Robotic-assisted esophageal surgery is safe and feasible, but more studies are needed to assess its benefits and drawbacks.

Robotic-Assisted Esophageal Surgery

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Background: The adoption of minimally invasive approaches to the management of esophageal disease has been slow, except for the laparoscopic management of gastroesophageal reflux disease. However, the advent of new surgical technologies — in particular, robotic-assisted surgical systems — has revolutionized esophageal surgery.

Methods: The literature was systematically reviewed using the keywords “robotic,” “esophageal surgery,” “esophagectomy,” “fundoplication,” and “esophageal myotomy.” The reference lists from these articles were then also analyzed.

Results: Forty-nine studies were included in our comprehensive review of robotic-assisted esophageal surgery, and they consisted of literature reviews, case reports, retrospective and prospective case series, and randomized controlled trials.

Conclusions: Robotic-assisted esophageal surgery is a safe and effective way of treating esophageal disorders, including gastroesophageal reflux disease, achalasia, leiomyomas, and cancer. The use of robotic surgical systems has many benefits for managing disorders of the esophagus, but more studies, including randomized controlled trials, are necessary.

Introduction

Surgery is a major part of esophageal pathology, and esophageal surgery is still evolving with the continuous advances seen in science and technology. Prior to the 1990s, esophageal surgery was performed through large incisions in the abdomen, the chest, or both.1 With the advent of minimally invasive surgery (MIS), rates of morbidity and mortality related to esophageal surgery using traditional approaches were considered in part to be related to larger thoracotomy incisions, laparotomy incisions, or both. The theoretical advantages of MIS were not only “smaller incisions,” but also decreased pain, decreased use of opioids, fewer complications (eg, arrhythmias), shorter hospital length of stay (LOS), shorter recovery times, and, thus, a faster return to work and other normal activities of daily living.2-6 However, laparoscopy and thoracoscopy have drawbacks, including a 2-dimensional visual field, limited movements of instruments, and uncomfortable positioning for the surgeon. In addition, comparison of minimally invasive esophagectomy with open esophagectomy revealed higher esophagogastric anastomotic leak rates with MIS compared with the open approach.7

Building on the theoretical advantages of MIS,
the use of robotic surgical systems, such as the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, California), provides a 3-dimensional field of view, 7 degrees of freedom of movement with endo-wristed instruments, scaled-down movement, a 60-Hz motion filter to help eliminate tremors, and an ergonomic-seated operating position.8-10 Although robotic-assisted surgery is relatively new, surgeons are attempting to identify its niche, including its role in surgery of the esophagus.

Fundoplication

The first robotic-assisted Nissen fundoplication was reported in 1999.11 Following this initial report, small case series demonstrated that robotic-assisted fundoplications were safe to perform, and none of the morbidity seen was directly attributed to the use of the robotic system.12-13 Meininger et al14 described a robotic-assisted Nissen fundoplication in a 10-year-old girl without any change in pH, arterial oxygen pressure, arterial carbon dioxide pressure, heart rate, or mean arterial pressure, physiologically demonstrating that robotic-assisted Nissen fundoplication was a safe procedure even in the pediatric population.

The efficacy of robotic-assisted fundoplications has also been assessed for the treatment of gastro-esophageal reflux disease (GERD). In a study of 9 consecutive robotic-assisted Toupet fundoplications, Wykypiel et al15 noted that none of the study patients had symptoms of reflux 6 months following surgery. After demonstrating that robotic-assisted antireflux procedures were safe and efficacious, robotic-assisted fundoplication was then compared with the gold standard of laparoscopic fundoplication. The first such retrospective comparison was performed in Italy.16 Average operative times were less in the robotic-assisted group (110 minutes) than those in the laparoscopic group (120 minutes).16 The 2 groups had similar conversion rates to laparotomy, but improved morbidity rates and hospital LOS were noted in the robotic-assisted group.16

Following the Italian report, prospective comparison studies were performed, all of which showed that the operative times for the robotic-assisted groups were significantly longer than the laparoscopic groups.17-19 However, Melvin et al19 showed that robotic-assisted fundoplications might be more efficacious than laparoscopic fundoplications in the treatment of reflux disease. At the first postoperative visit, 6 of the 18 study patients (33%) from the laparoscopic group required antisecre-tory medications for symptoms of GERD, whereas none of the 18 of the study patients from the robotic-assisted group required further medical treatment.19

GERD can also be present in pediatric patients, who represent a unique population in which to study robotic-assisted fundoplication.20 Gutt et al21 showed that robotic-assisted fundoplication was a feasible and safe operation in children, because no conversions were made to open procedure and no complications were present in the study cohort. Another study demonstrated the efficacy of robotic-assisted Nissen fundoplication in children.22 Following surgery, this group of 40 children had significantly decreased DeMeester scores; in addition, a significant decrease was seen in the number of study patients requiring medical treatment for reflux and asthma.22

