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# A Review of Experimental Studies for Available Evidence on the Use of Prosthetic Material in Hiatal Hernia Repair

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author CM designed the study, wrote the protocol, managed the literature search and wrote the first draft of the manuscript. Authors PT and MS managed the literature searches. Authors DP and DD performed the study selection. Authors DM and AW performed data extraction. All authors contributed in the final manuscript.*

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## ABSTRACT

**Aim:** The benefits of prosthetic material in hiatal hernia repair have been well documented. However, the associated risks are substantial and they are related to the technique, and also the choice of material. Experimental data are invaluable to understand and evaluate the interaction of different meshes with the host tissue. The purpose of this article is to summarize the available experimental evidence in the repair of hiatal hernias with the use of prosthetic materials in animal models.
**Methods:** A review of the literature from January 1990 to December 2014 was carried out for articles presenting experimental data on hiatal hernia repair.

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**Results:** After discarding non relevant articles, 28 articles were identified. A variety of synthetic and absorbable materials were studied. Review of the available studies showed that there is great variability between synthetic materials regarding tissue integration, shrinkage and adhesion formation, however they have greater mechanical strength when compared to biological/absorbable materials, which have a tendency to better integration. Biological adhesives seem to be an effective alternative method of mesh fixation.

**Conclusions:** Experimental data are essential in order to fully appreciate the process of repair of a hiatal hernia with a prosthetic material. The articles reviewed provide insight into the properties of different prosthetic materials. However, there were large variations in their quality and the methods used. Data from animal studies are an excellent way of evaluating the multitude of materials that have recently become available. Good quality, comparative animal studies are essential in an effort to further improve outcomes for patients who undergo hiatal hernia repair.

*Keywords: Hiatal; hernia; mesh; animal; experimental; review.*

## 1. INTRODUCTION

The introduction of laparoscopic techniques in hiatal hernia repair resulted in a significant increase in the number of annually performed anti-reflux procedures in the last decade [1]. There are now ranintroductin domized trials supporting the use of surgical management as a first-line treatment in selected patients [2]. In some patient subgroups, however, such as patients with large paraesophageal hernia, recurrence rates can reach 42% [3]. It usually occurs after disruption of the crural closure as the tissues approximated are frequently attenuated and sutured under tension [4].

In an effort to overcome these limitations, selective mesh use has been reported since the 1970s. In the first large series of patients published, Carlson et al. were able to achieve excellent results with polypropylene repair, without any clinical recurrences in long term follow up [5]. A number of clinical trials have established the efficacy of prosthetic mesh in preventing recurrence in the hiatus [6], however, the emergence of relatively few, but in some cases devastating, complications such as mesh erosion, highlight the need for further research [7].

As new materials are continuously being developed it is important for surgeons to make an informed decision on which material to use. Animal studies are essential in evaluating the interaction between the different prosthetic materials and the host tissue and their relative safety and efficacy in hiatal hernia repair. We have performed a literature review in order to examine the contribution of the available experimental evidence towards selecting the optimal prosthetic material and surgical technique in mesh repair of hiatal hernia.

## 2. MATERIALS AND METHODS

We searched for articles on hiatal hernia repair meeting the criteria outlined below and analyzed them for specific outcomes using the PRISMA guidelines.

### 2.1 Eligibility Criteria

1) Type of study: Experimental animal (in vivo) study of repair of hiatal/paraesophageal or congenital diaphragmatic hernia using prosthetic material (mesh). Models of congenital diaphragmatic hernia were included in this review, because, although the mesh was not placed in the hiatus in these models, they can be considered orthotopic models, usually involving creation of a hernia by excision of part of the left hemidiaphragm, mimicking conditions like those found in a giant paraesophageal hernia (large defect, attenuation of muscular tissue).
2) Language: English.
3) Publication year: 1990-2014.

### 2.2 Literature Search Strategy

Studies were identified by searching the PubMed/Medline and Scopus databases. The following key words were used as search strings: hiatal, diaphragmatic, mesh, animal, experimental.

