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Review

Implementation of robot-assisted Ivor Lewis procedure: Robotic hand-sewn, linear or circular technique?

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ABSTRACT

Background: Robot-assisted surgery for esophageal cancer is increasingly applied. Despite this upsurge, the preferential technique to create a robot-assisted intrathoracic anastomosis has not been established.
Data sources: Bibliographic databases were searched to identify studies that performed a robot-assisted Ivor Lewis esophagectomy and described the technical details of the anastomotic technique. Out of 1701 articles, 16 studies were included for systematic review.
Conclusions: This review shows that all technique used to create a thoracoscopic anastomosis can be adopted to robotic surgery. Techniques can be divided into three categories: robotic hand-sewn, circular stapling or linear stapling and robotic hand-sewn closure of the stapler defect. With limited robotic experience, circular stapling might be the preferred technique, however requires a well-trained bedside assistant. The linear stapling technique or hand-sewn technique are more challenging but enable experienced robotic surgeons to perform a controlled anastomosis without bedside support.

Introduction

Robot-assisted surgery increases precision of tissue handling by high-resolution 3D imaging, articulating instruments and suppression of physiological tremor.[1] Hence its popularity among oncological surgeons has grown strongly. Over 500.000 procedures are performed every year and it has become the standard of care in oncological urology and gynecology.[2,3] With regard to esophageal surgery, the pre-existing techniques of minimally invasive esophagectomy have been adapted to incorporate the use of robotic platforms. These innovations were first implemented in the transhiatal approach and it took over a decade before the first robot-assisted intrathoracic anastomosis was reported.[4,5]

In every esophagectomy, regardless of the approach, the creation of the anastomosis is a critical step. Current evidence indicates that an intrathoracic anastomosis might be associated with reduced anastomotic leakage rates and improved functional results compared to a cervical anastomosis.[6,7] Randomized prospective data will be shortly available to provide more solid conclusions.[8]

Most studies focusing on robotic esophageal cancer surgery involve the creation of a cervical anastomosis. It seems that performing a robotic intrathoracic anastomosis is an obstacle for esophageal surgeons. There is a clinical demand for details on how to create the anastomosis as the preferred way has not been determined. Our study aims were to perform a systematical review of all aspects of the techniques used to create a robotic intrathoracic anastomosis. This overview can be used by surgeons to help reduce learning curves when implementing robotic platforms.

Methods

A comprehensive systematic review of published literature on the creation of a robot-assisted intrathoracic anastomosis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement.[9]

Search strategy

A comprehensive search was performed in the bibliographic

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databases PubMed, Embase and the Cochrane Library (via Wiley) from inception to August 20, 2019, in collaboration with a medical librarian. Search terms included controlled terms (MesH in PubMed, Emtree in Embase) as well as free text terms. In the Cochrane Library only free text terms were used. The following terms were used (including synonyms and closely related words) as index terms or free-text words: 'esophagus' and 'robotics'. The search was performed without date, language or publication status restriction. Duplicate articles were excluded. The full search strategies for all databases can be found in the supplementary information.

Inclusion and exclusion criteria

The inclusion criteria were as follows. (1) articles had to address the intrathoracic anastomosis following a robot-assisted esophagectomy, (2) the technique used for the creation of the anastomosis had to be described in detail, (3) articles had to be published between inception and August 20, 2019, (4) articles had to be published in English, (5) full-text had to be available. Letters, review articles, conference abstracts and articles with a small sample size ($n \leq 5$) were excluded.

Screening

Title and abstract of all identified citations were screened by two independent researchers (VP and WS) and compared to the inclusion criteria. Full-text of the remaining articles was assessed. All articles meeting the eligibility criteria were included in this systematic review. References of included articles were searched for additional studies.

