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Robotic Surgery in Achalasia: State of the Art

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Rezumat

Chirurgia robotică în acalazie: stadiul cunoașterii

Introducere: Acalazia este o afecțiune esofagiană primară, rară, caracterizată prin perturbarea actvității sfincterului esofagian inferior. Scopul tratamentului este ameliorarea simptomelor şi îmbunătățirea calității vieții. Standardul de aur al tratamentului chirurgical este miotomia Heller-Dor. Scopul acestui review de literatură este de a descrie rolul chirurgiei robotice în tratamentul acalaziei.
Metode: Cercetarea a inclus articole publicate în bazele de date PubMed, Web of Science, Scopus şi EMBASE, între 1 ianuarie 2001 şi 31 decembrie 2022. În plus, au fost identificate articole relevante din lista de referințe ale acestor publicații.
Concluzii: Miotomia Heller robotică (RHM) cu fundoplicatura parțială poate reprezenta viitorul tratamentului chirurgical al acalaziei. Această abordare este sigură, eficientă, confortabilă pentru chirurg şi este caracterizată printr-o reducere a ratei de perforare intraoperatorie a mucoasei esofagiene.

Cuvinte cheie: acalazie, chirurgie robotică, miotomie Heller-Dor, miotomie robotică, chirurgie minim invazivă, fundoplicatură

Abstract

Introduction: Achalasia is a rare primary esophageal disorder characterized by impaired functioning of the lower esophageal sphincter. The goal of treatment is to reduce symptoms and improve the quality of life. The gold standard of surgical approach is Heller-Dor myotomy. The aim of this review is to describe the use of robotic surgery in patients with achalasia.

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Methods: The literature review was performed by searching on PubMed, Web of Science, Scopus and EMBASE for all studies on robotic surgery for achalasia, published from January 1, 2001, to December 31, 2022. We focused our attention on randomized controlled trials (RCTs), meta-analysis, systematic reviews, and observational studies on large cohorts of patients. Furthermore, we have identified relevant articles from the reference list.
Conclusions: Taking into consideration our review and experience, RHM with partial fundoplication is safe, efficient, comfortable for the surgeon and characterized by a reduction of the intraoperative perforation rate of the esophageal mucosa. This approach may represent the future for the surgical treatment of achalasia especially with a reduction in costs.

Key words: achalasia, robotic surgery, Heller-Dor myotomy, robotic myotomy, minimally invasive surgery, fundoplication

Introduction

Esophageal achalasia is a rare disease characterized by impaired peristalsis with abnormal relaxation of the lower esophageal sphincter (LES) (1). Several studies showed the role of autoimmune, infective, neurodegenerative and, genetic factors in its etiopathogenesis (1-5). The symptoms are not specific, dysphagia is present in 90-95%, regurgitation in 75-90%, chest pain in 40-45% and weight loss in 35-40% (5-7). In addition, patients may have symptoms less frequent such as night cough, heartburn, and increased risk of developing esophageal carcinoma (2.2–3.4%) (5-8).

The severity of the disease can be assessed through Eckardt score. This is a valid score to assess the severity of symptoms and efficacy of treatment given from zero to 3 points for the following symptoms: dysphagia, regurgitation, chest pain, and weight loss (9).

High resolution manometry (HRM) represents the gold standard for diagnosis (10). Furthermore, HRM is used to divide Achalasia in subtypes. According to the Chicago classification 4.0: type I with absent or minimal esophageal pressurization, type II with panesophageal pressurization, type III with spastic and premature contractions and, esophagogastric junction outflow obstruction (EGJOO) with intermittent peristalsis (10-12).

Laparoscopic Heller-Dor (LHD) myotomy is gold standard surgical approach to treatment of type I and type II achalasia (6,12-15). Several guidelines recommend the use of peroral endoscopic myotomy (POEM) in the treatment of patients with type III achalasia (6,15-16). This a safe and effective surgical procedure to improve manometric parameters and Eckardt score in the short and long term (6,13-15). In recent years, the surgical treatment of this disease has been enriched with the robotic approach. However, although various advantages are described, there is still no definitive data on superiority over the other approaches. The aim of this review was to describe the use of robotic surgery in patients with achalasia in terms of different surgical techniques, types of fundoplication, perioperative outcomes, postoperative management, and difference with other minimally invasive surgeries.