Potentially relevant articles were identified by the title and abstract and full papers were obtained and assessed in detail by two of the authors (M.S. and P.T., both senior surgeons) prior to their inclusion in the review. The reference list for each article was also screened to identify further relevant publications.

### 2.3 Study Selection

Eligibility assessment was performed independently by 2 reviewers. Disagreements between reviewers were resolved by consensus.

### 2.4 Data Extraction

Data collection and analysis were carried out independently by 2 researchers. Studies were classified into two experimental model groups which investigated mesh repair of either hiatal or congenital diaphragmatic hernia. Articles were reviewed for a number of variables examining their design (number and type of animals, mesh implantation time, use of comparative/control group, biomechanical/histopathological analysis) and the technique used (Mesh type and shape, fixation type, surgical technique).

Study results were specifically assessed for findings relevant to controversial topics in hiatal hernia repair with prosthetic mesh (Table 1).

## 3. RESULTS

### 3.1 Literature Search

Our search strategy initially returned 924 studies which we evaluated based on title and abstract and we selected 21 articles based on our inclusion criteria. The full text of these articles was downloaded and another 9 studies were obtained from their reference lists. After excluding 2 articles studying hiatal hernia repair in the context of fetal tissue engineering, 28 articles were assessed in detail (Fig. 1).

### 3.2 Study Design

Large animals (swine, dogs) were used in most studies. The number of animals in each study was small (6-36 animals). Implantation time ranged from 2 weeks to 12 months (Table 2). The majority of the studies included a comparison or control group and histopathological analysis, however only a few studies used endoscopic or radiological assessment or biomechanical analysis.

### 3.3 Mesh Characteristics and Surgical Technique

A variety of meshes were evaluated, including conventional (polypropylene, polytetrafluoroethylene - PTFE) and newer (polypropylene/ polyglactin 910 - PP-PG, poly(lactic-co-glycolic acid) - PLGA) synthetic materials, biologically derived materials such as bovine pericardium and newer biologic meshes (Small intestinal submucosa - SIS, acellular dermal matrix - Alloderm). Most authors used a rectangular piece of mesh, but circular and U-shaped meshes were also used. The surgical technique used in most studies was mesh fixation in the hiatus using an open technique, with or without excision of part of the left hemidiaphragm, while in two studies an endoscopic approach was utilized: laparoscopic creation of a defect in the left hemidiaphragm and repair in one study and thoracoscopic creation of a paraesophageal hernia and subsequent laparoscopic repair in another. Finally, mesh fixation was achieved with sutures in most cases, while a few of the authors used biological adhesives, such as fibrin glue and polyethylene glycol (Table 3).

### 3.4 Results of Individual Studies

#### 3.4.1 Mesh shape

Although circular, rectangular and U-shaped meshes were used, no study directly compared meshes of different shapes.

**Table 1. Controversial topics in hiatal hernia repair with prosthetic mesh**

| | |
|---|---|
| 1. Mesh shape | |
| 2. Mesh type | a. Infection potential |
| | b. Handling characteristics |
| | c. Durability of repair |
| | d. Adhesion potential, tissue incorporation, fibrosis/stenosis/shrinkage potential |
| | f. Migration/erosion potential |
| 3. Fixation method | |
| 4. Sutured vs tension-free hiatoplasty | |

