Review Article

Laparoscopic paraesophageal hernia repair with absorbable mesh: a systematic review

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Background: Laparoscopic repair is the standard of care for patients with paraesophageal hernia (PEH). Different prosthetic materials have been proposed to bolster the hiatus thus theoretically minimizing the probability for hernia recurrence. The use of non-absorbable mesh has been reported however, their safety profile has been questioned because the noteworthy mesh-related complication rate. Opposite, absorbable mesh (synthetic and biologic) seems associated with mitigated mesh-related complications and comparable hernia recurrence in the short- and medium-term.

Methods: PubMed, MEDLINE, EMBASE, Scopus, Google Scholar, and ClinicalTrials.gov were executed according to the PRISMA statement until May 2022. Primary endpoints were technical details and surgical outcomes of adult patients (≥18 years old) that underwent laparoscopic PEH repair and crural reinforcement with absorbable mesh. The ROBINS-I tool was used to assess the methodological quality of included studies.

Results: Thirty-nine studies (3,103 patients) were included. The age of the patient population ranged from 18 to 93 years old and 62.8% were females. Posterior cruroplasty was performed in all patients. U-shape (83.7%), circumferential (8.1%), keyhole (5.4%) and starburst (2.8%) mesh configuration were described. Different methods for mesh fixation (sutures vs. fibrin glue *vs.* absorbable tacks) were adopted while Nissen (75.1%) and Toupet (21.1%) fundoplication were mainly fashioned. The overall postoperative complication rate was 2.5%. Pulmonary and cardiac complication rates were 1.8% and 0.9%, respectively while in-hospital mortality was 0.2%. Postoperative follow-up ranged from 12 to 166 months. Mesh-related complication rate was 0.06% (esophageal stricture related to fibrosis). Hernia recurrence rate was 12.7% while re-do surgery was required in 1.9% of patients. Postoperative dysphagia rate was 5.1%.

Discussion: Consensus concerning the optimal mesh material for crural buttressing is lacking. Given the potential for tissue ingrowth rather than encapsulation and reduced degree of perivisceral inflammation, absorbable meshes are mostly preferred over non-absorbable meshes. The use of absorbable mesh seems safe and effective with low overall and mesh-related complications, acceptable recurrence rate and low need for re-do surgery in the short/medium-term. Because heterogeneity related to different hernia characteristics, intraoperative technical variations (i.e., method for mesh fixation, etc.), definition of hernia recurrence and diverse follow-up, a conclusive evidence is still to be defined.

Keywords: Paraesophageal hernia (PEH); cruroplasty; crural repair; absorbable synthetic mesh; absorbable biologic mesh

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Introduction

Hiatus hernia (HH) is a heterogeneous anatomic/clinical entity wherein abdominal viscera, most commonly the stomach, are dislocated across the esophageal hiatus. The current classification recognizes four types of HH. Type I (sliding HH) is associated with hiatal widening, laxity of the phrenoesophageal membrane and upward migration of the cardia. These are the most common HH type and are often associated with gastroesophageal reflux disease (GERD). Paraesophageal hernias (PEH) are less common types and approximately account for 5–15% of HH (1,2). Type II hernia consist in an upward herniation of the gastric fundus with a normally located gastroesophageal junction. Type III hernia has elements of both type I and II hernias with herniation of both fundus and displacement of the gastroesophageal junction above the diaphragm. Type IV HH is characterized by larger hiatal defects with upward migration of the stomach and other intra-abdominal organs or omentum. Although these hernias may be associated with GERD their clinical significance lies in the potential for mechanical complications, pulmonary impairment, and chronic bleeding (3).

Proper management and surgical indication of PEH is debated. Laparoscopic repair is the standard of care for symptomatic patients. Surgery is also recommended in asymptomatic patients with type III–IV hernia because the potential to develop related complications (4). Hernia recurrence is a puzzling problem with a reported incidence up to 60% (5-8). Since the first laparoscopic crural mesh reinforcement, different prosthetic materials have been proposed to bolster the hiatus in attempt to minimize recurrence (9). The ideal mesh material should be able to reinforce the hiatus and reduce crural tension without causing visceral erosion or dysphagia. While the use of non-absorbable mesh has been reported to be promising in term of recurrence minimization, recent studies questioned their safety profile because concerns of mesh-related complications (i.e., infection, migration, stenosis, esophageal/gastric erosion) (10-15). Opposite, absorbable mesh seems associated with mitigated related complications and similar short/medium-term hernia recurrence (16). Interestingly, a recent assessment by the Society of American Gastrointestinal Endoscopic Surgeons (SAGES) revealed that the majority of surgeon treating PEH preferred the use of absorbable mesh (17). Absorbable mesh can be both synthetic or biological with different technical/engineering characteristics, scaffold structure and resorption time (18,19). Nowadays, literature data reporting outcomes for absorbable mesh reinforced cruroplasty are sparse and puzzled.

