Review Article on Thoracic Surgery

Robotic technological aids in esophageal surgery

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Abstract: Robotic technology is an emerging technology that has been developed in order to overcome some limitations of the standard laparoscopic approach, offering a stereoscopic three-dimensional visualization of the surgical field, increased maneuverability of the surgical tools with consequent increased movement accuracy and precision and improved ergonomics. It has been used for the surgical treatment of most benign esophageal disorders. More recently, it has been proposed also for patients with operable esophageal cancer. The current evidence shows that there are no real benefits of the robotic technology over conventional laparoscopy in patients undergoing a fundoplication for gastroesophageal reflux disease (GERD), hiatal closure for giant hiatal hernia, or Heller myotomy for achalasia. A few small studies suggest potential advantages in patients undergoing redo surgery for failed fundoplication or Heller myotomy, but large comparative studies are needed to better clarify the role of the robotic technology in these patients. Robot-assisted esophagectomy seems to be safe and effective in selected patients; however, there are no data showing superiority of this approach over both conventional laparoscopic and open surgery. The short-term and long-term oncologic results of ongoing randomized controlled trials (RCTs) are awaited to validate this approach for the treatment of esophageal cancer.

Keywords: Robotic; fundoplication; myotomy; esophagectomy

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Introduction

During the last 25 years, there has been a shift in the surgical approach to most esophageal diseases. Nowadays, the minimally invasive approach is standard of care for the surgical management of gastroesophageal reflux disease (GERD), achalasia and symptomatic epiphrenic diverticula. Patients treated laparoscopically have significantly better postoperative short-term outcomes than patients treated with an open approach, with similar long-term functional outcomes. More recently, the implementation of minimally invasive approaches occurred also in patients with esophageal cancer, leading to lower cardiopulmonary complications rates and shorter hospital stay.

However, conventional laparoscopic surgery has some drawbacks, including the 2-dimensional vision of the surgical field, tremor and limited degrees of freedom of the surgical tools movements. Robotic technology has been developed aiming to overcome these limitations of the standard laparoscopy. It offers several potential technical improvements, such as the three-dimensional visualization of the operating field, increased movement accuracy and precision secondary to the enhanced maneuverability of the surgical tools, and better surgeon ergonomics. To date, several studies have been conducted aiming to assess the benefits and the limitations of this technology for esophageal diseases (1-4).

The aim of this article is to critically revise the evidence available about the use of the robotic technology for the treatment of both benign and malignant esophageal diseases.

Robotic fundoplication for GERD

A laparoscopic total fundoplication is the surgical procedure of choice for the treatment of GERD. Patients experience very low perioperative morbidity and recovery is very fast. Good to excellent control of GERD-related symptoms is obtained in the vast majority of patients at 10 years after surgery.

During the last 15 years, the robotic technology has been proposed to further enhance the surgical results, mainly through a 3-dimensional vision and increased dexterity during the creation of the wrap. Several studies [five prospective randomized controlled trials (RCTs)] have compared robotic and conventional laparoscopic total fundoplication for GERD (5-9). For instance, we randomized 50 GERD patients to robot-assisted fundoplication (n=25) or to standard laparoscopic fundoplication (n=25) (6). The da Vinci Surgical System was used to perform all robotic surgeries. Robotic fundoplications took significantly longer than standard laparoscopic fundoplications (mean total operative time 131.3 *vs*. 91.1 min, P<0.001). None of the 50 procedures were converted to open surgery, while one of 25 robot-assisted fundoplications was converted to standard laparoscopic fundoplication. No significant differences were observed in the length of hospital stay. Higher total costs were recorded in the group of patients undergoing robotic surgery (euro 3,157 *vs*. euro 1,527; P<0.001). There was no surgery-related mortality. With a mean follow-up of 22.3 (range, 6–32) months, no significant differences in symptom control, endoscopic findings and functional outcomes were observed between the two groups. At 1 month after surgery, mild transient dysphagia rate was 12% (n=3) in each group. The GORD-HRQOL score analysis failed to show any significant difference in symptoms and quality of life at 3, 6 and 12 months postoperatively. At 6 months after surgery, upper endoscopy did not show esophagitis in any of the 50 patients; however, Barrett's esophagus did not regress in those patients who were diagnosed with preoperatively.

