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Review Article

Analysis of Outcomes of Prosthetic Reinforcement in Hiatal Hernia Repair: A Systematic Review

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Abstract

Introduction: Prosthetic reinforcement in hiatal hernia (HH) repair was thought to decrease recurrence. Recent studies show equal recurrence rate with or without mesh and therefore question the role of mesh in HH repair.

Methods: Literature search was performed using PubMed and Medline for articles addressing HH repair using mesh from 1998 to December 2018. Findings regarding HH size selected for mesh reinforcement, surgical details, symptom outcomes, recurrence and mesh related complications were reviewed across studies.

Results: Thirty-nine articles met inclusion criteria: 7 Randomized control trials (RCT's), 20 observational studies and 12 articles including systematic reviews, surveys and meta-analyses. Primary and secondary outcomes varied across studies with the most common outcome measured being HH recurrence. Significant variability existed in the hiatal hernia size and the type and composition of mesh utilized. Most studies reported symptom improvement compared to baseline and showed no significant difference between prosthetic reinforcement and suture cruroplasty. A meta-analysis on four RCT's reported similar recurrence rate while some meta-analyses reported reduced recurrence with prosthetic reinforcement. Mesh related complications were reported in four observational studies and all four studies used non-absorbable mesh. Meta-analyses reported similar complication rate between groups.

Conclusion: Literature addressing mesh outcomes varied enormously across studies. More long-term studies with clear criteria for prosthetic reinforcement are required.

Keywords: *Paraesophageal Hiatal Hernia; Hiatal Hernia; Mesh; Suture Cruroplasty; Hiatal Hernia Repair*

Abbreviations

HH: Hiatal Hernia; RCT: Randomized Control Trial; GEJ: Gastroesophageal Junction; QOL: Quality of Life; PPI: Proton Pump Inhibitor; GERD: Gastroesophageal Reflux Disease; HRQL: Health Related Quality Of Life Index; GIQLI: Gastrointestinal Quality of Life Index; PCS: Physical Component Scale; MCS: Mental Component Scale; SAGES: Society of American Gastrointestinal and Endoscopic Surgeons

Introduction

A hiatal hernia (HH) is a pathological enlargement of a normal anatomical diaphragmatic defect with abdominal organs (usually stomach) traversing the defect into the mediastinum. This results in reflux of gastric contents into the esophagus accounting for 50% of anti-reflux laparoscopic procedures [1] with 40,000 surgeries done each year in United States [2]. Factors that contribute to HH include developmental defects, diaphragmatic/peri-diaphragmatic fibromuscular degeneration especially with increasing age and increase in

abdominal -thoracic pressure gradient with the later primarily due to obesity [3]. HH is classified into 4 types. In Type I HH, gastro-esophageal junction (GEJ) is displaced above the diaphragm. In Type II HH, GEJ is in its normal anatomical position with fundal herniation through the diaphragm. In Type III, GEJ and fundus herniate with fundus above the GEJ and in Type IV HH other abdominal structures (e.g. omentum, colon, small bowel) herniate into the thorax along with the stomach. Most sliding (Type I) hernias are managed medically and symptomatic, large HH para-esophageal hernias (Type II - IV) undergo surgical repair [4]. As the post-surgical recurrence rate for HH was higher, mesh use was introduced and was thought to decrease recurrence [2]. Although initial studies supported the use of mesh, recent long-term studies have produced less successful mesh outcomes. There has been an ongoing debate on mesh use, type/composition, shape, surgical technique for mesh placement and associated long-term complications [1]. In this article, we performed a review on HH size for mesh repair, type and shape of mesh used, surgical technique performed, symptom outcomes including quality of life, recurrence and complications associated with mesh use.

Methods

A PubMed and Medline databases search was performed using the keywords hiatal hernia, paraesophageal hernia, repair, mesh, laparoscopic and open, used isolated or in combination. Google scholar search engine was also checked for articles on hiatal hernia mesh repair. Data was collected independently by three reviewers (HB, MS, MA). The search included articles in English language published during 1998 to December 2018. All articles were screened according to the title and/or abstract. Randomized control trials (RCT), observational, systematic reviews and meta-analyses studies which focused on mesh outcomes in hiatal hernia repair were included. Articles involving animals, grafts/ligaments/sphincter augmentation with non-mesh involving studies, surveys, case reports, case series, studies with less than 10 patients, articles with same patient population, articles with concomitant procedures to hiatal hernia repair and those related to any kind of benign and malignant neoplasms, were excluded.

Results

Thirty-nine articles met the inclusion criteria. The breakdown based on the type of article is as follows: 7 RCT's, 20 observational studies (Table 1) and 12 articles including systematic reviews, surveys and meta-analyses. Primary and secondary outcomes of the studies are listed in table 1. Literature findings regarding hiatal hernia (HH) size selected for mesh reinforcement, surgical details, symptom outcomes, recurrence and mesh related complications are described below.

Hiatal hernia size

HH size ranged from any evidence of hernia on imaging up to > 8 cm. HH size was also defined as gastric pouch herniation above the diaphragm [5], percentage (> 30%, > 50%) of intrathoracic stomach [6-10], hernia types (II to IV) [1,6,9,11-13], intraoperative measurement of hiatal size based on the hiatal surface area [14,13] and intraoperative hernia size length (e.g. > 3 cm, > 5 cm) [15,16]. Twelve studies intraoperatively measured HH size [7,9-12,14-19,]. Seven of these studies reported how HH was measured: Flexible measuring tape [11], endoscopic ruler [16,17], based on number of sutures [15,19] and percentage of intrathoracic stomach (>30%, >50%) [7,9]. As shown in table 2, some studies did not provide a clear definition of hernia size, but included patients enrolled with symptomatic gastro-esophageal reflux disease who underwent laparoscopic fundoplication [15,17,20-22].

Surgical details

Twenty-two studies described hernia sac reduction or sac removal. Nineteen studies described esophageal mobilization or esophageal lengthening as a part of their procedure (Table 3). Four studies used Collis gastroplasty as an esophageal lengthening procedure [10,11,15,16]. Posterior crural suture repair was done in twenty studies (Table 3). In nine studies, anterior crural repair was performed in addition to posterior repair for additional reinforcement (Table 3). Anti-reflux surgery was described in all studies with the most common procedure being Nissen fundoplication. Other techniques included Toupet, partial, Nissen-rossetti and Tilley fundoplication.

Mesh was placed on repaired crura (onlay repair) in twenty-three studies [1,5-8,11-13,15-21,23-29,31]. Sandwich or sublay repair technique was performed in one study where mesh was sutured to crura as in tension free repair and crura were then approximated together with sutures [14]. Tension free repair was performed in two studies [10,20]. Keyhole mesh with different mesh configurations was used in five studies [12,18,23,24,29]. Mesh was secured to diaphragm with sutures [5,6,9-11,14,17,21,26,28,30], stapler [15,16,18,20,23,24,27], sutures or tackers [1,7,12,25], sutures with fibrin sealant [31] and laparoscopic screws [19]. Self-adhesive mesh was used in one study [13]. One study performed tension free repair in one group and suture cruroplasty with prosthetic reinforcement in the other group and found no significant difference between groups (mean follow-up of 95.1 ± 38.7 months) [20]. Mesh repair with diaphragmatic relaxing incisions was performed by one study [31] and reported no difference between groups (suture cruroplasty, mesh reinforced suture cruroplasty and mesh reinforced sutured cruroplasty with relaxing incision) at a median follow up of 9 months.

Shapes and composition of mesh varied across studies. U shaped mesh was used in eleven studies [1,5-7,10-13,15,26,29]. Rectangular mesh was used in two studies [9, 25]. Oval shaped mesh was used in two studies [18, 24]. Horse shoe shaped mesh [28], C-shaped mesh along with a relaxing incision [31], V-shaped mesh [19], Triangular patch [14], Butterfly shaped mesh [27], Square shaped mesh [23] was used in one study each. Four studies mentioned mesh shape in dimensions (3x4, 3x5, 1x3) [16,17,20,30].

