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Robot-assisted gastrectomy and oesophagectomy for cancer.

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Abstract

Background:

Robot-assisted surgery is a technically feasible alternative to open and laparoscopic surgery which is being more frequently used in general surgery. We undertook this review to investigate whether robotic assistance provides a significant benefit for oesophago-gastric cancer surgery.

Methods:

Electronic databases were searched for original English language publications for robotic-assisted gastrectomy and oesophagectomy between January 1990 and October 2013.

Results:

Sixty-one publications were included. Thirty-five included gastrectomy, 31 included oesophagectomy, and 5 included both operations. Several publications suggest that robot-assisted subtotal gastrectomy can be as safe and effective as an open or laparoscopic procedure, with equal outcomes with regard to the number of lymph nodes resected, overall morbidity and perioperative mortality, and length of hospital stay. Robotic assistance is associated with longer operation times but also with less blood loss in some reports. A significant benefit for robotic assistance has not been shown for the more extensive operations of oesophagectomy or total gastrectomy with D2 lymphadenectomy. There are very few oncologic data regarding local recurrence or long-term survival for any of the robotic operations.

Conclusions:

No significant differences in morbidity, mortality, or number of lymph node harvested have been shown between robot-assisted and laparoscopic gastrectomy or oesophagectomy. Robotic surgery, with its relatively short learning curve, may

facilitate reproducible minimally invasive surgery in this field but operation times are reportedly longer and cost differences remain unclear. Randomised trials with oncologic outcomes and cost comparisons are needed.

Background

During the last decade many reports have demonstrated the clinical advantages of laparoscopic surgery compared to open surgery, emphasising faster postoperative recovery time and a shorter hospital stay, better cosmetic results with a lower rate of wound infection, and reduced morbidity with equivalent symptomatic and physiologic benefits [1-4]. Minimally invasive oesophagogastric resections are widely practised, especially for laparoscopic distal gastrectomy or gastrointestinal stromal tumour (GIST) resections rather than the more technically demanding laparoscopic total gastrectomy or oesophagectomy. Laparoscopic distal gastrectomy (D1 + β) is now considered a safe and technically feasible procedure, although if the more extensive D2-lymph node dissection is performed, significantly more morbidity (anastomotic leakage, luminal bleeding) and mortality are reported compared to open surgery[5].

Further refinements in surgical technique, which could theoretically be provided by robotic assistance, are needed in surgical oncology. Despite improvements in conventional laparoscopic and thoracoscopic surgery, there are limitations with this technology including two-dimensional imaging, limited instrument maneuverability, uncomfortable surgeon position which continue to hinder the ability to perform more complex operations. Robotic surgery technology was developed to overcome these limitations. Among the reported advantages of robotic compared to conventional laparoscopic surgery are a more comfortable and ergonomic surgeon position, improved hand-eye alignment, and increased accuracy and precision of movement resulting from motion scaling and tremor filtering. There is also a three dimensional view of the operative field and the instrument tips have superior dexterity. The learning curve for experienced surgeons moving from laparoscopic to robot-assisted surgery is estimated to be only around 20 cases[6, 7].

Robot-assisted surgery is increasingly performed for gastric cancer in Asia, especially in Japan, Taiwan and South Korea, where the advantage of robotic surgery is claimed to be the ease and reproducibility of the D2-lymphadenectomy[8, 9]. We conducted this review in order to determine whether robot-assistance provides a benefit for surgical resections for malignancies in the oesophagus and stomach.

Methods

The electronic databases MEDLINE, Pre-Medline, EMBASE, Current Contents, CINAHL and the Cochrane Library database were searched to identify relevant studies published in the English language between January 1990 and October 2013 using Medical Subject Heading terms and text words for robot, robotic, or robotic-assisted surgery (see Figure 1). All publications, including single case reports, which evaluated clinical outcomes for robot-assisted oesophagectomy or gastrectomy, or both, for cancer in adult humans were then included. Bariatric surgery, paediatric surgery, animal and experimental laboratory studies, and reports in abstract form only, were excluded. We also excluded case reports on robot-assisted gastrectomy for the treatment of gastrointestinal stromal tumours (GISTs) because of the lack of standardised surgical resections and lymphadenectomy for this type of tumour[10, 11]. The latest publication with the largest patient numbers was emphasised if the same surgery unit had published multiple reports. A statistical data analysis such as a meta-analysis was not performed because of the general lack of high quality data[8, 9, 12, 13]. Each paper's data were analysed to allow a comparison of safety and effectiveness, with outcomes assessed separately for gastrectomy and oesophagectomy.

Results

A total of 61 publications met the search criteria for inclusion in this review. The excluded publications were original articles reporting case series in non-English languages. There were 35 publications on robot-assisted gastrectomy and 31 on robot-assisted oesophagectomy. Five publications reported on a mix of these operations. Most publications were case series: 69% (24/35) of the gastrectomy publications and 90% (28/31) of the oesophagectomy papers. All case series included only consecutive patients. No data from randomised controlled trials have been reported.

Robot-assisted gastrectomy

As shown in Table 1, earlier publications on robot-assisted gastrectomy were mostly case reports or small case series, but in later years larger sample sizes are seen in non-randomised trials[6-8, 14-46]. The earlier papers demonstrate feasibility but also report long operating times (350 - 656 min) and major complications. In later publications a more systematic report of complications has been performed[6, 29, 30, 32, 33, 39].

