ROBOTIC ESOPHAGEAL SURGERY: UP-TO-DATE

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ROBOTIC ESOPHAGEAL SURGERY: UP-TO-DATE (Abstract): Esophageal cancer remains an important health problem mainly due to the rising incidence of the adenocarcinoma of the gastro-esophageal junction. Esophagectomy is often performed on a fragile patient with an impaired nutritional status and requires often an open thoracic approach. Minimally invasive techniques were accepted in treatment of esophageal cancer in order to decrease the morbidity and postoperative mortality. However, several limitations of conventional minimally invasive techniques (e.g. two-dimensional view, camera operator fatigue, lack of tactile feedback during the complex maneuvers) imposed the use of surgical robots in esophageal surgery. We review the literature data about the use of robotic assissted surgical techniques in esophageal surgery. The postoperative outcomes, as well technical details and learning curve and training are highlighted.

KEY WORDS: ESOPHAGEAL CANCER; ESOPHAGECTOMY; MINIMALLY INVASIVE SURGERY; ROBOTIC SURGERY

SHORT TITLE: Robotic esophageal surgery

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INTRODUCTION

Esophageal cancer represents a major health care problem in Europe, with a rising incidence due to the increasing number of adenocarcinomas developed in gastro-esophageal reflux disease. It is the eight most common cancers in the world and the sixth most frequent cause of death, with a 5-year survival of 17%.

Surgery is currently the only widely available treatment that provides a realistic possibility of cure for patients with gastric and oesophageal cancer that has progressed beyond the earliest stages.

Esophagectomy for esophageal cancer is one of the most treacherous operations of any done in surgery. First successful esophageal resection was performed in 1877 by Czerny [1] in a patient with a cervical esophageal tumor.

History of esophageal cancer surgery was marked by the introduction of the transthoracic esophagectomy techniques of Ivor Lewis [2] (1946), the left thoraco-abdominal approach popularized by Richard H. Sweet and John H. Garlock [3], as well as the 3-hole approach described by McKeown [4] in 1976.

Transhiatal esophagectomy was introduced into the mainstream by the pioneering work of Mark B. Orringer [5] and Herbert Sloan in 1978 and remains a popular approach for esophageal resection. The most frequently performed procedures for surgical treatment of oesophageal carcinoma are transthoracic esophagectomy (TTE) and transhiatal esophagectomy (THE), but controversy exists about the best surgical treatment. TTE employs a combined cervico-thoraco-abdominal resection, with wide excision of the tumor and peritumoral tissues as well as extended lymph node dissection in the posterior mediastinum and the upper abdomen. In contrast, THE

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employs limited cervico-abdominal esophagectomy without formal lymphadenectomy. To date, no single procedure has emerged as superior in the management of esophageal cancer. The choice of a specific approach should be tailored to individual patient characteristics and surgeon expertise.

Esophagectomy has been associated with high rates of morbidity and mortality. In a retrospective study published in 1941 [6], on 191 patients, postoperative mortality was 72%. In the mid 1970s the mortality rate dropped to 29%, in the 1980s was 13%, and in the 1990s was about 9% [6]. In the first decade of 21st century the mortality rate varies around 5%, depending of surgical level of expertise and experience and global morbidity rates range between 30% and 60%. Most common complications are respiratory (pneumonia, pleural effusion, ARDS, empyema) in 20% to 40% of all patients [7]. Other major complications include anastomotic leaks in 15% of cases, cardiac arrhythmias, pulmonary embolism, myocardial infarction, chylothorax and vocal cord palsy [7]. Up to this moment there is no study that clearly shows a benefit in terms of postoperative mortality and morbidity regarding surgical approach: transthoracic or transhiatal esophagectomy. However the neoadjuvant therapy improves the survival rate in patients with locally advanced tumors [7]. New advances in surgical therapy, staging, postoperative care, could reduce surgical morbidity and mortality. One of these advances is minimally invasive esophagectomy.