Data extraction

The following technical specifications for the creation of the anastomosis were obtained from included studies; (1) anastomotic configuration: end-to-end (ETE), end-to-side (ETS), side-to-end (STE) and side-to-side (STS), (2) technique (Fig. 1) (i.e. robotic hand-sewn, circular stapling or linear stapling and robotic hand-sewn closure of the stapler defect), (3) suture technique (i.e. single layer, double layer, continuous and interrupted), (4) materials (i.e. suture and staplers) (5) additional reinforcement of the anastomosis (i.e. the omentum and pleural coverage), and (6) the type of robot. Additionally the following study characteristics and outcomes were derived: first author, year of publication, study design, number of patients, gender, age, American Society of Anesthesiologists (ASA) classification, neoadjuvant therapy and pathological tumor stage. In addition, the occurrence of anastomotic leakage, gradation of leakage according to the Esophagectomy Complications Consensus Group (ECCG),[10] other complications and 30-day mortality were documented due to the interest in the quality of the anastomosis. Leakage of the gastric conduit staple line was not listed as anastomotic leakage. When additional data was not provided in the article (or was not stratified for robot-assisted Ivor Lewis procedures), the corresponding authors were contacted to complete the missing data.

Results

A total of 1701 articles were identified through a combined search in PubMed, Embase and the Cochrane Library. Duplicate articles were removed and 1267 articles were screened on title and abstract. Screening yielded 93 articles and after full-text assessment, 16 articles were included for qualitative synthesis. A flow chart of the article selection is presented in Fig. 2. Technical specifications for the creation of the anastomosis are summarized in Table 1.

Robotic hand-sewn anastomosis

Five articles comprising 126 patients were included that used a completely robotic hand-sewn technique.[5,11–14] Generally, authors agreed on using a double-layered technique for both the anterior and posterior aspect of the anastomosis. Egberts et al.[13] used 4 to 6 running sutures (4-0 Stratafix, Ethicon) to fixate the serosa of the gastric conduit to postmuscular layer of the esophageal remnant. They used a new running suture to close the mucosal layers of the posterior wall starting at 9 o'clock running via 6 o'clock to finish at 3 o'clock by creating an extraluminal knot. Throughout the procedure the fourth robotic arm was used to create optimal visualization and the gastric conduit is fixated by the bedside assistant. The inner layer of the anterior aspect of the anastomosis was created using two running sutures starting at 9 o'clock and 3 o'clock to both finish at 12 o'clock. The outer layer was completed by interrupted sutures (4-0 Vicryl, Ethicon) incorporating the pleura as buttress. Cerfolio et al.[5] created the anastomosis in a similar fashion, except that they preferred to use 5 interrupted sutures to create the outer layer of the posterior aspect of the anastomosis. A

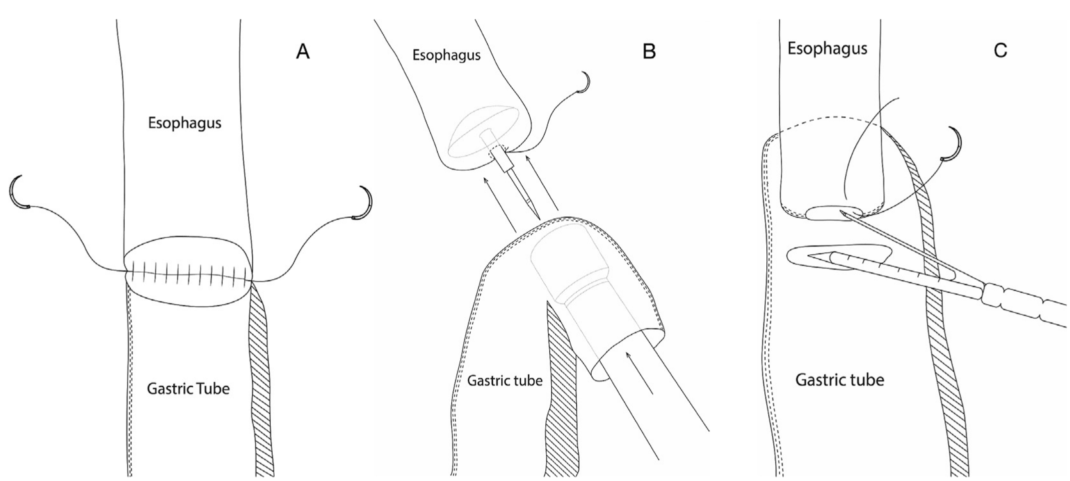

Fig. 1. Available techniques for the creation of a robot-assisted intrathoracic esophagogastric anastomosis. (A) Completely robotic hand-sewn technique. (B) Circular stapling technique. (C) Linear stapling technique with robotic hand-sewn closure of the stapler defect.

