Review Article

Comparison of laparoscopic *vs*. robotic paraesophageal hernia repair: a systematic review

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Background: In both clinical practice and residency training, the use of robotic platforms in surgery is becoming more common. The aim of this study was to perform a systematic review of the perioperative outcomes of robotic and laparoscopic paraesophageal hernia (PEH) repair.

Methods: The PRISMA statement guidelines were used to perform this systematic review. We conducted a database search which included Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, and Daily, Ovid EMBASE, Ovid Cochrane Central Register of Controlled Trials, Ovid Cochrane Database of Systematic Reviews, and Scopus. There were 384 articles discovered in the initial search using various keywords. From those 384 articles, after duplicates were removed and publications were eliminated based on eligibility criteria, 7 publications were then chosen for analysis. Risk of bias was assessed using Cochrane Risk of Bias Assessment Tool. Narrative synthesis of results has been provided.

Results: When compared to standard laparoscopic approaches, robotic surgery for large PEHs may offer benefits in terms of decreased conversion rate and shorter hospital stay. Some studies found a decrease in need for esophageal lengthening procedures and fewer long-term recurrences. The perioperative complication rate is similar between the two techniques in most studies; however, one large study of nearly 170,000 patients in the early years of robotics adoption demonstrated a higher rate of esophageal perforation and respiratory failure in the robotic group (2.2% increase in absolute risk). Cost is another disadvantage of robotic repair when compared to laparoscopic repair. Our study is limited by the non-randomized and retrospective nature of the studies.

Conclusions: More studies into recurrence rates and long-term complications are needed to determine the efficacy of robotic versus laparoscopic PEHs repair.

Keywords: Paraesophageal hernia (PEH); hiatal hernia (HH); diaphragmatic hernia; laparoscopy; laparoscopically; robotic surgery; robotic-assisted

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Introduction

A hiatal hernia (HH) is the herniation of abdominal contents into the mediastinum through the diaphragm. There are four types of HHs (I–IV) (1,2). Paraesophageal hernia (PEH) is a rare (5–10% of all HHs) type of HH, in which the abdominal viscera herniates through the dilated diaphragmatic hiatus along with the esophagus (2,3). The incidence of PEH increases with age, thus with an aging population an increase in the overall incidence of PEH may be expected (3). Treatment options range from watchful waiting, pharmacological management for symptom control, and surgical repair (1,4). A wide array of surgical techniques to repair PEH have been developed. With the advent of minimally invasive surgery (MIS), there has been an overall improvement in patient outcomes in terms of morbidity and mortality when compared to trans-thoracic and trans-abdominal open surgical procedures (5,6). The first laparoscopic PEH repair was performed in 1990 and over the years, it has become the gold standard surgical treatment choice for PEH (3,7). Despite ongoing advancements in laparoscopic instruments, there still are technical challenges which surgeons can encounter, such as limited mobility to work in small spaces and reach challenging angles, 2-D image visualization, and suboptimal camera handling or motion (4,6). To overcome some of the shortcomings of laparoscopic surgery, robotic surgical solutions have been developed. These modalities have a unique set of advantages over traditional laparoscopic MIS, including improved mobility to work in small spaces to reach challenging angles, improved ergonomics, and 3-D image visualization. However, robotic surgery has its own disadvantages, such as longer operative time and increased cost and complexity (8). Though laparoscopic PEH repair is generally considered superior to the open approach, the increasing popularity of robotic PEH repair has led to a debate on which approach represents the optimal form of MIS (5). There is limited data on laparoscopic versus robotic PEH repair and no known randomized controlled trials. The aim of this study was to compare laparoscopic versus robotic PEH repair with regards to perioperative outcomes. We present the following article in accordance with the PRISMA reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-819/rc).

Highlight box

Key findings

- Robotic paraesophageal hernia repair may result in similar, if not improved, outcomes compared to laparoscopic repair in terms of patient satisfaction, hospital stay, conversion rate, and ability to perform difficult cases. This technique, however, is associated with higher costs and potentially a higher rate of perioperative complications, especially for those early on in their robotic experience.

What is known and what is new?

- Laparoscopic paraesophageal hernia repair is currently considered the gold standard, with a recent paradigm shift in minimally invasive surgery towards robotic paraesophageal hernia repair.
- We reported the first systematic review comparing robotic and traditional laparoscopic paraesophageal hernia repair.

What is the implication, and what should change now?

- Robotic paraesophageal hernia repair is safe and feasible.
- Further prospective studies and/or clinical trials should be conducted to compare the robotic and laparoscopic paraesophageal hernia repair.