Noteworthy reports include a retrospective analysis comparing robot-assisted gastrectomy in 236 patients with laparoscopic assisted gastrectomy in 591 patients [29]. There was a similarly large lymph node harvest in both groups and an extended D2-lymphadenectomy, with a mean 42 nodes removed, was performed in 105 (45%) of the robotic operations[29]. Another retrospective analysis found no significant differences in overall complication (10.5%), reoperation (1%) and mortality rates (0.4%) in 5839 patients who underwent gastrectomy (4542 open, 861 laparoscopic and 436 robotic)[47]. Anastomotic leak occurred significantly more often after a minimally invasive approach[47].

The comparative study results (Table 1) indicate that there are similarly high morbidity rates after robot-assisted (up to 47.3%), laparoscopic (up to 38.5%) and open surgery (up to 42.5%). A similar number of lymph nodes seems to be harvested with each operative approach, although selection bias should be taken into account when evaluating these results[29, 30, 33, 39].

Huang et al. noted that because of the technical difficulty in performing a D2-lymphadenectomy during laparoscopic gastrectomy, D2-lymphadenectomy was only performed in 18.8% of patients in the laparoscopic group, compared to 88.1% in the open group and 87.2% in the robotic group[33].

A meta-analysis by Xiong et al. included only three non-randomised controlled trials comparing robot-assisted gastrectomy and laparoscopic gastrectomy for cancer[8]. Robot-assisted gastrectomy was associated with a significantly longer operative time and significantly less intraoperative blood loss. No differences were found between the groups with regard to the number of lymph nodes removed, overall morbidity, perioperative mortality, or length of hospital stay.

Robot-assisted oesophagectomy

The results of publications that included robot-assisted oesophagectomy are shown in Table 2[14, 16, 17, 20, 21, 48-73]. As for gastrectomy, early reports are case reports or small case series but more recent reports have larger numbers and results comparable to conventional surgery. The level of evidence is predominantly based on cohort studies, case series or expert opinion (Level 4 or 5)[74]. The robot system has predominantly been used for the thoracic dissection. There are no long-term data on comparative disease-free survival between different approaches.

van Hillegersberg et al. reported a case series of 21 consecutive patients who underwent robot-assisted thoracoscopic dissection as part of a 3-stage oesophagectomy[57]. Conversion to thoracotomy occurred in three patients due to adhesions, bulky adhesive tumour and bleeding from an aorto-oesophageal artery respectively. Of the 27 post-operative complications the majority were pulmonary relating to the transthoracic approach. Of note there were 3 anastomotic leaks, 3 chylous leaks and vocal cord paralysis in 3 patients. The one death was due to tracheo-neoesophageal fistula. Another patient required re-operation for an ischaemic distal neo-oesophagus[57]. Another series of 14 patients reported one conversion to thoracotomy, one death, two anastomotic leaks, and vocal cord paralysis in two patients[58]. Transhiatal oesophagectomy was completed robotically in all 18 patients in another study, with the complications of anastomotic leak in six patients, one thoracic duct injury, and one vocal cord paralysis[60].

In the largest series, Boone et al. reported on 47 patients who underwent robot-assisted thoracoscopic oesophagectomy as part of a 3-stage oesophagectomy[61]. Conversion to thoracotomy was needed in 7 patients and complications are shown in Table 2. Eleven (23%) patients had an R1 resection, with tumour at a resection margin. Patients were followed up for a median time of 35 months. 30 patients developed symptomatic recurrent disease at a median of 9 (range 3–29) months after oesophagectomy[61].

Several non-randomised clinical trials and case series from later years reported high overall morbidity (rates up to 42%), with major complications (anastomotic leakage, gastric leakage, empyema, airway fistulas, respiratory failure, others) that sometimes required re-operation or other interventions (see Table 2)[64-67, 70-72]. There is an ongoing randomised controlled trial, which has yet to report results[68].

A comparative study found no significant differences between the robotic and thoracoscopic groups with respect to blood loss, operation time, or number of resected lymph nodes, but the anastomotic leak rate was higher (38%) in the robot-assisted group (10%)[66]. The incidence of vocal cord palsy in this study was relatively high overall (all patients were examined by laryngoscopy postoperatively), but was lower after robotic (38%) compared to thoracoscopic (75%) surgery. Another comparative study showed equivalent outcomes for robot-assisted compared to thoracoscopic surgery and no significant differences in operative time, blood loss, number of resected lymph nodes, postoperative complications, days of mechanical ventilation, length of intensive care unit stay or length of hospital stay[67].

Discussion

This review demonstrates that robot-assisted gastrectomy for gastric cancer is feasible and safe. Both the rate of conversion to open surgery and the mortality rate are low in large series. Several case series and non-randomised trials also suggest that it is possible to perform an oncologically adequate gastrectomy, with large numbers of lymph nodes resected[23, 24, 29, 31-33]. The reports include far more robot-assisted subtotal gastrectomy than total gastrectomy operations. Prospective studies with factors including long-term oncological outcomes are needed, especially since a real clinical advantage to overcome the presumed cost disadvantage has not yet been shown.

The potential role of robotic assistance for oesophagectomy for cancer is difficult to evaluate. Unlike gastric cancer, all studies include fewer than 50 patients and have a low quality design. The publications also include a variety of different operations (transhiatal, 2 stage, 3 stage oesophagectomy) and part, full, or hybrid use of the robot for either the chest, the abdomen or both cavities. A robotic approach is technically feasible for oesophageal cancer resections irrespective of the approach taken or role of the robot, as shown by the low conversion rate to open operation. The reported mortality rate (up to 6.4%) for the robotic approach is comparable to open surgery, and an extended lymphadenectomy is possible[61].