Hence, the aim of this systematic review was to summarize current knowledge on laparoscopic PEH repair with absorbable mesh crural reinforcement. We present the following article in accordance with the PRISMA reporting checklist (available at https://vats.amegroups.com/article/view/10.21037/vats-22-27/rc) (20,21).

Methods

The present systematic review was not registered. Ethical approval was not required. PubMed (1949–present), MEDLINE (1946–present), EMBASE (1947–present), Scopus (2004–present), Google Scholar (2004–present), and ClinicalTrials.gov (2000–present) were executed (22,23). The last date of search was the May 31st, 2022. A combination of the following MeSH terms (Medical Subject Headings) was adopted ("hiatus hernia" (tiab), OR "hiatal hernia" (tiab)) AND ("mesh" (tiab), OR "reinforcement" (tiab)) AND ("hiatoplasty" (tiab), OR "cruroplasty" (tiab)) AND ("recurrence" (tiab), OR "reoperation" (tiab)) AND ("absorbable" (tiab), OR "resorbable" (tiab)) AND ("synthetic" (tiab), OR "biologic" (tiab)). Five authors (AA, AS, FL, AL, and CO) independently conducted the literature search and separately evaluated suitable titles, abstracts and cited references contained in every article. In case of disagreement among authors, a sixth senior author (GC) clarified discrepancies.

Eligibility criteria

Inclusion criteria: (I) cohort studies and randomized controlled trials (RCTs) reporting outcomes for elective laparoscopic PEH repair with cruroplasty and absorbable mesh reinforcement in adult patients (≥18 year old); (II) English written; (III) when two or more papers were

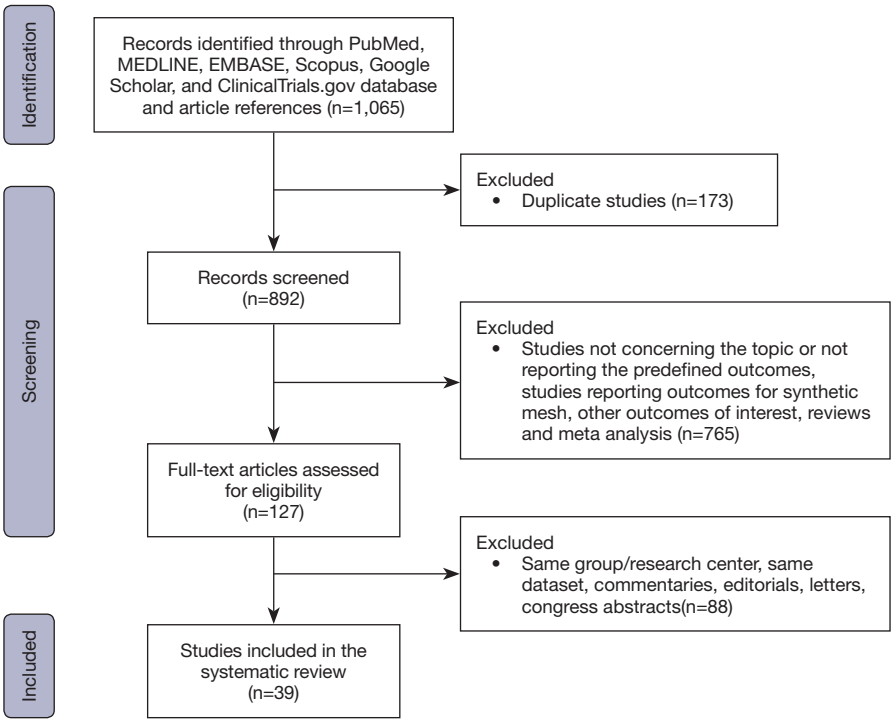

Figure 1 The PRISMA diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

published by the same institution or study group, articles with the longest follow-up or the largest sample; (IV) in case of duplicate studies with accumulating numbers of patients only the most complete reports were included. Exclusion criteria: (I) not English-written; (II) studies with follow-up shorter than 12 months; (III) articles with less than 10 patients per study arm; (IV) articles reporting data for open or non-absorbable mesh reinforced cruroplasty.

Data extraction

The following data were retrieved: authors, country, year of publication, design of the study, number of included patients, gender, age, body mass index (BMI), American Society of Anesthesiologists (ASA) physical status, comorbidities, surgical indication, type of surgical procedure, type of mesh (synthetic *vs.* biologic), follow-up and outcomes. All data were independently processed by five authors (AA, AS, FL, AL, and CO) and matched at the end of the revising process. A sixth author (DB) determined disagreements.

Quality assessment

Three authors (AE, VP, MC) judged the methodological quality of included studies with the ROBINS-I tool (24). Confounding bias, selection bias, classification bias, intervention bias, missing data bias, outcomes measurement bias, and reporting bias were pondered. Each domain was evaluated with one of the following: "yes", "probably yes", "probably no", or "no". The categories of judgement for each study are low, moderate, serious, and critical risk of bias. Incongruities were clarified.