Materials and Method

We performed a search on PubMed, Web of Science, Scopus and EMBASE using the following keywords: “achalasia” AND “robotic surgery“ OR “robotic Heller“ OR “robotic myotomy“ OR “robotic Dor“ OR “robotic Toupet“ OR “robotic myotomy“ OR “robotic fundoplication“. Articles in the literature on robotic surgery for achalasia with any fundoplication from January 2001 to December

2022 were analyzed (*Fig. 1*). The last check was done on December 31, 2022. Furthermore, we have identified relevant articles from the reference list. Only English studies were included. Incomplete and non-peer reviewed in preprint articles were excluded. We found 40 for our review (*Fig. 1*). We focused our attention on randomized controlled trials (RCTs), meta-analysis, systematic reviews, and observational studies on large cohorts of patients. *Table 1* shows the studies characteristics and *Table 2* the perioperative results.

Surgical Techniques

Surgical intervention is performed under general anesthesia with patient in supine position with arms extended, legs abducted and the bed in 20-25° reverse Trendelenburg. Pneumoperitoneum is induced with Verres needle at Palmer point in the left upper quadrant. Nasogastric tube is placed at induction of anesthesia to deflate the esophagus. There are some differences in the port placement between the surgeons. Kaaki et al. described robotic approach for this surgery in 12 steps (17). These authors inserted 6 trocars: one 8-mm robotic trocar at 10 to 15 cm under xyphoid process in the midline near umbilicus, two 8-mm trocars at 4 and 8 cm from the previous one at the level of the costal margin, one 8-mm trocar below the right costal margin for liver retraction, and two 8-mm and 5-mm assistant trocars at the level of the left midclavicular line below the umbilicus and at the level of the left costal margin, respectively (17). Some authors used four 8-mm robotic ports, along a straight line 4-10 cm above the umbilicus, and two different assistant trocars (12 and 5-mm) (18,19). Similarly, other authors placed three 8-mm trocars for robotic arms, an 8.5-mm robotic camera port and a 5-mm retractor trocar straight line 13 cm below the xiphoid process (20,21). Schrier et al. positioned 5 trocars: a 12-mm camera port 2 cm above the umbilicus, two 8-mm arm port 10 cm diagonally to form the base of a triangle with umbilical port, 5-mm port placed medial to right anterior axillary line as liver retractor and an additional 12-mm port in the left middle abdomen for the assistant (22). Santi et al and Pallabazzer et al, placed the optic trocar on the midpoint of the xifo-umbilical line, two 8-mm trocars in the upper quadrants along the midclavicular line