Methods

A comprehensive search of several databases from each database's inception to May 11th, 2022, in English was conducted. The databases included Ovid MEDLINE(R) and Epub Ahead of Print, In-Process & Other Non-Indexed Citations, and Daily, Ovid EMBASE, Ovid Cochrane Central Register of Controlled Trials, Ovid Cochrane Database of Systematic Reviews, and Scopus. The search strategy was designed and conducted by a researcher with input from the study's principal investigator, and no help was sought from a biomedical librarian. Controlled vocabulary supplemented with keywords was used to search for robotic *vs.* laparoscopic PEH repair in humans, keywords used: "esophageal hernia", "hiatal hernia", "hiatus hernia", "oesophageal hernia", "paraesophageal hernia", "paraoesophageal hernia", "Robotic Surgery", "Robotic Surgical", "robot*", "Laparoscopy", "keyhole" or "key-hole" or "Laparoscop*" or "minimally invasive surg". This search eventually yielded 384 articles. The actual strategy listing all search terms used and how they are combined is available in the appendix (see Appendix 1).

The inclusion and exclusion criterion were as follows. Studies were included using the following criteria: (I) all articles related to PEH repair; (II) peer reviewed articles; (III) articles published in the last 10 years; (IV) articles in English; (V) full text articles; (VI) study population—humans; (VII) age—above 18 years. Studies were excluded using the following criterion: (I) papers unrelated to PEH repair; (II) non peer reviewed articles including grey literature (master's thesis, white papers); (III) unpublished literature including abstracts, conference abstracts; (IV) articles older than 10 years; (V) articles not in English; (VI) articles on pediatric patient population. After applying the inclusion and exclusion criteria, we were left with 7 articles. Assessment for bias and risk was done using Cochrane Risk of Bias Assessment Tool and Newcastle-Ottawa Scale, respectively. Data analysis of demographics and perioperative outcomes such as operative time, intraoperative complications, length of stay, perioperative complications and mortality, recurrence, cost, and patient

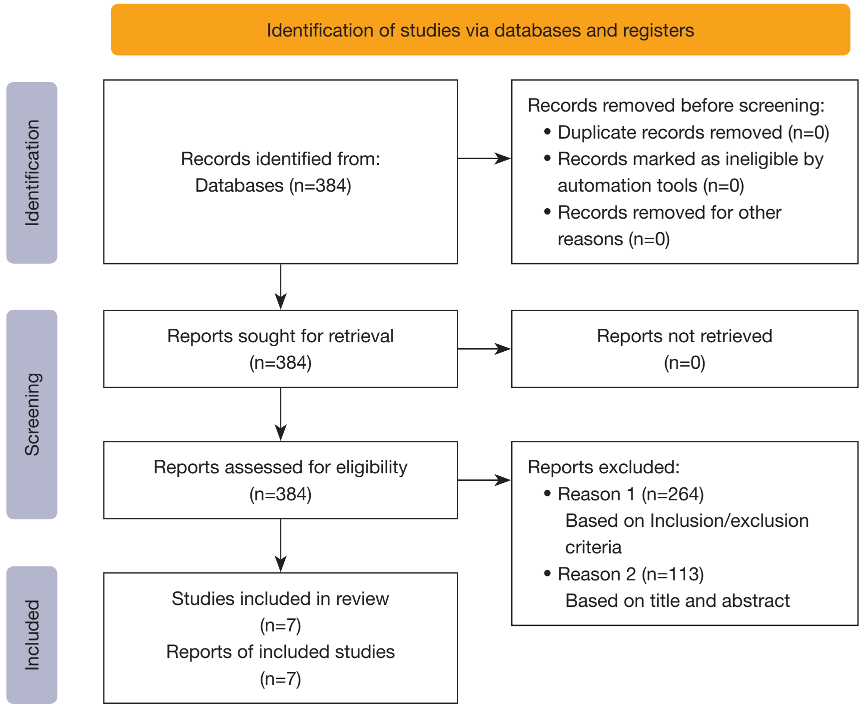

Figure 1 PRISMA flow chart.

reported outcomes from all the studies were included in this systematic review using a narrative synthesis approach.

Results

We retrieved a total of 384 published articles during the initial search. After removing duplicates and eliminating publications based on eligibility criteria, 7 studies were selected for analysis from a total of 384 articles found in the database search (*Figure 1*).

Synthesis of results

Narrative synthesis has been provided for the findings obtained from the studies. The data extracted has been presented in a tabular form in *Table 1*.

Ultimately our review included 171,093 patients from seven observational studies. Generally, in these studies, retrospective analysis of prospectively collected data was being used to identify patients undergoing PEH repair either laparoscopically or robotically. This data was then used to compare their perioperative outcomes. Demographics, clinical characteristics, and perioperative outcomes from the included studies are given in *Table 2*.

Operative time/intraoperative complications

In a prospective comparative clinical study by Wilhelm *et al.*, 55 patients underwent complete upside-down stomach (cUDS) hernia (subgroup of HH) repair. The median operation time was significantly higher for robotic approach *vs.* laparoscopic approach (232 *vs.* 163 min) (9). Similarly, longer operative time [median (IQR), 186.5 (152.0, 232.0) *vs.* 158.0 (132.0, 188.0) min; P≤0.001] was seen in the study by Soliman *et al.*, whereas Gerull *et al.*, found a statistically significant shorter operative time in robotic PEH repair [mean (SD), 174.1 (±63.8) *vs.* 187.3 (±65.3) min; P≤0.001] (12,13). On the other hand, two studies found no difference in the operative times between robotic and laparoscopic approach (10,11). One study noted a higher rate of intraoperative complications for a robotic approach as compared to a laparoscopic approach (0.6% *vs.* 2.7%, P<0.001) (6).