The robotic surgical system also provides other specific advantages during various steps of the robot-ic-assisted surgical procedure. Costi et al9 mentions some of these advantages, including easier passage behind the esophagus, better mobilization of the greater curvature of the stomach, improved suturing and knot tying, and superior visualization. Ruurda et al23 also suggest that certain portions of fundoplication are easier with the robotic system, such as dissection behind the esophagus and suturing of the crura. The robotic system may also aid in difficult operations, such as repeat fundoplication.24,25

Esophageal Myotomy

Melvin et al26 described the first case of Heller myotomy performed with the aid of a robotic system in a 76-year-old woman with achalasia, and larger studies have since reported that robotic-assisted Heller myotomy is a safe and effective treatment option for achalasia.27,28 A multicenter, retrospective comparison of robotic-assisted and laparoscopic Heller myotomy was performed by Horgan et al.29 Effectiveness of treating dysphagia was comparable in both groups, but a significantly decreased number of esophageal perforations were seen in the robotic-assisted group compared with the laparoscopic group (0% vs 16%, respectively).29 Other retrospective studies have demonstrated similar results, with a 0% esophageal perforation rate in the robotic-assisted group and an 8% perforation rate in the laparoscopic group.30,31 Iqbal et al30 found that the robotic group also had a better long-term failure rate as judged by the lower need for reoperation. Although Huffman et al31 demonstrated a longer average operative time in the robotic-assisted group compared with the laparoscopic group (355 vs 287 minutes, respectively), no differences were seen in the rate of estimated blood loss (EBL) and hospital LOS between the 2 groups.

The largest comparison study to date was performed by Shaligram et al32 and included patients undergoing Heller myotomy for achalasia. The study was composed of 418 open, 2,116 laparoscopic, and 149 robotic-assisted surgical cases.42 When comparing the robotic-assisted and laparoscopic groups, no signif-
ity, admission rate to the intensive care unit, hospital LOS, or 30-day readmission rates. The robotic-assisted operation was superior to the open technique in terms of morbidity, admission rate to the intensive care unit, and hospital LOS; however, hospital costs associated with the robotic-assisted group were significantly higher compared with the laparoscopy group ($9,415 ± 5,515 vs $7,441 ± 7,897; P = .003). It is worth noting that the cost of hospitalization associated with the robotic-assisted group was not increased compared with the open group, as was initially expected.

**Esophagectomy**

Surgical resection remains a key component of the multimodality treatments for esophageal cancer. However, esophagectomies — despite the type of approach employed — have been associated with high morbidity and mortality rates (60% and 14%, respectively), although 1 series reports mortality rates to be as low as 4%.

Minimally invasive esophagectomy was introduced and popularized by Luketich et al. As surgical techniques have evolved, surgeons have begun to employ robotic assistance for esophagectomy. Initially, the robotic system was employed for thoracic dissection of the esophagus and was shown to be feasible but time consuming, with an average robotic-assisted time of 174 minutes, and, notably, the authors commented on the ability to achieve a thorough lymphadenectomy using the robotic system. Another study demonstrated similar median time required for robotic-assisted thoracic esophageal dissection.

As robotic technology becomes more popular, surgeons will begin to utilize it during additional steps and for other approaches to esophagectomy. Kernstine et al reported their experience using a robotic system in thoracic dissection as well as in the abdominal portion of a 3-field esophagectomy and lymphadenectomy. However, they noted long mean operative and robotic-assisted times in this initial experience (11.1 and 5.0 hours, respectively).

de la Fuente et al published in 2013 the initial experience of robotic-assisted Ivor–Lewis esophagectomy at the H. Lee Moffitt Cancer Center & Research Institute (Tampa, Florida). The series included 50 study patients who all underwent the operation following a diagnosis of cancer. All study patients received an R0 resection, and an average of 20 lymph nodes were removed. Of the 50 study patients, 28% experienced a complication (the most common of which was atrial fibrillation), 1 study patient had an anastomotic leak, and 1 study patient had a gastric conduit staple-line leak. The median hospital LOS was 9 days, and the average operating time was 445 minutes. de la Fuente et al demonstrated that a learning curve exists for the procedure, as the second half of their cases took less time than the first half (410 vs 479 minutes, respectively).

Regarding the learning curve involved with robotic-assisted esophagectomy, Hernandez et al demonstrated that proficiency in performing the procedure appears to begin after 20 cases. This group recently updated their series, which now has 134 study patients, and found that study patients 70 years of age or older did not have increased median operative room time. They also had lower rates of EBL, adverse events (including pneumonia, cardiac arrhythmia, deep venous thrombosis/pulmonary embolus, wound infection, or anastomotic leak), decreased rates of intensive care unit and hospital LOS, and decreased mortality following robotic-assisted Ivor–Lewis esophagectomy.

Other groups have also reported using robotic assistance during transhiatal esophagectomies. One such study reported on 40 study patients who underwent robotic-assisted transhiatal esophagectomy. The median operative time was 311 minutes and the median hospital LOS was 9 days. This group accomplished an R0 resection in 95% of their study patients. Recurrent laryngeal nerve paresis and anastomotic leak rates were 35% and 25%, respectively, which are higher than those reported in the literature.