DEVELOPMENT OF MINIMALLY INVASIVE TECHNIQUES

Minimally invasive approach was a revolution in abdominal and thoracic surgery. Smaller incisions and less abdominal wall trauma contribute to less postoperative pain, shorter hospitalization and quicker recovery and improved cosmetics results.

Minimally invasive surgery was found to be feasible in the management of abdominal and thoracic malignancies in terms of safety, efficacy, and oncologic value.

Laparoscopic techniques have been widely adopted in a variety of foregut procedures. Several limitations inherent to a laparoscopic approach have prevented its widespread use in some areas of general surgery. The visualization during laparoscopic surgery is typically two-dimensional and limited by camera operator fatigue and abrupt movements. There is diminished tactile feedback, and complex maneuvers are sometime difficult secondary to fixed trocar position and non-articulated instruments. In addition, the length of the instruments amplifies one’s natural tremor at the tip of the instrument. During a standard laparoscopic procedure, surgeons frequently must stand in ergonomically awkward positions for extended periods of time.

Minimally invasive transhiatal esophagectomy was first reported by De Paula et al. in 1995 [8] and by Swanstrom and Hansen [9] in 1997. Luketich et al. [10] described the combined thoracoscopic and laparoscopic approach for esophagectomy. Multiple minimally invasive approaches have been described that combine thoracoscopic or laparoscopic procedures with various operative positions of the patient and anastomotic techniques (Table I).

In a meta-analysis published in 2010 [11] that compares the outcomes of minimally invasive esophagectomy (MIE) versus open techniques it was showed that minimally invasive techniques have the same potential as open techniques in terms of perioperative morbidity and 30-day mortality, but with a descending trend for minimally invasive techniques, with the same outcomes regarding oncological benefit. A faster postoperative recovery and, therefore, a reduction in morbidity can be achieved with MIE. Furthermore, less mortality with the implementation of MIE can be realised. In a more recent multicentre, open-label, randomised controlled trial at five study centres in three countries during 2009 and 2011 there were randomly

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assigned 115 patients to receive either open transthoracic or minimally invasive transthoracic esophagectomy [12]. As for the results, 29% patients in the open esophagectomy group had pulmonary infection in the first 2 weeks compared with 9% in the minimally invasive group (RR=0.30, 95% CI: 0.12-0.76; *P*=0.005). Nineteen (34%) patients in the open esophagectomy group had *in-hospital* pulmonary infection compared with seven (12%) in the minimally invasive group (RR=0.35, 95%CI: 0.16-0.78; *P*=0.005). As for *in-hospital* mortality, one patient in the open esophagectomy group died from anastomotic leakage and two in the minimally invasive group from aspiration and mediastinitis after anastomotic leakage. These findings provide evidence for the short-term benefits of minimally invasive esophagectomy for patients with resectable oesophageal cancer.

Table I Minimally invasive esophagectomy (MIE) techniques [13]

1) Thoracoscopic esophagectomy with laparotomy and cervical anastomosis
2) Thoracoscopic esophagectomy with laparotomy and intrathoracic anastomosis
3) Thoracoscopic esophagectomy with laparoscopy and cervical anastomosis
4) Thoracoscopic esophagectomy with laparoscopy and intrathoracic anastomosis
5) Laparoscopic gastric mobilization with thoracotomy and intrathoracic anastomosis
6) Laparoscopic THE with cervical anastomosis
7) Laparoscopic hand-assisted THE with cervical anastomosis
8) Laparoscopic esophagectomy with prone thoracoscopic esophageal mobilization

