Journal of Robotic Surgery (2019) 13:469–474
https://doi.org/10.1007/s11701-018-0872-8

ORIGINAL ARTICLE

Robot-assisted esophageal surgery using the da Vinci® Xi system: operative technique and initial experiences

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Received: 29 January 2018 / Accepted: 9 September 2018 / Published online: 12 September 2018
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Abstract
In this review, we would like to illustrate our experience with the da Vinci® Xi system in case of esophageal surgery. Since the da Vinci® Xi system was installed in our department, it has resulted in a great improvement in cases of minimally invasive surgery. After the successful establishment in the field of colorectal surgery, the next step was surgery of the upper gastrointestinal tract. Due to the features of the robotic system, we can definitely observe the advantages and a positive effect in case of minimal invasive esophagectomy (MIE). We have also tried to develop an adequate surgical standard of the robotic-assisted minimal invasive esophagectomy with the da Vinci® Xi.

Keywords Esophageal cancer · Robotic surgery · Robot-assisted minimal invasive esophagectomy · da Vinci® Xi

Introduction

Robotic surgery is an exciting emerging technology with great potential. Due to its growing availability, surgeons try to treat more and more diseases using robotic surgical systems. At our hospital, the da Vinci® Xi was introduced in April 2015. Since then, we started our robotic program. Apart from abdominal surgery, urologists, gynaecologists, and ENT physicians also use it. In our department, the Xi system is of prime importance in case of colorectal surgery, and since September of 2016, we are also using it in case of esophageal cancer. Minimally Invasive Esophagectomy (MIE) refers to performing either or both thoracic abdominal portions of the case with laparoscopic or robotic assistance. After the first esophageal resection by thoracoscopy in 1993 [1], Melvin et al. did some pioneering work by performing the first robotic esophagectomy in 2002 [2, 3]. A review of the literature shows the growing importance of the robotic surgical systems in case of esophagus surgery [4, 5].

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Advantages and technical features of the robotic system

Reduced surgical trauma, less blood loss, shorter ICU-, shorter hospital stay, and reduced in hospital mortality are well-known advantages of the minimally invasive esophagectomy (MIE) against the open esophagectomy [6]. However, what are the differences between the laparoscopic and the robotic surgery? The da Vinci® Xi systems offers a 3D visualization, and the Firefly™ fluorescence imaging allows surgeons to identify intravascular near infrared fluorescence signals using indocyanine green (ICG) in real time. This technology can be used to identify hidden vessels, assess blood supply to bowel segments, and locate sentinel lymph nodes [7], an improved dexterity, seven degrees of freedom, the elimination of the fulcrum effect and physiologic tremor, the ability to scale motions, the possibility of micro-anastomosis, and an ergonomic position. In contrast, conventional laparoscopic surgery has a compromised dexterity, limited degrees of motion, a fulcrum effect (the tool endpoints move in the opposite direction due to the pivot point [8]) and an amplification of physiologic tremor [9]. Another important point is the robotic camera system, which is directly under surgeon's control and which ensures a steady visualization of the operative field.

In contrast to the da Vinci® Si, the Xi has thinner arms, which offer a greater range of motion and instruments with long reach for a more flexible port placement. The four

overhead arm architecture allows a multi-quadrant access and the robotic camera can be placed into any of the robotic ports (so-called port hopping). If necessary, you can easily switch the da Vinci® instruments/camera in accordance with the surgical steps.

All these features should help to make complex surgical procedures easier.

Setting

In Fig. 1, you can see our setting in the operating room. The da Vinci® tower is placed on the left side, the patient-side cart on the right side of the patient. This setup does not require any changes during the whole surgery. We are using a "4-arm-technique". This means that we have four da Vinci® ports using the camera and three da Vinci® instruments. Therefore, traction–countertraction technique is possible without the help of the assistance and the operation situs can be easily prepared by the surgeon on the console only with the installed instruments.

In case of Ivor Lewis esophagectomy, we usually start with the abdominal phase (in contrast to the Akiyama procedure). After surgery of the abdomen the anesthetist changes, the single-lumen tube into a left-side double-lumen tube for one-lung ventilation, and after repositioning the patient, the thoracic phase is performed.