Length of stay

A significant decrease was found in the length of hospital stay following robotic PEH repair as opposed to laparoscopic PEH repairs (11-13). Four studies denote no

Table 1 Summary of findings from studies comparing robotic and laparoscopic PEH repair

Name	Study	Type of study	Population	Intervention	Comparison	Outcome	Quality assessment
Short-Term Outcomes in Patients Undergoing Paraesophageal Hiatal Hernia Repair	Howell *et al.*, April 2020 (2)	Retrospective	128 cases of isolated HH repair from January 2012 through April 2017	84 laparoscopic hiatal hernia repairs; 44 robotic hiatal hernia repairs	30-day outcomes, e.g., 1. LOS; 2. readmissions; and 3. reoperations; 4. complications	Length of stay for laparoscopic and robotic: 1.0 day (1.0–3.0) and 2.0 days (1.0–2.5); P=0.483; thirty-day readmission occurred in 9 patients, 7 (8.3%) laparoscopic and 2 (4.6%) robotic; P=0.718; two 30-day reoperations occurred, both laparoscopic; P=0.545; no increased risk of 30-day readmission or complications. Associated with minimally invasive HH repair	NOS: 6 stars
Complications Following Robotic Hiatal Hernia Repair Are Higher Compared to Laparoscopy	Ward *et al.*, Dec 2021 (8)	Retrospective	168,329 patients underwent laparoscopic or robotic paraesophageal hernia repairs, Jan 2010–Sep 2015	158,432 laparoscopic PEH repair; 9,897 robotic PEH repair	1. Mortality; 2. post-operative complications; and 3. length of stay; 4. total charges	Overall adjusted rate of complications in robotic PEH repair vs laparoscopic PEH OR (95% CI): 1.17 (1.07, 1.27). Robotic hiatal hernia repairs—increased length of stay and increased charges	NOS: 6 stars
Robot-assisted *vs.* laparoscopic repair of complete upside-down stomach hiatal hernia (the RATHER-study): a prospective comparative single center study	Wilhelm *et al.*, July 2022 (9)	Prospective, comparative clinical study	55 patients' cUDS hernias (subgroup of HH), July 2015 and June 2019	19 laparoscopic cUDS hernias repair; 36 robotic cUDS hernias repair	1. Intra-and postoperative complications; 2. 30-day morbidity; and 3. mortality; 4. recurrence; 5. quality of life	Robot-assisted surgery clinical outcome is equal to that obtained by standard laparoscopic surgery	NOS: 8 stars
Robotic-assisted paraesophageal hernia repair--a case-control study	Gehrig *et al.*, July 2013 (10)	Retrospective, case control	42 patients with PEH from 2003 to 2007	13 open surgery PEH repairs; 17 conventional laparoscopic PEH repairs; 12 robotic PEH repairs	1. Operating time; 2. intraoperative blood loss; 3. intra- and postoperative complications; 4. mortality; and 5. readmission within 30 days of discharge	Operating time robotic group—longer (38 min); intraoperative blood loss lower (217 mL) compared to OS. Similar to the CLS group; intraoperative complication rate similar in all groups; postoperative complication rate in the RAS group similar to the CLS group; hospital stay similar to the CLS group	NOS: 6 stars
Robotic Versus Laparoscopic Approach to Hiatal Hernia Repair: Results After 7 Years of Robotic Experience	O'Connor *et al.*, Sept 2020 (11)	Retrospective observational cohort study	392 cases of HH repair from 2006 through 2019	278 laparoscopic hiatal hernia repairs; 114 robotic hiatal hernia repairs	1. Operative; 2. demographic; and 3. outcomes data were compared between laparoscopic and robotic groups	No significant difference in median operative time; need for reoperation, or readmission to the hospital; perioperative complication rate; laparoscopic repairs—longer LOS—than robotic repairs (3.3 *vs.* 2.3 days, respectively; P=0.003); recurrence rates at 1 year lower after robotic repair (13.3% *vs.* 32.8%; P=0.008)	NOS: 5 stars
Robot-assisted hiatal hernia repair demonstrates favorable short-term outcomes compared to laparoscopic hiatal hernia repair	Soliman *et al.*, July 2020 (12)	Retrospective	293 consecutive patients who underwent elective hiatal hernia repair	151 laparoscopic hiatal hernia repairs; 142 robotic hiatal hernia repairs	1. Previous hiatal hernia repair; 2. postoperative complications; 3. hospital LOS; 4. mortality; and 5. duration of hospital stay	Higher ASA III and IV (7.9% *vs.* 4.2%, P=0.03); hospital stay was significantly shorter (1.3±1.8 *vs.* 1.8±1.5 days, P=0.003); lower rates of complications (6.3 *vs.* 19.2%, P=0.001) after robotic compared to laparoscopic hiatal hernia repair; no difference—readmission rate, mortality	NOS: 6 stars
Favorable peri-operative outcomes observed in paraesophageal hernia repair with robotic approach	Gerull *et al.*, June 2021 (13)	Retrospective	1,854 patients underwent PEH repair from January 2009–December 2019	1,024 laparoscopic PEH repair; 830 robotic PEH repair	1. Operative time; 2. conversion to open; 3. need for an esophageal lengthening procedure; 4. operative equipment costs; and 5. LOS	Robotic PEH repair—a significant reduction in esophageal lengthening procedures performed (0.1% *vs.* 11.0%; P<0.001); conversion to open (0% *vs.* 7.0%; P<0.001), and LOS (1.8 days *vs.* 3.1 days; P<0.001); intra-operative equipment costs were similar	NOS: 5 stars