Thirteen studies [1,7,10,12,13,15-18,20,23,24,30] used synthetic, non-absorbable mesh and nine studies used biological, absorbable mesh [5,6,9,21,26,28,29,31,32]. In the non-absorbable mesh group, nine studies [10,13,15,17,18,20,23,24,30] reported significant difference and three studies [1,7,12] reported no significant difference in recurrence between groups. In the absorbable mesh group, four studies [5,6,31,32] reported no significant difference in recurrence between groups.

Symptom assessment

Most of the studies reported symptom improvement compared to baseline. Ten studies reported no significant difference in symptom outcomes between prosthetic reinforcement and suture cruroplasty [1,6,7,14,15,17,25,27,30,32]. Symptom outcomes across studies are listed in the table 2. Among the RCT's, Granderath., *et al*. reported no significant difference in symptoms (heartburn, dysphagia and regurgitation) with absorbable mesh at a 12-months follow-up [17]. Oelschlager., *et al*. reported no significant difference in symptoms (heartburn, regurgitation, dysphagia, chest pain, abdominal pain, bloating, nausea, post prandial pain, early satiety) with absorbable mesh at 6 months [11] and at a median follow-up of 58 months [32]. Watson., *et al*. reported no significant difference in symptoms (heartburn, chest pain, epigastric pain, regurgitation, dysphagia, odynophagia, early satiety, epigastric bloating, anorexia, nausea, vomiting, nocturnal coughing, wheezing, diarrhea) with absorbable and non-absorbable mesh at a follow-up of 12 months [25]. Oor., *et al*. reported significant improvement in inability to belch in the mesh (non-absorbable) group at 12 months [7]. Twelve studies reported no statistical significance regarding dysphagia between suture and mesh group [1,6,7,9,14,15,17,22,25-27,32]. Among the RCT's, Oelschlager., *et al*. reported no difference in dysphagia between groups at 6 months and at a median of 58 months with absorbable mesh [11,32]. Granderath., *et al*. (with non-absorbable mesh) [17], Watson., *et al*. (with absorbable and non-absorbable mesh) [25], Oor., *et al*. (with non-absorbable) reported no difference in dysphagia between groups at 12 months [7]. Eleven studies reported QOL assessment [1,6,8,10,13,19,20,25,30,32,33]. Follow-up for QOL ranged from 12 months to a median of 118 months. Ten of these studies reported no significant difference between suture and mesh group but reported significant overall improvement in QOL compared to preoperative baseline. One study reported significant improvement in QOL in the mesh (non-absorbable) group compared to non-mesh group [13]. Among the RCT's, Oelschlager., *et al*. reported significant improvement in primary repair group and mesh (non-absorbable) group with greater improvement in mesh group on emotional problems and mental health at 6 months and with no difference between groups at a median follow-up of 56 months [11,32]. Watson at al reported no significant difference between groups (primary repair, absorbable mesh and non-absorbable mesh groups) in QOL at 24 months follow-up [25]. Llyashenko reported significant improvement in QOL in the mesh group at a mean follow-up of 58 months [13].

Complications

Four studies reported mesh related complications [10,12,20,23] and all four studies used non-absorbable mesh. Esophageal stenosis was reported in four patients at a follow up of 12 months [12]. Three of these patients underwent esophageal dilatation and one patient underwent reoperation where mesh and scar tissue was removed and esophageal stumps were sutured by open approach [12]. Esophageal erosion was reported in two patients among the studies [20,23] at a mean follow up of 89 29.8 and at 12 months [23] respectively. In one patient, mesh was removed with no further intervention [20] and in the other patient esophagectomy was performed at 12 months for mesh erosion and migration [23]. Esophageal perforation was reported on post-operative day twelve in one patient and the presence of prosthetic material was attributed as one of the factor for worsening clinical consequence of leakage [10]. None of the RCT's reported mesh related complications.

Recurrence

Definition of recurrence varied across studies and are shown in the table 4. Fifteen studies provided a clear definition for recurrence. Follow up for recurrence varied across studies with a range of six months to a median of 118 months (Table 4). Eight studies [1,6-8,12,25,31,32] demonstrated no significant difference in recurrence rates between primary cruroplasty and prosthetic reinforcement while eight studies [5,10,13,15,17,20,23,24] supported the use of mesh to reduce recurrence. Among the RCT's comparing mesh use to suture cruroplasty, Frantzides., *et al*. study reported a recurrence reduction from 22% to 0% ($p < 0.006$) at median follow-up of 2.5 years (30 months) [24]. Granderath., *et al*. reported a reduction of 26% to 8% at one year [17]. Oelschlager., *et al*. reported a reduction from 24% to 9% at 6 months but in his subsequent five-year follow-up revealed equal recurrence rates of 59% versus 54% in suture versus mesh group [32]. Watson., *et al*. reported a recurrence rate of 23.1% in the suture group, 30.8% in absorbable mesh group and 12.8% in non-absorbable mesh group at 12 months with no statistical significance between groups in regard to recurrence [25]. Oor., *et al*. did not report any difference in recurrence rates over a period of one year [7]. Llyashenko., *et al*. report increased recurrence in non-mesh group at a mean follow-up of 58 months [13].

Discussion

Literature recommendations and criteria addressing whether mesh use is indicated in hiatal hernia repair is diverse and varies enormously across studies. A majority of the studies included in this review focused on hernia recurrence as the primary outcome. Secondary outcomes included symptom frequency, symptom severity, quality of life assessment, operative time, complications, hospital stay and patient-reported surgical satisfaction.

Hiatal hernia size

Definition of hernia size varied across studies. A SAGES (Society of American Gastrointestinal and Endoscopic Surgeons) survey of 275 members who performed hiatal hernia repair reported that 24% of surgeons opted 5 cm, 13% opted 8 cm and 9% opted 3 cm as the size at which they would consider the use of the mesh [33]. Hiatal hernia size at which mesh was used was heterogeneous across studies. Definition and measurement of size varied enormously in the literature reviewed.

There is no consensus on the exact hernia size that should be repaired with a mesh. A cutoff diameter of 5 cm to differentiate small and large hiatal hernia was first mentioned by Champion., *et al*. in 1998 [14]. Frantzides., *et al*. in his randomized control trial included large hiatal hernias (>8 cm) reported that prosthetic reinforcement decreased recurrence rate from 22% to 0% at a median follow up of 2.5 years [24]. Similar to hiatal size, hiatal surface area (HSA) was first described by Granderath., *et al*. [34] by using the formula HSA = $\arcsin (s/2/r) \times r^2$, with "s" being the transverse dimension of the hiatus and "r" the vertical dimension [14]. He reported an association between increasing HSA, increasing recurrence risk and therefore a higher need for mesh. Grubnik., *et al*. further divided patients into three groups based on HSA: small (<10 cm^2), large (10-20 cm^2) and giant (>20 cm^2). He proposed different repair options for each group: primary suturing for small, sub-lay technique with partially absorbable light weight mesh for large and original repair as recommended

in the literature for giant hernias [14]. Zhang., *et al*. conducted a meta-analysis and subgrouped patients into three categories based on endoscopic measurements: small (< 5 cm), large to very large (>5 cm), very large (>8 cm). Total group analysis revealed a significant difference between mesh and non-mesh group regarding the size of hernia (OR 0.19, 95% CI 0.10 - 0.38, P/0.00001, I^2 = 0%) and results favored mesh augmentation for all hernia sizes [35]. Schmidt., *et al*. studied the need for mesh reinforcement in small HH (1 - 5 cm) and found a recurrence rate of 16% (5/32) in the suture cruroplasty group and 0% (0/38) in the absorbable mesh group at one year (P = 0.017) [5]. In a study by Oor., *et al*., a sub-analysis done for > 50% intrathoracic stomach found intraoperatively did not show any significant difference in recurrence [7].