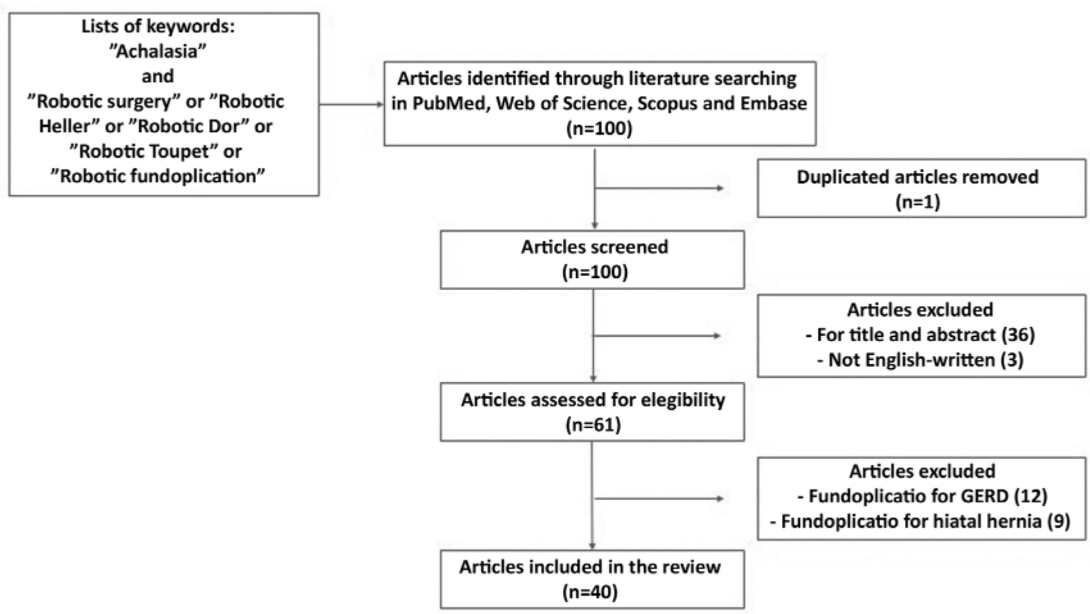

Figure 1. Flow chart of search

Table 1. Characteristics of studies

	Design	Type of surgery	Type of study	Number pt.
Melvin et al,2005	Prospective	RHM+F	Multicenter	104
Horgan et al,2005	Retrospective	RHM+F LHM + F	Multicenter	59 RHM 62 LHM
Ruurda et al, 2005	Retrospective	RHM	Single center	24
Huffman et al,2007	Prospective	RHM+F LHM+F	Single center	24 37
Shaligram et al,2012	Retrospective	RHM + F LHM+ F Open	Multicenter	149 2116 418
Iqbal et al.,2006	Retrospective	RHM+F	Single center	19
Wykypiel et al., 2009	Prospective	RHM + F	Single center	6
Galvani et al.,2006	Retrospective	RHM +F	Single center	54
Sanchez et al.,2012	Prospective	RAHM LHM	Single center	13 18
Diez del Val et al, 2013	Retrospective	RHM + F	Single center	22
Perry et al., 2014	Retrospective	RHM + F LHM + F	Single center	56 19
Prats et al., 2022	Prospective	RHM + F	Single center	45
Saurabh et al., 2013	Retrospective	RHM	Single center	12
Schrier et al.,2021	Retrospective	RHM + F	Single center	30
Darwish et al.,2021	Retrospective	RHM +F RHM	Single center	48 13
Santi et al., 2021	Retrospective	RHM + F	Single center	69
Uzunoglu et al.,2022	Retrospective	RHM + F	Single center	6
Liu et al.,2022	Retrospective	RHM LHM	Single center	51 72
Romanzi et al.,2022	Prospective	RHM + F	Single center	34
Arcerito et al.2022	Retrospective	RHM +F LHM + F	Single center	15 96
Gass et al.,2022	Retrospective	RHM +F LHM + F	Single center	11 32
Engwall Gill et all.,2022	Retrospective	RHM +F LHM + F	Single center	35 14
Khashab et al,2018	Retrospective	RHM +F POEM	Single center	52 52
Kim et al, 2018	Retrospective	RHM +F	Single center	37
		LHM + F		35
Ali et al, 2020	Retrospective	RHM + F LHM + F POEM	Single center	40 40 87
Pallabazer et al, 2020	Prospective	RHM + F	Single center	66

RHM: robotic Heller myotomy; LHM: laparoscopic Heller myotomy: F: fundoplication;
POEM: peroral endoscopic myotomy

and a 12-mm accessory trocar for liver retraction along the right anterior axillary line (23,24). Galvani et al, performed trocar placement like laparoscopy: two 8-mm trocars robotic, two 12-mm trocars and 5-mm trocar in the subxiphoid area are inserted (25).

The robotic cart Da Vinci® is docked, the arms are connected to the trocars and the instruments are introduced under vision. The most used robotic instruments are the following:

- liver retractor: small grasping retractor, Endo Paddle Retract® (Medtronic, Minneapolis, Minnesota, US), laparoscopic snake retractor, Nathanson liver retractor and Diamond-Flex retractor (Genzyme Surgical Products, Tucker, GA) (17-26).
- Vessel sealer, Harmonic scalpel (Ethicon