Results

The PRISMA flow chart is reported in *Figure 1*. Overall, 1,065 publications were identified. After duplicates removal, 892 titles were screened, and 127 studies were found possibly relevant for full-text assessment. After full text evaluation, 39 studies (3,103 patients) meet the inclusion/exclusion criteria and were included in the systematic review (*Table 1*). Notably, 26 studies were of retrospective design, 10 were prospective while 3 were RCTs. The quality of included studies is summarized in Table S1.

The patient population ranged from 10 to 399 patients. The age ranged from 18 to 93 years old, 62.8% were females and the preoperative BMI ranged from 20 to 59 kg/m^2. Hernia sac dissection and excision was reported in all

Table 1 Demographic, clinical, and operative data for patients undergoing laparoscopic paraesophageal hernia repair and crural closure reinforced with absorbable mesh

	Study, year	Study design	No. of pts	Sex, F/M	Mean age (years)	BMI (kg/m^2)	Type of mesh	Mesh shape	Fixation method	Antireflux procedure, N-T-O	OT (min)	MRC (No.)	Follow up (mos)	Recurrence (No.)	Redo surgery (No.)
Synthetic mesh	Massullo *et al.*, 2012, (25)	Ret	11	9/2	60 [42–85]	30.7 [21.9–42.5]	Bio-A®	U	AT	NR-NR-0	NR	0	13 [11.6–15.7]	1	NR
	Powell *et al.*, 2013, (26)	Ret	70	47/23	50.7	28.3	Bio-A®	U	Glue	70-0-0	NR	0	12	0	NR
	Priego Jiménez *et al.*, 2014, (27)	Ret	10	7/3	65.5 [53–82]	31.65 [27.2–39.6]	Bio-A®	U	6 AT; 4 AT + Glue	10-0-0	162 [120–240]	0	20.3 [10–30]	1	NR
	Alicuben *et al.*, 2014, (28)	Ret	114	65/49	66	NR	Bio-A®	U	AT, AS or Glue	76-38-0	NR	0	12	1	0
	Silecchia *et al.*, 2014, (29)	Pros	10	9/1	52±9.3	26.4±2.4	Bio-A®	U	AT + Glue	10-0-0	70±11	0	17.4	0	0
	Asti *et al.*, 2016, (30)	Ret	41	29/12	65.9±10.5	27.2±3.7	Bio-A®	U	NAS	7-34-0	175 [IQR 78]	0	24 [IQR 29]	4	0
	Gebhart *et al.*, 2013, (31)	Ret	92	55/37	57.3±14.3	NR	Bio-A®	U	NAS	67-0-25 none	88±25	0	30±11	17	NR
	Olson *et al.*, 2018, (32)	Pros	399	261/138	59.6±13.4	29.9±5.0	Bio-A®	U	AT	225-170-4 Dor	NR	1 esophageal stenosis	44.7±22.8	49	24
	Iossa *et al.*, 2019, (33)	Ret	28	18/10	46±23	23±5	Bio-A®	U	NR	28-0-0	90±13	0	41 [17–51]	2	0
	Tartaglia *et al.*, 2021, (34)	Ret	44	29/15	62 [18–85]	24.5 [21–29]	Bio-A®	U	AS	26-18-0	127 [99–150]	0	36	2	0
	Abdelmoaty *et al.*, 2020, (35)	Pros	50	32/18	67 [44–84]	30.6 [20–41.5]	Phasix-ST®	U	24 pledgets; 26 AT + pledgets	17-33-0	161	0	12	4	0
	Panici Tonucci *et al.*, 2020, (36)	Ret	73	47/26	68.2±23	26.9±3.5	Phasix-ST®	U	MC	0-73-0	NR	0	17 [9–24]	2	0
	Aiolfi *et al.*, 2022, (37)	Ret	68	54/14	66.3±12.7	26.3±5.1	Phasix-ST®	U	AS	0-68-0	148 [96–188]	0	27 [1–53]	6	0
	Zehetner *et al.*, 2010, (38)	Ret	35	25/10	70 [48–89]	30.4 [20.4–44.8]	Vicryl®	NR	Bio Glue	35-0-0	144 [101–311]	0	14 [11–34]	2	0
	Parsak *et al.*, 2011, (39)	RCT	75	33/42	48.4±11	27.4±5.5	Vicryl®	U	AT	75-0-0	65 [40–110]	0	36.1±15	3	0
	Reynolds *et al.*, 2016, (40)	Ret	190	132/58	68 [36–93]	NR	Vicryl®	Y	Bio Glue	NR-NR-0	NR	0	24.5 [12–88]	12	NR