Surgical details

Key steps in hiatal hernia repair include: 1) reduction of the herniated organ and dissection of the hernia sac off the crura to avoid re-herniation, 2) esophageal mobilization to ensure adequate esophageal length thereby avoiding tension closure, 3) closure of the crura inferio-posteriorly to the esophagus and 4) fundoplication [36]. When sufficient esophagus could not be mobilized, an esophageal lengthening procedure (e.g.- Collis gastroplasty) was added, as repair under tension was thought to contribute to recurrence. Two distinctive approaches for prosthetic hiatal hernia repair include, mesh repair with primary cruroplasty and mesh repair without primary cruroplasty (tension free repair) [37]. Kuster and Gilory in 1993 reported the first prosthetic hiatal hernia repair. To avoid tension closure of their large paraesophageal hernias, a non-absorbable mesh overlapping the crura in all directions was approximated without primary cruroplasty in six patients. Two of their six patients had small posterior segment slippage with no mesh related complications at a follow-up of 8-22 month [37]. Due to concern of complications with mesh encircling techniques, posterior crural repair with prosthetic reinforcement has been commonly employed by most surgeons [25].

In a study by Morino., *et al*. thirteen patients were diagnosed with short esophagus preoperatively or intraoperatively. Four patients did not initially undergo an esophageal lengthening procedure and developed recurrence. Collis gastroplasty was then performed on the remaining nine patients to prevent similar outcomes and no recurrence occurred [10]. Esophageal lengthening was not performed in Watson., *et al*. study. Two of his hundred and twenty six patients had short esophagus and both patients underwent early reoperation for recurrence and had excellent outcomes when reassessed postoperatively at 6 months [25]. Goers., *et al*. did not include patients who underwent Collis gastroplasty and partial fundoplication [9]. In Gouvas., *et al*. study, esophageal lengthening procedure extended from cardia to the pulmonary veins proximally [12]. Posterior crural suture repair was done in twenty studies (Table 3). In seven studies, anterior crural repair was performed in addition to posterior repair for additional reinforcement (Table 3). An anti-reflux procedure was described in all studies with the most common procedure being Nissen fundoplication. Other techniques included Toupet, partial, Nissen-Rossetti and Tilley fundoplication. Initial patients with impaired esophageal motility enrolled in Gouvas., *et al*. study underwent Toupet fundoplication. Due to inadequate reflux control with Toupet fundoplication, subsequent patients underwent Nissen fundoplication. Post-operative reflux was reported more after Toupet fundoplication compared to Nissen fundoplication (p = 0.031) [12].

Reasons considered for prosthetic reinforcement included disruption of the crural pillars, large hernia defects, crural closure under tension. Although various shapes (U, C, V, A-configuration, rectangular, triangular, butterfly, oval, keyhole) and composition (absorbable, non-absorbable, partially absorbable etc.) of the mesh exists, the use of mesh in hiatal hernia repair still remains controversial. Shapes and composition of mesh varied across studies and was solely based on surgeon's decision. Watson's randomized control trial (RCT) studied the recurrence for both synthetic and biological mesh [25]. Grubnick used partially absorbable mesh [14]. Dallemagne reinforced few patients with synthetic mesh and few patients with biological mesh [8]. Ozmen used double sided composite implant with polypropylene on one side and silicon on other side [19]. Zaninotto., *et al*. use double mesh with gortex mesh hand sewn over polypropylene mesh, with gortex side facing the abdominal viscera and polypropylene side facing the diaphragm [23].

Some studies supported the use of synthetic mesh while others supported the use of biological mesh with no clear preference overall in the literature. Complications associated with synthetic mesh led to consideration of biological mesh. Oelschlager., *et al*. initially reported

significant recurrence reduction with biological mesh at a follow-up of 6 months [11]. However, long-term follow-up of biological mesh, over a period of five years showed no difference in the recurrence outcomes with and without mesh [32]. Overall pooled recurrence rate was lower in synthetic mesh group than biological mesh group [0.30 (95% CI 0.12 - 0.73); P = 0.008 vs. 0.69 (95% CI 0.26 - 1.83); P = 0.457] in a meta-analysis which included nine studies with total of 676 patients. A survey conducted in the same study on 503 surgeons (in 2016) reported that, 67% of the surgeons preferred synthetic mesh over biological mesh [38]. A similar survey by 2518 SAGES members (in 2012) had reported, 67% of the surgeons preferred using biological mesh [2].

Symptom assessment

Gastroesophageal reflux disease symptoms, quality of life (QOL) and post-operative symptom outcomes with mesh use were assessed in many studies. Symptom outcomes of each study were reviewed and are reported in the table 2. Among the RCT's, Granderath., *et al*. reported dysphagia in the mesh group at three months, which was not statistically significant when followed to one year [17]. Oelschlager in his RCT reported an overall decrease in frequency and severity of symptoms at 6 months [11]. Chest pain ($p < 0.03$) and early satiety ($p < 0.02$) were significantly severe in patients with recurrent hernia with worst physical functioning. On further follow-up over a period of 5 years, he found significant decrease in severity of symptoms with no statistical difference in symptom outcomes in mesh and suture group including dysphagia. In Watson at al study, symptoms found to be significantly worse in the absorbable mesh group included: odynophagia at one month, nausea at three and 12 months, wheezing at 6 months and inability to belch at 12 months. Patients with non-absorbable mesh had less bloating at twelve months. However, the clinical outcomes in all groups were very minor and were considered insignificant. In an RCT by Oor., *et al*., postprandial fullness and inability to belch were reported more in suture group (60.0% and 25.7% respectively, $p = 0.040$) compared to mesh group (35.3 and 5.9% respectively; $p = 0.024$) at six months follow-up [7].

In Dallemagne's study, regurgitation, heartburn, dysphagia, chest pain, respiratory symptoms and anemia were assessed pre- and post-operatively by grading symptom severity and frequency on a four-point scale. Significant improvement was seen in all symptoms ($p < 0.001$) [8]. In Kepenekci at al study, post-operative symptoms were assessed using Visick grading (grade 1, no symptoms; grade 2, minimal symptoms, no lifestyle changes, no need to see a physician; grade 3, significant symptoms despite proton pump inhibitor (PPI) therapy that required lifestyle changes with a physician's help; grade 4, symptoms as bad as or worse than preoperatively despite PPI use). Grade 3 and 4 were considered as recurrence. Recurrence was more in suture group compared to mesh group by the end of two years (not statistically significant) [15]. Frequency and severity of reflux symptoms were assessed in Goer's., *et al*. study and revealed significantly more chest pain, inability to belch in suture group at six months [9].

Dysphagia is a common symptom in patients undergoing mesh repair. Postoperatively dysphagia usually resolves within few weeks but can persist further beyond indicating a need for reassessment. Analog scales for dysphagia for solids and liquids, dysphagia score (analyzing nine types of solids and liquids) was used by Watson [25]. Dakkak scoring for dysphagia was used by Oor., *et al*. [7]. Kamolz., *et al*. used simple verbal rating scale (none, mild, moderate, severe) [22]. Significant improvement from the baseline dysphagia was reported by Dallemagne ($p < 0.05$) [8]. Initial significant dysphagia (at 3months) in the suture and mesh group in Kamolz., *et al*. study [22] and in mesh only group in Granderath., *et al*. study [17] was non-significant by the end of one year. In Zaninotto study, 22% of patients reported dysphagia along with regurgitation and retrosternal pain [23]. In their mesh group one patient developed severe dysphagia on postoperative day two, due to malposition of mesh requiring reoperation. Four patients in Soricelli., *et al*. study had dysphagia beyond three to six weeks and underwent balloon dilatation (did not specify mesh or suture group) [20]. In a meta-analysis by Zhang., *et al*., better improvement in dysphagia was found following suture compared to mesh repair (MD = 13.68, 95% CI 2.51 - 24.85, P = 0.020) [35]. Persistent dysphagia was seen in four patients in mesh group in Jacobs., *et al*. study, of which three of four underwent balloon dilation and one patient was converted to Toupets fundoplication [21].

QOL, assesses over-all well-being of individual patient post-surgery [39]. Various QOL assessment tools were used among the studies: short form survey (SF)-36 [11,39], gastroesophageal reflux disease health related quality of life instrument (GERD-HRQL) 2 [6,10,20]

gastrointestinal quality of life index (GIQLI) [8,19,22] and QOL questionnaire [7]. Post-surgical patient satisfaction questionnaire [7,8,25] was used in few studies. Oelschlager., *et al*. used SF-36 questionnaire and reported an overall improvement in QOL, more so in the mesh group specially with mental and emotional health at six months postoperatively and no significant difference between groups at a median follow-up of five years [11]. Watson., *et al*. RCT reported a detail outcome of QOL in same set of patients followed for a period of two years in a different article [39]. In their paired analysis, physical and mental component scales (PCS and MCS) were significantly high in absorbable and non-absorbable mesh groups but when compared separately, MCS were not significantly different to preoperative scores in the suture group. In the absorbable mesh group MCS scores were significantly high at 12 months ($p = 0.012$, posthoc alpha = 0.013) and in non-absorbable group at 12 and 24 months ($p = 0.028$, $p = 0.168$, $p < 0.001$, $p < 0.001$ respectively) but not at other points. Patients with recurrence had significantly lower PCS with no significant difference in MCS.