Abdominal procedure

The patient lies in supine position and we usually use a single incision port (OCTO™ port) placed in the anterior median line slightly above the navel. We also place the da Vinci® camera trocar via the OCTO™ port. The remaining three da Vinci® trocars are placed in the same line supraumbilical (1× left mediclavicular line, 1× lateral left mediclavicular line, and 1× right mediclavicular line). Lateral to the right mediclavicular line, we place another 5 mm trocar for the liver retractor, as well as a 12 mm assistant trocar subxiphoidal (Fig. 2a). The 12 mm assistant trocar is necessary for creating the gastric conduit with the Endo GIA™. Our experience has shown that it is better to place the 12 mm assistant trocar near the right mediclavicular line in a subcostal position to have a better working angle (see Figs. 2b, 3). From right to left, we are using the following da Vinci® Xi instruments: Vessel Sealer, Camera, Permanent Cautery Hook, and Fenestrated Bipolar Forceps.

First step is the preparation of the hilus and the division of the right and left crus of the diaphragm. After a sterile cotton tape is placed around the esophagus to facilitate traction

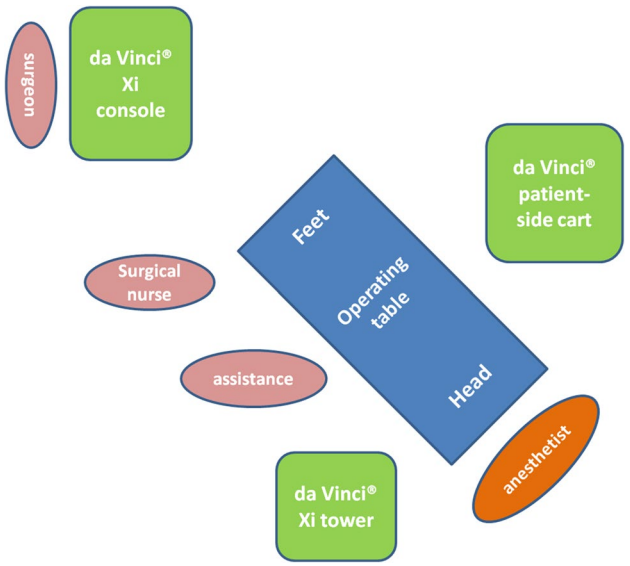

Fig. 1 Operating room setup

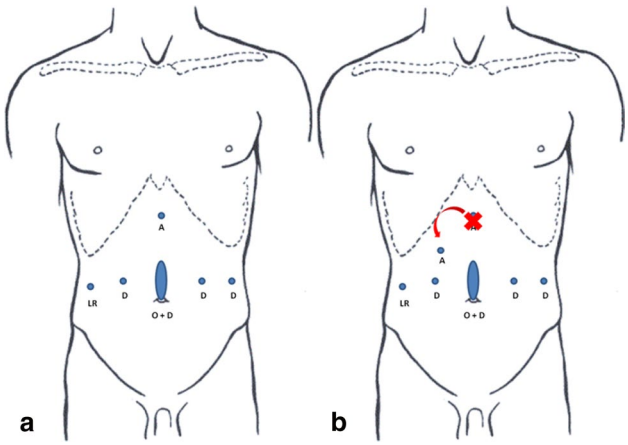

Fig. 2 **a** (old), **b** (new): trocar placement abdomen (Akiyama and Ivor Lewis): A—assistant (12 mm), D—da Vinci®, O+D OCTO port+daVinci®, and LR liver retractor (5 mm)

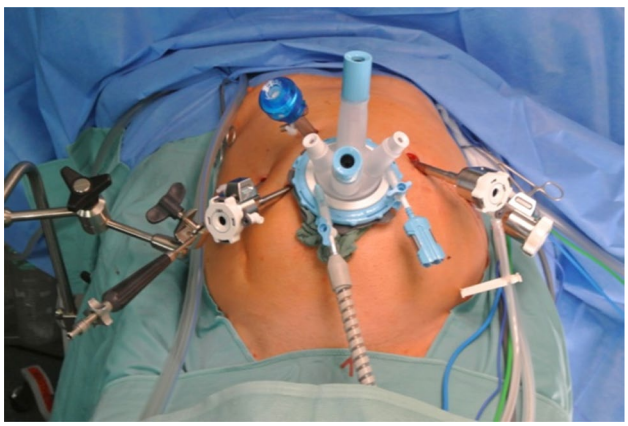

Fig. 3 Trocar placement abdomen (Akiyama and Ivor Lewis)