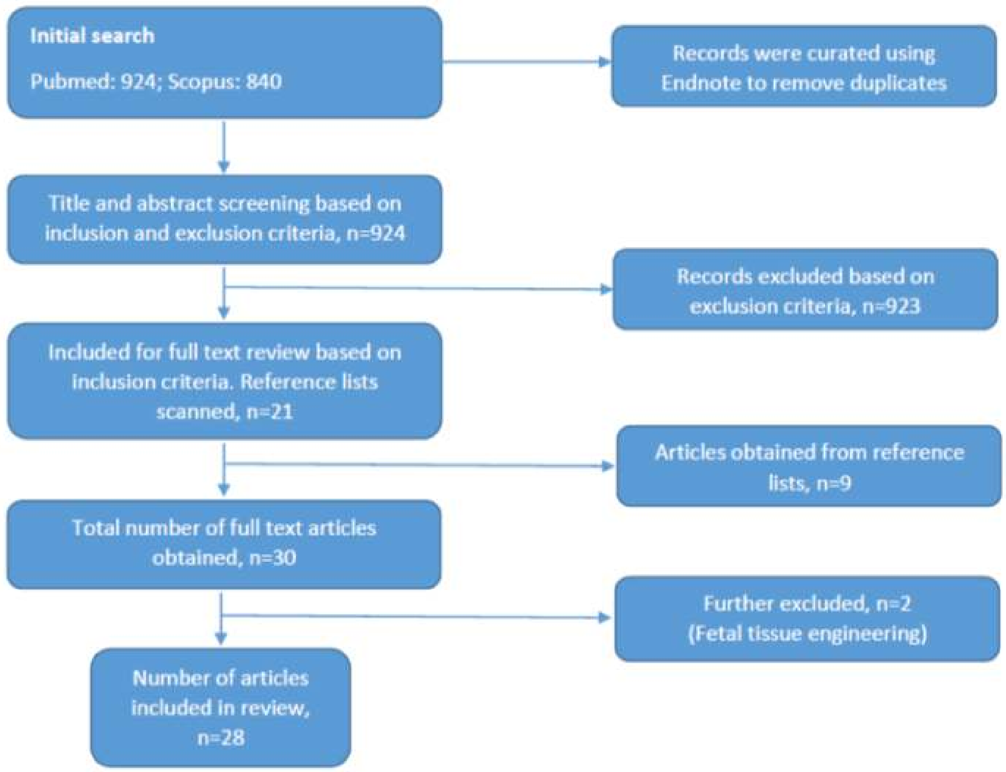


**Fig. 1. Flow diagram of literature search**

### 3.4.2 Mesh type

*3.4.2.1 Infection potential*

No study on mesh use in contaminated fields has been carried out.

*3.4.2.2 Handling characteristics*

The handling characteristics of each mess i.e. the ease of its use in laparoscopic surgery was not addressed in any study.

*3.4.2.3 Durability of repair*

Most of the studies showed that the mesh repair remained successful during the observation period of up to 12 months. SIS was shown to have equivalent strength to PTFE when applied on the diaphragm [8,9], although it was not as strong as polypropylene meshes [10,11]. In another study comparing two forms of SIS mesh in a dog model, the first comprised of 4-ply and the other from 8-ply, the thicker version was shown to be stronger, while both showed more strength than native diaphragmatic tissue [12]. Fascia lata was also shown to be equivalent to PTFE in mechanical strength [13].

*3.4.2.4 Adhesion potential, tissue incorporation, fibrosis/stenosis/shrinkage potential*

Polypropylene mesh consistently caused formation of strong adhesions [10,11], which were less pronounced with low-weight polypropylene [14]. Dualmesh showed less extensive adhesions than polypropylene [15], while Surgisis showed less adhesions than PTFE in two studies [16,9], but dense adhesions were comparable to polypropylene in another [10].

Mesh shrinkage was shown to be around 50-70% of original size for polypropylene [14,17,18], while the percentage of shrinkage was higher for the low-weight mesh [14]. When PTFE, polyester and polypropylene were compared, PTFE showed considerably more shrinkage that reached 34.9% of its original size [19].

Bohm et al. [10,11] compared two composite polypropylene meshes (Ultrapro, Proceed) to Surgisis in a rabbit model. Inflammatory reaction at the border of the mesh was more pronounced with Proceed, followed by Ultrapro and Surgisis. On the other hand Surgisis and Ultrapro showed better tissue regeneration compared to Proceed. Collagen maturation was slower for Surgisis compared to the synthetic meshes. A composite polypropylene mesh was compared to a conventional polypropylene mesh and the composite mesh showed better integration and reduced inflammatory response, which could be associated with a lower risk of erosion and postsurgical dysphagia [18]. Histological examination and cross-polarization microscopy showed differences in cell proliferation rate, apoptosis and collagen I/III ratio, which were statistically significant and show better tissue integration for the composite mesh [20,18] Another study showed excellent integration, for a titanium-polypropylene mesh [21].