Recurrence

Robert Condon first addressed unacceptably high recurrence rates associated with hiatal prosthetic reinforcement in the open surgical approach in the late 1970's [37]. Laparoscopic prosthetic reinforcement recurrence rate ranged from 5 - 42% [40]. Some of the considered contributing factors for recurrence included: dynamic nature of the hiatal region (with active constant movement of stomach, diaphragm, esophagus), patient revolving factors like sudden increase in intra-abdominal pressure (e.g.- coughing, constipation, lifting heavy weight, vomiting, respiratory movement of the diaphragm) [15], hiatal anatomy related factors (shortening of the esophagus, weak crural muscles, suturing diaphragmatic pillar under tension) [23] and early surgeons experience on repair. When recurrence was classified based on symptoms, asymptomatic (anatomical) recurrence rates were reported to be 30 - 42% and symptomatic recurrence rates were 5% [1].

Most studies reported anatomical recurrence. Anatomical recurrence was assessed using esophagram, esophagogastroduodenoscopy (EGD), pH study and manometry. Symptomatic recurrence was mainly defined as patient reported discomfort confirmed with radiological evaluation. In a study by Grubnick., *et al*., heartburn, discomfort, sever belching, persistent dysphagia for more than three months were considered as symptoms of recurrent herniation [14]. Kepeneckci patients were evaluated by Visick grading based on symptoms and patients with grade 3 and 4 were considered to have recurrence and when evaluated radiologically, all patients with Visick grade IV had radiological recurrence [15]. In a study by Champion., *et al*., only symptomatic patients underwent barium study and gastroscopy initially, which was later changed to routine yearly assessment with upper gastro-intestinal series [16]. Influence of mesh on both symptomatic and anatomical recurrence was studied by Koetje., *et al*. [1] and reported no significant difference between both groups. Oelschlager., *et al*. studied long term clinical and anatomical outcomes of laparoscopic large hiatal hernia repair with biological mesh and reported that patients with large recurrent hernias (>4 cm) are more likely to report heartburn [41]. Wang., *et al*. followed 115 symptom free patients who were radiologically diagnosed with recurrent hiatal hernia for a period of five years for any symptom development. He reported that these asymptomatic patients were more likely to experience heart burn and dysphagia and used anti-secretory medication on subsequent follow-up [42].

Excellent outcomes with mesh use in Frantzides., *et al*. paper, was attributed to use of PTFE mesh (keyhole) and esophageal mesh encircling technique, however it was not frequently employed by most surgeon's due to concern for mesh associated complications [24]. In a meta-analysis by Memon [43]., *et al*. which included four RCT: Frantzides., *et al*. [24], Granderath., *et al*. [17], Oelschlager., *et al*. [32] and Watson., *et al*. [25] with a total of 406 patients (Suture = 186, Mesh = 220) showed no significant difference in recurrence of hiatal hernia/wrap migration, operation time and complication rates. Only pooled effect size for reoperation rate favored prosthesis group [43].

Grubnick studied hiatal hernia recurrence with mesh use based on hiatal surface area. He found giant hernia (>20 cm^2) mesh repair results in higher recurrence rate than large hernias (10 - 20 cm^2) (20% vs 4.9%; $p = 0.0028$) [14]. Soricelli compared recurrence rate between suture only, mesh only and mesh reinforced suture group. Significant difference was seen between suture and mesh only groups ($p = 0.004$), suture and mesh reinforced group ($p = 0.003$) with more recurrence in suture group. No significant difference was seen between mesh only and mesh reinforced group ($P > 0.05$) [20]. Schmidt., *et al*. study focused on recurrence associated with small hiatal hernia (< 5 cm) and reported significant reduction in recurrence ($p < 0.017$) [5]. Crespin., *et al*. reported no significant difference in recurrence

between groups with diaphragmatic relaxing incisions. He reported that biological mesh use on left sided diaphragmatic incisions was associated with development of diaphragmatic hernia [31]. Age, previous abdominal surgery and BMI were associated with higher rate of reoperation [1].

Two meta-analyses that compared suture cruroplasty with prosthetic reinforcement reported decrease in recurrence rate following prosthetic reinforcement [2.6 vs. 9.4%, OR 0.23 (95% CI 0.14 - 0.39), P\0.00001], (pooled proportions, 12.1% vs. 20.5%; odds ratio (OR), 0.55; 95% confidence interval (CI), 0.34 to 0.89; p = 0.04) [35,44]. Similarly, overall odds ratio of recurrence was less after prosthetic reinforcement in large hiatal hernia in a meta-analysis by Vernissia., *et al*. (OR 0.51, 95% CI 0.30 - 0.87; overall p = 0.014) [45]. A meta- analysis which included nine studies with 676 patients reported overall decrease in mesh group compared to suture group [14.5 vs. 24.5%; POR = 0.36 (95% CI 0.17 - 0.77); P = 0.009] [38].

Conclusion

Size and measurement of HH varied across studies limiting clear comparison. Clear criterion or cutoff size for use of mesh has not yet been delineated in the literature. Mesh composition and shape varied across studies and was used at surgeon's discretion. Symptom outcomes and QOL improvement was reported in most studies with no difference between groups. Early studies supported prosthetic reinforcement while recent RCT's and observational studies reported similar recurrence with mesh use. Follow-up varied across studies. A meta-analysis on four RCT's reported similar recurrence rate while some meta-analyses reported reduced recurrence with mesh use. Similar complication rate between suture cruroplasty and prosthetic reinforced groups was reported in meta-analyses. Four observational studies reported mesh related complications with non-absorbable mesh.

Literature recommendations and criteria addressing whether mesh use is indicated in hiatal hernia repair is diverse and varies enormously across studies. There is no clear consensus or criteria for mesh selection or surgical technique for hiatal hernia repair. Further rigorous studies are needed as well as long-term follow up to further delineate the effectiveness of mesh reinforcement.

Acknowledgment

The authors have nothing to disclose.

Author	Number of patients	Study design	Primary/ secondary outcomes measured	Final outcomes
Carlson [18] 1999	#31 S = 16 M = 15	RCT	-Mesh outcomes.	No recurrences in mesh group at follow-up of 12-36m. Operating time and cost significantly more in the mesh group. No mesh related complications.
Frantzides [24] 2002	#72 S = 36 M = 36	RCT	-HH Recurrence, -Complications, -Hospital stay, -Operative time, -Cost.	Recurrence- significantly low in mesh group at a median follow-up of 2.5y. Complications and hospital stay not significant between groups. Operative time and cost- significantly more in the mesh group.
Granderath [17] 2005	#100 S = 50 (45/50 had HH) M = 50 (45/50 had HH)	RCT	-Recurrence, -Symptom outcomes, -Esophageal manometry, 24-hour pH monitoring, EGD, barium results. -Complications.	Recurrence- Significant reduction in mesh group at a follow-up of 1y. Symptom outcomes- no difference between groups at 1y. Esophageal manometry, 24hr pH monitoring, EGD – no difference between groups. Complications- No mesh related complications.