Table 2. Perioperative outcomes

	Type of surgery	Conversion	Intraoperative complications	Operative Time	LOS	PO Symptoms	Re-operation	Follow-up
Melvin et al,2005	RHM+F	1 to lap, 1 to open	8 GI bleeding, colon injury	141 min	NR	no	NR	79 pt to 16 months
Horgan et al,2005	RHM+F	No	1 incarcerated port site hernia , 1 perforated transverse colon	141±49 min	NR	92 % nil	NR	10 months
	LHM + F	No	10 MP	122 ±44 min	NR	92% nil	NR	10 months
Ruurda et al, 2005	RHM	1 to lap, 2 to open	2 MP	95 (75-170) min	NR	NR	NR	NR
Huffman et al,2007	RHM+F	No	Nil	332 - 378	NR	QoL improved	NR	15 months
	LHM+F	No	3 MP	287 ±9	NR	QoL improved	NR	15 months
Shaligram et al,2012	RHM + F	NR	0 % mortality 4.02 % morbidity	NR	NR	NR	NR	NR
	LHM+ F	NR	0.14 % mortality 5.19 % morbidity	NR	NR	NR	NR	NR
	Open	NR	0.24 % mortality 9.08%morbidity	NR	NR	NR	NR	NR
Iqbal et al.,2006	RHM+F	NO	NR	NR	NR	NR	NR	NR
Wykypiel et al., 2009	RHM + F	NIL	NIL	236 (220-316)	NR	NR	NR	6 months
Galvani et al.,2006	RHM +F	NIL	1 incarcerated port site hernia, 1 perforated transverse colon	162 (62-110) min	NR	93 % QoL improved	NR	17 months
Sanchez et al.,2012	RAHM	NIL	0%	79±20	2 (5 with perforation)	93-100% QoL improved	NR	12 months
	LHM	NIL	5.5 % MP	76 ±13	2 (5 with perforation)	93-100% QoL improved	NR	12 months
Diez del Val et al, 2013	RHM + F	NIL	nil	NR	3 (2-4)	NR	NR	NR
Perry et al., 2014	RHM + F	NIL	0	133±29	1	95.5% satisfation	NR	9.1 years
	LHM + F	NIL	3 (15.8 %)	121 ±22	2	90.9 % satisfation	NR	9.9 years
Prats et al., 2022	RHM + F	NIL	4.4 % MP	211	5 ±3	94.6 % QoL improved	2	64 months
Saurabh et al., 2013	RHM	NIL	0	150	1.5	1 (8.3 %) disphagia	NIL	NR
Schrier et al.,2021	RHM + F	NIL	NIL	77	NR	NR	NIL	30 weeks
Darwish et al.,2021	RHM +F	NIL	nil	104	2	Dysphagia 4, GERD 3, regurgitation 4	NIL	NIL
	RHM	NIL	nil	97	2	Dysphagia 8, GERD 4, regurgitation 6	NIL	NIL
Santi et al., 2021	RHM + F	NIL	1.5 % MP	170	3	14.5 % 7 Dysphagia 3 GERD	NIL	23.3 months
Uzunoglu et al.,2022	RHM + F	NIL	nil	165	3.6	NIL	NIL	55 months
Liu et al.,2022	RHM	NIL	1	127	1.5	NIL	1	NR
	LHM	2	13	107	3	NIL	4	NR
Romanzi et al.,2022	RHM + F	NIL	1 MP	115	3	NR	NR	6 months
Arcerito et al.2022	RHM +F	NIL	nil	105	NR	1 dysphagia	NR	157 months
	LHM + F	1	nil	158	NR	6 dysphagia	NR	157 months
Gass et al.,2022	RHM +F	NIL	nil	150	NR	66 % satisfation	NR	28 months
	LHM + F	NIL	nil	140	NR	87.5 % satisfation	NR	89 months
Engwall Gill et all.,2022	RHM +F	nil	5 MP	NR	1.5; 2.8 with perforation	NR	NR	NR
	LHM + F	nil	7 MP	NR	1.28; 3.4 with perforation	NR	NR	NR

Table 2 (continued). Perioperative outcomes

	Type of surgery	Conversion	Intraoperative complications	Operative Time	LOS	PO Symptoms	Re-operation	Follow-up
Khashab et al,2018	RHM +F	NR	9.6 %	263	NR	NR	NR	NR
	POEM	NR	19%	106	NR	NR	NR	NR
Kim et al, 2018	RHM +F	No	1 MP	158	2.02	1 dysphagia	NR	15 months
	LHM + F	3	4 MP	157	2.17	5 dysphagia	NR	15 months
Ali et al, 2020	RHM + F	No	0	184	1	NR	NR	NR
	LHM + F	2	3 MP	157	1	NR	NR	NR
	POEM	No	1 MP	169	1	NR	NR	NR
Pallabazer et al, 2020	RHM + F	NR	Nil	2.69 ±0.67 h	NR	5 dysphagia	NR	39 months

NIL Nothing; NR not reported; MP Mucosal perforation; GI: gastrointestinal; QoL: quality of life

Endosurgical, Cincinnati, USA), fenestrated bipolar forceps, bipolar Maryland dissectors and a monopolar cautery hook as energy devices (17-26).