A recent meta-analysis (2) of the 5 RCTs including a total of 160 patients showed that the robotic and the standard laparoscopic approach are similar in conversion to laparotomy, length of hospital stay, dysphagia at 1 month after surgery, and need for redo surgery. These findings from small RCTs have been confirmed by the analysis of the large University Health System Consortium (UHC) database, including a total of 9,572 laparoscopic and 339 robot assisted fundoplication performed between 2008 and 2012 in the United States (10).

Only a few studies have assessed the esophageal function and the reflux profile by esophageal manometry and 24-hour pH monitoring. Frazzoni *et al*. (11) found in a retrospective review of 88 patients treated by standard laparoscopic (n=44) or robotic (n=44) Nissen fundoplication no postoperative differences in lower esophageal sphincter (LES) pressure between the two groups, while the esophageal acid exposure was significantly lower after robotic surgery. Abnormal values were observed in 6 (14%) and in none of patients after standard laparoscopic and robotic Nissen fundoplication (P=0.026). The authors concluded that the robotic fundoplication should be the approach of choice in those Institutions where the robotic technology is available. They suggested that the better results obtained after robotic surgery were the consequence of movement filtrations, enhanced view, and very limited bleeding. Unfortunately, two RCTs (6,7) did not confirm these findings. We found (6) that the resting pressures of the LES were similar after robotic or standard laparoscopic fundoplication: patients undergoing robot-assisted fundoplication had a mean resting LES pressure of 21.8 mmHg, while patients undergoing conventional minimally invasive fundoplication had a mean LES resting pressure of 22.3 mmHg (P=0.503). Postoperative 24-hour ambulatory pH monitoring showed normal values in all patients, with no differences between robotic and standard laparoscopic surgery groups in the mean DeMeester score (5.8 and 4.2, P=0.231). Similar perioperative outcomes and functional results were observed by Draaisma *et al*. (7) in a RCT comparing 25 patients undergoing laparoscopic Nissen fundoplication and 25 patients submitted to robot-assisted Nissen fundoplication for GERD.

In conclusion, the current evidence shows the equivalence in conversion and complication rates between laparoscopic and robotic approach. In-hospital outcomes, quality of life and functional outcomes are also similar, while the use of robotic technology is associated with longer operative time and higher total costs. Based on the lack of additional benefits, the use of the robotic technology for the surgical treatment of GERD is not considered justified and therefore it has been abandoned in many centers.

Robotic giant hiatal hernia repair

The laparoscopic approach for the surgical treatment of giant hiatal hernia is effective with limited morbidity and negligible mortality. However, it is technically demanding

that requires advanced skills in upper GI laparoscopic surgery and recurrence rates are high. Robotic technology with the stereoscopic vision might help the surgeon perform a more precise dissection of the sac and the esophagus, reduction of the herniated organs into the abdomen, and cruroplasty (12). To date, very few studies have specifically assessed the impact of the robotic technologies on the outcomes in patients undergoing minimally invasive repair of a giant hiatal hernia, showing no real clear benefits to the patients. No long-term follow-up are available. Gehrig *et al*. (13) conducted a case-control study comparing 12 patients operated with the aid of the robot and 17 patients undergoing laparoscopic hiatal hernia repair. No advantages were found in operative time, intraoperative complications and early postoperative course.

Robotic Heller myotomy for achalasia

Laparoscopic Heller myotomy with partial fundoplication is currently the standard of care for the treatment of achalasia. It is associated with symptom improvement or relief in about 90% of patients. However, it is a challenging procedure with the potential risk of esophageal perforation reported in up to 10% of cases. Recently, the use of the robotic technology has been proposed claiming that it might reduce intraoperative esophageal perforation rates and improve postoperative quality-of-life after Heller myotomy, mainly due to the 3-D view and enhanced dexterity of the surgeon (3). However, comparative data are scarce (14-16). For instance, Huffmanm *et al*. (15) prospectively evaluated 61 consecutive achalasia patients submitted to standard laparoscopic or robot-assisted myotomy. A total of 37 patients were treated with a standard laparoscopic Heller myotomy, while 24 patients underwent robotic Heller myotomy. Operative time was longer in the robotic group (355 *vs*. 287 minutes). Intraoperative estimated blood loss was similar. No esophageal perforations or other operative complications were recorded during robotic surgeries, while 3 esophageal perforations (8%) occurred during standard laparoscopic Heller myotomy. Patients after robotic surgery had significantly better SF-36 Role Functioning (emotional) and General Health Perceptions than patients interviewed after standard laparoscopic surgery. Horgan *et al*. (16) retrospectively evaluated a total of 121 patients undergoing Heller myotomy: 59 patients had a robotic Heller myotomy and 62 had a laparoscopic Heller myotomy. The two groups were similar in demographic characteristics, symptoms and preoperative treatments. Intraoperative esophageal perforation occurred more frequently in the laparoscopic group (16% *vs*. 0%). The rates of relief of symptoms, and postoperative heartburn were similar after robotic and laparoscopic Heller myotomy after 18 and 22 months of follow-up. The results of these two studies suggest that the robotic approach decreases the incidence of esophageal perforation even in patients who had previous treatment. However, the poor quality of the studies limits the interpretation of these results.