Oelschlager [11,32] 2006, 2011	**2006**#108 S = 57 M = 51 **2011** 72/108 (were available for follow-up) S = 39 M = 33	RCT	**2006** 1°- Recurrence 2°- -Symptom outcomes and QOL, -Perioperative complications, -Operative time. **2011** 1° -Recurrence 2°- -Symptom severity, - QOL outcomes - Vertical height of HH and cross-sectional area	Recurrence- significantly low in mesh group at 6m. Symptom outcomes and operative time- no significant difference between groups. QOL- role limitations due to mental and emotional health in SF-36 QOL were seen only in mesh group at 6m follow-up. Perioperative complications- 10 patients in suture group and 12 patients in mesh group reported perioperative complications. Mortality was reported in 2 patients on POD 14 and 7 for myocardial infarction and pulmonary embolus respectively. **2011** No significant difference between groups regarding R, symptom severity, QOL, vertical height and cross-sectional area.
Watson [25] 2015	#126S = 43 Ab = 41 NAb = 42	RCT	1°- Recurrence. 2°- -Clinical outcomes	Recurrence- no difference between groups at 6m follow-up. Clinical differences between three groups were considered minor and unlikely significant.
Oor [7] 2018	#72 S = 36 S+M = 36	RCT	1° -Recurrence 2°- -Operative time, -Perioperative morbidity, -Clinical outcomes -Surgical satisfaction	Recurrence- no difference between groups at 1yr follow-up. Operative time, intra/post-operative complications and satisfaction score- no difference between groups. clinical outcomes- mentioned in Table 2.
Ilyashenko [13] 2018	#98 S = 48 M = 50	RCT	1°- Recurrence 2°- -Safety, -Long term QOL	Recurrence more in the non-mesh group at a mean follow-up of 58m. No mesh related complications. Significantly higher patient satisfaction in the mesh group. Significantly improved QOL score in mesh group.
Kamolz [30] 2002	#200 S = 100 S+M = 100	Unspecified	-Recurrence -QOL -Dysphagia.	Recurrence- Patients with mesh reinforcement had less recurrence at follow-up of 12m. (significance not calculated) QOL – no significant difference between groups. Dysphagia- no difference between groups at 1y follow-up.
Champion [16] 2003	# 52 M = 52	Retrospective with prospective follow-up.	Mesh outcomes	Less recurrence with mesh reinforcement at a mean follow-up of 25m. (significance not calculated)

Muller-Stich [27] 2006	#56 S = 39 M = 17	Retrospective	-Recurrence rate -Side effects	No recurrence in the M group at a mean of 20±13m follow-up. No mesh related complications
Ringley [26] 2006	#44 S = 22 M = 22	Prospective	Mesh outcomes	No recurrences were reported in the M group at mean of 6.7m follow-up. No difference in dysphagia score between groups.
Morino [10] 2006	#65 -S = 14 -Tension free mesh repair = 37 -Collis Nissen fundoplication = 14	Retrospective	Optimal surgical technique for management of laparoscopic large HH	Rate of recurrence significantly lower in mesh group. No recurrence in patients who underwent Collis -Nissen esophageal lengthening procedure.
Jacobs [21] 2007	#220 S = 93 M = 127	Retrospective	Symptomatic recurrence.	Less patients in the mesh group developed symptomatic recurrence.
Kepenekci [15] 2007	#-551 S = 335 M = 176	Prospective	Mesh outcomes.	Recurrence significantly low in mesh group at 2y follow-up. No correlation between size of hernia and recurrence No mesh related complications.
Zaninotto [23] 2007	#54 S = 19 M = 35	Retrospective	-Recurrence -Symptomatic outcomes -Objective outcomes (radiological/ endoscopic).	Recurrence significantly low in mesh group at 33m median follow-up. Symptom outcomes- mentioned in table 2. Radiological/ endoscopic follow-up for 5y showed no recurrence in mesh group with 54.5% recurrence in non-mesh group.
Soricelli [20] 2009	#297 S = 93pts M only = 113 pts S + M = 91pts	Retrospective	Mesh outcomes	Recurrence- significant increase in the S group when compared to M only group and suture reinforced with mesh group (S+M). No significant difference between M only and M+S group. Significant improvement in QOL.
Dallemagne [8] 2011	#85 S = 60 M = 25	Retrospec-tive review of prospectively collected data	1º Recurrence (radiological) 2º -Symptom outcomes -QOL -Patient satisfaction,	Radiological recurrence – not significant between groups. Significant symptom improvement. Did not stratify symptoms by groups. QOL- no difference between groups. Recurrence no impact on QOL Satisfaction score- no difference between groups.

Goers [9] 2011	#89 S = 33 M = 56 Follow up- S = 32/33 M = 40/56	Retrospective	Dysphagia after biological mesh placement.	No significant increase in post-operative dysphagia rates with the use of biological mesh compared to primary repair.
Gouvas [12] 2011	#68 S = 48 M = 20	Retrospective	Mesh outcomes	No significant difference in recurrence between groups
Ozmen [19] 2013	#60 S = 31 M = 29	Prospective	-Results of laparoscopic Nissan fundoplication with and without mesh -QOL	No significant difference in QOL between groups Double sided composite mesh is a safe and effective as prosthetic material.
Grubnick [14] 2013	#658 Group 1 HSA<10cm^2 = 343 Group 2-HSA 10-20cm^2 = 261 Subgroup 2A (suture repair) = 103 2B (mesh repair) = 158 Group 3- HSA>20cm^2 (mesh repair) = 54	Unspecified	Long-term results (i.e., anatomic recurrences, repair-related dysphagia, and reoperation rates) of hiatal hernia repair depending on the hiatal surface area (HSA).	Higher recurrence rate with primary repair for large hernias (11.9%) than small hernias(p = 0.0016) Sub-lay lightweight partially absorbable mesh showed significantly low R than primary repair for large hernias. Giant hernia mesh repair results in significantly higher recurrence rate than large hernias. Time to recurrence, percentage of reflux esophagitis, Demeester score, rate of anatomical recurrence combined with reflux recurrence, asymptomatic pure anatomical recurrence and reoperation – no statistical difference between groups.
Schmidt [5] 2014	#70 S = 32 M = 38	Retrospective	Recurrence in small HH (measuring ≤5cm).	Recurrence rate significantly low in mesh group (no recurrences) at 1y follow-up.
Asti [6] 2016	#84 M = 41 S = 43	Observational-unspecified.	1°- Recurrence 2°- -Safety -QOL	Recurrence- No difference between groups with early failure rate in S group at 12m. Toupet fundoplication might reduce recurrence compared to NF. Safety- No mesh related complications, dysphagia and infections over a period of 5y follow-up. QOL- no difference between groups.
Crespin [31] 2016	#146 S = 36 M = 94 Relaxing incision + M = 16 [Rt-12, Lt-3, Bilateral-1]	Retrospective.	-HH recurrence (radiological and clinical) in patients undergoing hiatal closure with dia-phragmatic relaxing incisions -Outcomes of biological mesh with relaxing incision.	Rate of recurrence- similar between three groups. Biological mesh when used on left side of the diaphragmatic incisions might be associated with risk of diaphragmatic hernia development.

Sasse [28] 2016	#15 M = 15	Unspecified	Mesh outcomes	No recurrences at a median follow-up of 37m. No long-term complications. GERD HRQL- indicated a mild reflux symptomatology.
Koetje [1] 2017	#189 S = 127 M = 62	Retrospective analysis of prospectively followed cohort	-Symptomatic with anatomical Outcomes: -Recurrence -Reoperation -Complications -Patient reported outcome measures	Radiological and symptomatic recurrence were comparable in both groups. Reoperations rates comparable between groups. Equal complication rates. Patient satisfaction high in both groups with no significant difference. Sub-analysis of 85 patients based on size (75% of intrathoracic stomach) showed no statistical difference in postoperative complications, radiological and symptomatic recurrence and reoperation between groups.
Howell [29] 2018	#121 S = 65 M = 56	Retrospective	Mesh outcomes	Postoperative complications- not significant difference between groups. Longer mean operative time in M group.

Table 1: *Primary and secondary outcomes.*

RCT: Randomized Control Trial; EGD: Esophagogastroduodenoscopy; QOL: Quality of Life; GERD HRQL: Gastroesophageal Reflux Disease Health Related Quality of Life; HAS: Hiatal Surface Area; NF: Nissen Fundoplication; Ab: Absorbable Mesh; Nab: Non-Absorbable Mesh; HH: Hiatal Hernia; Rt: Right; Lt: Left; R: Recurrence; S: Suture Repair Group; M: Mesh Repair Group; m: Months; y: Years.

Author	Hernia definition	Symptom measured	Symptom measurement	Symptom outcomes
Carlson [18] 1999	HH defect ≥ 8 cm.	NM	NM	NM
Frantzides [24] 2002	HH defect ≥ 8 cm.	NM	NM	NM
Granderath [17] 2005	Patients who underwent laparoscopic NF were included in the study.	Heartburn, dysphagia, regurgitation.	Quantified by standardized score system then categorized into mild, moderate, severe.	Dysphagia more in mesh group post -operative at 1 wk, 6 wk and 3m but equals out in groups by 1y. No significant difference in symptoms between groups at 1y follow-up.
Oelschlager [11,32] 2006, 2011	HH defect >5 cm.	Heartburn, regurgitation, dysphagia, chest pain, abdominal pain, bloating, post prandial pain, early satiety.	Symptom severity using VAS (0 = no affect, 10- extreme) QOL = SF-36	**2006** No significant difference with overall improvement in symptoms in both groups at 6m follow-up. Patients with recurrence had significantly more chest pain, early satiety and worse physical functioning. QOL – role limitation due to mental and emotional health was seen in mesh group only. **2011** No significant difference in symptoms and QOL between groups.

Watson [25] 2015	HH containing ≥50% of the stomach.	Heartburn, chest pain, epigastric pain, regurgitation, dysphagia, odynophagia, early satiety, epigastric bloating, anorexia, Nausea, vomiting, nocturnal coughing, wheezing, diarrhea.	Evaluation of symptoms with a structured questionnaire. Analog score (0 - 10) for heartburn, dysphagia. Validated dysphagia score (0 = no, 45 = severe). Modified Visick grading (1 - 5 being no-worse symptoms). Analog satisfaction score QOL –SF 36.	No significant difference between groups. Patients with non-absorbable mesh had less heartburn at 3 and 6m, and less bloating at 12m. Patients with absorbable mesh reported more heartburn at 3m, odynophagia at 1m, nausea at 3 and 12m, wheezing at 6m and inability to belch at 12m. Clinical outcomes were considered small and therefore insignificant. Satisfaction scores were similar in all groups.
Oor [7] 2018	Diaphragmatic defect >5 cm with stomach or other viscera in the hernia. -Sub-analysis of >50% intrathoracic stomach intraoperatively	Heartburn, chest pain, epigastric pain, regurgitation, dysphagia for solids and/or liquids, pain during swallowing, postprandial fullness, inability to belch, gas bloating, anorexia, nausea, vomiting, nocturnal coughing, increased flatulence and diarrhea.	Analogue scale for severity and frequency of symptoms for Chest pain, heartburn and dysphagia for solids and liquids Dakkak dysphagia score Modified Visick score Satisfaction analogue score. Question choice to undergo surgery was correct- Y/N Changes in proton pump inhibitors and histamine blockers were recorded.	Post prandial fullness and inability to belch was more in suture group than mesh group at 1yr follow up. No significant difference between groups at 1y follow up in Dakkak dysphagia score, modified Visick score, satisfaction analogue score, choice of undergoing the surgery, in usage of acid-suppressing medication and rest of the symptoms.
Ilyashenko [13] 2018	HSA>10 cm^2. Type III	NM	Symptoms measured by GERD-HLQR questionnaire.	Significant improvement in the mesh group than in the non-mesh group.
Kamolz [30] 2002	NM	Dysphagia	Dysphagia rated by simple verbal scaling- none, mild, moderate, severe. QOL-GIQLI	Dysphagia more in mesh group at 3m post operatively which equals out at 1y. No significant difference between groups with QOL.
Champion [16] 2003	Hiatal defect ≥5 cm or presence of gastric fundus in the mediastinum.	Heartburn, dysphagia, chest pain.	Symptom questionnaire yearly.	Nine patients reported heartburn and regurgitation. Two patients reported dysphagia and chest pain. Two patients with dysphagia underwent dilatation with resolution of symptoms.

Muller-Stich [27] 2006	Paraesophageal hernias.	Epigastric pain, cough, fullness, dysphagia, vomiting, anemia, thoracic pain, dyspnea, nausea, postprandial collapses.	Present or absent.	No significant difference between groups at mean follow-up of 52 ± 31m.
Ringley [26] 2006	Hiatal defect >5 cm.	Heartburn, dysphagia, chest pain, hoarseness, regurgitation.	Symptoms scored on a scale of 0-4 0 = Never, 1 = once a month, 2 = once a week, 3 = once a day 4 = several times a day.	Significant hoarseness was seen in non-mesh group. No difference in post-operative dysphagia scores between groups.
Morino [10] 2006	50% or > intrathoracic stomach herniation on contrast radiograph, 6 cm or greater on endoscopy from top of gastric fold to crural pinch, intraoperative distance between crura exceeding 5 cm.	Postprandial epigastric pain, heartburn, dyspnea, anemia, postprandial vomiting, postprandial palpitation.	Gastroesophageal reflux health related quality of life. (GERD-HRQL) Symptom outcomes graded with Visick classification.	Visick grade- 1 and 2 = 65 and 11 % respectively 3 and 4 = 15 and 9 % respectively. Did not stratify by groups. Persistent dysphagia was seen in 10 patients after a mean of 3.5m from surgery and all these patients underwent reoperation.
Jacobs [21] 2007	Patients who underwent anti-reflex surgery were included.	NM	NM	Symptoms improved post-surgery when compared to baseline.
Kepenekci [15] 2007	Patients who underwent laparoscopic fundoplication for GERD were included in the study. Size of hernia was graded intraoperatively according to the number of sutures needed to close the hiatus. <3 cm = 1 suture, >3 cm = more than 1 suture.	NM	Visick classification- Grade 1 – no symptoms, Grade 2-minimal symptoms, Grade 3- significant symptoms despite PPI that required life changes with physician help, Grade 4 – bad-worst symptoms compared to preoperative state despite PPI use Dysphagia scale (0 - 5)	Patients with Visick grade 3 and 4 were considered as recurrence. Difference between the groups was statistically significant in terms of recurrence at 2y follow-up. No significant difference in dysphagia between groups at 6m follow up.

Zaninotto [23] 2007	>1/3 intrathoracic stomach. Type III hernias.	NM	NM	22% of patients reported dysphagia, regurgitation and retrosternal chest pain at a median follow-up of 71m. Dysphagia on post-operative day 2 was noticed in a patient due to erroneous positioning of mesh and partly due to tight fundoplication.
Soricelli [20] 2009	Patients who underwent lap fundoplication for GERD with or without hiatal hernia were included.	NM	Demeester grading scale for reflux symptoms Long term satisfaction and QOL-GERD-HRQL	-All patients were symptom free at a mean follow-up of 105m. -QOL showed improvement in all groups with significant difference between groups S only and S reinforced with mesh and M only and suture reinforced with mesh groups.
Dallemagne [8] 2011	>50% stomach above diaphragm, Type II-IV hernia.	Pyrosis, heart burn, regurgitation, dysphagia, chest pain, cough, asthma, dyspnea, anemia.	Symptom questionnaire Graded symptoms on 4-point scale based on frequency-none, occasional, moderate, severe GIQL1 Satisfaction score.	Significant improvement in pyrosis, chest pain, regurgitation, respiratory symptoms and anemia, dysphagia at a median follow-up of 118m. Did not stratify symptoms by group. No difference in QOL and satisfaction score between groups.
Goers [9] 2011	Types II, III, IV Patients with >30% of intrathoracic stomach, widened hiatus with thinning of hiatal pillars were considered for mesh placement.	Reflux symptoms, heart burn, dysphagia.	Frequency and severity grading scale (0 -4) with 3-4wks and 6m follow-up.	At 3 - 4 weeks, suture group reported more heart burn and mesh group reported dysphagia and bloating. At 6m, suture group reported significantly more chest pain, abdominal pain, inability to belch to relieve discomfort and heart burn. Patients reported no significant increase in dysphagia with biological mesh.
Gouvas [12] 2011	Type II, III, IV hernia's	Heartburn, regurgitation, dysphagia, chest pain, epigastric pain, chest discomfort, abdominal bloating.	Questionnaire-severity, frequency of each symptom (graded I-IV = no, mild, persistent, severe)	Significant improvement of reflux symptoms, dysphagia, chest discomfort at 3y follow-up. Symptoms not stratified by group. Dysphagia significantly lower in S group compared to M group at 12 m follow-up. Post-operative dysphagia grading significantly correlated to esophageal transit time.
Ozmen [19] 2013	Size of hernia graded intraoperatively based on the no of sutures needed to close the hiatus (<3 = Suture group, >3 = Mesh group).	GIQLI-5 dimensions, gi symptoms, Emotional status, Physical functions, Social functions, Stress of medical treatment.	GIQLI	GIQLI: no difference between groups