Polytetrafluoroethylene (ePTFE/ Dualmesh) was evaluated and caused the formation of minimal adhesions except in segments of the mesh where folding exposed its superior surface. There were no erosions or migration noted. Microscopic evaluation showed only an unstable capsule encompassing the mesh underlining the importance of a stable fixation [15,22,23].

Biologically-derived materials were evaluated in several studies. The authors reported complete mesh replacement by fibrovascular scar tissue with SIS mesh, with significant muscular regeneration, without any erosion in surrounding hollow viscera [24]. The 8-ply SIS mesh shows a slower rate of degradation compared to the 4-ply, which can in turn lead to better integration into host tissue [12]. SIS shows equivalent capillary ingrowth to Alloderm (acellular human cadaveric dermis), but a higher level of thinning [25]. When compared to PTFE, SIS shows better integration [16], more collagen deposition and skeletal muscle regeneration and neovascularization [22]. Finally, fascia lata showed superior integration and capillary ingrowth to ePTFE [13] and, in a separate study, excellent tissue integration and neovascularization, along with a mild to moderate inflammatory reaction [16].

*3.4.2.5 Migration/erosion potential*

The level of migration and the extent of foreign body reaction were higher when a conventional polypropylene mesh was used compared to a composite one [17,20,18]. The part of the mesh close to the diaphragm showed less mechanical stability compared to the one close to the esophagus. In a comparative study of PTFE and SIS in a pig model of congenital diaphragmatic hernia repair, the authors were able to demonstrate PTFE has a poorer integration into host tissue compared to SIS and tends to migrate and fold [22].

#### <u>3.4.3 Fixation method (sutures/tacks/glue)</u>

Biologically compatible adhesives like fibrin glue and polyethylene glycol were used with no evidence of migration, no evidence of any adverse effect to the incorporation of the mesh and equivalent strength to suture fixation. Krpata *et al*. used an acellular porcine dermal matrix and compared fibrin sealant to fixation with sutures [26]. Meshes fixed with fibrin glue showed no folding, while there was minimal folding in the control group. Esophagograms did not exhibit any signs of strictures. The authors used a “peel” test to compare the force needed to separate the mesh from the crura and found no difference between the two techniques, whilst the introduction of glue between the crura and the mesh did not result in a significantly different cellular response. Use of fibrin sealant resulted in a significant reduction in operative time. Jenkins *et a*l. compared two biological adhesives and found both equally effective in mesh fixation [27]. In conclusion data from 6 experimental studies show that both adhesives seem very promising as an alternative, safe, faster fixation method in hiatal hernia repair.

#### <u>3.4.4 Sutured or tension free hiatoplasty</u>

In reviewing the available published studies we did not find any study comparing sutured to tension-free hiatoplasty.

## 4. DISCUSSION

There are a number of controversial points regarding the best surgical technique in hiatal and paraesophageal hernia surgery [28]; the most controversial concerns the placement of mesh in the oesophageal hiatus [29-31]. There are reports of a significant reduction in recurrence rates when mesh is used in the surgical repair of hiatal hernia [32,33]; on the other hand, the surgical community is now conscious that there are important drawbacks in the form of mesh-related complications, reports of which were scarce for two decades and have now begun to appear in the literature [7,34,35]. Polypropylene mesh in the hiatus can cause devastating complications including dense fibrosis, oesophageal stenosis and intraluminal mesh erosion, the management of which may necessitate a reoperation ranging from mesh removal to oesophagectomy [7]. A mesh placed in the diaphragm is subject to the constant movements of breathing, which are likely to affect its incorporation to the host tissue. Therefore, although there are multiple articles available studying mesh use in animal models for a variety of indications, it is important to evaluate results from animal models of hiatal hernia repair.