Robotic excision of epiphrenic diverticula

The surgical approach for the treatment of patients with symptomatic epiphrenic diverticulum has radically changed during the last 20 years. To date, minimally invasive laparoscopic epiphrenic diverticulectomy with myotomy and fundoplication is the most popular surgical option since it is associated with excellent postoperative outcomes. However, it is a technically demanding operation and is burdened by high postoperative morbidity rates. A leak of the staple line is described in up to 23% of patients, pulmonary complications occur in up to 10% of patients; mortality rates reported in the literature vary between 0% and 7%. In addition, a thoracoscopic approach may be required to perform the diverticulectomy in those patients with a high upper part of the diverticulum that cannot be safely dissected with the rigid laparoscopic instruments tools or when there are severe adhesions between the diverticulum and the pleura.

During the last few years, a few case reports describing the feasibility and safety of the robotic approach have been published (17,18). Some authors have stated that the stereoscopic endoscope, the articulated robotic instruments, the 3-dimensional visualization, the robotic motion scaling and the tremor-filtering might help dissect the upper part of the diverticulum safely, minimizing the risk of injury to the pleura. In addition, the vision magnification may allow performing a safe myotomy up into the mediastinum, with reduced risk of mucosal perforation (17). However, the data currently available in the literature are very preliminary, the level of evidence very low and further studies are awaited to confirm the potential benefits of the robotic technology over the laparoscopic approach.

Robotic redo surgery

Laparoscopic redo surgery for recurrent hiatal hernia, failed fundoplication for GERD or recurrent dysphagia after

Heller myotomy is associated with increased morbidity when compared with primary surgery and less predictable functional outcomes. Currently, most cases are performed by an open approach (laparotomy or thoracotomy), while the laparoscopic approach is used in selected cases. Redo surgery is challenged by adhesions and inflammation of the anatomical planes that become much more difficult to be identified and dissected. As a consequence, complication rates and conversion to laparotomy of laparoscopic redo surgery significantly increase. The use of robotic technology in these patients might lead to better visualization of the surgical field with improved dissection of the planes and, subsequently, to reduced risk of intraoperative complications. A recent single-institution study by Tolboom *et al*. (19) included 75 patients undergoing redo surgery for recurrent GERD-related symptoms or dysphagia: 30 patients had standard laparoscopic redo surgery, while 45 patients had a robot-assisted procedure. A significantly higher number of patients having the primary antireflux procedure performed by an open abdominal approach were present in the robotic group. However, conversion to open surgery occurred more frequently during laparoscopic than robotic redo surgery (17% *vs*. 2.2%, P=0.035). Early postoperative complication rates were similar. Postoperative length of hospital stay was shorter after robotic surgery.

Long-term follow-up outcomes from large prospective comparative (randomized) studies are necessary to prove these preliminary data in support of the use of robotic systems in patients with failed antireflux surgery.

Robotic esophagectomy for cancer

Open esophagectomy is the gold standard for the surgical management of resectable esophageal cancer. However, it is technically challenging and is burdened by significant early postoperative morbidity, despite advances in surgical techniques and perioperative patient management. The optimal approach to esophageal cancer is still under debate. While transhiatal esophagectomy is advocated for the reduced postoperative cardiopulmonary complication rates, transthoracic (Ivor Lewis) esophagectomy is considered in many centers the preferred approach since it is associated with lower esophago-gastric anastomotic leak rates and it may lead to a more extended mediastinal lymphadenectomy. Furthermore, mortality rates do not differ in patients developing cervical or intra-thoracic anastomotic leak after esophageal resection performed in high volume centers.