Some authors insert a 30-mm Rigiflex® balloon (Boston Scientific) or bougie as guide during surgery (23-25). Our group use four 8-mm robotic ports, distanced at 8 cm, on the straight line 2 cm above the umbilicus and a 10-mm assistant port in the left midclavicular line below the two trocars (*Fig. 2*). The camera is inserted in port 3, prograsp forceps as liver retractor in port 1, fenestrated bipolar forceps in port 2 and cautery hook for myotomy or vessel sealer for short gastric vessels in port 4

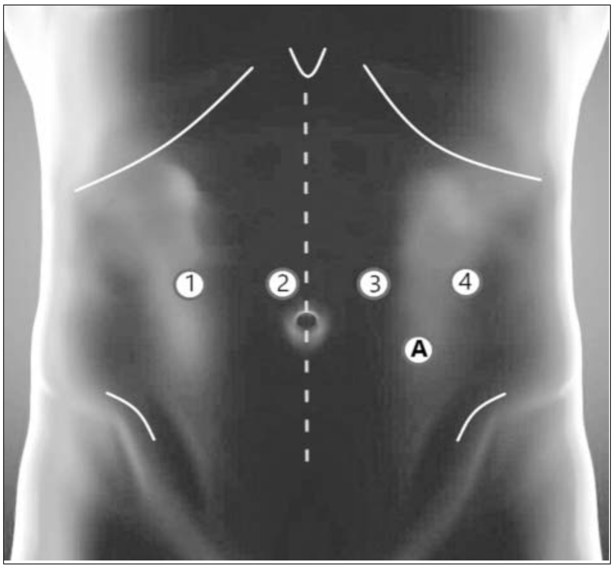

Figure 2. Robotic port position. 1) Prograsp forceps; 2) Fenestrated bipolar forceps; 3) Camera; 4) Cautery hook or vessel sealer; A) Atraumatic grasper.

(*Fig. 2*). After the exploration of esophago-gastric junction (EGJ), left lobe of liver is retracted by atraumatic grasper. During dissection of the phreno-esophageal ligament (Laimer-Bertelli membrane), identification of the vagus nerve is mandatory. Greater curvature dissection with short gastric vessels may be necessary to increase stomach mobilization and reduce tension during fundoplication. In the assistant port (A) we insert atraumatic grasper to straighten the stomach during the section of the phreno-esophageal ligament and sub-sequently the esophagus before the myotomy. The myotomy is performed with a cautery hook via sharp dissection on a low amperage. The length of the myotomy is still debated. Most authors perform a myotomy of 6 to 10 cm in length with 2-3 cm involving the gastric oblique fibers below the EGJ (17-21, 24-27). We obtain excellent short-term and long-term results with a myotomy of about 8 cm, of which 2-3 cm on the gastric side. Once the myotomy is completed, some authors use a methylene blue test to identify any iatrogenic mucosal leaks (21,22). An esophago-gastroduodenoscopy (EGDS) is routinely performed during surgery. The role of EGDS is to evaluate the length of myotomy, the passage through cardias and iatrogenic mucosal leak. As described in depth in the new technology paragraph, Romanzi et al used indocyanine green (ICG) instead of EGDS as a support to complete the myotomy and identify iatrogenic perforations (28).

A partial fundoplication is routinely

performed after myotomy. The fundoplication used are the anterior the anterior Dor (180 degree) or posterior Toupet (270 degree). Finally, Ballouhey et al showed a Heller myotomy (HM) in children with a Thal fundoplication by suturing the fundus on the right side of the myotomy (29).

Fundoplication

The Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) recommends a partial fundoplication after myotomy preventing the postoperative gastroesophageal reflux disease (GERD) (30,31). Two procedures are proposed to perform fundoplication for this surgery: the Toupet fundoplication, consisting of a posterior (270°) wrap, and the Dor fundoplication of an anterior (180°) wrap.