Our literature review showed that there were large variations in the quality of experimental studies, only a few of which incorporated histopathological, biomechanical, endoscopic and radiological assessment. The number of animals was small and the implantation time was limited. The surgical technique used in most cases is a disadvantage, since neither the creation of a hiatal hernia nor minimally invasive techniques were used, although similar experimental models have been described as in the article by Desai et al. where a study incorporating the creation of a diaphragmatic hernia and its subsequent repair using laparoscopy is presented, in a model closely resembling the current clinical practice and enabling the surgeon to appreciate the handling characteristics of each mesh [24]. Finally, due to the heterogeneity of the studies quantitative analysis of the results was not possible.

We evaluated studies regarding specific topics and a number of these were not addressed at all (infection potential, handling characteristics, sutured/ tension free hiatoplasty), while there was limited data on the impact of mesh shape and the migration/erosion potential and durability of each mesh.

A test of the durability of the hiatoplasty should ideally compare biological/bioabsorbable prostheses to materials like polypropylene or PTFE, the efficacy of which has been demonstrated in randomized trials [32,33]. Biological meshes made from small intestinal submucosa have been shown to reduce recurrence rates in a randomized trial with short-term follow-up [36] and can also be used as a control to evaluate newer biological materials. The ability of the mesh to prevent recurrence can be investigated at autopsy or radiologically. However, new recurrences have been known to occur for a long time after surgery. Indeed, long term observation of the patients in the previously mentioned trial showed no benefit in recurrence rates with SIS mesh [37]. The practical limitations of observation time in animal studies lead authors to perform biomechanical evaluation of mesh materials to evaluate the durability of the repair. Results confirm the better results obtained clinically with polypropylene compared to biologics, but are surprising since PTFE was weaker than expected [32].

Most of the authors focused on the potential of adhesion formation, biocompatibility and tissue integration of each mesh and adequate experimental data on several materials is available. The safety profile of each material i.e. its potential to adhere to and erode into viscera, to cause extended fibrosis resulting in oesophageal stenosis, or to migrate from its position is the most pressing issue, since it is the reason mesh-augmented hiatoplasty is not widely used in clinical practice. Polypropylene meshes showed good integration, but also caused significant adhesions. Experimental studies will be very useful for the comparison of the new generation lightweight meshes, so as to evaluate their advantages compared with standard polypropylene meshes. PTFE resulted in less adhesions, but poor integration with the host tissue. SIS mesh showed an excellent safety profile in experimental studies. These results are in accordance with those obtained from clinical trials including a prospective randomized trial [36] but a marked fibrous response was observed in a previous comparative experimental study, published in abstract form, where significant esophageal stenosis was shown [38]. This finding is significant since esophageal stenoses have been reported in clinical series of patients operated on with SIS mesh [7]. Compared to polypropylene, Surgisis induced a milder inflammatory reaction, with slower collagen maturation [10,11]. Fascia lata has been used as a prosthetic material in the hiatus during the 1970s with mixed results, showing efficacy but also some complications [39]. It is, however, in our opinion a very interesting material because it is the only easily obtainable strong autologous patch and has been shown to possess strength equal to PTFE and better incorporation on the diaphragm [12].