There is no evidence that the robotic approach is any safer than open or conventional minimally invasive gastrectomy or oesophagectomy. There is a risk of robot-related complications, such as iatrogenic injury due to the combination of lack of haptic feedback, the immense strength of the robotic arms, and perhaps a more limited operative field. The large non-randomised trial reported by Huang et al. found similar overall complication rates for robotic, laparoscopic, and open gastrectomy although the anastomosis leak rate was higher for robotic (7.7%) compared to open (4.6%) or laparoscopic (4.7%) surgery[33]. Some authors report high complication rates for robot-assisted oesophagectomy, with an anastomotic leak rate as high as 38%[66]. Most patients in the robotic oesophagectomy series seem to have had a cervical anastomosis, which is thought to have a higher leak rate than a thoracic anastomosis, although this concept was not supported by a randomised trial[55].

In the absence of long-term survival data or information on local or regional recurrence rates, the oncologic adequacy of robot-assisted gastrectomy or oesophagectomy can only be assessed at present by the tumour-free resection margin rate and the number of lymph nodes removed. Robotic gastrectomy publications that included resection margin results reported that all resection margins were macroscopically and microscopically free of tumour (R0 resections) but they also include a large proportion of early cancers[19, 22, 24, 25, 27-29]. For oesophagectomy, the reported R0 resection rate is around 85%, which is similar to the rate in reviews of minimally invasive and open oesophagectomy[49, 50, 53, 56-58, 61, 62, 75, 76]. In general the larger studies reviewed here report a lymph node harvest that is comparable to that for minimally invasive or open gastrectomy or oesophagectomy, with the exception of “en bloc” oesophagectomy[77]. This suggests that the robotic approach is oncologically sound but an alternative interpretation is that, with similar R0 resection and lymph node yields, there is currently no advantage for the robotic operation over the quicker, possibly less expensive open or laparoscopic operations.

Oesophagectomy and gastrectomy are long, sometimes tiring cancer operations when performed open or by conventional minimally invasive means. When operating with the robot the surgeon is sitting at a console with the arms resting and only making small forearm, wrist, and hand movements to manipulate the robot arms. This position theoretically provides much greater surgeon comfort, which may in turn allow the surgeon to concentrate better for the duration of the operation. These factors have not been objectively addressed in the publications reviewed here, but one report considered that robotic thoracic oesophagectomy was less stressful for the surgeon than thoracoscopic oesophagectomy[63].

Robotic assistance for upper gastrointestinal resections may make some parts of the operation easier. A consistent comment is that suturing seems easier with the robot, which is supported by studies showing faster and more accurate suturing and dexterity skills compared to laparoscopic surgery[78, 79]. As well as theoretically facilitating the construction of the anastomoses for gastrectomy, this ease of suturing with the robot means that a “handsewn” intrathoracic anastomosis, which is difficult thoracoscopically, should be readily achievable, but there are no published data to support this possibility.

It is anticipated that the competition provided by emerging new robot manufacturers will result in substantially lower costs. The future of robotic surgery will also include improvements in haptic feedback and vision, and easier port placement and docking mechanisms. Even with the current robot, a study that used Nationwide Inpatient Sample (NIS) data, representing 20 per cent of U.S. community hospital discharges, showed that the use of robotic general surgery in the operations selected increased from 0.8% in 2008 to 4.3% in 2009[80]. This study also reported that, overall, robot-assisted general surgery was more cost effective than open or laparoscopic general surgery if hospitalisation costs were included, and robotic general surgery was associated with lower morbidity and mortality. This large study is subject to multiple potential confounders, including the likelihood that robotic surgery was typically used in less acute and less complicated procedures[80].

In conclusion, robot-assisted resection for gastric or oesophageal cancer is feasible but a real benefit has not been demonstrated due to the absence of randomised trial data and long term oncological data. The shortcomings of reported studies are usually several and include selection bias, such as healthier patients with earlier stage cancer in the robotic cohorts. Operation times are generally longer and there are few cost analysis data. Robot-assisted gastrectomy, especially subtotal gastrectomy, can be performed safely with impressive interim oncological measures. The role of robotic oesophagectomy is unclear at present and high complication rates have been reported. It may be difficult to show a significant advantage for robotic oesophagectomy over other minimally invasive forms of oesophagectomy as even high volume expert centers report few advantages for minimally invasive oesophagectomy over open surgery[81].