In laparoscopic surgery several studies have compared the Dor and Toupet fundoplication after myotomy (30-34). Rawlings et al. in their multicenter randomized controlled trial (RCT) found no difference in terms of postoperative symptoms or GERD between two fundoplications (32). These results were confirmed by other two RCT by two meta-analyses (31,33-35).

However, for robotic surgery, there are no studies comparing the two approaches. Many authors prefer Dor fundoplication for the protection of the exposed esophageal mucosa after myotomy. The gastric fundus is wrapped at the left edge of the myotomy with three detached stitches with 2-0 silk (17,21,23). The first upper stitch also includes the left diaphragmatic pillar (17,21,23). Then the stomach is wrapped anteriorly completely covering the esophageal myotomy with additional sutures between the gastric fundus and the right edge of the myotomy (17,21,23). In this case, the first superior suture includes the right diaphragmatic pillar (17,21,23). There is no need to perform posterior dissection with this fundoplication (18). Furthermore, Dor fundoplication reduces the torsion and migration of the stomach into the diaphragmatic hiatus, the inflammatory events and fibrosis at the EGJ (20,27,31,36,37).

In the literature, some authors have described good results with a robotic Toupet fundoplication following HM (27,38,39,40,41). According to these authors, this fundoplication improves postoperative reflux control and dysphagia (27,38,39,40). The dissection starts with the omentum minus over the lesser gastric curvature to the right diaphragm and continues posteriorly (27,38,39,40). The valve is performed with four stitches anchoring the gastric fundus either side of the myotomy (27, 38). The upper stitches join the valve to the hiatus (27,38).

Finally, Darwish et al showed in their retrospective single center study of 61 patients that Robotic Heller myotomy (RHM) without fundoplication improved dysphagia and long-term (4-55 months) acid reflux compared to RHM with Dor (42). However, these authors concluded with the need to perform RCTs (42).

In our opinion fundoplication is essential for this surgery. We perform a Dor-fundoplication because the Toupet in addition to increasing the operating time and bleeding risk, weakens the anatomy of the EGJ. We perform this plastic only in the simultaneous presence of a hiatal hernia.

Postoperative Management

The postoperative (PO) management of achalasia patients treated with RHM is similar to patients treated with LHM. PO pain is treated with analgesic medications, nausea and vomiting with intravenous antiemetics to avoid an increase in intra-abdominal pressure preserving the myotomy and fundoplication in the early PO period. Most authors perform an X-ray of the digestive tract with oral Gastrografin® on the first PO day (1POD) to evaluate the passage and the absence of mucosal leak (19,23,24,43). After radiographic check, drain and nasogastric tube (if placed) are removed and liquid diet starts on 1POD and semi-liquid diet on the second POD (17-20,23,24,43). We do not place the nasogastric tube and drainage. Length of stay is approximately three days, and the patients are discharged with semisolid diet avoiding meats and solid foods in the first 2 weeks (16,22). Similarly, our protocol agreed with gastroenterologists and nutritionists consists of a semi-liquid diet for 5 days after discharge and then starting a gradual solid diet. Within a month and gradually patients resumed a normal diet (17,36).

Robotic versus Laparoscopic Heller Myotomy

Minimally invasive surgery is the gold standard surgical approach for achalasia (16). Laparoscopic Heller Myotomy (LHM) was introduced about thirty years ago (44). Several studies describe the safety, low rate of postoperative complications, short-term and long-term efficacy of the laparoscopic approach (45-47). The myotomy associated with fundoplication reduces the risk of postoperative GERD (48-50). The intraoperative esophageal perforation rate is between 5 and 15% (51-53). Robotic surgery emerged as an evolution of laparoscopy, it is used successfully in many fields (54-56). In recent years many studies have compared the two methods, this comparison is heated in the literature. However, there are still few studies comparing RHM and LHM in achalasia.