PEH, paraesophageal hernia; HH, hiatal hernia; cUDS, complete upside-down stomach; LOS, length of stay; OS, overall survival; CLS, conventional laparoscopic surgery; RAS, robotic assisted surgery; ASA, American Society of Anesthesiologists; OR, odds ratio; CI, confidence interval; NOS, Newcastle-Ottawa Scale.

Table 2 Demographics, clinical characteristics, and perioperative outcomes from studies comparing robotic and laparoscopic PEH repair

Outcomes	Gehrig T (n=42) (10)				Soliman BG (n=293) (12)			Howell RS (n=128) (2)			Gerull WD (n=1,854) (13)			Wilhelm A (n=55) (9)			O'Connor SC (n=382) (11)			Ward M (n=168,329) (8)		
	Robotic	Laparoscopic	Open	P value (RAS *vs.* CLS)	Robotic	Laparoscopic	P value	Robotic	Laparoscopic	P value	Robotic	Laparoscopic	P value	Robotic	Laparoscopic	P value	Robotic	Laparoscopic	P value	Robotic	Laparoscopic	P value
Age (years)	68.1±7.9	60.2±11.8	64.9±15.4	0.084	61.0	63.0	0.11	63 (51.5–72.5)	61 (50–70.5)	0.392	65.1 (±13.1)	63.1 (±14.2)	<0.001	71 [44–90]	76 [44–91]	0.12	Not statistically significant		0.099	59.1 (15.2)	54.9 (15.7)	<0.01
Sex (female) (%)	75	29.4	53.8	0.253	72.7	73.5	0.75	68.2	69	1.000	64.7	67.1	0.280	64	74	0.55	More females		–	76.0	77.3	0.15
Operation time (minutes), mean ± SD or median (IQR)	172±31	168±42	134±52	0.785	186.5 (152.0, 232.0)	158.0 (132.0, 188.0)	<0.001	–	–	–	174.1 (±63.8)	187.3 (±65.3)	<0.001	232 [145–420]	163 [112–280]	<0.001	Median 179	Median 175	0.681	–	–	–
Intraoperative complications (%)	8.3	5.9	7.7	1.0	–	–	–	–	–	–	0.6	2.7	<0.001	12.5	26	0.28	–	–	–	–	–	–
Length of stay (days), mean ± SD or median (IQR)	7.8±3.9	6.5±1.6	12.4±3.7	0.272	1.3 (±1.8)	1.8 (±1.5)	0.003	2.0 (1.0–2.5)	1.0 (1.0–3.0)	0.483	1.8 (±0.6)	2.9 (±1.4)	<0.001	8.5 [4–21]	8 [4–15]	0.96	Median 3.3	Median 2.3	0.003	Not statistically significant		–
Peri-operative complications (%)																						
Post-operative complications	8.3	11.8	46.2	0.765	6.3	19.2	0.001	13.6	11.9	0.784										–	–	–
Intraoperative + postoperative complications	16.7	17.6	58.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Overall complications	–	–	–	–	–	–	–	–	–	–	–	–	–	36	2	0.36	Not statistically significant		0.86	Odds ratio [95% CI] 1.17 [1.07; 1.27]		–
Perioperative mortality	0	0	0	–	0	0	–	0	0	–	0	0.5%	0.104	0	0	–	Not statistically significant		0.86	Odds ratio [95% CI] 1.42 [0.56; 3.60]		–
Postoperative results (%)																						
30-day Reoperation (%)	–	–	–	–	2.0	0.7	0.62	0	2.4	0.54	0.2	0.8	0.114	0	0	–	Not statistically significant		0.21	–	–	–
Readmission within 30 days of discharge	–	–	–	–	3.5	4	0.84	4.6	8.3	0.718	–	–	–	–	–	–	Not statistically significant		0.38	–	–	–
Recurrence	–	–	–	–	–	–	–	–	–	–	–	–	–	6	0	0.53	Median 13.3	Median 32.8	0.008	–	–	–
Expenses intra-operative equipment costs (USD)	–	–	–	–	–	–	–	–	–	–	2147 (±312.5)	2058 (±345.5)	0.012	–	–	–	–	–	–	–	–	–
Patient satisfaction	–	–	–	–	–	–	–	–	–	–	–	–	–	100%	100%	–	–	–	–	–	–	–
GERD-HRQL-score (median, IQR)	–	–	–	–	–	–	–	–	–	–	–	–	–	0 (0–20)	1 (0–2)	0.79	–	–	–	–	–	–

PEH, paraesophageal hernia; RAS, robotic-assisted surgery; CLS, conventional laparoscopic surgery; SD, standard deviation, IQR, interquartile range.

Table 3 Risk of bias assessment

Study	Selection bias, random sequence generation	Allocation concealment	Reporting bias	Performance bias, blinding participants and personnel	Detection bias, blinding outcome	Attrition bias	Others
Gehrig *et al.*, July 2013 (10)	High risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk
Soliman *et al.*, July 2020 (12)	High risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk
Howell *et al.*, April 2020 (2)	High risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk
Gerull *et al*., June 2021 (13)	High risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk
Wilhelm *et al.*, July 2022 (9)	High risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk
O'Connor *et al.*, Sept 2020 (11)	High risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk
Ward *et al.*, Dec 2021 (8)	High risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk

difference and even a possible increase in hospital stay in robotic PEH repair, but all these findings were statistically insignificant (2,8-10).

Perioperative complications/mortality

A retrospective study by Ward *et al.*, among 168,329 patients undergoing PEH repair between 2010–2015 reported overall adjusted rate of complications to be significantly higher in robotically assisted patient's *vs.* laparoscopic surgery, even in high-volume centers (8). Postoperative complication rates in the robotic surgery group were similar to the laparoscopic surgery group in one study, but a higher postoperative complication rate was associated with laparoscopic technique in another (10,12). A retrospective study by Soliman *et al.*, on 293 patients who underwent elective PEH repair found significant reductions in complication rates in the robotic surgery group (6.3 *vs.* 19.2%), whereas three other studies state no significant difference in postoperative complication rate (2,10,11). No statistical difference was found in reoperations, readmission rates and mortality between the modes of MIS (2,11,12).

Recurrence

A yearlong follow up showed significantly lower recurrence rates after robotic repair (13.3% *vs.* 32.8%). Consideration needs to be made regarding mean follow up differences between robotic approach *vs.* laparoscopic approach (23.7±28.4 *vs.* 15.1±14.9 months) (11). Robotic PEH repair was associated with a significant decrease in esophageal lengthening procedures being performed (0.1% *vs.* 11.0%), and conversion to open procedures (13).

Cost

Intraoperative costs were similar between robotic *vs.* laparoscopic repairs, whereas higher costs overall were associated with robotic PEH repairs (8,13).

Patient-reported outcomes

Patients in the study by Wilhelm *et al.* had similar GERD-HRQL scores regardless of the approach to repair PEH (9).

Risk of bias assessment

The Cochrane Risk of Bias Assessment Tool was used to assess the risk of bias. Individual factors from five domains are given a score (high, low, or unclear) to determine bias (selection, performance, attrition, reporting, and other). Using the guidance provided at the end of the form, risk of bias was selected as "high", "low" or "unclear" for each judgment. A detailed description about the risk of bias assessment is provided in *Table 3*.

Discussion

One large 2012 study demonstrated that minimally invasive techniques account for 80% of surgical interventions for PEH (14,190 out of 17,830 procedures) (5). The advantages of MIS over open surgery include decreased pain, faster postoperative recovery, and lower morbidity. Over the last three decades, a laparoscopic approach for HH repair has become the gold standard procedure. Robotic surgery has been gaining popularity ever since the Food and Drug Administration (FDA) approved the DaVinci robotic surgical system for clinical use in the year 2000. Improved visualization, ergonomics, and additional degrees of freedom of the instrumentation has resulted in accelerating usage of robots in numerous surgical subspecialties. Despite these advantages, the entrance of robotic techniques into these different surgical subspecialties has not always resulted in improved outcomes (14,15).

The focus of our work was to compare robotic and laparoscopic PEH repair in the existing literature. Given the lack of any randomized trials comparing laparoscopic and robotic PEH repair, we decided to conduct a systematic review, which included seven articles with a total of 171,093 patients (160,005 laparoscopic repairs and 11,075 robotic repairs) published between 2012 and 2022. Patient demographics were similar to the previous studies including an average age 63.7 year and sex with female preponderance, making up to 67.5% of the study population (16), making our study results applicable to the typical patient population presenting for PEH; 168,329 of these patients were included in a single study, which deserves further comment (8). In this study, the difference in perioperative complication rate was driven mainly by an increased risk of esophageal perforation (OR 2.19, 95% CI: 1.42–3.93) and respiratory failure (OR 1.68, 95% CI: 1.37–2.05). The increased complication rate applied to even high-volume centers (defined by >20 operations/year), however the clinical significance of a 12.6% *vs.* 10.4% overall complication rate among high-volume centers is likely minimal. In addition, the years 2010–2015 would be considered relatively early in the worldwide experience of robotic PE repair, given that the earliest series of robotic PEH repair were published in 2008 (17,18). Nonetheless, this large, "real world" study demonstrates that robotic PEH repair may have some disadvantages, especially for those early in their experience.