**Table 2. Design of experimental studies in hiatal hernia repair**

| | Author | Pub year | Animal type | N | Implantation time | Comparative/ control group | Biomechanical analysis | Histopathological analysis | Endoscopic/ radiological assessment |
|---|---|---|---|---|---|---|---|---|---|
| ***Hiatal hernia repair models*** | | | | | | | | | |
| 1 | Muller-Stich [19] | 2014 | Swine | 24 | 8 weeks | ✓ | | ✓ | |
| 2 | Senft [14] | 2014 | Swine | 24 | 8 weeks | ✓ | | | |
| 3 | Krpata [26] | 2012 | Swine | 20 | 30 days | | | | |
| 4 | Vereczkei [16] | 2012 | Dogs | 3 | 1/3/6 months | ✓ | | ✓ | |
| 5 | Jenkins [27] | 2011 | Swine | 32 | 2 weeks | | | | |
| 6 | Fortelny [21] | 2010 | Swine | 7 | 4 weeks | | | ✓ | |
| 7 | Muller-Stich [17] | 2008 | Swine | 9 | 6 weeks | | | ✓ | |
| 8 | Otto [20] | 2008 | Rabbits | 20 | 3 months | ✓ | | ✓ | |
| 9 | Jansen [18] | 2007 | Rabbits | 20 | 3 months | ✓ | ✓ | | ✓ |
| 10 | Smith [15] | 2007 | Swine | 18 | 3/28 weeks | ✓ | | ✓ | |
| 11 | Desai [24] | 2006 | Dogs | 6 | 12 months | | | ✓ | ✓ |
| ***Congenital diaphragmatic hernia repair models*** | | | | | | | | | |
| 12 | Brouwer [40] | 2013 | Lambs | 7 | 6 months | ✓ | | ✓ | |
| 13 | Zhao [41] | 2013 | Rats | 52 | 1, 2, 4, and 6 months | ✓ | | ✓ | |
| 14 | Brouwer [42] | 2013 | Rats | 36 | 12 weeks | ✓ | | ✓ | |
| 15 | Brouwer [43] | 2013 | Rats | 36 | 2/12 weeks | ✓ | | ✓ | |
| 16 | Brouwer [44] | 2013 | Rats | 25 | 2/4/8/12/24 weeks | ✓ | | ✓ | |
| 17 | Gonzalez [22] | 2011 | Swine | 20 | 6 months | ✓ | | ✓ | |
| 18 | Bohm [10] | 2010 | Rabbits | 33 | 4 months | ✓ | | ✓ | |
| 19 | Bohm [11] | 2010 | Rabbits | 33 | 4 months | ✓ | ✓ | | |
| 20 | Urita [8] | 2008 | Rats | 24 | 1-3 months | | | | |
| 21 | Sandovalb [12] | 2006 | Dogs | 11 | 6 months | ✓ | ✓ | ✓ | |
| 22 | Suzuki [13] | 2002 | Dogs | 24 | 15/30 days | | | | |
| 23 | Upadhyaya [45] | 2001 | rat | 8 | 3 weeks | ✓ | ✓ | ✓ | |
| 24 | Steinau [46] | 2000 | pigs | 24 | 3/6 months | ✓ | ✓ | ✓ | |
| 25 | Lantis II [9] | 2000 | Rabbits | 32 | 6/12 weeks | ✓ | ✓ | ✓ | |
| 26 | Kimber [23] | 2000 | Lambs | 12 | 1,3,6 months | ✓ | ✓ | | |
| 27 | Dalla Vecchia[25] | 1999 | Rats | 87 | 2 weeks - 4 months | ✓ | | ✓ | |
| 28 | Lally [47] | 1993 | Rats | 37 | 400 gr | ✓ | | ✓ | |