and esophageal mobilization, abdominal lymphadenectomy is performed, starting at the common hepatic artery including the lymph nodes surrounding the celiac trunk up to the aorta. The splenic artery is displayed as the caudal resection margin. The next step is the division of the coronary vein and the left gastric artery; the vessels can either be ligated with Hem-o-lok® clips and divided with the Vessel Sealer or divide it with the Endo Gia™ 30 mm gold load. Lymphadenectomy is completed along the lesser gastric curvature until the level of the right gastric artery. Now, the greater omentum is dissected using the Vessel Sealer while preserving the gastroepiploic artery; the blood circulation is controlled with the Firefly™ fluorescence imaging. In case of Ivor Lewis procedure, gastric conduit is now performed laparoscopic with the Endo GIA™, whereas in case of Akiyama procedure, the dissected esophagus inclusive the gauze bandage (see below) is removed through the single incision port and the gastric conduit is performed in open technique.

Thoracic procedure

The patient is placed into the left lateral decubitus position (Fig. 4) and we use a five port method. The da Vinci® trocars are placed on the right anterior axillary line at the 4th, 6th (camera), 8th, and 10th intercostal space. A 12 mm assistant trocar is placed in the anterior axillary line at the 9th intercostal space (Fig. 5). From cranial to caudal, we use the following da Vinci® Xi instruments: Permanent Cautery Hook, Camera, Vessel Sealer, and Fenestrated Bipolar Forceps. If necessary carbon dioxide is insufflated out to 12 mmHg to compress the lung and to lower the diaphragm.

Dissection is performed along the pericardium up to the level of the azygos arch. The vein is divided with the Endo GIA™ 30 mm gold load via the 12 mm assistant trocar. Afterwards dissection of the esophagus continues along the azygos vein caudal towards the diaphragm, where the

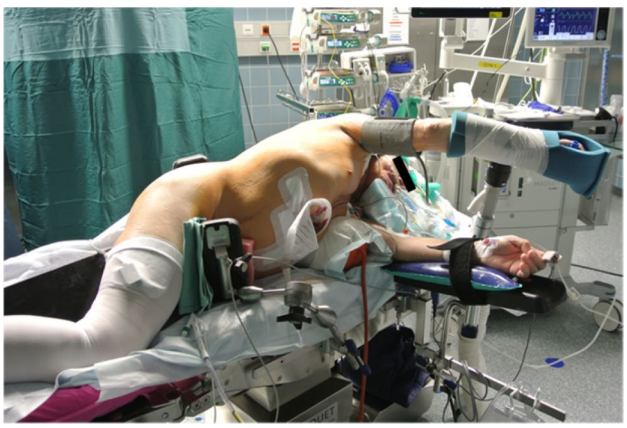

Fig. 4 Left lateral decubitus position

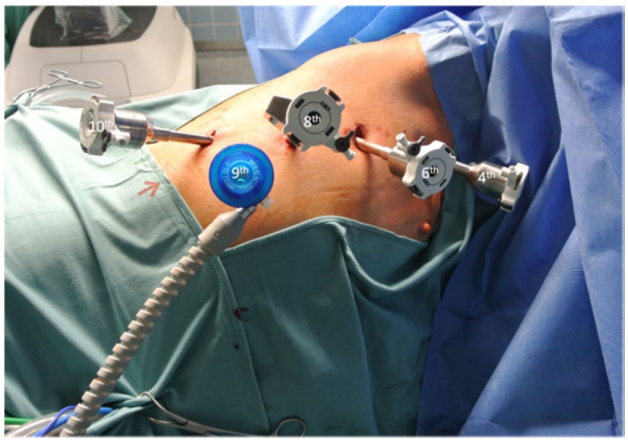

Fig. 5 Thoracic trocar placement

thoracic duct is clipped. After the aorta is displayed—single aortoesophageal arteries are divided with the vessel sealer—a sterile cotton tape is placed around the esophagus to facilitate traction and esophageal mobilization. The next step is the dissection of the esophagus at the level of the bifurcation of the trachea, whereby an injury of the main bronchus should be avoided. The vagus nerve as well as the recurrent laryngeal nerve should be displayed. In case of Ivor Lewis procedure, the esophagus is now transected with the Endo GIA™ 60 mm purple load, in case of Akiyama procedure lymph node dissection of the upper thoracic aperture is completed.

