EXPERT REVIEWS

Prosthetic mesh materials used in hernia surgery

Expert Rev. Med. Devices 9(2), 159–179 (2012)

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It is estimated that 20 million prosthetic meshes are implanted each year worldwide. It is clear that the evolution of meshes is not yet complete and the ideal mesh is yet to be found. There is a vast array of prosthetics available for hernia repair. This review outlines the properties of available meshes and the evidence to be considered when choosing a prosthetic for hernia repair.

Keywords: hernia • inguinal hernia • surgical mesh • ventral hernia

Repairs of abdominal wall hernias are the most frequently preformed operations in general surgery [1]. The last 50 years has seen rapid advances in our understanding of the biological basis of hernia development, surgical technique for repair and, most significantly, the use of prosthetics. Although exact figures are unknown, it is estimated that more than 20 million prosthetic meshes are implanted worldwide each year [2,3]. Today, the surgeon is faced with an array of different prosthetics from numerous manufacturers, and each year sees further meshes released onto the market. With so many prosthetics available, it can be difficult for surgeons to choose the most appropriate mesh for their patients. This review aims to highlight the basis of prosthetic development, the available hernia meshes and the evidence supporting their use.

Search methods

A literature search was performed in PubMed, EMBASE and the Cochrane Library databases from their inception to July 2011, using the MeSH key words "surgical mesh, pore size, strength, recurrence, complications, lightweight, properties" combined with "hernia" using the Boolean operator "AND". To capture all potentially relevant articles with the highest degree of sensitivity, the search terms were intentionally broad. Articles in English or with English translation were included in the review. Abstracts of all articles were reviewed and articles felt to be of relevance to the review by the authors were obtained in full text. Priority was given to review articles and randomized controlled trials comparing meshes. Electronic and bibliographic searches of all retrieved articles were performed to identify further studies of interest.

The history of hernia prosthetics

Historically, there has been a long evolution leading to the development of the modern hernia meshes. The first hernia prosthetics were made of metal. As early as 1900, Phelps, Goepel and Witzel used silver wire braided meshes (known as silver filigrees) [4–7]. These early meshes were far from ideal. They were stiff, fragile and toxic silver sulfate formed on their surface. They were modified to contain braided stainless steel and were used as a bridging material between the two edges of the rectus muscles, sometimes as a double layer [8–10]. These prosthetics were used extensively up until the late 1980s [8,9,11–13]. In 1948, Douglas and Throckmorton used tantalum gauze, as did Koontz and Kimberly several years later [14–16]. These meshes still fragmented and had extremely high rates of infection. Prefabricated perlon and nylon meshes were used by Cumberland; however, the nylon fell apart and the perlon caused an intense inflammatory response [17–19]. Throughout the mid-to-late 20th century, a number of biomaterials were developed, tested via animal models and clinical trials, but finally abandoned owing to lack of permanent success in hernia repair. These included: nylon mesh, polyvinyl sponge (Ivalon®), silicon, orlon cloth, Teflon® mesh and others [20].

 10.1586/ERD.11.65 ISSN 1743-4440

The plastics industry came of age during the Second World War. Steel and tantalum became precious metals allocated for military use. Desperate fabricators, who had never thought of plastic as a manufacturing material, began to reconsider. These 'new plastics' caught the attention of hernia surgeons and several new meshes with much more promising characteristics became available. These were polypropylene, polyester and expanded polytetrafluoroethylene (ePTFE), which paved the way for the prosthetic meshes available today [19,21,22].

What is the purpose of prosthetic mesh?

The basic principles of abdominal wall hernia repair is to restore the normal anatomy and to prevent the hernia from recurring by reinforcing the site of the hernia defect, while attempting to maintain the normal function of the abdominal wall. The task of a surgical mesh implant is to provide biomechanical strength to the attenuated fascial structures. To more fully understand the role of mesh, it is important to review the biological basis of wound healing and the pathophysiology of the foreign-body reaction.

Wound healing

Wound healing and scar formation are dynamic processes that are of paramount importance in hernia repair. The sequence of events that normally occurs in wound healing involves coagulation, inflammation, angiogenesis, epithelialization, fibroplasia, matrix deposition and contraction [23]. These processes are mediated mostly by blood-borne elements, such as platelets, monocytes, macrophages and polymorphonuclear leukocytes. However, there are also fibroblasts, endothelial cells and smooth muscle cells that, together with circulating inflammatory cells, elicit a complex cascade of events resulting in the activation of inflammatory cells and the production of a variety of growth factors (PDGF, FGF, TGF-β, IGF and EGF), which augment wound healing [23].