**Table 3. Mesh characteristics and surgical technique**

| | Mesh type | Mesh shape | Surgical technique | Fixation method |
|---|---|---|---|---|
| **Hiatal hernia repair models** | | | | |
| 1 [19] | PP/ PET/ PTFE | Circular | Open hiatoplasty and placement of patch in the oesophageal hiatus | Fibrin glue |
| 2 [14] | Heavyweight small-porous/heavyweight large-porous/lightweight large-porous PP | Circular | Open hiatoplasty and placement of patch in the oesophageal hiatus | Fibrin glue |
| 3 [26] | acellular porcine dermal matrix | U shaped | Laparoscopic hiatal hernia repair | Sutures/Fibrin sealant |
| 4 [16] | Pericardial and fascia lata patches | Rectangle | 3x3 cm patches fixed on muscular part of diaphragm | Polypropylene 3/0 |
| 5 [27] | SIS | U shaped | Laparoscopic placement of patch in oesophageal hiatus | Fibrin glue/ polyethylene glycol |
| 6 [21] | Titanium polypropylene mesh | Keyhole | Open placement of the patch without prior hiatoplasty | Fibrin glue |
| 7 [17] | Heavy-weight polypropylene | Circular | Open hiatoplasty and placement of patch in the oesophageal hiatus | Fibrin glue |
| 8 [20] | PP/ PP–polyglecaprone 25 composite | Circular | Open hiatoplasty and placement of patch in the oesophageal hiatus | Polypropylene 6/0 |
| 9 [18] | PP/ PP–polyglecaprone 25 composite | Circular | Open hiatoplasty and placement of patch in the oesophageal hiatus | Polypropylene 6/0 |
| 10 [15] | DualMesh | U shaped | Open transabdominal excision of left hemidiaphragm and open placement of patch in the oesophageal hiatus without prior hiatoplasty | Interrupted ePTFE |
| 11 [24] | SIS | U shaped | Thoracoscopic creation of diaphragmatic hernia and subsequent laparoscopic repair, with hiatoplasty and placement of patch | Interrupted 2/0 polyester |
| ***Congenital diaphragmatic hernia repair models*** | | | | |
| 12 [40] | Collagen-Vicryl | Rectangle | Posterolateral 3x1.5 cm diaphragmatic defect | Running 4/0 prolene |
| 13 [41] | poly(ε-caprolactone) and collagen type I | Rectangle | Excision of 70% of the left hemi-diaphragm (approximately 2-3 cm2) | Interrupted 6/0 Prolene |
| 14 [42] | Dual layered collagenous scaffolds | Rectangle | 12 mm diameter right diaphragm defect | Interrupted 6/0 Prolene |
| 15 [43] | Cross-linked collagenous scaffolds | Rectangle | 12 mm diameter right diaphragm defect | Interrupted 6/0 Prolene/ interrupted 5/0 Vicryl |
| 16 [44] | Cross-linked collagenous scaffolds | Rectangle | Excision of 1/3 of the right hemidiaphragm | Interrupted 6/0 Prolene |
| 17 [22] | SIS, ePTFE | Rectangle | Excision of the left hemidiaphragm | Running 3/0 prolene |
| 18 [10] | SIS, PP plus Polyglecaprone-25, and PP plus polydioxanone and cellulose plus Tachosil | Rectangle | A defect of 1cm in diameter was made into the lateral left diaphragm at the interface of tendon and muscle | Running 5/0 Prolene |
| 19 [11] | SIS, PP plus Polyglecaprone-25, and PP plus polydioxanone and cellulose plus Tachosil | Rectangle | A defect of 1cm in diameter was made into the lateral left diaphragm at the interface of tendon and muscle | Running 5/0 Prolene |

| | Mesh type | Mesh shape | Surgical technique | Fixation method |
|---|---|---|---|---|
| **Hiatal hernia repair models** | | | | |
| 20 [8] | PLGA - collagen mesh | Rectangle | Open transabdominal left hemidiaphgragm excision and repair | N/A |
| 21 [12] | SIS | Rectangle | Open transabdominal left central hemidiaphragm excision and repair | N/A |
| 22 [13] | Autologous fascia lata/ ePTFE | Rectangle | Left thoracotomy, left hemidiaphragm excision and repair | N/A |
| 23 [45] | Integra | Rectangle | Open excision of left hemidiaphragm and patch repair | Interrupted 6/0 Vicryl |
| 24 [46] | lyophilized dura/ transverse abdominal bovine pericardial serosa | Rectangle | Open excision of left hemidiaphragm and patch repair | Polypropylene 3-0 |
| 25 [9] | SIS/ PTFE | Rectangle | Open transabdominal left hemidiaphragm excision and repair | N/A |
| 26 [23] | PTFE/ fluoropolymer-coated PET | Rectangle | Laparoscopic creation of 2x2 cm defect in left hemidiaphragm and repair | 3-0 braided polyester |
| 27 [25] | SIS/AlloDerm | Rectangle | Open transabdominal left central hemidiaphragm excision and repair | N/A |
| 28 [47] | ePTFE/oxidized cellulose/polyglactin 910 | Rectangle | Excision of the left hemidiaphragm followed by repair with a patch | Running 4-0 silk. |