Table 1 *(Continued)*

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	Study, year	Study design	No. of pts	Sex, F/M	Mean age (years)	BMI (kg/m^2)	Type of mesh	Mesh shape	Fixation method	Antireflux procedure, N-T-O	OT (min)	MRC (No.)	Follow up (mos)	Recurrence (No.)	Redo surgery (No.)
Biologic mesh	Wisbach *et al.*, 2006, (41)	Pros	11	2/9	41 [26–60]	NR	AlloDerm®	Y	AT	11-0-0	NR	0	12 [8–19]	0	NR
	Lee E *et al.*, 2007, (42)	Ret	17	13/4	65±12 [45–85]	31±4	AlloDerm®	U	AS	17-0-0	273±48	0	14.4±4.4	1	0
	Lee YK *et al.*, 2008, (43)	Ret	52	28/24	56.7 [34–74]	NR	AlloDerm®	U	AS	52-0-0	121 [75–235]	0	16 [12–24]	2	1
	Bell *et al.*, 2013, (44)	Ret	252	164/88	57±13.4	30±5.7	AlloDerm®	52 U 140 C	AS	224-28-0	NR	0	17.7 [6–51]	24	NR
	Shmidt *et al.*, 2014, (45)	Ret	38	21/17	51	31.4	AlloDerm®	U	AS	NR	NR	0	13.3 [1–42]	0	0
	Ward *et al.*, 2015, (46)	Pros	17	4/13	64.3±10	32.6±6.5	AlloDerm®	U	NR	17-0-0	244±29.8	0	30.7±13	3	0
			37	6/31	60.8±10.5	31.3±4.7	FlexHD®	U	NR	37-0-0	214±34.4	0	29.5±13.4	5	4
	Rosen *et al.*, 2019, (47)	Pros	41	33/8	63.3±12.5	30.7±7.0	Miromesh®	39 U 2 C	NAS	20-11-1 Dor. 9 gastropexy	142.6±45	NR	24	3	0
	Antonakis *et al.*, 2016, (48)	Pros	10	7/3	73±13 [26–81]	NR	Permacol®	C	NAS + Glue	10-0-0	NR	1 dysphagia due to dense fibrosis	27±18	0	1
	Lomelin *et al.*, 2017, (49)	Ret	35	26/9	63.1±12	30.8±6.3	Strattice®	U	AS	29-5-1 Dor	147.8±29	0	12	5	NR
	Shrestha *et al.*, 2019, (50)	Ret	30	22/8	70 [49–85]	30 [23–39]	Strattice®	NR	NAS	30-0-0	180 [120–510]	0	50 [36–60]	2	0
			30	24/6	71 [42–89]	29 [19–42]	Veritas®	C	NAS	30-0-0	180 [135–330]	0	71 [60–84]	2	1
	Jacobs *et al.*, 2007, (51)	Ret	93	52/41	47.4	NR	Surgisis®	U	NAS	78-15-0	NR	0	38	3	NR
	Oelschlager *et al.*, 2011, (52)	RCT	26	20/6	64±10	31.1±5.8	Surgisis®	U	AS	26-0-0	NR	NR	58 [40–78]	14	0
	Wassenaar *et al.*, 2012, (53)	Pros	73	53/20	62.3±13.2	30.3±5.5	Surgisis®	U	AS + Glue	70-3-0	NR	0	12	3	1
	Watson *et al.*, 2015, (54)	RCT	41	31/10	68 [65.1–70.9]	29.4 [27.8–31]	Surgisis®	U	AT	NR	110 [96.7–124]	0	12	4	4
	Wang B *et al.*, 2016, (55)	Ret	32	16/16	NR	NR	Surgisis®	U	AS	NR	NR	0	40 [37–49]	6	NR
	Korwar *et al.*, 2019, (56)	Ret	154	99/55	65±12	NR	Surgisis®	U	NR	148-6-0	NR	0	33.7±23	10	5
	Nie *et al.*, 2021, (57)	Ret	36	24/12	68.4±17.2	28.6±6.8	Thomal GEN®	U	Glue + AS	NR	92.6 [73–135]	0	18.4 [13–24]	1	0
	Wang CQ *et al.*, 2019, (58)	Ret	32	22/10	68±9.7	NR	UBM	U	NAS	NR	115 ±30	0	12	12	3
	Sasse *et al.*, 2016, (59)	Ret	15	9/6	53 [27–72]	34 [22–59]	UBM	U	AS	NR-NR-0	56 [36–136]	0	37 [24–56]	0	0
	Lidor *et al.*, 2015, (60)	Pros	111	70/41	61.5±13.5	NR	Veritas®	NR	NR	111-0-0	314.5	0	19.9±16.4	19	1
	Grimsley *et al.*, 2022, (61)	Pros	51	45/6	67±11	29.9±6.5	UBM OR acellular bovine dermal collagen matrix	Key	NR	22-24-1 None. 4 Dor	NR	0	33±38	8	7
			58	46/12	67±12	29.6±4.5	UBM OR acellular bovine dermal collagen matrix	Star	NR	23-26-6 none. 3 MSA	NR	0	33.3±38	11	6
Multiple	Jones *et al.*, 2015, (62)	Ret	159	98/61	57.6±14.4	30.0±5.3	AlloDerm®	NR	NR	149-9-1	NR	0	25 [0–101]	32	NR
			35	8/27	57.6±14.4	30.0±5.3	Bio-A®	NR	NR	28-6-1	NR	0	25 [0–101]	2	NR
			15	14/1	57.6±14.4	30.0±5.3	Strattice®	NR	NR	10-4-1	NR	0	25 [0–101]	1	NR
	Armijo *et al.*, 2021, (63)	Ret	162	66/96	60 [49–69]	29.44 [26.8–32.3]	Human tissue matrix	U	NAS	149-NR-NR	157 [90–244]	0	27 [1–166]	67	NR
			83	37/46	57 [48–66]	28.61 [26–31.16]	Bio-A®	U	NAS	53-NR-NR	188 [90–382]	0	27 [1–166]	30	NR
			47	10/37	62 [58–74]	29.7 [25.8–34]	Porcine tissue matrix	U	NAS	38-NR-NR	198.5 [91–439]	0	27 [1–166]	17	NR