Collagen is initially secreted from fibroblasts and smooth muscle cells as a monomer. The collagen monomers polymerize into a thick helical arrangement of insoluble fibers in the extracellular space. Collagen synthesis remains elevated for several months in the wound area; however, at approximately day 21 after surgery, collagen remodeling begins. During this process, collagen is remodeled into an interlocking network of fibers that are compact, thick and parallel to one another – referred to as mature collagen (or type 1 collagen).

The extent of the wound, and the interaction of inflammatory mediators and growth factors, affect the nature of the final remodeled wound. During the remodeling phase following hernia repair, the bursting strength of the wound continues to increase for a period of up to 6 months but is thought to reach an equivalent of 95% of its peak strength by 12 weeks [24]. Ultimately, healed tissue regains only 80% of its normal strength [25]. Moreover, the development of hernias has been shown to be associated with patients who have abnormal connective tissue [26–28]. This group of patients have high levels of type 3 collagen (thin and flexible compared with type 1 collagen), altered matrix metalloproteinase activity and altered fibroblast activity, which makes them more susceptible to hernia development and hernia recurrence [29,30]. The presence of prosthetic material is aimed to supplement wound strength by providing a mechanical reinforcement.

The foreign-body reaction

Despite the increased use of prosthetics in hernia repair, our knowledge of the tissue response to implanted meshes in humans and their long-term biocompatibility is still poor. Nearly all of the data about the biological behavior of these implants are obtained from animal experiments. Available hernia meshes on the market are all regarded as physically and chemically inert, stable, nonimmunogenic and nontoxic. However, none of the materials are biologically inert, and experimental and clinical studies have revealed a foreign-body reaction when prosthetic meshes are inserted [31]. The aim of this process is to isolate the foreign body from the host tissues forming an artificial 'outside world' at the place of implantation. The same process is thought to be responsible for the formation of prototypic granulomas in tuberculosis; in this case the host is not able to remove the inflammatory agent, namely *Mycobacterium tuberculosis* [32].

The foreign-body reaction to implanted meshes is thought to occur because of the adsorption of host proteins by the mesh [33–37]. This occurs within seconds of the mesh being implanted, and once this dynamic process has begun, the proteins undergo conformational changes and replacement by other proteins of increasing molecular weight [38]. The hydroelectric surface properties of the mesh strongly influence these changes, by attracting or repelling the proteins [39]. The nature and extent of these changes influence the magnitude of the inflammatory response [33–35,38].

In contrast to solid biomaterials, the process of fibrosis in mesh structures is not usually associated with the formation of a capsule, but with the progressive ingrowth of fibrous tissue [40–42]. Animal studies have shown that tissue ingrowth begins early (within 2 weeks) and increases in strength over time (up to 12 weeks) [37,39,40,43]. The extent and velocity of ingrowth, which is part of the inflammatory response, depends on the properties of the mesh [24,42–44]. Ingrowth of collagen provides long-term adhesive strength [24]. While this produces a strong mechanical barrier, florid ingrowth can also be detrimental. Examination and measurement of the abdominal wall after implantation of mesh in humans was performed by Welty *et al.* using 3D stereography and ultrasound [45]. Patients with heavyweight monofilament meshes (which have been shown to promote fibrosis) had higher levels of paraesthesia and pain than those with lightweight monofilament meshes (which have lower rates of fibrosis). The abdominal wall stiffness was increased in all patients, but the extent of stiffness increased with mesh weight and decreased with pore size. This has been supported by several animal models, which have shown decreased compliance with extensive mesh ingrowth [46–48]. Furthermore, in situations where the mesh is in contact with the abdominal viscera, ingrowth results in adhesion formation and possible fistula formation [42,49,50]. In some patients, chronic inflammation and progressive fibrosis may result in the mesh shrinking after implantation and this can result in hernia recurrence [51–53].

In summary, meshes should aim to encourage enough ingrowth (preferentially of type 1 collagen) to allow sufficient mechanical strength to prevent recurrence, but not so much as to reduce abdominal wall compliance, cause pain, adhesion formation or unpredicted mesh shrinkage.

What are the characteristics of the ideal mesh?

Attempts have been made by several surgeons to describe the ideal mesh [44,54–58]. However, there are different requirements for inguinal hernia repairs versus ventral/incisional hernia repairs, small hernias versus large hernias, and open versus laparoscopic techniques. Furthermore, the requirements vary depending on the position of implantation within the abdominal wall (onlay, sublay, intraperitoneal onlay mesh [IPOM]). Therefore, the desirable properties vary depending on the characteristics of the hernia and technique for its repair. Thus, the criteria for the ideal mesh should be described in broad terms, and these are shown in Box 1. For clarity, the characteristics of the ideal mesh are divided into five key sections. These are biocompatibility, infection risk, handling, socioeconomics and longevity.

Box 1. 'Sanders–Kingsnorth' properties of the 'ideal' mesh.

Biocompatibility
- Must not do any harm
- Should reinforce and resist mechanical strains
- Should allow normal physiological function
- Should be physically and chemically inert
- Should produce a controlled/predicted biological response
- Should be noncarcinogenic
- Should not produce a state of allergy or hypersensitivity
- Should not migrate/dislocate from tissues
- Should not adhere to viscera

Infection risk
- Should be resistant to infection
- Should not transmit infectious diseases

Handling
- Should be easily implantable
- Should be easy for the surgeon to handle
- Should not restrict future surgical access or radiological imaging

Socioeconomics
- Should be easy to manufacture
- Should be easy to sterilize
- Should be widely available
- Should be inexpensive

Longevity
- Should maintain all of the characteristics of the above in the long term

What mesh properties are variable?

In order to differentiate between hernia prosthetics, it is important to discuss the variables that exist in mesh design and, perhaps more importantly, define the common terminology used by mesh manufacturers to describe their prosthetics.

Polymer type

The polymer type refers to the type of material that the mesh is constructed from. Broadly speaking, polymers can be divided into plastics or biological materials.

Plastic meshes

The term plastic refers to any of the numerous organic, synthetic, or processed materials which are mostly thermoplastic polymers of high molecular weight that can be modeled, cast, extruded, drawn or laminated into objects, films or filaments. Three polymers have dominated within plastic mesh construction. These are polypropylene, polyester and ePTFE. More recently other plastic polymers, namely condensed PTFE (cPTFE) and polyvinylidene fluoride (PVDF), have been used and are also described below.

Polypropylene mesh

Polypropylene mesh (PPM) is derived from the controlled polymerization of propylene, which in turn is derived from propane gas (pioneered by the Italian scientist Guilio Natta) [1]. Using a regulating meter, the liquid polymer is extruded as a single filament of predetermined width and strength. PPM can be fashioned by braiding the filaments to form fibers, which are then knitted together to create the mesh, which is hydrophilic in nature. Varying the size of the fibers and the knitting of the mesh creates different forms of PPM. Usher popularized PPM for use in hernia surgery in 1962, when a polypropylene version of Marlex® (Bard) (initially made of polyethylene) was developed [19,59]. This had the advantage of being amenable to sterilization via autoclaving. This mesh has subsequently undergone a name change to Bard™ Mesh. Several mesh manufacturers produce a PPM, and these are shown in Tables 1–3. In a survey of 29 hernia experts, PPM was the most widely used polymer for both inguinal hernia repair (67.6% used PPM) and incisional hernia repair (44.4% used PPM) [60].

The wide use of PPM is attributed to its favorable reputation [61–68]. The positive characteristics of PPM are that it has a high tensile and bursting strength and provides a strong mechanical reinforcement [69–71]; it encourages rapid ingrowth of connective tissue (albeit often of poor-quality collagen) [42,71]; it is cheaper than several other meshes; and has long-term data supporting its use [68,72–80]. The disadvantages of PPM are that the intensity of the foreign-body reaction has been attributed to reduced compliance and increased pain (especially heavyweight PPM) [76,81,82], and adhesion formation if in contact with the viscera [47,83–87].

Polyester mesh

Polyester mesh is a polymer of ethylglycol and terephthalate, and was developed in 1941 (by Whinfield and Dickinson) [1]. Like polypropylene, the raw material is melt extruded to produce fibers, which can be woven or bonded to produce threads or assembled sheets of material, which are hydrophilic in nature. The first monofilament polyester mesh was popularized by DuPont and was called Dacron® [1]. Subsequently a multifilament polyester mesh called Mersilene® (Ethicon) was produced and, later,

Table 1. Commonly used commercially available synthetic noncomposite meshes.

Noncomposite meshes	Special characteristics	Mesh and manufacturer
Nonabsorbable		
PPM	Monofilament: heavyweight/ small pore	Atrium™ Mesh (Atrium) Bard Mesh® (Bard) Biomesh® P1 (Cousin) Prolene® (Ethicon) Surgipro™ Monofilament (Covidien™) Trelex® Mesh (Meadox)
	Monofilament: heavyweight/ small pore pre-shaped	3D-Max® (Bard)
	Monofilament: lightweight/ large pore	Bard SoftMesh® (Bard) Biomesh® P8 (Cousin) Optilene®/ Optilene LP®, Optilene Elastic® (Braun) Permilene® Mesh (Braun) ProLite™ Mesh/ ProLite Ultra™ Mesh (Atrium) Surgipro™ Open Weave (Covidien)
	Monofilament: lightweight/ large pore pre-shaped	3DMax™ Light Mesh (Bard)
	Monofilament: lightweight/ large pore coated	C-Qur™ Mesh (Atrium; Omega-3 fatty acid-coating) TiMesh®ExtraLight/TiMesh® Light/TiMesh® