

Dissection of the Oesophagus

Depending on the location of the tumour, the dissection usually removes all tissues superiorly 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.[9] If the dissection level cannot be kept clear due to the assumed tumour extension or preoperative neoadjuvant therapy, an extension of the resection level is possible with removal of the mediastinal pleura and/or pericardium. The oesophagus is transected slightly above the level of the usually ligated azygos vein with a linear stapler and is then cranially separated from it with scissors so that a frozen section can be obtained from the oral resection.

Stomach Pull-up

This manoeuvre should be done with extreme caution due to the risk of damaging the fragile gastric tube. The patient-side assistant should support the pull-up with laparoscopic graspers. Special attention is given to not twisting it by keeping the gastroepiploic arcade dorsally. The stomach is pulled into the thorax through the extended hiatus until the area of the unfinished gastric tube at the remnant stomach is comfortably located in the middle of the right thoracic cavity. This ensures that the maximum available length of the stomach tube is utilised.

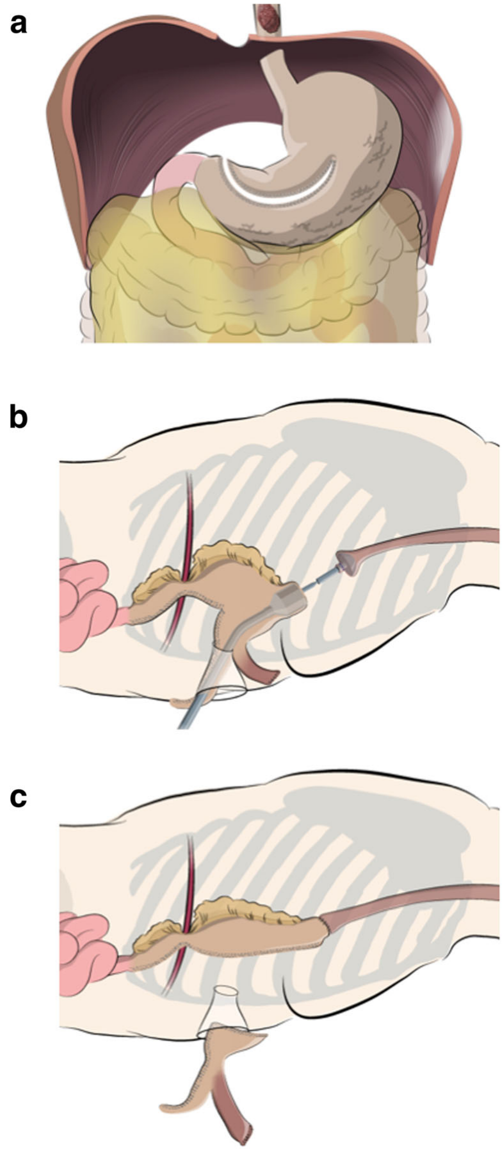

Fig. 4 **a** Creation of the stomach remnant and initial tube for oesophagogastrostomy. **b** Positioning of the circular stapler device before connecting the anvil. **c** Removal of the resected specimen through the thoracotomy incision

Circular Stapled Anastomosis

The circular stapler anvil (a 28/29-mm sized circular stapler device with a long handle is recommended) is inserted transthoracically through the Alexis wound retractor into the oesophageal stump and secured with a purse-string suture constructed, for example, using a StratafixTM Spiral® PDS 3-0, SH needle, 15 cm length or Prolene 2/0 (Fig. 5a). The intact minor gastric curvature of the transected specimen is brought out of the chest through the mini-thoracotomy. The circular stapler handle is then introduced into the stomach conduit via an incision in the minor curvature (Fig. 4b), and the best position for the anastomosis near the greater curvature of the conduit is chosen. The camera might be positioned in Trocar 1 for this manoeuvre to have a superior overview. The perfusion of the gastric conduit can also be checked again for confirmation with indocyanine green (Fig. 5b, c).

The gastric conduit is then straightened by the assistant and stapled to the oesophageal stump. Next, a bougie is inserted 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 with a linear stapler (Figs. 4c and 5d) and removed through the mini-thoracotomy. In the case of a widely opened hiatus, a fixation suture can be applied to the hiatus to avoid possible herniation. Due to the mobility of the instruments, this is easily possible with the robot.

Discussion

Surgical robots are increasingly being used because of their potential advantages, especially in challenging operations where traditional minimally invasive techniques partly reach their limitations. However, in many institutions, this technique is still in the phase of implementation, and the experiences made so far in the learning curve are often only described in individual reports and retrospective descriptions.[10] Therefore, it has not been possible to speak of a standardised procedure.

By the interactive exchange of our seven robotic surgery centres, we were able to debate our experiences and learning curves. During this discussion, the difficulties and problems that arose during the implementation phase were analysed. The biggest discussed challenges with suggested solutions are highlighted in Table 2. As expected, the main focus was on the anastomosing techniques for the oesophagogastrostomy. It emerged that different methods were initially applied in almost all centres, starting with the established methods—some of which were completely minimally invasive or carried out using hybrid techniques, for example, the hand-sutured end-to-end or end-to-side technique, and the linear stapled side-to-side or the circular-stapled anastomosis. Some of the technical difficulties and systemic limitations have already been described by two centres.[2,11] The type of anastomosis is the most debated part of the Ivor Lewis operation, no matter if the surgery is performed minimally invasive or open. So far it can be concluded that the surgical robot allows the anastomotic technique used in each centre before implementation of a robotic system to be maintained, but also allows evolution of the procedure. For the time being, each centre should decide which technique is preferred. After standardising the procedure as described above, further studies will allow comparison of these technical nuances.