*SIS: small intestinal submucosa; PTFE: polytetrafluoroethylene; PP: polypropylene; PLGA: poly(lactic-co-glycolic acid); PET: polyester*

**Table 4. Summary of results**

1. Mesh shape : No differences
2. Mesh type
   a. Infection potential : no differences
   b. Handling characteristics : no differences
   c. Durability of repair : Polypropylene stronger than PTFE, biologics
   d. Adhesion potential, tissue incorporation, fibrosis/stenosis/shrinkage potential:
      - More adhesions with synthetic meshes, especially polypropylene. Significant amount of shrinkage for PTFE (34.9%), but also polypropylene.
      - Better integration for composite compared to conventional polypropylene, unstable integration for PTFE.
      - Better tissue integration and regeneration for SIS compared to synthetic materials.
      - Mesh shrinkage was shown to be around 50-70% of original size for polypropylene [14, 17, 18], while the percentage of shrinkage was higher for the low-weight mesh [14]. When PTFE, polyester and polypropylene were compared, PTFE showed considerably more shrinkage that reached 34.9% of its original size[19].

   f. Migration/erosion potential : PTFE has a poorer integration compared to SIS, while composite is better than conventional polypropylene,
3. Fixation method: Biologically compatible adhesives comparable to suture fixation

The method used to fix the prosthesis to the crura presents a problem since laparoscopic suturing is challenging and time consuming (and potentially risky for the inexperienced) and use of tacks, although fast and effective, places large vessels and the heart at risk of serious injury with potentially catastrophic results [48]. The stability of the mesh depends on both the fixation method but also the material itself and the strength of its incorporation. T-peel testing is an elegant method of quantifying the strength of mesh incorporation [26]. Directly observing the tendency of the mesh to migrate and cause adhesions is tempting, however results must be interpreted with caution; failure of known complications to emerge in these studies could be caused by the relatively short observation time (erosions occur up to nine years after surgery) [7], but could also be interpreted to a lesser extent as proof of the importance of surgical technique (i.e. to strengthen the argument that the reported complications are not inherent in the mesh type but rather are a result of inadequate surgical technique). Indeed, there was a striking difference in mesh migration of polypropylene mesh in the article by Fortelny *et al*. compared to the study of Jansen et al. [21, 18]; the difference in the ratio of thickness between the mesh and the tissues of the two different animal models was offered as an explanation. In the study by Jansen et al polypropylene meshes of a circular shape were fixed by sutures in a rabbit model, but the meshes had usually moved from their implantation bed and had eroded into the esophagus [18]. However, in another study a circular polypropylene mesh was fixed in place using fibrin glue in a swine experimental model and in this case the authors reached conflicting results as they found the meshes stayed in position and their inner edge had retracted evenly from the esophagus [17].

## 5. CONCLUSION

The introduction of the new collagen-based biomaterials and the preliminary encouraging results from their use raised great expectations for improved outcomes. The biomaterials from porcine small intestinal submucosa and porcine or human acellular dermis are already widely used in clinical practice (they were being used in 1/3 of all mesh-augmented hiatal hernia repairs a few years ago [49]) and experimental data are invaluable to further our understanding of their incorporation in host tissue. Although the reviewed articles study most of the types of meshes currently in clinical use, new biological and bioabsorbable materials are being introduced in clinical practice without any available published experimental data [50,51].

There is an ever growing need for experimental studies, which should also be well-designed in order to also tackle ethical concerns with regards to animal sacrifice. Studies on mesh-augmented hiatoplasty should include a laparoscopic animal model, biomechanical evaluation and histopathological evaluation of no less than two different biomaterials at the very minimum. In the absence of good quality clinical trials, which are invariably difficult to put together due to the relatively small number of patients, good quality, comparative animal studies are essential in order to identify the mesh with the best safety/efficacy profile, determine the optimal shape and fixation method and enable surgeons to make an inform decision on the merits of using mesh in hiatal hernia.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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