Coker et al described a cohort of 23 study patients who underwent robotic-assisted transhiatal esophagectomy, 19 of whom had neoadjuvant chemoradiation. The results of this study showed that the robotic system could be safely and effectively used after patients underwent neoadjuvant therapy, which has now become an integral part of the treatment of locally advanced esophageal cancer. Of note, this robotic-assisted transhiatal approach has also been validated in patients considered too ill to undergo single-lung ventilation, as would be necessary in the Ivor–Lewis approach.

Cerfolio et al demonstrated that a completely hand-sewn esophagogastric anastomosis in the chest with robotic assistance is feasible and safe. During that study, no anastomotic leaks occurred in their cohort of 16 patients. Comparison studies for robotic-assisted esophagectomy are lacking at this time, but prospective, randomized controlled trials are actively accruing.

**Other Esophageal Pathology Treated With Robotic-Assisted Resection**

Although the robotic system has been used to treat common esophageal pathology, this surgical system has also become a tool in the treatment of less-prevalent esophageal disease. For example, many case reports and small series of robotic-assisted enucleation of esophageal leiomyomas can now be found in the literature. Although these tumors reside in the submucosa of the esophagus, resecting them requires
careful dissection of the muscular layers without perforating the mucosa. Surgeons have noted that the superior vision and dexterity provided by the robot allows for meticulous dissection and minimizes perforation during extirpation.48

Other rare esophageal pathology can include esophageal diverticula, for which case reports of robotic-assisted transhiatal esophageal diverticulectomies alone (for epiphrenic diverticulum) have been reported to date.53,54 Robotic-assisted esophageal metastasectomy for primary hepatocellular carcinoma has also been reported.55

Discussion
Esophageal surgery has undergone a revolution from the days of large, morbid incisions in the chest and abdomen and now includes the option for MIS. The first attempts at MIS of the esophagus with laparoscopy and thoracoscopy showed benefits compared with the traditional open approaches, including lower mortality rates and shorter hospital LOS.2,6 Although these new techniques seemed to benefit the patients, many drawbacks were evident, such as 2-dimensional vision and the limited movement of instruments.

Robotic surgical technology became popularized for general surgery after the US Food and Drug Administration approved the da Vinci Surgical System in 2000.56 The robotic-assisted approach to surgery still affords the same benefits as laparoscopy and thoracoscopy, including small incisions, while also adding improvements, such as a high-definition, 3-dimensional view, articulating instruments, and tremor filtration.57 Because the robotic system could be used for delicate surgery in small spaces, robotic-assisted procedures have become important for esophageal surgery.

Early on, the robotic system was shown to be safe and efficacious for esophageal surgery. However, when compared with laparoscopic fundoplication in early studies, the robotic groups tended to require longer operative times. It should be mentioned that most of the studies included in our review had fewer than 25 study volunteers and may have been the first robotic-assisted esophageal procedures performed by the respective surgeons. This qualification is important to keep in mind, because many reports have since demonstrated a learning curve associated with robotic-assisted esophageal surgery.9,16,40,46,58 In fact, when Costi et al9 compared the first robotic-assisted Nissen fundoplications performed by Cádière et al13 to their first 80 laparoscopic Nissen fundoplications, they found no difference in operative time. Therefore, the increased operative time shown in these early studies may be a reflection of each surgeon becoming accustomed to the new robotic-assisted surgical technology. However, subjecting patients to longer operations performed with robotic assistance without any obvious improved patient outcomes may not be justified.

Furthermore, aside from the multiple technical benefits afforded by the robotic system, some studies have shown that outcomes in study volunteers undergoing robotic-assisted procedures may be superior to the outcomes seen in study volunteers undergoing laparoscopic procedures. For example, Melvin et al19 described how none of the study patients in his trial required antireflux medication following robotic-assisted fundoplication compared with 6 study patients in the laparoscopic cohort who still required medication. In addition, several studies have demonstrated a lower esophageal perforation rate following robotic-assisted Heller myotomy compared with the laparoscopic approach.29-31 Although these results are promising, more studies are needed to better establish the advantages of robotic-assisted esophageal surgery when compared with other minimally invasive approaches.

Another criticism of robotic surgery is its increased cost. Robotic instruments used during fundoplication can cost 55% more than those used for traditional laparoscopic fundoplication.9 However, robotic technology is relatively new and not yet widely adopted. It is possible that, with an increased supply and competition between manufacturers, cost for robotic surgical systems could decrease in the future. However, it is important to note — particularly given the present state of the US health care system — that using more costly techniques like robotic-assisted esophageal surgery without any definitive patient benefit may not be economical at the present time.

Conclusions
Robotic-assisted esophageal surgery is a young field, but its application continues to expand. Although a paucity of literature currently exists, the overall use of robotic-assisted surgical systems for esophageal surgery is associated with benefits and drawbacks. As the field expands and surgeons become comfortable with the technology, robotic-assisted surgical systems may improve the technical aspects of esophageal surgery as well as patient outcomes in the not-too-distant future.

References