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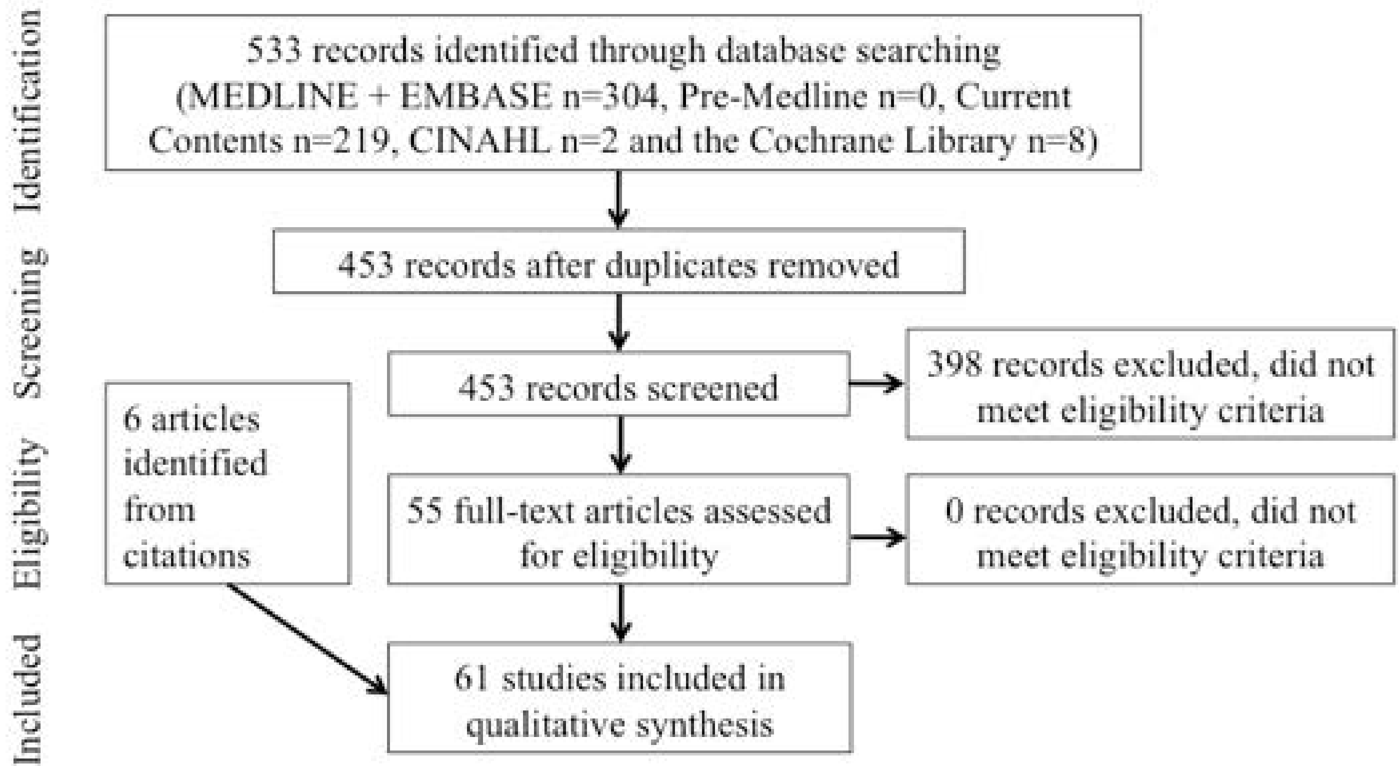
Identification
Screening
Eligibility
Included
533 records identified through database searching (MEDLINE + EMBASE n=304, Pre-Medline n=0, Current Contents n=219, CINAHL n=2 and the Cochrane Library n=8)
453 records after duplicates removed
453 records screened
398 records excluded, did not meet eligibility criteria
6 articles identified from citations
55 full-text articles assessed for eligibility
0 records excluded, did not meet eligibility criteria
61 studies included in qualitative synthesis