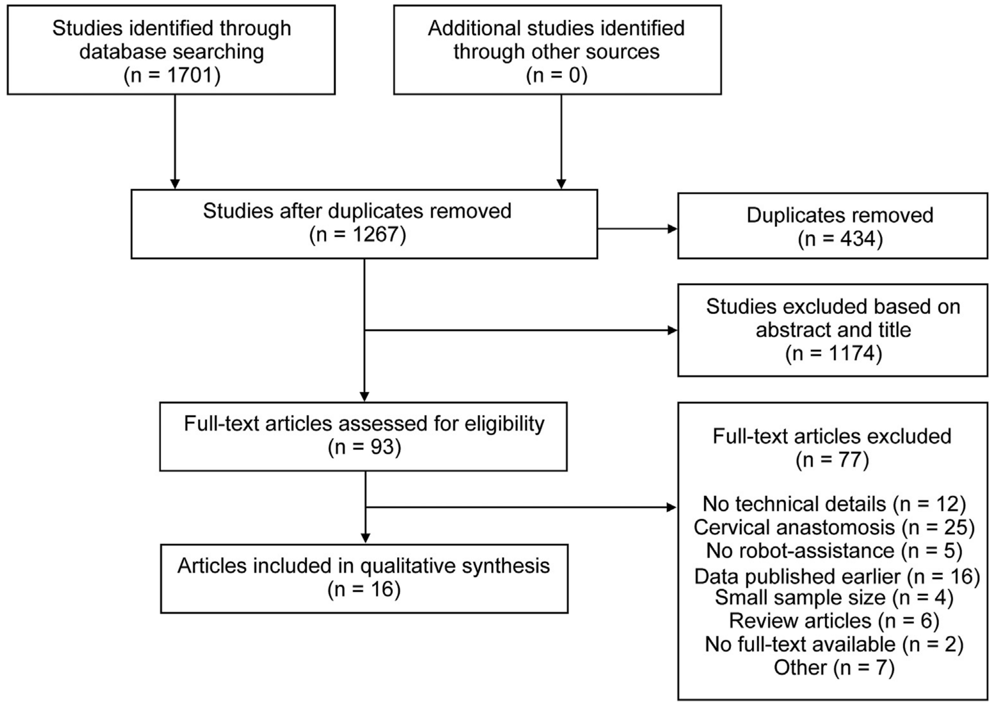

Fig. 2. Flowchart of the included articles.

single running suture was used to create the inner layer of the anterior aspect of the anastomosis. Furthermore, they emphasized to carefully select the gastrotomy location, preferably on the direct opposite site of the lesser curvature staple line and 3–4 cm below the gastric staple line creating an ETS configuration. Zhang et al.[14] created the anastomosis is a similar fashion, except using interrupted sutures (3-0 Vicryl, Ethicon) to complete the inner mucosal layer of the posterior aspect of the anastomosis.

Circular stapled anastomosis

Ten studies comprising 697 patients were included that utilized circular stapling.[14–23] A transoral introduction of the anvil was proposed by Amaral and Meredith[18,20] and represented the largest series of robot-assisted Ivor Lewis procedures. De la Fuente[15] and Potscher[21] reported the same procedure, involving a smaller cohort of patients. Potscher et al. reinforced the reconstruction by oversewing (3-0 V-loc) the anastomosis in a circular fashion. A detailed publication reporting the intracorporal introduction of the anvil was provided by Sarkaria.[16,24] Throughout the procedure the bedside assistant played a pivotal role as he or she was responsible for introducing and maneuvering the circular stapler. The thoracic space is limited by multiple robotic arms, making the rigid stapler difficult to maneuver. The anvil was secured by two robotic hand-sewn purse-sting sutures. The first purse-string was sutured within 2–3 mm of the esophageal edge, followed by a second more superficial purse-sting suture. Tagkalos et al.[22] disconnected the robot after performing a first purse-string suture. The more superficial purse-string suture, introduction of the stapler, docking the stapler spike to the anvil and transection of redundant gastric conduit were performed thoracoscopically. After removal of the specimen the robot was reconnected to reinforce the anastomosis by excessive omentum around the anastomosis.