Data are presented as mean ± SD, median [range] or numbers. pts, patients; F, females; M, males; BMI, body mass index; N, Nissen fundoplication; T, Toupet fundoplication; O, other procedures; OT, operative time; MRC, mesh-related complications; mos, months; Ret, retrospective; Pros, prospective; RCT, randomized controlled trial; UBM, urinary bladder matrix; U, U-shape; Y, Y-shape; C, circular shape; Key, keyhole shape; Star, starburst shape; NR, not reported; AT, absorbable tacks; AS, absorbable sutures; NAS, non-absorbable sutures; MC, metal clips; MSA, magnetic sphincter augmentation device.

studies. Posterior cruroplasty was performed in all included studies while anterior cruroplasty was reported in four studies. The most commonly reported mesh configuration was U-shape (83.7%), followed by circumferential (8.1%), keyhole (5.4%) and starburst (2.8%). Different methods for mesh fixation (sutures *vs.* fibrin glue *vs.* absorbable tacks) were adopted depending on operating surgeon preference and experience. Nissen (75.1%) and Toupet (21.1%) fundoplication were commonly performed while gastropexy was reported in two studies. The operative time ranged from 36 to 510 minutes.

The overall postoperative complication rate was 2.5%. Inadvertent intraoperative iatrogenic esophageal/gastric perforation related to viscera manipulation was reported in six patients (0.19%). Postoperative pulmonary complication rate was 1.83%; pneumonia, pneumothorax and pulmonary embolism were the most commonly reported complications. Postoperative cardiac complications occurred in 0.92% of patients and atrial fibrillation was commonly reported. Postoperative in-hospital mortality was 0.22%. Postoperative follow-up ranged from 12 to 166 months. Mesh-related complication rate was 0.06% with two patients reporting esophageal stricture related to dense visceral fibrosis (1 synthetic and 1 biologic mesh). No full-thickness erosions were reported. Hernia recurrence according to different definitions (Table S2) was diagnosed in 393 patients (12.7%) while re-do surgery for recurrence was required in 1.9% of patients. Postoperative dysphagia occurred in 158 patients (5.1%).

Discussion

The use of mesh to reinforce the hiatus is highly discussed with two recently published meta-analyses reporting no significant differences for simple suture cruroplasty versus cruroplasty reinforced with mesh (64,65). Nevertheless, some limitations and significant heterogeneity limit the validity and robustness of such studies. First, the definition of hernia recurrence, inclusion criteria, and surgical indications were heterogeneous. Second, surgeon experience, mesh materials, shape and crural fixation further contributed to inter-study heterogeneity. Finally, the follow-up was limited (up to 42 months). Therefore, a definitive and robust evidence-based indication is still to be defined. Our study group recently described a "patient-tailored algorithm" based on four measurable parameters (type of HH, hiatus diastasis, pillar tropism and recurrence) to decide if it is necessary to place or not a mesh to bolster the crural repair during laparoscopic PEH repair (66,67). This algorithm has been shown to be possibly valuable to assure procedure reproducibility, standardization, and uniformly interpret outcomes in a field where the decision to place or not the mesh is left to the operating surgeon "feeling of a weak crura" and experience. Nowadays, there is still a lack of consensus regarding the best mesh material for crural buttressing after repair. Given the potential for tissue ingrowth rather than encapsulation, absorbable meshes (synthetic and biologic) are generally preferred over non-absorbable meshes (68). Advantages include reduced perivisceral inflammation and consequent tissue fibrosis with minimization of related complications such as esophageal and gastric erosion, mesh migration, and visceral stenosis (13-15). Three absorbable synthetic meshes are currently available for laparoscopic PEH repair: Bio-A® (Gore Medical, Newark, DE, USA), Phasix® (Bard, Warwick, RI, USA) and Vicryl® (Ethicon, Somerville, NJ, USA).