Most of the other studies we analyzed, however, showed comparable if not favorable perioperative outcomes when comparing robotic to laparoscopic surgery (19-21). Robotic PEH repair demonstrated equivalent or superior hospital length of stay, compared to laparoscopic PEH repair. Perioperative outcomes were generally similar as a whole, though individual studies did show an improved complication rate, decreased conversion rate, lower recurrence rate, and decreased rate of esophageal-lengthening procedures in the robotic group compared to the laparoscopic group. Laparoscopic redo PEH repair conversion rates have been reported to be as high as 11% in the literature (13,16). Prior HH repair was more likely in robotic cases in four of the studies, and all of the studies in which this variable was reported (Howell, 20.4% *vs.* 5.9%, P=0.042; Soliman, 21% *vs.* 7.9%, P<0.00; Gerull, 32.5% *vs.* 24.2%, P<0.001; O'Connor, 24% *vs.* 12.9%, P=0.08) (2,6,11,12). The fact that near equivalent perioperative results were achieved in the robotic cohort in spite of a higher likelihood of reoperative PEH repair should be noted.

Limitations of our study include the non-randomized and retrospective nature of the studies included; therefore, selection bias could play a role in terms of influencing the results. Selection bias could favor either robotic or laparoscopic PEH repair; it was impossible to determine the relative size or complexity of hernias in patients who underwent robotic *vs.* laparoscopic PEH repair. One could argue that surgeons would be more likely to offer repair to patients with more sizeable hernias on the robotic platform, which has some advantages in terms of camera maneuverability (a significant concern in PEH repair, which is a transabdominal operation that takes place primarily in the chest) and control of retraction (no need for a potentially inexperienced assistant to retract). On the other hand, it is possible that surgeons early in their robotic experience may have preferred to perform "difficult" cases laparoscopically. A significant learning curve may be seen when transitioning toward robotic surgery. Unsurprisingly, shorter operative times are linked with an increased number of operations performed by a surgeon (22,23). The study by Lin *et al.*, describe the transition into three phases. Phase 1 included cases 1 to 40 and had an increasing console time (CT). Phase 2, the improvement phase included cases around 41 to 84, and reflected a plateau in terms of CT. Phase 3, the mastery stage was seen at around 85 cases with a decrease in CT (22). These learning curves should be kept in mind while comparing laparoscopic and robotic approaches. Many robotic studies reflect the entire experience of the investigators, which includes cases done in the early and improvement phases cited above.

Another weakness is the inability to control for inter-operator variability between different providers in different studies (10,22). In addition, there could be an era effect that partially explains some of the improved outcomes seen in robotic PEH repair. Generally speaking, surgeons are more likely to transition from laparoscopic PEH repair to robotic PEH repair than from robotic to laparoscopic; therefore, lessons learned and experience gained over time with regards to both intraoperative conduct of PEH repair and perioperative management would be more likely to favor robotic approaches.

Finally, due to the small number of studies for this research question, heterogeneity and sensitivity analyses for comparison of variables between the studies was not feasible.

As in many other procedures, robotic surgery is increasingly utilized for PEH repair; for now, however, the existing evidence shows that most perioperative outcomes are comparable between the robotic and laparoscopic approaches.

Conclusions

When compared to traditional laparoscopic techniques, robotic surgical treatment of PEH may provide the surgeon with enhanced dexterity and comparable outcomes. Current evidence generally demonstrates that robotic HH repairs may be linked to a decrease in hospital stay, lower recurrence rate, fewer conversions to open, and less of a need for esophageal lengthening procedures. Conversely, PEH repairs may be associated with higher complication rates and overall cost. More studies, ideally in a randomized fashion, are needed to compare laparoscopic and robotic PEH repair. Given the fact that equipoise between the two techniques is unlikely for any given surgeon or even institution, however, assessing these competing methods may depend on large, multi-center propensity-matched cohorts studies.

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Footnote

Reporting Checklist: The authors have completed the PRISMA reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-819/rc