It was interesting to note that the robot-assisted techniques applied in each of the centres had gradually harmonised,

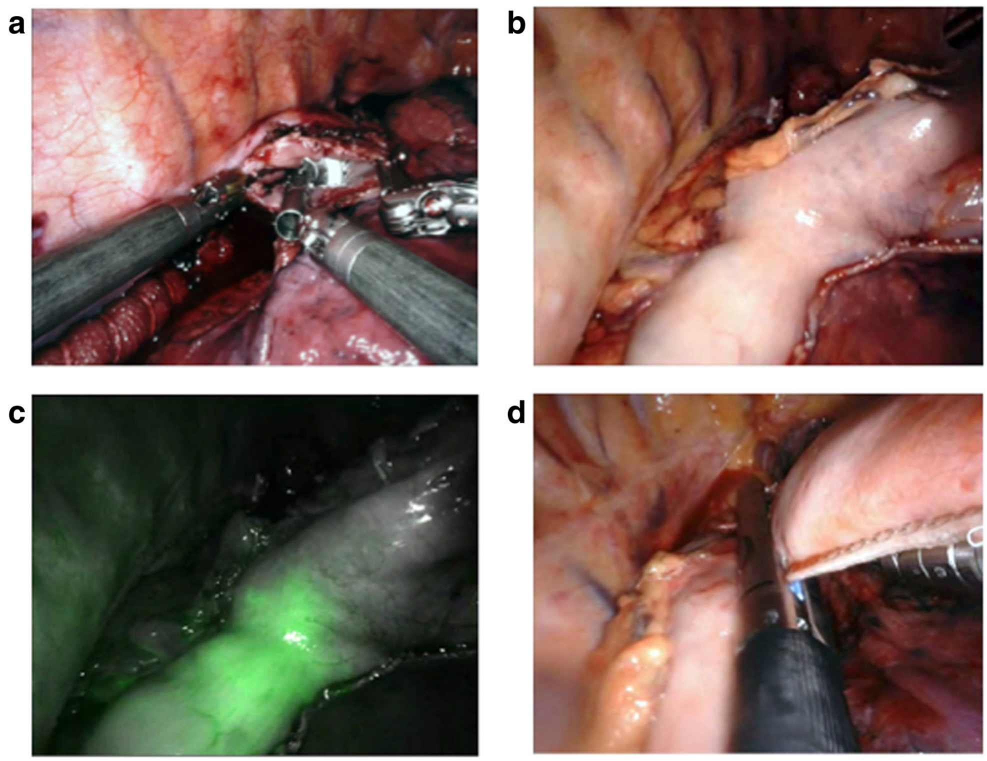

Fig. 5 **a** Inserted anvil into oesophageal stump before starting the purse-string suture. **b** Gastric conduit with smaller curvature. **c** Perfusion control with indocyanine green. **d** Final linear stapling of the conduit

independent from and prior to the workshop. This is certainly due to the iterative learning curve each centre went through, repeating similar "trial and error" scenarios along the way, and the initial exchange of experiences that this had generated. It was remarkable that the robot-assisted surgical technique could be introduced in the centres with a high patient safety. The conversion rate was below 8% in all centres, with conversions almost exclusively required during the first 25 procedures as an expression of the learning curve. A step-by-step implementation was carried out in many centres. The average

Table 2 Challenges and suggested solutions during the implementation phase of robot-assisted oesophagectomy

Challenge	Solution proposal
Gastrolysis: mobilisation of the greater curvature and fundus	Gastric mobilisation from medial to lateral with dissection retro-gastric adhesions, as well as the short gastric arteries. For this step, arm R4 is helpful by lifting the stomach.
Extent of transhiatal dissection	It is necessary to dissect only a few centimetres transhiatally. This can be performed more easily and precisely in the thoracic phase due to the optimal view.
Patient positioning during the thoracic phase	The patient is positioned in a left lateral decubitus position, with the right side of the chest up and the arms in a swimmer's position to display the axilla; the ventral table is rotated into a modified prone position (~ 45° rotation of the lateral chest).
Stomach pull-up without haptic feed-back (extent of tractive force)	This manoeuvre should be done with extreme caution. The patient-side assistant should support the pull-up with laparoscopic graspers.
Instrument/camera position during anastomosis	Change camera into arm 1 or 2. Remove instrument from arm 3 to get more working space for the assistant. Depends on the incision for the specimen removal/stapler insertion
Avoid extended OR time	Step-wise, module-based approach: - Start with robot in the abdominal phase. - Extend to oesophageal dissection in the thoracic phase. - Finalise the anastomosis using the robot.

OR time was 383 min, which also decreased considerably after the learning curve was repeated (OR time in the centres with the largest numbers decreased to 294 min).

We divided the complex operation into individual steps and defined a standardised approach for each one. It should be noted that we have agreed on the key features of the surgical steps, knowing that smaller modifications might certainly be applied in each centre. Nevertheless, this makes it possible to systematically increase our horizon of experience and compare results objectively—a prerequisite for defining clinical studies that are required by all. The expected increase in expertise and number of experienced robot oesophageal surgeons should provide a basis for future developments and modifications, which will then take place using other formats such as Delphi surveys.

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Author Contribution All above listed authors contributed significantly to the conception and drafting of this work and approved this final version.

Compliance with Ethical Standards

Conflict of Interest MB, JP, JI, JW, and TB received the da Vinci® Xi robotic surgical system from Intuitive Surgical Sàrl for the purpose of clinical research. JHE, DP, and PG are proctors for Intuitive Surgical.

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