Horgan et al, comparing the two approaches, found that robotic surgery had a lower rate of esophageal perforation (57). Similarly, other authors in their prospective study showed no difference between the two techniques except for a lower rate of esophageal leak in the robotic group (37,58). Shaligram et al. in their retrospective study analyzed 2683 patients who underwent open, laparoscopic, and robotic HM (59). These authors showed that there is no difference between robotic and laparoscopic surgery in terms of perioperative outcomes with higher costs in robotic approach (59). Some authors showed, in addition to a lower rate of esophageal perforations, a shorter length of hospital stay in the robotic group (39, 60). Maeso et al. in their systematic review and meta-analysis on efficacy of the Da Vinci® surgical system compared with laparoscopy analyses various surgeries including HM (61). They found only three studies and concluded that robotic surgery is associated with a lower risk of perforation and a better quality of life (61) (*Table 2*). Kim et al showed that both laparoscopic and robotic HM have given good results and few complications with robotic approach that allows a more complete myotomy (62).

In terms of operative time, there is generally no difference between the two methods. Arcerito et al in their study showed a longer operative time in the laparoscopic group, while in other authors it was longer in the robotic group (21,43,60).

Two recent systematic reviews with meta-analysis comparing robotic and laparoscopic approaches for the treatment of achalasia, showed that robotic surgery is associated with a lower rate of intraoperative mucosal leak with no difference in terms of long-term outcomes (52,63).

From the data in the literature, it seems that the RHM is safe, efficient and characterized by a reduction of the intraoperative perforation rate of the esophageal mucosa (19,22, 25,29,36,64). However, there is no difference in short- and long-term perioperative outcomes, because in most cases, mucosal leaks are identified and successfully repaired during LHM (19,22,25,29,36,52).

Finally, the high costs are an important aspect to consider (20,30,52,59). Prospective trials and RCTs should be performed to justify if the benefits outweigh the costs of robotic surgery (20,23,52).

RHM versus POEM

POEM is a technique developed in Japan in 2010 to perform endoscopic myotomy (65). This method is used successfully in the treatment of patients with type III achalasia because the length of the myotomy can be adjusted according to the results of the length of the spastic segment shown by HRM (6,16).

In literature there are not many studies comparing RHM and POEM. A retrospective single center review showed no difference in term of adverse events, clinical response rate or length of stay (40). However, the costs of POEM were significantly lower than RHM (40).

A retrospective study on patients with achalasia or other esophageal dysmotility disorder undergoing laparoscopic, robotically assisted, or POEM procedures between 2013 and 2017 showed higher rates of full-thickness injury in the laparoscopic approach compared to robotic technique and POEM (66). However, between the three groups, no differences were observed in terms of morbidity, length of stay, 30-day readmission rate, and mortality (66). The main limitation of the POEM is the increased risk of GERD compared to patients treated with Heller-Dor myotomy (40,41, 66,67). Finally, to redo surgery after HM both POEM and the robotic approach are safe and feasible (19).

Perioperative Outcomes

RHM may represent the future for the surgical treatment of achalasia. The result shows some advantages over classical minimally invasive approach.

The main observed advantage of this technique is the important reduction of iatrogenic mucosal leaks during myotomy (26,68, 69). The use of the robot can decrease this complication for three-dimensional visualization, a greater degree of instrumental freedom and better ergonomic conditions for the operator (30,44,70). Furthermore, increasing magnification helps identify small structures such as thin muscle fibers near the EGJ and refine myotomy (69). Moreover, the wristed instrumentation allows the surgeon to change the visual angle of the cautery hook or scissors avoiding parallax between camera and operating instrument, especially in a slim patient (23,69). Melvin et al. showed in their study of 104 patients over four years that RHM can be performed without major complications, including esophageal perforation (68). Many authors reported the absence of intraoperative esophageal perforations with robotic approach (25,26,38,68,69,71). Moreover, RHM is particularly safe in cases of reoperation because fibrosis and distorted anatomy increase the risk of iatrogenic injury (36). In most studies the operative time was greater than 130 minutes, almost zero conversion rate, and the hospital discharge was within 3 POD (18,20,24,28,29, 60, 61,68,69,71) (*Table 2*). Some authors reported an average length of stay of 1.5 days, others up to 5 days (20,28,37,61) (*Table 2*).

Finally, good results are described in terms of postoperative complications, Eckardt score decrease, GERD control and improvement of manometric parameters both in the short and long term (20,25,28,60).