Table 1. Robot-assisted gastrectomy

Author	Year	Studydesign	No pat´s	Operation	Op time (min)	Lymph nodes retrieved	Conversion	Morbidity	Follow-up
Hashizume[14]	2002	Case series, Retrospective	2	2 Robot Subtotal	395 (310 - 580)	-	Nil	Nil	-
Talamini[15]	2002	Case series	1	1 Robot Gastric mass resectio	-	-	-	Nil	-
Giulianotti[16]	2003	Case series, Retrospective	109	10 Robot Total	350 (250-420)	-	1 to open	30% (3). Severe anastomotic leak. Mortality 0	-
				8 Robot Subtotal	365 (270-480)	-	0	9% (1) Re-op post-op bleeding. Mortality 9% (1) resp failure	
		Historic control		40 Open Total	185 (140-310)	-	-	12.5% (5). Mortality 2.5% (1)	-
				51 Open Subtotal	135 (100-220)	-	-	7.8% (4). Mortality 0	
Talamini[17]	2003	Case series	1	1 Robot Gastric mass resectio	-	-	-	-	-
Kakeji[18]	2006	Case series, Retrospective	5	2 Da Vinci-ass Subtotal	445	-	Nil	20% (1) Anastomotic leak	-
				3 Zeus-ass Subtotal	656	-			
Anderson[19]	2007	Case series, Retrospective	7	7 Robot Subtotal	420 (390-480)	24 (17-30)	Nil	71% (5) i.e. Bowel devascularasation	No recurrence, 3 months
Anderson[20]	2007	Case series, Retrospective	11	9 Robot Subtotal	430 (160-480)	26 (6-41)	Nil	-	6 (1-23)months
Braumann[21]	2008	Case series, Retrospective	2	1 Robot Total	312 (110-515)	-	2 (to open, to lap)	Nil	-
				1 Robot Subtotal					
Patriti[22]	2008	Case series, Retrospective	13	4 Robot Total	286 ± 32.6	28 ± 8	Nil	Total 46% (6) complications including:	No recurrence,12 months
				8 Robot Subtotal				Re-op for trochar site bleed, Duodenal stump leak	
				1 Robot Proximal					
Song[23]	2009	Case series, Retrospective	40	20 Robot Subtotal	230 (171-312)	35 ± 10	Nil	5% (1) Wound infection	-
		Historical control group		20 Laparoscopic Subtotal	134 (90-260)	43 ± 15	Nil	10% (2) Wound infection, Bleeding	-
Song[24]	2009	Case series, Prospective	100	33 Robot Total	231 (155-330)	37 (11-83)	Nil	Total 13% (13) Wound inf (9), Intraluminal Bleeds (2)	-
				67 Robot Subtotal				Anastomotic leaks (2), and Mortality (1).	
Pugliese[25]	2010	Non-randomised clinical tri	70	18 Robot Subtotal	344 ± 62	25 ± 4	2 to open	5.6% (1) Pancreatic leak, Mortality (1)	78%, 3 year survival
				52 Laparoscopic Subtotal	235 ± 23	31 ± 8	3 to open	11.5% (6) Complications, Mortality (1)	85%, 3 year survival
Kim M-C[26]	2010	Non-randomised clinical tri	39	16 Robot Subtotal	259 ± 39	41 ± 11	Nil	Nil	-
				11 Laparoscopic Subtotal	204 ± 36	37 ± 10	Nil	9% (1) Paralytic ileus	-
				12 Open Subtotal	127 ± 24	43 ± 10	-	16.7% (2) Wound infection, Bleeding	-
Hur[43]	2010	Non-randomised clinical tri	7	2 Robot Total	205 (190-240)	36	Nil	No morbididty. Remitted for gastric stasis, conservative	-
				5 Robot Subtotal				No mortality.	
D'Annibale[27]	2011	Case series, Retrospective	24	11 Robot Total	267 (255-305)	28 (23-34)	Nil	8% (2) Pleural collection, Anastomotic leak	75%, 28 months survival
				13 Robot Subtotal					
Lee[28]	2011	Case series, Retrospective	12	12 Robot Subtotal	253 (170-365)	46 (21-115)	Nil	8% (1) Post-operative pancreatitis	-
Woo[29]	2011	Non-randomised clinical tri	827	Robot-assisted (tot 236)	219 (140-439)	39	Nil	Total 11% (26). Wound (11), Fluid Collections (1),	-
				62 Robot Total				Bleeding (4), Obstruction (1), Leakage (4), Pulmonary (4)	
				172 Robot Subtotal				Mortality 0.4% (1)	
				2 Completion total					
				Laparoscopic-assisted (tot 59	171 (75-420)	37	Nil	Total 13,7% (81). Wound (35), Fluid collection (9),	-
				108 Laparoscopic Total				Bleeding (12), Intestinal obstruction (2), Leakage (9),	
				481 Laparoscopic Subtotal				Stenosis (4) etc.	
				2 Completion total				Mortality 0.4% (2)	
Caruso[30]	2011	Non-randomised clinical tri	149	Robot-assisted (tot 29)	290 ± 67	28 ± 11	-	Total 41.4% (12). Pancreatitis 10.3% (3), Anastomotic	25 ± 15 months
				12 Robot Total				leakage 3.4% (1), Wound 3.4% (1), Duodenal stump leak	
				16 Robot Subtotal				6.9% (2), Fluid collection 3.4% (1), Chest compl 17% (5),	