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-819/coif). BW serves as an unpaid editorial board member of *Journal of Thoracic Disease* from October 2022 to September 2024. The other author has no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. Staerkle RF, Rosenblum I, Köckerling F, et al. Outcome of laparoscopic paraesophageal hernia repair in octogenarians: a registry-based, propensity score-matched comparison of 360 patients. Surg Endosc 2019;33:3291-9.
2. Howell RS, Liu HH, Petrone P, et al. Short-Term Outcomes in Patients Undergoing Paraesophageal Hiatal Hernia Repair. Sci Rep 2020;10:7366.
3. Ceccarelli G, Pasculli A, Bugiantella W, et al. Minimally invasive laparoscopic and robot-assisted emergency treatment of strangulated giant hiatal hernias: report of five cases and literature review. World J Emerg Surg 2020;15:37.
4. Galvani CA, Loebl H, Osuchukwu O, et al. Robotic-Assisted Paraesophageal Hernia Repair: Initial Experience at a Single Institution. J Laparoendosc Adv Surg Tech A 2016;26:290-5.
5. McLaren PJ, Hart KD, Hunter JG, et al. Paraesophageal Hernia Repair Outcomes Using Minimally Invasive Approaches. JAMA Surg 2017;152:1176-8.
6. Gerull WD, Cho D, Kuo I, et al. Robotic Approach to Paraesophageal Hernia Repair Results in Low Long-Term Recurrence Rate and Beneficial Patient-Centered Outcomes. J Am Coll Surg 2020;231:520-6.
7. Davila DG, Stetler JL, Lin E, et al. Laparoscopic Paraesophageal Hernia Repair and Pulmonary Embolism. Surg Laparosc Endosc Percutan Tech 2019;29:534-8.
8. Ward MA, Hasan SS, Sanchez CE, et al. Complications Following Robotic Hiatal Hernia Repair Are Higher Compared to Laparoscopy. J Gastrointest Surg 2021;25:3049-55.
9. Wilhelm A, Nocera F, Schneider R, et al. Robot-assisted vs. laparoscopic repair of complete upside-down stomach hiatal hernia (the RATHER-study): a prospective comparative single center study. Surg Endosc 2022;36:480-8.
10. Gehrig T, Mehrabi A, Fischer L, et al. Robotic-assisted

paraesophageal hernia repair--a case-control study. Langenbecks Arch Surg 2013;398:691-6.
11. O'Connor SC, Mallard M, Desai SS, et al. Robotic Versus Laparoscopic Approach to Hiatal Hernia Repair: Results After 7 Years of Robotic Experience. Am Surg 2020;86:1083-7.
12. Soliman BG, Nguyen DT, Chan EY, et al. Robot-assisted hiatal hernia repair demonstrates favorable short-term outcomes compared to laparoscopic hiatal hernia repair. Surg Endosc 2020;34:2495-502.
13. Gerull WD, Cho D, Arefanian S, et al. Favorable peri-operative outcomes observed in paraesophageal hernia repair with robotic approach. Surg Endosc 2021;35:3085-9.
14. Lane T. A short history of robotic surgery. Ann R Coll Surg Engl 2018;100:5-7.
15. Tagkalos E, Goense L, Hoppe-Lotichius M, et al. Robot-assisted minimally invasive esophagectomy (RAMIE) compared to conventional minimally invasive esophagectomy (MIE) for esophageal cancer: a propensity-matched analysis. Dis Esophagus 2020;33:doz060.
16. Colavita PD, Belyansky I, Walters AL, et al. Nationwide inpatient sample: have antireflux procedures undergone regionalization? J Gastrointest Surg 2013;17:6-13; discussion p.13.
17. Dunnican WJ, Singh TP, Guptill GG, et al. Early robotic experience with paraesophageal hernia repair and Nissen fundoplication: short-term outcomes. J Robot Surg 2008;2:41-4.
18. Draaisma WA, Gooszen HG, Consten EC, et al. Mid-term results of robot-assisted laparoscopic repair of large hiatal hernia: a symptomatic and radiological prospective cohort study. Surg Technol Int 2008;17:165-70.
19. Markar SR, Karthikesalingam AP, Hagen ME, et al. Robotic vs. laparoscopic Nissen fundoplication for gastro-oesophageal reflux disease: systematic review and meta-analysis. Int J Med Robot 2010;6:125-31.
20. Melvin WS, Needleman BJ, Krause KR, et al. Computer-enhanced vs. standard laparoscopic antireflux surgery. J Gastrointest Surg 2002;6:11-5; discussion 15-6.
21. Wang Z, Zheng Q, Jin Z. Meta-analysis of robot-assisted versus conventional laparoscopic Nissen fundoplication for gastrooesophageal reflux disease: Meta-analysis of RALF versus CLF for GORD. ANZ J Surg 2012;82:112-7.
22. Lin EL, Sibona A, Peng J, et al. Cumulative summation analysis of learning curve for robotic-assisted hiatal hernia repairs. Surg Endosc 2022;36:3442-50.
23. Sarkaria IS, Latif MJ, Bianco VJ, et al. Early operative outcomes and learning curve of robotic assisted giant paraesophageal hernia repair. Int J Med Robot 2017. doi: 10.1002/rcs.1730.

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Supplementary

Appendix 1

Ovid

Database(s): EBM Reviews - Cochrane Central Register of Controlled Trials April 2022, EBM Reviews - Cochrane Database of Systematic Reviews 2005 to May 5, 2022, Embase 1974 to 2022 May 10, Ovid MEDLINE(R) and Epub Ahead of Print, In-Process, In-Data-Review & Other Non-Indexed Citations, Daily and Versions 1946 to May 10, 2022

Search Strategy:

#	Searches	Results
1	exp Hernia, Hiatal/	20133
2	("esophageal hernia*" or "hiatal hernia*" or "hiatus hernia*" or "oesophageal hernia*" or "paraesophageal hernia*" or "para-esophageal hernia*" or "paraoesophageal hernia*" or "para-oesophageal hernia*").ti,ab,kf.	18886
3	1 or 2	25352
4	exp Robotic Surgical Procedures/	30981
5	("Da Vinci" or "Da Vincitm" or DaVinci or DaVincitm or robot*).ti,ab,kf.	156516
6	4 or 5	160270
7	exp Laparoscopy/	299079
8	(keyhole or "key-hole" or Laparoscop* or "minimally invasive surg*").ti,ab,kf.	438750
9	7 or 8	493249
10	3 and 6 and 9	384
11	limit 10 to english language [Limit not valid in CDSR; records were retained]	372
12	limit 10 to no language specified [Limit not valid in CDSR; records were retained]	2
13	11 or 12	374
14	limit 13 to ("all adult (19 plus years)" or "young adult (19 to 24 years)" or "adult (19 to 44 years)" or "young adult and adult (19-24 and 19-44)" or "middle age (45 to 64 years)" or "middle aged (45 plus years)" or "all aged (65 and over)" or "aged (80 and over)") [Limit not valid in CCTR,CDSR,Embase; records were retained]	338
15	limit 14 to (adult <18 to 64 years> or aged <65+ years>) [Limit not valid in CCTR,CDSR,Ovid MEDLINE(R),Ovid MEDLINE(R) Daily Update,Ovid MEDLINE(R) PubMed not MEDLINE,Ovid MEDLINE(R) In-Process,Ovid MEDLINE(R) Publisher; records were retained]	217
16	limit 13 to ("all infant (birth to 23 months)" or "all child (0 to 18 years)" or "newborn infant (birth to 1 month)" or "infant (1 to 23 months)" or "preschool child (2 to 5 years)" or "child (6 to 12 years)" or "adolescent (13 to 18 years)") [Limit not valid in CCTR,CDSR,Embase; records were retained]	298
17	limit 16 to (embryo or infant or child or preschool child <1 to 6 years> or school child <7 to 12 years> or adolescent <13 to 17 years>) [Limit not valid in CCTR,CDSR,Ovid MEDLINE(R),Ovid MEDLINE(R) Daily Update,Ovid MEDLINE(R) PubMed not MEDLINE,Ovid MEDLINE(R) In-Process,Ovid MEDLINE(R) Publisher; records were retained]	21
18	17 not 15	11
19	13 not 18	363
20	(exp animals/ or exp nonhuman/) not exp humans/	11815835

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21	((alpaca or alpacas or amphibian or amphibians or animal or animals or antelope or armadillo or armadillos or avian or baboon or baboons or beagle or beagles or bee or bees or bird or birds or bison or bovine or buffalo or buffaloes or buffalos or "c elegans" or "Caenorhabditis elegans" or camel or camels or canine or canines or carp or cats or cattle or chick or chicken or chickens or chicks or chimp or chimpanze or chimpanzees or chimps or cow or cows or "D melanogaster" or "dairy calf" or "dairy calves" or deer or dog or dogs or donkey or donkeys or drosophila or "Drosophila melanogaster" or duck or duckling or ducklings or ducks or equid or equids or equine or equines or feline or felines or ferret or ferrets or finch or finches or fish or flatworm or flatworms or fox or foxes or frog or frogs or "fruit flies" or "fruit fly" or "G mellonella" or "Galleria mellonella" or geese or gerbil or gerbils or goat or goats or goose or gorilla or gorillas or hamster or hamsters or hare or hares or heifer or heifers or horse or horses or insect or insects or jellyfish or kangaroo or kangaroos or kitten or kittens or lagomorph or lagomorphs or lamb or lambs or lemur or lemurs or llama or llamas or macaque or macaques or macaw or macaws or marmoset or marmosets or mice or minipig or minipigs or mink or minks or monkey or monkeys or mouse or mule or mules or nematode or nematodes or octopus or octopuses or orangutan or "orang-utan" or orangutans or "orang-utans" or ostrich or ostriches or oxen or parrot or parrots or pig or pigeon or pigeons or piglet or piglets or pigs or porcine or primate or primates or quail or rabbit or rabbits or rat or rats or reptile or reptiles or rodent or rodents or ruminant or ruminants or salmon or sheep or shrimp or slug or slugs or swine or tamarin or tamarins or toad or toads or trout or urchin or urchins or vole or voles or waxworm or waxworms or wildlife or worm or worms or xenopus or "zebra fish" or zebrafish) not (human or humans or patient or patients)).ti,ab,hw,kf.	10097987
22	19 not (20 or 21)	363
23	limit 22 to (conference abstract or editorial or erratum or note or addresses or autobiography or bibliography or biography or blogs or comment or dictionary or directory or interactive tutorial or interview or lectures or legal cases or legislation or news or newspaper article or overall or patient education handout or periodical index or portraits or published erratum or webcasts) [Limit not valid in CCTR,CDSR,Embase,Ovid MEDLINE(R),Ovid MEDLINE(R) Daily Update,Ovid MEDLINE(R) PubMed not MEDLINE,Ovid MEDLINE(R) In-Process,Ovid MEDLINE(R) Publisher; records were retained]	170
24	22 not 23	193
25	remove duplicates from 24	127

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