Redo Surgery

After treatment for primary achalasia, recurrence of symptoms occurs in approximately 10-20% of patients (7). Guidelines and literature evidence do not establish the most appropriate treatment after failed HM (6,15). Revisional surgery seems to have similar functional results to primary treatment but higher risk of complications, particularly for mucosal esophageal perforation (72). In these cases, robotic surgery, if performed by experienced surgeon, can be a valid alternative to other methods such as pneumatic dilatation or POEM. High-defnition magnifed view, 3D stereoptic visualization, EndoWrist instruments and surgeon ergonomics allow a safe and accurate redo surgical myotomy. Adhesiolysis and more careful dissection are needed for altered anatomy of EGJ and cautery hook with a reduced coag power setting is useful. Any perforation during the myotomy can be promptly repaired with interrupted stitches absorbable (18, 36). However, future prospective trials are needed to better evaluate the role of robotic platform for redo HM.

New Technologies

Emerging technologies in the surgical scenario concern the use of supports such as ICG, intraoperative endoscopy, artificial intelligence (AI), and new types of robotic/laparoscopic approaches (70,73).

The use of ICG for fluorescence-guided intraoperative assessment of myotomy could reduce margins of error and complications (29,74). The esophageal myotomy technique remains the same, the accuracy is high, allowing to bypass intra-operative and post-operative checks in a safer way.

Romanzi et al reported preliminary data about intraoperative use of ICG. They injected 4 ml of the prepared solution (6.4 mg of ICG) intravenously (28). The robotic system used was the da Vinci Si® (Intuitive Surgical Inc.) (29). This system is equipped with the Firefly® mode to acquire near-infrared (NIR) fluorescent images: a simple click allows the surgeon to switch between visible light and NIR imaging (29). Fluorescence imaging, with the magnified robotic view, can be helpful to perform a more accurate myotomy visualizing no vascularized remnant muscular fibers and to exclude iatrogenic micro-perforations intra-operatively showing hypoperfused ischemic areas (29). The use of the ICG could be an alternative to the use of intraoperative endoscopy reducing the operative time (29).

A new type of robotic surgical approache in the treatment of esophageal motility disorders such as achalasia could be the use of a single port, which reduces docking times and post-operative complications related to multiple accesses. Some authors showed excellent results in LHM with the use of single access (75,76). Miyazaki et al found out that in approximately 27% of cases it was not necessary to add additional ports (76). All patients showed uneventful postoperative recovery and clinical improvement of their preoperative symptoms with satisfactory cosmetic outcome (76).

AI and computer vision allows simultaneous vision and the superimposition of different diagnostic parameters that help the operator to choose the best approach mode.

Currently AI is widely used in the diagnostic field for esophageal motility disorders, the first approaches during operation and endoscopy have wide margins of use and improvement.

The limits of these new technologies, at present, are represented by a valid use. Discernment and know-how play a fundamental role in the correct application of technology.

Limitations

Despite the advantages described, RHM still has some limitations. The main ones of these are still the very high costs, as shown by Shaligram et al. in their multicenter retrospective analysis utilizing a large administrative database (59). Furthermore, robotic platforms are not yet accessible everywhere. It is hoped that robotic surgery will soon be more accessible and that structures will be able to train more surgeons.

Conclusion

The strength of this systematic review is to evaluate robotic surgery for the treatment of achalasia in every aspect by analyzing in detail all the articles present in the literature on this topic. The review of literature showed that RHM with partial fundoplication is safe and comfortable for the surgeon. It allows the achievement of narrow anatomical structures such as the EGJ, enhanced visualization and accurate dissection with low rate of intra-operative and postoperative complications (particularly esophageal perforation). Finally, robotic surgery is a valid alternative to other minimally invasive approaches and could become the procedure of choice in the treatment of achalasia especially with the cost reduction. However, RCTs should be performed to evaluate long-term functional outcomes.

Conflict of Interest

The authors declare that they have no conflict of interests.

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Ethics Statement

This study is in accordance with the ethical standards of the institutional research committee

Author's Contributions

GP: study conception, data acquisition, writing and final approval of the draft; MC, RB, GS, AF and PA: writing and editing; MM and GDDP: final approval and editing, GA: study conception, writing-review, editing and final approval.

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