The Bio-A® is an absorbable synthetic mesh made of 67% polyglycolic acid and 33% trimethylene carbonate (69). Specifically, the mesh acts as a scaffold for the network of cells related to the inflammatory response. During prosthesis absorption (up to 6 months), these cells progressively migrate into the interstice of the mesh with consequent synthesis of new collagen and connective tissue that gradually replace the mesh. Nowadays, there are a few published studies reporting outcomes with Bio-A®. Specifically, Massullo *et al.* reported their retrospective experience with 11 patients operated for PEH and managed with Nissen or Toupet fundoplication. Short-term outcomes (13-month follow-up) were encouraging with 9% recurrence rate and no reported mesh-related complications (25). Similarly, Powell *et al.* in their retrospective series described promising short-term outcomes (12 months) and no mesh-related complications (26). Similarly, Iossa *et al.* reported their medium-term results (42-month follow-up) on 120 patients with Bio-A®. Postoperative recurrence rate was 6.2% (33). Asti *et al.* described their retrospective experience with 100 patients operated for PEH with laparoscopic Toupet fundoplication. No mesh-related complications were observed, and the medium-term (30-month follow-up) recurrence rate was 9% (30). Olson *et al.* in their single-center experience, reported data for 399 patients. All patients underwent Nissen, Toupet or Dor fundoplication. Results in term of postoperative recurrence, need for reoperation and complications were assessed at 45-month follow-up. Overall, 7.9% of patients underwent reoperation

while 16% of patients had symptom recurrence (32). Tartaglia *et al.* described outcomes for 44 patients with HH treated with laparoscopic fundoplication (Nissen and Toupet) and Bio-A®. Radiologic recurrence rate was 4.5% with no need for reoperation nor mesh related complications at 3-year follow-up (34). Interestingly, in all included studies a rectangular 7×10 cm Bio-A®, shaped into a "U" configuration, was placed over the closed hiatus, and fixed with absorbable tacks, fibrin glue or stitches depending on operating surgeon preference.

The Phasix® mesh is made of poly-4-hydroxybutyrate (P4HB), a naturally derived polymer. The P4HB degrades through both hydrolysis and a hydrolytic enzymatic digestive process in about 12–18 months (35). As described for the Bio-A®, the Phasix® mesh is progressively resorbed and gradually replaced with connective tissue synthetized by patient fibroblast that migrates into mesh interstices in the early phase. The first report describing outcomes for the Phasix® mesh was published by Abdelmoaty *et al.* in 2020. The authors reported their experience with 50 patients. Mean length of hospital stay was 2.8 days with no major morbidity nor mortality. On the 1-year follow-up, hernia recurrence rate was 8% with no need for reoperation nor mesh infection/erosion (35). Panici Tonucci *et al.* described their retrospective experience with 73 patients with PEH and Toupet fundoplication. Results were reported at 17 months median follow-up. Postoperative hernia recurrence rate was 3.2% with no mesh-related complications or need for reoperation (36). Similarly, a study from our study group reported the experience with 68 patients with laparoscopic PEH repair and Toupet fundoplication. The median follow-up time was 26 months (range, 1–52 months). Hernia recurrence rate was 8.8%. The recurrence-free probability at 34 and 60 months was 0.89 (95% CI: 0.807–0.988) and 0.86 (95% CI: 0.76–0.97), respectively. During follow-up, hernia recurrence was predominantly observed between 21 and 36 months. No mesh-related complications were detected. None of the patients required surgical revision and all were managed with proton pump inhibitors (PPI). Patient-related quality of life, measured with both the GERD-HRQL and SF-36 was significantly improved compared to baseline (37). As described for Bio-A®, most of the studies reported a U-shape mesh configuration fixed, over the closed hiatus, with different methods. Finally, a recent report by Konstantinidis *et al.* described the use of Phasix-ST® in 40 patients that underwent robotic PEH repair and Nissen fundoplication. Over a median follow-up of 21 months no recurrences nor mesh related complications were observed (70).

Polyglactin 910 mesh (Vycril®) is another absorbable mesh with a degradation time ranging from 6 to 8 weeks. Zehetner *et al.* published their experience with polyglactin mesh placed in 35 patients with PEH (38). At 1-year follow-up, recurrence rate was 9.5% with no mesh-related complications. Similarly, Parsak *et al.* published a randomized trial comparing crural reinforcement with polypropylene *vs.* Vycril® including 150 patients (75 polypropylene *vs.* 75 polyglactin) (39). Postoperative morbidity was similar for both groups, with no mesh-related complications. At 36-month mean follow-up the overall recurrence rate was 7.5%.