Linear stapled anastomosis

Two articles comprising 62 patients reported their early experience with the linear stapling technique. Hodari et al.[25] created the posterior aspect of the anastomosis with a linear 45 mm stapler held by the bedside assistant. The stapler defect was closed with

Table 1a
Description of included articles and technical specifications of the robotic hand-sewn technique.

Author	Design	N	Robot	Configuration	Layered suture	Suture type	Additional reinforcement
Cerfolio[5] 2013	Retrospective	16	da Vinci Si	ETS	DL: PW (IS and RS) and AW (RS and IS)	IS: 3-0 Silk RS: 3–0 PDS	Omental wrap
Trugeda[11] 2014	Prospective	14	da Vinci Si	ETE	DL: PW (IS and RS), SL: AW (RS)	IS: 2-0 Silk RS: 2-0 V-loc Covidien	–
Bongiolatti[12] 2016	Retrospective	8	da Vinci Si	ETS	SL: PW (RS) and AW (IS)	IS: NR RS: 3–0 PDS	–
Egberts[13] 2017	Retrospective	52	da Vinci Si	ETE	DL: PW (RS and RS) and AW (RS and IS)	IS: 4-0 Vicryl, Ethicon RS: 4-0 Stratafix Ethicon	Omental wrap
Zhang[14 §] 2018	Prospective	36	da Vinci S	ETE	DL: PW (RS and IS) and AW (RS and RS)	IS: 3-0 Vicryl Ethicon RS: 3-0 V-loc Covidien	Omental wrap

AW: anterior wall anastomosis, DL: double layer, ETE: end-to-end, ETS: end-to-side, IS: interrupted, NR: not reported, PDS: polydiaxone, PW: posterior wall anastomosis, RS: running suture, SL: single layer suture.
[§]Same article.

Table 1b
Description of included articles and technical specifications of the circular stapling technique.

Author	Design	N	Robot	Configuration	Anvil placement	Purse-string suture	Stapler	Additional reinforcement
De la Fuente[15] 2013	Retrospective	50	da Vinci X	NR	Transorally	–	25 mm (Orvil)	Omental wrap
Sarkaria[16] 2016	Prospective	89	da Vinci Si	ETE	Intracorporeally	Robotic	28 mm	–
Wee[17] 2016	Retrospective	20	da Vinci Si	ETE	Intracorporeally	Robotic	25 or 28 mm	Omental wrap
Amaral[18] 2017	Retrospective	237	da Vinci Si and Xi	ETS	Transorally	–	25 mm (Orvil)	Omental wrap
Okusanya[19] 2017	Retrospective	23	da Vinci Si and Xi	ETS	Intracorporeally	Robotic	28 mm	Omental wrap
Meredith[20] 2018	Retrospective	147	da Vinci Si and Xi	ETS	Transorally	–	25 mm	Omental wrap
Zhang[14] § 2018	Prospective	40	da Vinci S	ETE	Intracorporeally	Robotic	25 mm	Omental wrap
Potscher[21] 2019	Retrospective	10	da Vinci Xi	ETS	Transorally	–	NR (Orvil)	Circular sutures (3-0 V-loc)
Tagkalos[22] ‡ 2019	Prospective	50	da Vinci Xi	ETS	Intracorporeally	Robotic and thoracoscopic	25 or 28 mm	Omental wrap
Wang[23] 2019	Prospective	31	NR	STE	Intracorporeally (side insertion)	Robotic	25 mm	–

ETS: end-to-side, ETE: end-to-end, NR: not reported.
§ Same article.
‡ non-robotic anastomosis.

robotic hand-sewn sutures in a double-layered fashion. They used interrupted sutures (3-0 Vicryl, Ethicon) to complete the inner mucosal layer and running sutures (3-0 V-loc, Covidien) to complete the (sero)muscular layer. The anastomosis was reinforced by additional horizontal sutures (2-0 silk) using the fundus as a buttress. Guerra et al.[26] used a robot-integrated (endowrist) 45 mm linear stapler. The stapler defect was closed in a double-layered fashion using running barbed sutures for the inner layer and interrupted sutures for the outer layer of the defect.