We install three chest drains (8th, 9th, and 10th ICS) for Ivor Lewis procedure (chyle fluid, anastomosis, and pneumothorax) and two chest drains for Akiyama procedure (chyle fluid and pneumothorax).

Neck procedure Akiyama

A cervical incision is made parallel to the medial part of the left sternocleidomastoid muscle. After the cervical vessels as well as the recurrent laryngeal nerve are displayed, the cervical esophagus is transected, and a sterile gauze bandage is attached to the specimen. As mentioned above, the specimen is removed through the single incision port and the created gastric conduit is pulled up through the mediastinum using a plastic tube (laparoscopic camera bag) as a sort of slide.

Anastomosis

In case of Ivor Lewis procedure, anastomosis can be performed with the EEA™ OrVil™ device (end-to-side anastomosis) or a hand-sewn end-to-end anastomosis can be carried out. The resection specimen is removed through a minithoracotomy at the level of the 6th intercostal space, and

through this minithoracotomy, it is also possible to create a video-assisted anastomosis. In both colorectal and thoracic surgery, we are using the Firefly™ fluorescence imaging as mentioned above. With the help of the system, we can control the blood circulation of the organ and this helps us to define the resection margin. Circulation is controlled before and after anastomosis has been performed. In one patient, we performed a hand-sewn (robot-sewn) end-to-end double-layer anastomosis with a continuous 3–0 V-Loc™ suture. Anastomosis of the other ten patients was performed with the EEA™ OrVil™ device (end-to-side anastomosis) with additional circular suturing of the anastomosis with a 3–0 V-Loc™.

In case of Akiyama procedure, we usually create a hand-sewn end-to-end anastomosis using a 4–0 polydioxanone single-layer continuous suture.

Results

From June 2015 to January 2018, we performed 33 surgical interventions of the upper gastrointestinal tract with the da Vinci® Xi system (Table 1). For practice purposes, we primarily started with hiatoplasties followed by oncologic gastric surgery. We payed special attention to the da Vinci® trocars and the assistant trocar placement to ensure an optimal handling during surgery. Therefore, the trocar placement changed over time. Our first robotic thoracic surgery was an esophageal leiomyoma enucleation in March 2016. In September 2016, we performed our first robotic Ivor Lewis esophagectomy—by the way, this was the first da Vinci Xi® assisted Ivor Lewis esophagectomy in Austria. Since then, there have been two Akiyama and ten more Ivor Lewis procedures. Conversion rate was zero and there were no intraoperative complications. Unfortunately, we had two anastomotic dehiscences, one patient developed a low output salivary fistula which healed up spontaneously. Anastomotic stricture was not seen in any of the patients. One patient developed a neurogenic dysphagia without organic cause; unfortunately, he died 5 months after initial surgery due to generalized metastasis.

Discussion

Oncological surgery requires very precise surgical work. A curative resection with complete lymphadenectomy with attention to important anatomic structures and less trauma to tissue also for higher tumor stage is required. Moreover, the surgeon and an exact preparation are also a prognostic factor. The features of the da Vinci® systems have a supporting role which facilitates surgery. The three-dimensional view depth perception, the surgeon's ability to directly control a stable visual field with increased magnification and maneuverability, the increased degrees of freedom, and the enhanced dexterity greatly enhance the surgeon's ability to identify and dissect anatomic structures as well as to construct microanastomoses. The overhead boom of the Xi system allows multi-quadrant surgery. In case of robotic esophagectomy, both the abdominal and the thoracic parts can be performed easily without changing the setup. Up