Biologic mesh was developed and introduced as alternative and substitute to non-absorbable synthetic mesh. They support hiatal repair during the early phase thus providing a temporary collagen matrix for native tissue ingrowth. Different types of biologic mesh have been produced. They are generally constituted by collagen matrix derived from human acellular cadaveric dermis, porcine small intestine submucosa, porcine dermal collagen, or bovine pericardium. A mild inflammatory response and neovascularization have been reported for biologic grafts (71,72). The theatre of biologic meshes is particularly heterogeneous therefore give an exhaustive overview is challenging. Surgisis® (Cook Medical, Bloomington, IN, USA), AlloDerm® (Allergan PLC, Dublin, Ireland) and Strattice® (Allergan PLC) are commonly used. Oelschlager *et al.* published in 2006 a trial comparing suture alone *vs.* Surgisis® reinforced cruroplasty for PEH. Overall, 108 patients with symptomatic PEH were included. At 6-month follow-up, there was a significantly reduced incidence of hernia recurrence in favor of Surgisis® (24% *vs.* 9%) (73). However, the medium-term follow-up analysis (58-month) showed no differences between the two groups in terms of hernia recurrence (59% *vs.* 54%) (52). Watson *et al.* compared outcomes between patients undergoing PEH repair by either synthetic (n=42) or biologic (n=41) mesh *vs.* patients with no mesh reinforcement (n=43). No significant differences were found at 6-month follow-up in term of hernia recurrence (21.8% *vs.* 23.1%; P=NS) (54). Lee *et al.* retrospectively reviewed their experience with AlloDerm® mesh (52 patients). At 16-month follow-up the recurrence rate was 3.8% with no mesh-related complications. Another recent experience from the same group consisted of a retrospective review of 35 patients treated with crural repair and Strattice® mesh. In the short-term follow-up (12-month) the recurrence rate was 14% (42,43). Finally, Lidor *et al.* described their experience with the Veritas mesh (Baxter International, IL, USA). At 12-month follow-up

the postoperative recurrence rate was 27% with no mesh-related complications (60).

Intra and postoperative complications have been described. In the present study, intraoperative esophageal/gastric perforation was reported in six patients. This complication may be attributable to intraoperative difficulties in hernia reduction and visceral manipulation. Furthermore, operating surgeon inexperience, learning curve, improper traction of the gastric fundus/esophagogastric junction, and thermal injury may cause full thickness perforation (74). In case the perforation is immediately recognized, primary repair with interrupted sutures is advisable (75). The overall postoperative complication rate was 2.5% with pneumonia and pneumothorax commonly reported. Pneumonia may occur in patients with preoperative lung comorbidities or poor lung function therefore, a prompt postoperative pulmonary rehabilitation should be pursued (76). Pneumothorax generally occur because of inadvertent pleural injury during hernia sac dissection and excision. Surgeons should be aware of this potential complication while preventive trans-hiatal chest tube has been described in case of pleural injury (77,78). Mesh-related complications and postoperative dysphagia were reported in 0.06% and 5.1% of patients, respectively. The limited inflammatory response and minimized perivisceral fibrosis typical of all absorbable synthetic and biologic mesh may explain these findings.

Notably, there was a significant heterogeneity including indications for PEH repair, different types/sizes of HH, mesh configuration and shape (i.e., U-shape *vs.* keyhole *vs.* starburst, etc.), mesh position, diverse methods for mesh fixation and different type of fundoplication (i.e., Nissen *vs.* Toupet *vs.* Dor). In addition, some studies reported data for esophageal lengthening procedure (Collis gastroplasty) and/or diaphragmatic relaxing incisions. Finally, the definition of hernia recurrence (i.e., anatomical or radiological recurrence *vs.* >2 cm intrathoracic stomach in association with recurrent symptoms) and duration of follow-up were different among studies. Therefore, this significant interstudy heterogeneity limits the robustness of any conclusions. Hence, a definitive indication on the best mesh absorbable mesh for crural reinforcement during laparoscopic PEH repair is still to be defined.

Conclusions

Laparoscopic PEH repair with crural buttressing using absorbable mesh (synthetic or biological) is gaining acceptance within the surgical community. Both synthetic and biologic mesh are safe and effective in the short- and medium-term with acceptable postoperative complications, minimized mesh-related complications and acceptable recurrence rates. The safety and efficacy profile in the long-run mandates future well-designed studies. Focused trials are necessary to appraise the best absorbable mesh for crural buttressing thus possibly defining a treatment algorithm to guide surgeons in the choice of the most appropriate mesh material.

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Footnote

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Supplementary

Table S1 Quality assessment of the included studies (ROBINS-I tool). Each domain is evaluated with one of the following: y "yes", py "probably yes", pn "probably no", and n "no". The categories of judgement for each study are low, moderate, serious, and critical risk of bias.