Anastomotic leakage

A robotic hand-sewn anastomosis was performed in 126 patients, of which 14 developed an anastomotic leak (11.1%). Ten patients had a grade 2 anastomotic leak (7.9%) and four patients had a grade 3 leak (3.2%). Anastomotic leakage following circular stapling was observed in 60 out of 697 patients (8.6%), consisting of 20 (3.3%) grade 1, 26 (4.2%) grade 2 and 10 (1.6%) grade 3 anastomotic leaks (gradation was not reported in three articles). The linear stapling technique was used in 62 patients, three (4.8%) patients developed anastomotic leakage (two (3.2%) grade 2 and one (1.6%) grade 3). Additional patient characteristics, neoadjuvant therapy, pathology characteristics and outcomes are presented in Table 2.

Discussion

This overview shows that conventional thoracoscopic techniques used to create the anastomosis can be maintained in robotic surgery. The techniques can be divided in three main categories: the anastomosis was created by either a fully robotic hand-sewn technique, a circular stapling technique or a linear stapling technique with robotic hand-sewn closure of the stapler defect. However, within the hand-sewn and linear stapled groups, there were substantial differences in anastomotic configuration, suture type, number of layers and suture material. As expected the circular stapling technique was fairly homogeneous across studies.

Robotic hand-sewn anastomosis

In the open esophagectomy era, the hand-sewn anastomosis was preferred by many surgeons and some have reported extremely low anastomotic leakage rates.[27] However, only a few minimally invasive hand-sewn anastomosis have been published due to its high technical requirements of suturing ability combined with non-articulating instruments.[28,29] Nowadays robotic assistance provides surgeons the opportunity to execute this technique in a more reliable and simplified fashion. The angulating needle holder facilitates a double layer suture without the restricted freedom of movement of rigid thoracoscopic instruments. Cerfolio[5] was the first to report this technique and emphasized to use a robotic needle grasper and nontraumatic long-tipped robotic forceps instead of two needle drivers. This enables the surgeon to maintain tension on the suture without fraying. Most authors stress that hand-sewing increases operative time, but when performed by experts enables the surgeon to create a more controlled anastomosis.[5,13,14] On the other hand, this makes the technique difficult to reproduce or standardize and requires a long learning curve. No data regarding intersuture distance, suture distance to the anastomotic edge and suture tension is available.

Circular stapled anastomosis

Since Fain[30] described the first colorectal anastomosis using a circular stapling device, the technique has progressed significantly

Table 1c
Description of included articles and technical specifications of the linear stapling technique.

Author	Design	N	Robot	Configuration	Stapler	Suture	Additional reinforcement
Hodari[25] 2015	Retrospective	54	da Vinci Si and Xi	ETS	Linear 45 mm	DL: IS (3-0 Vicryl Ethicon) and RS (3-0 V-Lock Covidien)	Omental wrap
Guerra[26] 2018	Retrospective	8	da Vinci Xi	STS	Linear 45 mm (Endowrist)	DL: RS and IS	Omental wrap

DL: double layer, ETS: end-to-side, IS: interrupted suture, RS: running suture, STS: side-to-side.

Table 2
Characteristics and outcomes of the 16 included studies.