Table 1 Results—Landesklinikum Wiener Neustadt June 2015–January 2018

Surgical technique	*n*	Surgery time (min)
Hiatoplasty (1× + CHE)	7	174 (80–300)
Subtotal gastrectomy	7	260 (180–410)
Gastrectomy	4	
Atypical gastric resection (GIST)	1	110
Akiyama Surgery	2	412 (360–464)
Ivor Lewis Surgery	11	389 (340–420)
Esophageal leiomyoma enucleation	1	160

Robot-assisted esophagectomies	*n*	Anastomotic technique	Perioperative complications	30-day complications	Postoperative hospital stay (days)
Akiyama surgery	2	2× hand-sewn end-to-end anastomosis (4–0 polydioxanone single-layer continuous suture)	0	1× low output salivary fistula	17.5 (12–23)
Ivor Lewis surgery	11	1× robot-sewn end-to-end double-layer anastomosis (continuous 3–0 V-Loc™ suture) 10× circular stapled end-to-side anastomosis (EEA™ OrVil™) + circular over-sewing (3–0 V-Loc™)	2× anastomotic dehiscences	1× neurogenic dysphagia	16.7 (11–30)

to now, we have only performed a very small number of robot-assisted esophagectomies, but we see the advantages of the robotic system during surgery. Referring to the intrathoracic anastomosis, the range of motion of the robotic instruments makes hand-sewn anastomosis quite possible and easier in contrast to laparoscopy. Regarding the anastomosis technique, there is no significant difference between hand-sewn versus mechanical stapler technique in relation with anastomotic leak or cardiac complications. However, stapler technique increases the risk of anastomotic stricture [10, 11]. In our series, in case of Ivor Lewis procedure, hand-sewn (robot-sewn) anastomosis was performed once. A robot-sewn anastomosis is technically feasible, but still, a challenge with already advanced surgery time. For this reason, based on our positive experience with stapled anastomosis with the EEA™ OrVil™ device in open/laparoscopic gastric and esophageal surgery, we have chosen this procedure. In addition, the anastomosis is sewn circularly to ensure a "strain relief". This combined technique is quick and easy to do. Using the Firefly™ fluorescence imaging, a well-vascularized anastomosis can be ensured.

Van Hillegersberg et al. already have a great experience and expertise (> 300 cases) in robot-assisted minimally invasive esophagectomy (RAMIE) using the da Vinci® Si. Unlike us, they have only performed the thoracic part with the robotic system. Van Hillegersberg has also taken up the interesting and important topic if surgery of higher tumor stage (T4) is possible with the robotic system—after downstaging. He has already treated ten patients using following strategy: long-course chemoradiotherapy followed by RAMIE if restaging shows a response [12]. In our series, the advanced stage was a T3 tumor. However, definitely, an issue will demand our attention in the future.

Another topic is that robotic surgery might enable a more radical lymphadenectomy. Due to the technical features of the robot, the lymph node preparation around the celiac trunk, starting at the hepatic artery is facilitated. The 30° endoscope enables perfect visualization above the upper edge of the pancreas and the EndoWrist® instruments allow a preparation at a steep angle. Furthermore, the robot-assisted lymphadenectomy along the recurrent laryngeal nerve (RLN) is technically feasible and safe. A review of the literature shows contrary data [13]. There is still an open question whether a more radical and a better-quality lymphadenectomy offered by robotic surgery has the potential to improve the oncologic outcome.

Up to now, robotic esophagectomy is equivalent to open surgery especially referring to the oncologic outcome [14]. Due to the low number of cases in our department, we are not yet able to make a conclusive statement.

Conclusion

In our opinion, robotic surgery is a hot topic and the technical as well as the medical possibilities are not yet exhausted. Further technical development will help to open new "surgical doors".

In case of robotic esophagectomy, we see the technical advantages of the da Vinci® Xi. The different features facilitate surgery compared to the open or the laparoscopic surgery. Based on our personal experience, postoperative complications are reduced, and patients show a faster rate of recovery.

Further trials should help in validating these results and conclusions. They also prompt the question—will the mentioned features allow surgery for higher tumor stages and if robotic-sewn anastomosis is the new future.

All these topics certainly need further observation.

Compliance with ethical standards

Conflict of interest Author A. Pötscher, C. Bittermann, and F. Längle declare that they have no conflict of interest.

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