Despite these better outcomes minimally invasive is not widely accepted. However surgical robots, or computer-assisted tele-manipulators as they are more properly described, allow the surgeon to overcome many drawbacks of minimally invasive techniques. Ergonomics are improved as the surgeon sits at a console, remote from the patient and manipulates controls for the surgical instruments [14]. The computer eliminates tremor and scales all motions to a selected degree. This allows for very fine and precise movements of the surgical instruments. Since the robotic instruments are multi-articulated and capable of a full range of motion, complex maneuvers are possible (7 degree of freedom). These articulated instruments provide movements similar to the human arm and hand. In addition, high-definition, three-dimensional visualization provides image detail and depth superior to that of a standard laparoscopic system. The camera is manipulated by a robotic arm controlled by the operating surgeon. These features translate to certain advantages during complex foregut procedures when compared to a standard laparoscopic approach. The introduction of robotic technology into general surgery heralded an expectation for surgeons that many of the problems associated with the conventional laparoscopic approach could be overcome. Currently, the daVinci™ robot is the most globally recognized telemanipulator device worldwide; its use particularly in urology for the robotic assisted prostatectomy is unprecedented and the insurmountable evidence from the literature demonstrates not only comparable oncological outcomes when compared with the open approach but also the significant surgical as well as functional outcomes [15].

DEVELOPMENT OF ROBOTIC SURGERY

The AESOP (Automated Endoscopic System for Optimal Positioning) system was the first robotic device introduced in clinical use in 1994 [16]. This device was developed in association with Pentagon. AESOP holds the laparoscope steady without wandering, distraction, or fatigue. The laparoscope and AESOP can be redirected manually by the surgeon. It can be connected to the side of operating table and can accept any rigid laparoscope and facilitates solo surgeon procedures.

The next generation was the Zeus robotic surgical system in 2001 [16] that utilized the AESOP system for camera manipulation with two additional multi-articulated arms.

At this time the da Vinci™ robotic surgical system (Intuitive Surgical, Sunnyvale, CA, USA) is the only commercially available robotic system. This system consists of an operating console, a patient-side cart, and a tower for the insufflator and video electronics. The surgeon sits at the operating console remote from the patient, but usually within the same room. The surgeon's head rests on the console where a high definition, three-dimensional stereoscopic images is displayed. While in this position, the surgeon is able to manipulate the camera and two or three robotic arms in a more natural and ergonomic position than is often possible during standard laparoscopy. The surgeon can toggle manual controls between the camera and any two of the 3 additional arms. The da Vinci's surgical instruments are designed to mimic the dexterity of the human wrist [17] with a full seven degrees of freedom: 1) in-aut; 2) rotation; 3) pitch at wrist; 4) yaw at wrist; 5) pitch at fulcrum; 6) yaw at fulcrum; 7) grip strength.

In addition, the robotic arms allow improved motion stability with tremor filtration and motion scaling, potentially aiding fine movements [18].

In term of disadvantages the da Vinci system, compared with traditional minimally invasive surgery, requires a prolonged operating room set-up period especially early in the operative team experience. The initial fixed cost of the equipment is very high; the cost of the disposable instruments is typically higher than for other minimally invasive devices and maintenance costs are a real concern for medical institutions [19]. The da Vinci system lacks tactile feedback in a procedure where touch is an important component, and nevertheless learning procedures and training can be a challenge even for experienced surgeons [16].

USE OF ROBOTIC SURGERY FOR ESOPHAGEAL CANCER

Minimally invasive approaches to esophagectomy using da Vinci system, have been reported, using laparoscopic and thoracoscopic techniques. By performing a search on PubMed using "robotic esophagectomy" terms we found 54 articles related to this topic. After reading the abstracts and eliminating the articles who were not written in english and the articles who were reviews we analysed a number of 22 articles. One articles presented the results of an experimental study of cardio-respiratory and stress factors in esophageal surgery using robot assisted thoracoscopic or open thoracic approach in pigs [20]. The robot assisted approach was associated with improved intraoperative cardio-pulmonary function and seems to be a less stressful technique. In 2003 Horgan et al. [17] reported their initial experience with a case of robotically assisted transhiatal esophagectomy without major perioperative complications, and with a benefit of a better dissection and mobilization of the esophagus through a laparoscopic approach. The next year Kernstine et al. [21] reported the first thoracoscopic dissection using the robot. Other articles were focused on presenting the initial experience using the robot either in general or thoracic surgery [22,23], with special interest in presenting technical aspects of the interventions, early postoperative outcomes.