Author	Technique	N	Male gender	Age	ASA	Neoadjuvant therapy	Tumor stage	AL	Grade AL (n) *	Other Complications	30-day mortality
Cerfolio[5] 2013	HS	16	NR	NR	NR	NR	T0 9 (56) T1-T4 7 (44)	0 (0)	–	1 (6)	0 (0)
Trugeda[11] 2014	HS	14	14 (100)	56 (34–73)	II 13 (93) III 1 (7)	CRT 11 (79) None 3 (21)	T0 2 (14) T1 2 (14) T3 10 (71)	4 (29)	Grade 2 (3) Grade 3 (1)	2 (14)	0 (0)
Bongiolatti[12] 2016	HS	8	NR	64 ± 9	II 3 (38) III 5 (62)	None 8 (100)	T1-T2 4 (50) T3 4 (50)	2 (25)	Grade 3 (2)	0 (0)	0 (0)
Egberts[13] 2017	HS	52	NR	68 (29-82)	I 1 (2) II 32 (62) III 19 (37)	CT 28 (54) CRT 15 (29) None 9 (17)	T0 4 (8) T1-T2 14 (27) T3-T4 34 (65)	5 (10)	Grade 2 (4) Grade 3 (1)	22 (42)	NR
Zhang[14§] 2018	HS	36	29 (81)	63 (44–74)	I 20 (56) II 16 (44)	CRT 2 (6) None 34 (94)	T1-T2 15 (42) T3-T4 21 (58)	3 (12)	Grade 2 (3)	3 (9)	0 (0)
De la Fuente[15] 2013	CS	50	39 (78)	66 (42–82)	III 50 (100)	CRT 35 (70) None 15 (30)	T0 17 (34) T1-T2 21 (42) T3 11 (22) Other 1 (2)	1 (2)	NR	13 (26)	NR
Sarkaria[16] 2016	CS	89	68 (76)	62 (37–83)	NR	CT 2 (2) CRT 68 (76) None 19 (21)	T0 18 (20) T1-T2 51 (57) T3 16 (18) Other 4 (4)	5 (6)	Grade 2 (4) Grade 3 (1)	20 (22)	0 (0)
Wee[17] 2016	CS	20	14 (70)	64 (38–81)	II 1 (5) III 19 (95)	CT 1 (5) CRT 16 (80 None 3 (15)	T0 4 (20) T1-T4 13 (65) Other 3 (15)	0 (0)	–	11 (55)	0 (0)
Amaral[18] 2017	CS	237	166 (70)	65 ± NR	NR	CT 10 (4) CRT 185 (78) None 42 (18)	NR	35 (15)	Grade 1 (18) Grade 2 (9) Grade 3 (8)	NR	NR
Okusanya[19] 2017	CS	23	NR	NR	NR	NR	NR	1 (4)	Grade ≥2 (1)	NR	0 (0)
Meredith[20] 2018	CS	147	116 (79)	66.4 ± 10.1	2.6 ± 0.5	Yes 114 (78) None 33 (22)	T0 54 (37) NR 93 (63)	4 (3)	Grade 2 (3) Grade 3 (1)	37 (25)	1 (1)
Zhang[14§] 2018	CS	40	30 (75)	64 (43–74)	I 16 (40) II 21 (53) III 3 (8)	None 40 (100)	Tis 4 (10) T1-T2 20 (50) T3-T4 16 (40)	4 (10)	Grade 2 (4)	3 (8)	0 (0)
Potscher[21] 2019	CS	10	NR	NR	NR	NR	NR	2 (20)	NR	NR	NR
Tagkalos[22‡] 2019	CS	50	NR	62 ± NR	I-II 22 (52) III-IV 28 (48)	CT 16 (32) CRT 27 (54) None 7 (14)	T0 5 (10) T1-T2 15 (30) T3-T4 30 (60)	6 (12)	Grade 2 (6)	6[†]	0 (0)
Wang[23] 2019	CS	31	27 (87)	59.7 ± 7.5	NR	NR	T1-T2 10 (32) T3-T4 21 (68)	2 (6)	Grade 1 (2)	4 (13)	0 (0)
Hodari[25] 2015	LS	54	44 (81)	65 (45–81)	NR	CRT 38 (70) None 16 (30)	T0 10 (19) T1-T2 25 (46) T3-T4 14 (26) Other 5 (9)	3 (6)	Grade 2 (2) Grade 3 (1)	37[†]	1 (2)
Guerra[26] 2018	LS	8	7 (88)	66 (57–73)	I 3 (38) II 4 (50) III 1 (12)	CT 7 (88) None 1 (12)	T0 2 (25) T1-T2 3 (38) NR 3 (38)	0 (0)	–	2 (25)	0 (0)