				1 Robot Proximal				Heart compl 10% (3), Re-op 3.4% (1). Mortality 0	
				Open gastrectomy (tot 120) 37 Open Total 83 Open Subtotal	222 ± 94	32 ± 16	-	Total 42.5% (51). Pancreatitis 4.2% (5), Anastomotic leakage 5.8% (7), Wound 3.3% (4), Duodenal stump leak 4.2% (5), Fluid collection 3.3% (4), Chest compl 5.8% (7), Heart compl 2.5% (3), Bleed 4.2% (5), Re-op 10.8% (3). Mortality 3.3% (4)	44 ± 35 months
Isogaki[31]	2011	Case series, Retrospectiv	61	14 Robot Total 46 Robot Subtotal 1 Robot Proximal	520 ± 177 388 ± 85 -	43 ± 14 42 ± 18 -	Nil Nil Nil	7% (1) and Mortality 0 4% (2) and Mortality 2% (1)	- - -
Xiong[8]	2012	Meta-analysis	918	268 Robot gastrectomy 650 Laparoscopic gastrectom	274 (219-344) 203 (170-235)	35 (25-41) 35 (31-37)	2 3	10% (27) 13.5% (88)	- -
Kang[6]	2012	Non-randomised clinical tr	382	Robot-assisted (tot 100) 16 Robot Total 84 Robot Subtotal	202 ± 52	-	-	Total 14% (14) complictions i.e. Wound, Abscess, Bleeding, Intestinal Obstruction, Leakage and Pulmonary.	-
				Laparoscopic-assisted (tot 28 37 Laparoscopic Total 245 Laparoscopic Subtotal	173 ±145	-	-	Total 10.3% (29) complications i.e. Wound, Abscess, Bleeding, Intestinal Obstruction, Leakage, Pulmonary, Iatrogenic Colon perforation, Pseudomembranous colitis	-
Yoon[45]	2012	Non-randomised clinical tr	101	36 Robot Total 65 Laparoscopic Total	306 ± 116 210 ± 58	43 ± 13 39 ± 13	- -	16.7% (6) Wound, Abscess, Stricture, Spleenic infarct. 15.4% (10) Anastomotic leakage, Stricture, Abscess	- -
Eom[7]	2012	Non-randomised clinical tr	92	30 Robot Subtotal 62 Laparoscopic Subtotal	229 (165-307) 189 (125-272)	30 (13-60) 33 (10-67)	Nil Nil	13.3% (4) Pancreatitis, Fluid collection etc 6.5% (4) Abscess, Fluid, Ulcer bleeding	- -
Huang[33]	2012	Non-randomised clinical tr	689	Robot-assisted (tot 39) 7 Robot Total 32 Robot Subtotal	430	32 ± 14	-	Total 15.4% (6). Anastomotic leakage (3), Chylous leak Abscess, Wound, Intestinal Obstruction, Delayed emptying Mortality 2.6% (1)	-
				Laparoscopic assisted (tot 64) 7 Laparoscopic Total 57 Laparoscopic Subtotal	350	26 ± 12	-	Total 15.6% (10) Anastomotic leakage (3), Chylous leal Stenosis, Subcutaneous emphysema, Abscess, Pulmonary Mortality 1.6% (1)	-
				Open gastrectomy (tot 586) 179 Open Total 407 Open Subtotal	320	34 ± 15	-	Total 14.7% (86) Anastomotic leakage(27), Chylous lea Abscess, Wound, Bleeding, Pancreatitis, Pulmonary etc Mortality 1.4% (8)	-
Uyama[34]	2012	Case series, Retrospectiv	25	25 Robot Subtotal	361 ± 58	44 ± 18	Nil	Nil	-
Park JY[35]	2012	Non-randomised clinical tr	150	30 Robot Subtotal 120 Laparoscopic Subtotal	218 (200-254) 140 (118-175)	34 (28-45) 35 (25-44)	Nil Nil	Tot 17% (5). Duodenal stump leakage 3% (1), etc Tot 7.5% (9). Duodenal stump leakage 1.7% (2), etc	
Vasilescu[36]	2012	Case series	2	2 Robot Subtotal	incompl data	incompl data	Nil	Nil	No recurrence, at 23 and 26 months
Park SS[37]	2012	Case series	60	60 Robot Subtotal	247 ± 46	-	Nil	10% (6). Wound (3), Abscess (1), Duodenal stump leak and Common bile duct injury (1). Mortality 0	-
Kim HB[38]	2012	Case report	1	1 Robot Subtotal	300	40	Nil	Nil	No recurrence 15 months
Hyun[39]	2013	Non-randomised clinical tr	121	Robot-assisted (tot 38) 9 Robot Total 29 Robot Subtotal	234 ± 48	23 ± 7	Nil	47.3% (18). Small bowel damage, Anastomotic leakage Stricture, Bleeding, Abscess etc.	-
				Laparoscopic assisted (tot 83) 18 Laparoscopic Total 65 Laparoscopic Subtotal	222 ± 60,6	32 ± 12	Nil	38.5% (32). Acute renal failure, Lung failure, Bleeding, Anastomotic leakage, Abscess, Pancreatitis, Pulmonary	-
Kim KM[47]	2012	Case series, Retrospectiv	436	109 Robot Total 327 Robot Subtotal	226 ± 54	40.2 ± 15.5	Nil	Overall complic. rate 10.1%(44). Anastomotic leak 2.3% Abscess 1.4%(6), Wound 3.2%(14), Bleeding 0.5%(2). Ileus 0.2%(1). Re-operation 1.6%(7). Mortality 0.5%(2).	-

Tokunaga M[40]	2013	Case series	18	18 Robot Subtotal	311 (225-375)	40 (26-89)	Nil	22.2% (4). Wound (2), Liver dysfunction (1), Delayed gastric emptying (1).	-
Shim JH[41]	2013	Case series	35	5 Robot Total 30 Robot Subtotal	265 ± 24 217 ± 36	- -	-	20% (7). Ileus (2), Pulmonary (2), Anastomotic leak (1), Pleural effusion (2)	-
Kim YM[42]	2013	Case series	12	12 Robot Subtotal	235 (194-296)	42 ± 13	-	Nil	-
Liu Xin-Xin[44]	2013	Case series, prospective	110	54 Robot Total 38 Robot Subtotal 12 robot Proximal	302.5 ± 20.3 266.5 ± 35.3 264.8 ± 40.3	23 ± 5.3	2	Overall complic. rate 11.5%(12). Anastomotic leak 1%(Gastroplegia 1.9%(2), ileus 3%(3), Abscess 1%(1), Wound1.9%(2), Pulmonary infection 1.9%(2), Bleeding1%(1)	-

Table 2. Robot-assisted oesophagectomy

Author	Year	Studydesign	No pat´s	Operation	Op time (min)	Lymph nodes retrieved	Conversion	Morbidity	Follow-up
Hashizume[14]	2002	Case series	1	1 Oesophageal tumor extraction	270	-	Nil	Nil	-
Melvin[48]	2002	Case series	1	1 Oesophagectomy (thoracic robot dissection)	462	-	Nil	Nil	-
Giulianotti[16]	2003	Case series, Retrospective	5	5 Oesophagectomy (thoracic robot dissection)	490 (420-540)	-	Nil	1 Mortality; due to Anastomotic leakage and Sepsis	-
Horgan[49]	2003	Case series	1	1 Oesophagectomy Transhiatal	246	-	Nil	1 Wound infection	-
Talamini[17]	2003	Case series	1	1 Oesophagectomy (thoracic robot dissection)	-	-	Nil	-	-
Bodner[50]	2004	Case series , Retrospectiv	4	4 Oesophagectomy (thoracic robot dissection)	174 (160-190) (only thoracic time)	-	Nil	Nil	mean 6 months 1 mortality, (recurrance) 12 months
Elli[51]	2004	Case series	2	2 Transthoracic local resection leiomyoma	120 min (in 1 case)	-	Nil	Nil	6 months, both well
Kernstine[52]	2004	Case report	1	1 Oesophagectomy Thoracoabdominal	660	-	Nil	Nil	6 months, well
Bodner[53]	2005	Case series, Retrospective	6	4 Oesophagectomy (thoracic robot dissection) 2 Transthoracic local resection benign lesions	173 (160-190) 121 (95-147)	13 (8-19)	Nil	25% (1) Re-operation for lymph fistula	1 mortality (recurrance) at 12 months 1 local recurrence 19 months
Ruurda[54]	2005	Case series, Retrospective	22	22 Oesophagectomy (thoracic robot dissection)	180 (120-240)	-	3 (to open)	Anastomic leak 13,6%(3), Chyle leak 13,6%(3), Vocal cor paralysis 13,6%(3), Pulmonary complications in 11 patients, Cardiac failure in 3,Tracheo-oesophageal fistula 1, Mortality 1	-
Dapri[55]	2006	Case report	2	2 Oesophagectomy (thoracic robot dissection)	-	19 (18-21)	Nil	Nil	1 mortality (recurrence) at 22 months
Gutt[56]	2006	Case report	1	1 Oesophagectomy Transhiatal	465	14	Nil	Bronchpneumonia, Cervical anastamotic leak	-
van Hillegersberg[57]	2006	Case series, Prospective	21	21 Oesophagectomy (thoracic robot dissection)	450 (370-550)	20 (9-30)	3 (to open)	27 Complications occured: 48 % Pulmonary (10), 14% Cardiac failure (3), 14% Anastomotic leak (3), 14% Vocal cord paralysis (3),14% Wound (3) 14% Chylous leak (3), 5% Gastrostomy leak (1) 5% (1) Tracheo-esophageal fistula. 5% (1) Mortality	-
Kernstine[58]	2007	Case series, Retrospective	14	3 Oesophagectomy Robot thorax/Open abdominal 3 Oesophagectomy Robot thorax/Laparoscopic 8 Oesophagectomy Total Robot	NR NR 666 (570-780)	18 (10-32)	1 (to open)	48 Complications: 14% Anastomotic leaks (2),14% Vocal paralysis(2),14% Anastomotic stricture (2), 21% Aspiration (3), 36% Cardiac,7% Chyle leak(1),Pneumothx (1), Pneumonia (3), 7% (1) Mortality, pneumonia	87% survival, at median 17 months
Anderson[19]	2007	Case series, Retrospective	25	22 Oesophagectomy (thoracic robot dissection) 1 Oesophagectomy Transhiatal 2 Oesophagectomy (abdominal robot, open thoracic)	482 (391-646)	22 (10-49)	Nil	Total 32% (8/25). Major complications: 16% (4) Anastomc leak, 8% (2) Chylothorax, 16% (4) Pneumonia, 4% (1) Vocal cord palsy, 4% (1) Empyema, 4%(1) Wound dehisc. Mortality 0	6 (1-15) months
Braumann[21]	2008	Case series, Retrospective	4	4 Oesophagectomy (thoracic robot dissection)	60 (55-240)	-	2 (to open)	Nil	-
Boone[59]	2008	Case report	1	1 Oesophagectomy Robot thorax/Open abdominal (due to giant leiomyoma)	270	-	Nil	Nil	3 years, well
Galvani[60]	2008	Case series, Retrospective	18	18 Oesophagectomy Transhiatal	267 (180-365)	14 (7-27)	Nil	50% Morbididty. 18 Complic: 33% (6) Anastomic. leaks, 33% (6) Anastomotic strictures, 11% (2) Pulmonary, 11% (2) Cardiac, 5% (1) Vocal cord paralysis, 5% (1) Thoracic duct injury, 5% (1) Pleural effusion Mortality 0	Mean 22 ± 8 months 11 pat disease free (2 mortality, 3 recurrence)
Boone[61]	2009	Case series, Prospective	47	47 Oesophagectomy (thoracic robot dissection) (open or laparoscopic abdominal part)	450 (360 - 550)	29 (8-68)	15% (7) (to open)	60 Complications incl., 45% (21) Pulmonary, 21% (10) Anastomotic leaks,19% (9) Vocal cord par., 13% (6) Chylous leak, 13% (6) Cardiac, 8% (4) Wound, 8% (4) Thoracic empyema, Mortality 6.4%(3).	30 (12-54) months 30% disease free
Kim DJ[62]	2010	Case series, Prospective	21	21 Oesophagectomy (thoracic robot dissection)	410 ± 99.6	11.6 ± 6.2 (mediastinal)	Nil	15 Complications: 19% (4) Anastomotic leaks, 9.5%(2) Anastomotic strictures, 28.6%(6) Vocal cord paralysis 4.8%(1) Chylous leak, 4.8%(1) Intraabdominal Bleeding, 4.8%(1) Cardiac. Mortality 0.	3-months survival 100%
Puntambekar[63]	2011	Case series, Retrospective	32	32 Oesophagectomy (thoracic robot dissection)	210 (180-300)	20 (9-28) (mediastinal)	Nil	Complications: 9% (3) Anastomotic leaks, 9%(3) Chyle leak, 6%(2) Respiratory, 6%(2) Vocal cord palsy.	-
Patriti[64]	2011	Case series, Prospective	17	14 Extended gastrectomies 2 Oesophagectomy distal Transhiatal	327 ± 93	28 ± 9	Nil	Morbidity 41,1% incl complications: 6% (1) Anastomotic leak, 6% (1) Trocar bleeding, 6% (1) Duodenal stump leal	20-months survival 88% 20-months 76% disease free

				1 Oesophagectomy Transthoracic & Robot Abdomen				6% (1) Pneumonia, 6% (1) Atrial fibrillation, 6% (1) Deep venous trombosis, 6% (1) Pleural effusion. 6% (1) Lung-Heart failure. Mortality 0	
Sutherland[65]	2011	Case series	36	36 Oesophagectomy Transhiatal (34 cancer, 1 Benign stricture, 1 High-grade dysplasia)	312 (226-491)	-	-	19% (7/36) postoperative incarcerated hiatal hernias. 6% (2) reoperated due to incarceration. Mortality 2.8% (1) related to complications to hernia repair.	-
Suda[66]	2012	Non-randomised clinical tr	36	16 Oesophagectomy (thoracic robot dissection)	693 (536-788)	38 (23-63) and only chest 18 (11-39)	Nil	41 Complications incl: 56% (9) Laryngopharyngeal dysf, 38% (6) Vocal cord palsy, 38% (6) Anastomotic leak, 38% (6) Aspiration, 6% (1) Pulmonary, 13% (2) Cardiac,etc	-
				20 Oesophagectomy Thoracoscopic	650 (559-1023)	39 (24-63) and only chest 22 (13-41)	Nil	81 Complications incl: 85% (17) Laryngopharyngeal dysf, 75% (15) Vocal cord palsy, 10% (2) Anastomotic leak, 45% (9) Aspiration, 20% (4) Pulmonary, 30% (6) Cardio, 10% (2) Chylothorax, 10% (2) Empyema, etc	-
Weksler[67]	2012	Non-randomised clinical tr Retrospective	37	11 Oesophagectomy (thoracic robot dissection)	439 ± 70	19 (10-47)	Nil	Morbidity 36% (4/11). Total 9 events. 9% (1) Anastomotic leak, 9% (1) Vocal cord palsy, 18% (2) Pneumonia/atelectasis, 9% (1) Pulmonary embolus, 9% (1) Wound, 9% (1) Urinary tract infection, etc. Mortality 0	-
				26 Oesophagectomy Thoracoscopic	484 ± 77	22 (13-53)	1 (to open)	Morbidity 42% (10/26). Total 21 events. 15% (4) Anastom leak, 4% (1) Vocal cord palsy, 23% (6) Pneumonia/atelectasis, 8% (2) Urinary tract infection, etc. Mortality 7.6% (2).	-
van der Sluis[68]	2012	Randomised controlled tri	112	56 Oesophagectomy (thoracic robot dissection) 56 Oesophagectomy Open 3-stage	ongoing trial, no data	-	-	-	-
Ishikawa[69]	2013	Case series, Retrospective	4	4 Oesophagectomy (hybrid thoracoscopy + robot thoracic dissection)	450 (robot console time)	45	Nil	Nil	-
Dunn[70]	2013	Case series, Prospective	40	38 Oesophagectomy Transhiatal (exclude 1 benign stricture, 1 High-grade dysplasia)	311 (226-491)	20 (3-38)	5 (13%)	25% (10) Anastomotic leak, 35% (14) Laryngeal nerve palsy, 67,5% (27) Anastomotic strictures, 20% (8) Pneumonia, 45% (18) Pleural effusion. Mortality 1.	Median dis-free survival 22 months
Sarkaria[71]	2013	Case series, Prospective	21	21 Oesophagectomy (thoracic robot dissection)	556 (395-807)	20 (10-49)	24% (5 to open)	Total 20 complications. 24% (5) major complications. 14% (3) Anastomotic leaks >grade 2. 14% (3) Airway fistulas. 9% (2) Resp failure. 5% (1) Pulmonary embolus, etc. Mortality 4.7% (1).	
Cerfolio[72]	2013	Case series, Retrospective	22	22 Oesophagectomy (thoracic robot dissection)	367 (290-453)	18 (15-26)	No thoracic conversions 1 abdominal from laparo scopy to laparotomi	23% (5) Major complications as Anastomotic leak (1), Ga leak (1), Empyema (1), Colon herniation (1), Chylothorax (1). Re-operation during hospital stay (5). 14% (3) Minor complications as Atrial fibrillation (2), Urinary retention (1). Mortality 0.	5-months 100% disease free
de la Fuente[73]	2013	Case series, Retrospective	50	50 Oesophagectomy (thoracic robot dissection) (wereof 25 abdominal dissections performed robotically, 25 abdomens fully or hand-assisted laparoscopically)	445 ± 85	18.5 (8-63)	Nil	Complications in 28%(14) of patients. 2%(1) Anastomotic 2%(1) Conduit staple line leak. 4% (2)Chyle leak. 10%(5) Atrial fibrillation.10%(5) Pneumonia. Mortality 0.	-