The last 25 years have witnessed a slow increase in the implementation of minimally invasive approaches to esophageal cancer. Evidence from non-RCTs and small RCTs show that laparoscopic/thoracoscopic esophagectomy was associated with lower cardiopulmonary complication rates and early mortality, and shorter hospital stay than open Ivor Lewis esophagectomy. However, concerns about the technical complexity and oncologic adequacy have limited the adoption of the minimally invasive approach in patients with esophageal cancer.

More recently, robot-assisted thoraco-laparoscopic esophagectomy has been introduced aiming at overcoming the limitations and challenges of the conventional laparoscopic/thoracoscopic approach. To date, several case series and only a few comparative studies have been published, showing promising results in terms of both feasibility and safety of this approach. Ruurda *et al*. (4) published in 2015 a systematic review about robot-assisted esophagectomy for esophageal cancer. They included 16 papers, 5 of them (118 patients) reporting on the use of the robotic system for the abdominal dissection during a transhiatal esophagectomy. Conversion rate to open surgery ranges between 0% and 12.5%; anastomotic leak rates varies between 9% and 33%, and median hospital stay ranges between 9 and 11 days. The number of lymph nodes surgically removed varied between 15 and 22. The eleven studies that have assessed the role of the robotic technology in the transthoracic esophagectomy reported conversion rates up to 15%, anastomotic leaks in up to 38% of patients; median hospital stay ranged between 7 and 22 days. Cardiopulmonary morbidity rates did not significantly differ from those observed following open transthoracic esophagectomy. The number of lymph nodes harvested was as high as 43.

While the short-term outcomes from case series are encouraging, two studies comparing robotic and open esophagectomy or minimally invasive esophagectomy without robotic assistance failed to find differences in perioperative outcomes. Weksler *et al*. (20) compared 11 patients who had robot-assisted esophagectomy and 26 patients who had minimally invasive esophagectomy without the use of the robot. The two groups were similar in demographic characteristics and use of neoadjuvant treatments. Operative time, estimated blood loss and the number of resected lymph nodes were similar in the two groups. Also postoperative morbidity rates, the length of stay in intensive care unit and the length of hospital stay did not significantly differ. Also Yerokun *et al*. (21)

recently failed to find any clear advantage of the robot-assisted esophagectomy using population-level data. They compared perioperative outcomes and 3-year oncologic results obtained after open (n=2,958), standard minimally invasive esophagectomy without robotic assistance (n=1,077) and robot-assisted esophagectomy (n=231) for cT1-3N0-3M0 cancer of the middle or distal esophagus. Patients undergoing standard minimally invasive or robot-assisted esophagectomy had shorter hospital stay and more lymph nodes harvested than patients who had open surgery; however, no significant differences were observed in resection margin involvement, readmission and 30-day mortality. Three-year survival was also similar. The subgroup analysis of robotic versus standard minimally invasive esophagectomy found no differences between the two approaches in short-term and oncologic outcomes.

Some authors have speculated that the stable 3-dimensional view of the surgical field along with articulated surgical tools might help reach the upper mediastinum with better ergonomics, and allow a wide and precise dissection of the periesophageal tissues and the mediastinal structures thus leading to a higher number of lymph node harvested and possibly to higher rates of radicality in patients with large tumor (22). However, only limited short-term oncologic outcomes are available, and results from large RCTs with long-term outcomes like the ongoing ROBOT trial (23) are needed to validate the robotic approach for the surgical treatment of esophageal cancer. This is a single-institution superior trial comparing robot-assisted minimally invasive esophagectomy and open 3-stage transthoracic esophagectomy, with the hypothesis that robot-assisted esophagectomy has lower postoperative complications, less intraoperative blood loss and a shorter length of hospital stay, better quality of life and similar oncologic outcomes. A total of 112 patients with histologically proven and surgically resectable cT1–4 N0-3 M0 intrathoracic esophageal cancer are randomized to robot-assisted esophagectomy (n=56) or open 3-stage transthoracic esophagectomy (n=56). The primary outcome of this RCT is the rate of overall complications.

In conclusion, the use of the robotic technology to perform an esophagectomy for cancer seems to be safe and at least as effective as the open approach in the short-term. Potential benefits might come from future technological developments such as the integration of the robotic systems with advanced diagnostic imaging systems, including the fluorescence for the sentinel node biopsy and the image overlay for the identification of anatomical landmarks and the evaluation of the vascularization of the gastric conduit.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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