Study	Confounding Bias	Selection Bias	Classification Bias	Intervention Bias	Missing Data Bias	Measurement Bias	Reporting Bias	Bias
Massullo *et al.*, 2012 (25)	pn	pn	pn	pn	pn	pn	py	Moderate
Powell *et al.*, 2013 (26)	py	py	pn	pn	py	pn	py	Severe
Priego Jiménez *et al.*, 2014 (27)	pn	pn	pn	pn	pn	pn	py	Moderate
Alicuben *et al.*, 2014 (28)	py	pn	pn	py	pn	pn	pn	Moderate
Silecchia *et al.*, 2014 (29)	pn	pn	pn	py	pn	pn	pn	Moderate
Asti *et al.*, 2016 (30)	pn	pn	pn	py	pn	pn	pn	Moderate
Gebhart *et al.*, 2013 (31)	pn	pn	pn	py	pn	pn	py	Moderate
Olson *et al.*, 2018 (32)	py	py	pn	py	pn	pn	pn	Moderate
Iossa *et al.*, 2019 (33)	pn	pn	pn	pn	pn	pn	py	Moderate
Tartaglia *et al.*, 2021 (34)	pn	py	py	pn	py	py	pn	Severe
Abdelmoaty *et al.*, 2020 (35)	pn	pn	pn	py	py	pn	pn	Moderate
Panici Tonucci *et al.*, 2020 (36)	pn	pn	pn	pn	pn	pn	pn	Moderate
Aiolfi *et al.*, 2022 (37)	pn	pn	pn	pn	pn	pn	pn	Moderate
Zehetner *et al.*, 2010 (38)	pn	pn	py	py	pn	pn	pn	Moderate
Parsak *et al.*, 2011 (39)	pn	pn	pn	pn	pn	pn	pn	Moderate
Reynolds *et al.*, 2016 (40)	pn	pn	pn	py	pn	pn	py	Moderate
Wisbach *et al.*, 2006 (41)	pn	py	pn	pn	py	py	py	Severe
Lee E *et al.*, 2007 (42)	pn	py	pn	pn	py	py	pn	Moderate
Lee YK *et al.*, 2008 (43)	pn	py	pn	pn	py	py	pn	Moderate
Bell *et al.*, 2013 (44)	pn	pn	pn	pn	pn	pn	pn	Moderate
Shmidt *et al.*, 2014 (45)	pn	pn	pn	py	pn	pn	pn	Moderate
Ward *et al.*, 2015 (46)	pn	py	pn	py	pn	pn	pn	Moderate
Rosen *et al.*, 2019 (47)	py	pn	pn	pn	py	py	py	Severe
Antonakis *et al.*, 2016 (48)	py	pn	pn	py	py	pn	pn	Moderate
Lomelin *et al.*, 2017 (49)	py	pn	pn	py	py	pn	pn	Moderate
Shrestha *et al.*, 2019 (50)	pn	py	py	py	pn	pn	pn	Moderate
Jacobs *et al.*, 2007 (51)	pn	pn	pn	pn	pn	pn	pn	Moderate
Oelschlager *et al.*, 2011 (52)	pn	pn	pn	pn	pn	pn	pn	Moderate
Wassenaar *et al.*, 2012 (53)	pn	pn	py	py	py	pn	pn	Moderate
Watson *et al.*, 2015 (54)	py	py	pn	py	pn	pn	pn	Moderate
Wang B *et al.*, 2016 (55)	py	pn	pn	py	pn	pn	pn	Moderate
Korwar *et al.*, 2019 (56)	py	py	pn	py	py	pn	pn	Severe
Nie *et al.*, 2021 (57)	pn	pn	pn	py	py	py	py	Severe
Wang CQ *et al.*, 2019 (58)	pn	pn	pn	pn	pn	pn	pn	Moderate
Sasse *et al.*, 2016 (59)	py	py	pn	py	pn	pn	pn	Moderate
Lidor *et al.*, 2015 (60)	py	pn	pn	py	pn	pn	pn	Moderate
Grimsley *et al.*, 2022 (61)	py	pn	pn	py	pn	pn	pn	Moderate
Jones *et al.*, 2015 (62)	pn	pn	pn	py	py	pn	pn	Moderate
Armijo *et al.*, 2021 (63)	pn	py	pn	py	py	pn	pn	Moderate

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Table S2 Recurrence definition according to the included studies

Recurrence definition			
Radiologic	Radiologic and Endoscopic	Symptoms and Radiologic	Symptoms and Radiologic and Endoscopic
Alicuben *et al.*, 2014 (28)	Iossa *et al.*, 2019 (33)	Lee YK *et al.*, 2008 (43)	Massullo *et al.*, 2012 (25)
Silecchia *et al.*, 2014 (29)	Abdelmoaty *et al.*, 2020 (35)	Lomelin *et al.*, 2017 (49)	Priego Jiménez *et al.*, 2014 (27)
Tartaglia *et al.*, 2021 (34)	Reynolds *et al.*, 2016 (40)	Shrestha *et al.*, 2019 (50)	Asti *et al.*, 2016 (30)
Panici Tonucci *et al.*, 2020 (36)	Lee E *et al.*, 2007 (42)	Wassenaar *et al.*, 2012 (53)	Olson *et al.*, 2018 (32)
Wisbach *et al.*, 2006 (41)		Korwar *et al.*, 2019 (56)	Aiolfi *et al.*, 2022 (37)
Shmidt *et al.*, 2014 (45)			Zehetner *et al.*, 2010 (38)
Ward *et al.*, 2015 (46)			Bell *et al.*, 2013 (44)
Rosen *et al.*, 2019 (47)			Antonakis *et al.*, 2016 (48)
Oelschlager *et al.*, 2011 (52)			Jacobs *et al.*, 2007 (51)
Nie *et al.*, 2021 (57)			Watson *et al.*, 2015 (54)
Wang CQ *et al.*, 2019 (58)			Wang B *et al.*, 2016 (55)
Lidor *et al.*, 2015 (60)			Sasse *et al.*, 2016 (59)
Jones *et al.*, 2015 (62)			Grimsley *et al.*, 2022 (61)
Armijo *et al.*, 2021 (63)			

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