First series of cases using the AEOSP system was published in 2004 [24], the authors from Japan compared the intraoperative and postoperative outcomes in patients receiving hand-assisted laparoscopic surgery (HALS), video-assisted thoracoscopic surgery (VATS) (15 patients) and patients receiving open surgery (30 patients). In the AESOP group, the volume of blood loss was significantly less, but the total operation time was longer than in the open group. There were no significant differences in postoperative outcomes or the incidences of morbidity and mortality between the two groups.

First European consecutive series of cases was published in 2006 by a Dutch group from University Medical Center Utrecht [25] and included 21 patients with esophageal cancer who underwent thoracoscopic esophagectomy with gastric graft using cervical anastomosis using the Da Vinci robotic system. The operating time for the thoracoscopic phase was 180 min (range 120-240 min) with a median blood loss of 400 mL (range 150-700 mL), pulmonary complications occurred in 10 patients (48%) and one patient died of a trachea-gastric graft fistula.

Since then there were a total of 9 articles [26-34] presenting the results of different surgical centers using the robot assisted techniques with a total number of 229 patients. Surgical techniques included 60 transhiatal and 169 transtoracic esophagectomies. Intraoperative blood loss varied between 40 and 625 mL with a mean operative time between 267 and 556 minutes. Mean number of harvested lymph nodes varied between 14 and 38, when comparing the number of resected lymph nodes by performing a different technique, transtoracic esophagectomy resulted in a mean number of 26 nodes bigger than the mean 17 nodes in the transhiatal technique. Both techniques were associated with a significant number of lymph nodes according to the current recommendation for an accurate staging.

Up to now there is no prospective randomised study that clearly shows the benefit of robotic esophagectomy. Based on the results of a systematic review from 2010 [35], which included cohort studies (level 4) and case reports (level 5), R_0 resections were obtained in 90% of cases, during a transthoracic approach and the mean number of harvested lymph nodes consisted with the requirements for an accurate staging. The overall 30-day mortality was 2.4%, with a anastomotic leak rate of 18%. From all the series pulmonary complications occurred in 25% of cases, vocal cord paralysis in 13%, cardiac complications in 11% with thoracic duct injury in 8% [35]. No functional outcomes have been recorded from the literature search in terms of quality of life postoperatively. Comparative studies focused on postoperative outcomes in terms of morbidity [29,36] and showed similar results, special interest was foud in reduction of recurrent nerv injury [36]. In present, there is a randomised controlled parallel-group, superiority trial (*Robot-assisted Thoraco-laparoscopic Esophagectomy Versus Open Transthoracic Esophagectomy ROBOT-NCT01544790*) designed to compare robot-assisted minimally invasive thoraco-laparoscopic esophagectomy with open transthoracic technique with primary outcome the percentage of overall complications and secondary outcome mortality within 30 and 60 days, R_0 resections, operation related events, postoperative recovery, oncologic outcomes, cost-effectiveness and quality of life [37].

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CONCLUSIONS

Due to the high technicality and the elevated costs of the intervention there is limited experience with robotic esophagectomy. Furthermore, minimally invasive techniques for esophageal cancer are still considered experimental surgery; those techniques are performed in specialised high-volume centers. In contrast to the open procedures, robotics can improve visibility in the thoracic cavity, improving the exposure to the hiatus and the thoracic apex through the relatively unyielding chest wall incision.

One limitation is the fact that the surgeon is physically separated from the patient and is situated outside of the operating field and could raise potential safety concerns. The published data in literature proves that robotic esophagectomy is feasible with similar outcomes as minimally invasive techniques. In order to gain a widespread acceptance it is necessary to obtain a reduction of costs, an improved and accurate training of surgeons and operating room personnel; these results needs to be confirmed by randomized studies.

CONFLICT OF INTEREST

Authors have no conflict of interest to declare.

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