Data are n (%), mean ± standard deviation or median (range). * Leakage grade according to the Esophagectomy Complications Consensus Group (ECCG), [§] same article, [‡] thoracoscopic anastomosis, [†]total number other complications.
AL: anastomotic leakage, ASA: American Society of Anesthesiologists, CR: complete Response, CRT: chemoradiotherapy, CS: circular stapling, CT: chemotherapy, HS: hand-sewn, LS: linear stapling, NR: not reported, RT: radiotherapy, T: tumor stage.

and been adopted to esophageal surgery. Securing the anvil might be easier with robotic assistance, however this can also be achieved using thoracoscopy.[22] The circular stapler is currently not available as a robot-integrated instrument and is therefore introduced though a mini thoracotomy by the bedside assistant. Docking the stapler to the anvil requires close coordination and communication between the surgeon and bedside assistant.[14,16] As a circular stapled anastomosis is the most standardized technique and relatively easy to learn, it seems the preferential route for starting a robot-assisted Ivor Lewis esophagectomy.

Linear stapled anastomosis

The linear stapling technique typically results in a (functional) STS configuration. This results in a larger orifice of the anastomosis allowing easy passage of intraluminal content and a decreased circular pressure on the anastomosis. In addition, the tension on the anastomosis due to the weight of the gastric conduit is directed sideways. These attributes might account for the low incidence of anastomotic leakage[31,32] and strictures[33,34] reported. A robot integrated linear stapler (endowrist) was introduced a few years ago, improving maneuverability and omitting the bedside assistance during the creation of the anastomosis.

The type and configuration of the intrathoracic anastomosis is the most crucial phase of the robot assisted Ivor Lewis procedure, as it is for an open or minimally invasive approach.[33,34] The technique to create the reconstruction remains mainly decided based on surgeons preference. Especially surgeons changing from minimally invasive to a fully robotic approach appear to adapt their preferred minimally invasive anastomotic technique to robotic surgery. Research suggests that previous experience in laparoscopic surgery does not directly transfer to robot-assisted surgery.[35] Therefore, concerns for detrimental effects of robotic implementation and associated learning curves should be tackled by structured training pathways.[36] Perfection of outcomes could be achieved by sharing experiences within (high-volume) centers and ultimately reach consensus on the preferred anastomotic technique. Recently esophageal surgeons from seven robotic centers in Germany adopted a circular stapling technique and further results are awaiting.[37]

This review shows that all anastomotic techniques can be adopted to robotic surgery. Circular stapling is uniform, relatively easy to learn and currently the best-studied technique. The bedside assistant is controlling the stapler and plays a pivotal role. The linear stapling technique and fully robotic hand-sewn technique are largely non-defined and more challenging. These techniques enable experienced robotic surgeons to perform a precise and controlled anastomosis without bedside support. Unfortunately, the available scientific evidence regarding surgical outcomes is limited. In the transition to robotic technology, the circular stapling technique might be the preferred approach until sufficient robotic experience is achieved.

Author disclosure

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Author contribution

VD Plat, BSc, participated in the design of the study, collection and interpretation of data, wrote and submitted the manuscript and gave final approval of the version to be published.

WT Stam, BSc, participated in the collection and interpretation of data, wrote parts of the manuscript and gave final approval of the version to be published.

LJ Schoonmade, participated in the collection of data, wrote parts of the manuscript and gave final approval of the version to be published.

DJ Heineman, MD PhD, participated in the interpretation of data, revised the manuscript critically and gave final approval of the version to be published.

DL van der Peet, MD PhD Prof, participated in the interpretation of data, revised the manuscript critically and gave final approval of the version to be published.

F Daams, MD PhD, participated in the design of the study, interpretation of data, revised the manuscript critically and gave final approval of the version to be published.

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