Grubnick [14] 2013	Based on HSA Small- hsa<10 cm^2 Large hsa-10-20 cm^2 Giant hsa>20 cm^2	Pain, discomfort, heartburn, severe belching	Barium- anatomical R DeMeeter score- reflux recurrence Persistent dysphagia, if dysphagia >3m.	No significant difference in dysphagia between groups.
Schmidt [5] 2014	Presence of gastric folds or hernia pouch above the diaphragm.	Heartburn, regurgitation, dysphagia, abdominal pain, bloating, Nausea, chest pain, odynophagia, Globus, throat clearing, laryngitis, hoarseness, aspiration, wheezing, coughing, dyspnea, sore throat, water bash.	Questionnaire scale: 0 = never, 1 = once/month, 2 = once/week, 3 = daily, 4 = several times daily. Symptom scoring done at 6m and 1y post-operative.	Dysphagia, chest pain, aspiration, wheezing, sore throat significantly improved in S group but not M group at 12m follow up.
Asti [6] 2016	-Hiatal defect >5 cm. -Type III ->30% of intrathoracic stomach.	NM	GERD-HLQR questionnaire.	No difference in GERD-HRQL score between groups at median follow-up of 24m (median).
Crespin [31] 2016	NM	Heartburn, dysphagia, regurgitation, shortness of breath, chest pain.	Graded on a severity scale of 0 to 10, Frequency scale of 0-4 Symptom questionnaire preoperatively and six months postoperatively.	Did not provide information on statistical symptom outcomes but reported percentage change when compared preoperatively. Heart burn and dysphagia were the only symptoms with no improvement in few patients who underwent relaxing incision along with mesh repair. Rest of the symptoms showed improvement. Did not compare symptoms between groups.
Sasse [28] 2016	Hiatal defect >6 cm	NM	GERD HRQL	GERD HRQL had a median score of 6, indicating a mild reflux symptomatology.
Koetje [1] 2017	Type II, III, IV hiatal hernia's	Dysphagia, cough, dyspnea, chest pain, anemia, reflux.	Symptoms measured on 10-point visual analog scale Patient satisfaction on VAS GERD-hr-QOL QLQ-OES-24 for severity of dysphagia.	No significant difference between groups on all the measurements.
Howell [29] 2018	Patients with paraesophageal hernias	NM	NM	NM

Table 2: *Symptom outcomes.*

GERD: Gastroesophageal Reflux Disease; QOL: Quality of Life; VAS: Visual Analogue Scale; HAS: Hiatal Surface Area; GIQLI: Gastrointestinal Quality of Life Index; GERD-HRQL: GERD Health Related Quality of Life; GERD-hr-QOL: GERD Health Related Quality of Life; QOL-SF-36: Quality of Life-Short Form-36, QLQ-OES-24: Esophageal Module and Core Questionnaire; HH: Hiatal Hernia; NF: Nissen Fundoplication; NM: Not Mentioned; Wk: Week; m: Months; y: Years; Y/N: Yes/No; S: Suture Group; M: Mesh Group.

Author	Esophageal Lengthening	Cruroplasty Done/Suture Location	Mesh Placement	Antireflex -Procedure	Type of Mesh	Shape of Mesh
Carlson [18] 1999	5 cm of esophageal mobilization.	Y/Posterior	Onlay	NF	N-Ab	Oval Keyhole
Frantzides [24] 2002	4 – 5 cm of esophageal mobilization.	Y/Posterior	Onlay	NF	N-Ab	Oval Keyhole
Granderath [17] 2005	NM	Y/Posterior	Onlay	NF	N-Ab	1X3cm
Oelschlager [11,32] 2006, 2011	Collis gastroplasty.	Y/Posterior, anterior if needed	Onlay	NF	Ab	U-configuration
Watson [25] 2015	Not done	Y/Posterior, anterior if needed	Onlay	NF, Posterior partial, Anterior partial, Type at surgeon's discretion	Ab N-Ab	Rectangular
Oor [7] 2018	Esophageal mobilized.	Y/Posterior	Onlay	270 posterior or 180 anterior partial. At surgeon's discretion.	N-Ab	U-configuration
Ilyashenko [13] 2018	5 - 7 cm of intra -abdominal esophagus	Y/Posterior, anterior if needed	Onlay	NF	N-Ab Self-fixating mesh	U-shape
Kamolz [30] 2002	NM	Y/ NM	NM	NF	N-Ab	1x3
Champion [16] 2003	Collis gastroplasty	Y/Posterior	Onlay	NF Tilley	N-Ab	3x5
Muller-Stich [27] 2006	NM	Y/Posterior	Onlay	Toupets hemifundoplication NF Dor	N-Ab Partially absorbable	Butterfly
Ringley [26] 2006	2 - 3 cm of intra -abdominal esophagus	Y/Anterior	Onlay	NF	Ab	U-shape
Morino [10] 2006	Collis gastroplasty	S = Y M = N (tension free repair) Posterior	Mesh sutured to the crura with sutures.	NF Collis-NF	N-Ab	U shape
Jacobs [21] 2007	3 – 4 cm of esophagus was mobilized into the abdomen	Y/ Posterior	Onlay	NF TF No fundoplication in 6 patients	Ab	NM

Kepenekci [15] 2007	3 cm of intra-abdominal esophagus	Y/ NM	Onlay	NF	N-Ab	U shape
Zaninotto [23] 2007	NM	Y/ Posterior, Anterior if needed	Onlay	NF TF	N-Ab	Keyhole, square with 3cm hole cut in the middle
Soricelli [20] 2009	4 cm of intrathoracic esophagus	S = Y M only = N S+M = Y NM	Onlay	NF	N-Ab	3 x 4
Dallemagne [8] 2011	Esophageal mobilization	Y/ Posterior, anterior if needed	Onlay	NF (including Nissen rossetti) Partial posterior fundoplication	N-Ab Ab	NM
Goers [9] 2011	2.5 – 3 cm of intrathoracic esophagus	Y/ Posterior	NM	Partial fundoplicaton	Ab	Rectangular
Gouvas [12] 2011	Esophagus was mobilized from cardia to level of pulmonary veins proximally	Y/ Posterior, anterior if needed	Onlay	NF TF- if esophageal motility disorders	N-Ab	Keyhole (Polypropylene) U- shape (dual mesh)
Ozmen [19] 2013	Gastroesophageal junction widely mobilized	Y/ NM	Onlay	NF	Double sided composite implant, Polypropylene on one side and silicon on the other. PTFE (1pt)	V shape
Grubnick [14] 2013	3cm of intraabdominal esophagus	Y/ Posterior	Sub-lay	NF	Partially absorbable mesh	Triangular
Schmidt [5] 2014	3cm of intraabdominal esophagus	Y/ Posterior	Onlay	Gastric fundoplication	Ab	U-shape
Asti [6] 2016	3cmof intraabdominal esophagus	Y/ Posterior	Onlay	NF or TF	Ab	U- shape
Crespin [31] 2016	3 cm of intraabdominal esophageal length	Y/ Posterior, anterior if necessary	Onlay mesh covering repaired crura and relaxing incision	NF	Ab	C shaped – positioned to cover the hiatal closure along with relaxing incision

Sasse [28] 2016	2 – 3 cm of distal esophagus freed below the crura	Complete or partial fundoplication	Onlay	NM	Ab	Horse shoe shape (10 x 15 cm)
Koetje [1] 2017	Esophagus mobilized	Y/ Posterior, anterior if needed	Onlay	NF 180 anterior partial 270 posterior-partial	N-Ab	U-configuration
Howell [29] 2018	NM	Y/ NM	Onlay	NF/ TF	Ab	U shape / Keyhole

Table 3: *Surgery details.*

PTFE: Polytetrafluoroethylene; NF: Nissen Fundoplication; TF: Tilley Fundoplication; NM: Not Mentioned; N-Ab: Non-Absorbable Mesh; Ab: Absorbable Mesh; Y: Yes; M: Mesh Group; S: Suture Group.

Author	Recurrence Definition	Recurrence Follow-Up	Recurrence	Reoperation	Complication
Carlson [18] 1999	NM	12 - 36m	R = 3 S = 3(18.8%) M = 0	#2	No mesh related complications
Frantzides [24] 2002	NM	2.5y (median)	R = 8 S = 8(22%) M = 0	#5	No mesh related complications
Granderath [17] 2005	Intrathoracic wrap migration	12m	R = 17 S = 13(26%) M = 4(8%)	#4 M = 4	No mesh related complications
Oelschlager [11,32] 2006, 2011	Vertical height of stomach > = 2cm above diaphragm or the need for reoperation secondary to warp disruption, herniation, migration.	2006 6m 2011 58m (median)	**2006** R = 16 S = 12 (24%) M = 4 (9%) **2011** R = 34 S = 20 (59%) M = 14 (54%)	2006- #0 2011 #2 S = 2(3.5%) M = 0	2006 No mesh related complications. 2011 No mesh related complications.
Watson [25] 2015	Stomach above the diaphragm. Sub-analysis on size ≥ 2 cm in vertical height.	12m	R = 26 S = /39(23.1%) M (12 ab+ 5 Nab) = 17/78(21.8) Sub-analysis of > = 2 cm in height R = 5 S = 3/39(7.7%) M = 2/78(2.6%)	#10	No mesh related complications.

Oor [7] 2018	Stomach above the diaphragm. Sub-analysis of R in HH with vertical height of ≥ 2 cm on UGI/EGD.	12m	R = 15 S = 7(19.4) M = 8(25%) IF >2 CM R = 9 S = 5 M = 4 Sub-analysis of R in pts with >50% of intrathoracic stomach R = 6 S = 3 M = 3	#3(4.2%) S = 2 M = 1	No mesh related complications.
Ilyashenko [13] 2018	NM	58 m(mean)	R = 11 M = 1 S = 10	2 (2%)	No mesh related complications.
Kamolz [30] 2002	NM	12m	S = 11 M = 1	#7 S = 6 M = 1	NM
Champion [16] 2003	NM	25m (mean)	#1 M = 1(1.9%)	#1	No mesh related complications
Muller-Stich [27] 2006	NM	Mean-52 ± 31 M = 20 ± 13m S = 67 ± 24m	R = 7/52 S = 19% (7/36) M = 0 (0/26) Symptomatic = 4/7 -2 GERD -1 postprandial fullness -1 severe dyspnea	#2/56 (4%)	No mesh related complications.
Ringley [26] 2006	Fundoplication wrap herniation	S = 9.5m (mean) M = 6.7m (mean)	R = 2 S = 2(9%)	NM	No mesh related complications
Morino [10] 2006	Any evidence of stomach herniation above the level of the diaphragm.	58m (median)	S = 10/13(77%) M = 13/37(35%) Collis NF = 0/14	S = 5/13(38%) M = 5/37(14%)	One esophageal perforation was reported on POD 12. Emergency esophagectomy with temporary esophageal and digiuno stoma was performed and intestinal continuity was restored by esophagocolonplasty after 6m.

Jacobs [21] 2007	NM	M = 3.2 y (median) S = 3.8y (median)	M = 3/92(3.3%) S = 12/59(20%)	NM	No mesh related complications
Kepenekci [15] 2007	Intra thoracic wrap migration	2 y	S = 19/313(6%) M+S = 3/164(1.8%) **6m** S = #18 Symp R = 18/18 Anat R = 10/18 M #4 Symp R = 4/4 Anat R = 4/4 **1yr-**(includes 6m pts) Symp R = 21 (S) Anat R = 12 (S) Symp R = 5 (M) Anat R = 4 (M) **2yrs** (includes 6m and 1yr R pts) Symp R = 26 (S) Symp R = 5 (M)	#6 6m = 2 (S) 1y = 4 (S) 2y = 0	No mesh related complications
Zaninotto [23] 2007	Disruption of hiatus and migration of wrap	S = 64m (median) M = 33m (median)	#11/54 S = 8/19 M+S = 3/35	#5	1)Erroneous positioning of mesh on POD 2. Mesh was removed and repositioned and Toupet fundoplication was performed. 2)Migration and erosion of prosthesis in esophagus after 12m of insertion. Esophagectomy was performed.

Soricelli [20] 2009	Intrathoracic wrap migration	Mean-95.1 ± 38.7m S = 95.2 ± 49m M = 117.6 ± 18m S+M = 69.3 ± 17.6M	S = 9(9.6) M = 2(1.8) S+M = 1(1.1%) S = 9/37 (19%) (symp = 7, anat = 2) M = 2/81 (2.4%) (symp = 2, anat = 0) S+M = 1/57 (1.8%) (symp = 1, anat = 0)	#9 S = 6/9 M = 2/2 S+M = 1/1	Esophageal erosion was reported with polypropylene mesh in one patient at a mean follow up of 89.0 ± 29.8m. Mesh was removed without any further surgery or intervention
Dallemagne [8] 2011	Paraesophageal herniation or proximal migration of cardia (sliding hiatal hernia were classified as <3 cm, 3 – 5 cm, >5 cm.)	118m (median)	R = 23(66%) <3cm = 13patients 3 – 5 cm = 10pts >5cm = no recurrence	#2- for severe dysphagia and symptomatic R	No mesh related complications
Goers [9] 2011	NM	M = 195.7 ± 80.1 days (mean) S = 287.8 ± 173.1 days (mean)	NM	S = 0/32 M = 0/40	NM
Gouvas [12] 2011	NM	12m	R = 7 S = 4/48(8%) M = 3/20(15%)	S = 0/48(0) M = 2/20(10%)	Esophageal stenosis in 4 patients. 3 pts = esophageal dilatation 1pt = reoperation (for erosion and scarring).
Ozmen [19] 2013	Wrap herniation above the diaphragm	30.8m (mean)	R = 1 M = 1	1#	No mesh related complications
Grubnick [14] 2013	Migration of the stomach with or without wrap above the diaphragm (anatomical R) Esophagitis on Endoscopy and abnormal demeester score (Reflux R)	28.6m (mean)	#36 Small hernias = 9 Large hernias = 15 Giant hernias = 12	#10 Small = 4 Large = 5 Giant = 1	No mesh related complications
Schmidt [5] 2014	>2 cm vertical height of stomach /wrap above the hiatus	12m	R = 5(16%) S = 5 M = 0	#2	No mesh related complications

Asti [6] 2016	Vertical height of stomach >2 cm above the diaphragm	24m (median)	R = 12 M = 4 S = 12	#0	No mesh related complications
Crespin [31] 2016	Intra-abdominal contents above the diaphragm	9m (median)	R = 66 S = 21/36 (58%) M = 36/94 (38%) M+ Relaxing incision = 9/16 (56%)	#4 2- dysphagia 2- symptomatic diaphragmatic hernia in left sided incision with biological mesh.	No mesh related complications
Sasse [28] 2016	NM	37 m (median)	R = 0	#0	No mesh related complications.
Koetje [1] 2017	NM	39.3 ± 17.2m (mean)	Radiological R-46 (24.3%) S = 30 (23.6%) M = 16 (25.8%) Symptomatic R-13.2% S = 15 (11.8%) M = 10 (16.1%)	#14 (7.4%) S = 6 (6.3%) M = 8 (9.7%)	No mesh related complications
Howell [29] 2018	NM	NM	NM	NM	NM

Table 4: *Recurrence outcomes.*

UGI endo: Upper Gastrointestinal Endoscopy; EGD: Esophagogastroduodenoscopy; POD: Post-Operative Day; NF: Nissen Fundoplication; NM: Not Mentioned; Symp R: Symptomatic Recurrence, Anat R: Anatomical Recurrence; R: Recurrence; S: Suture Group; M: Mesh Group; R: Recurrence; y: Year; m: Month.

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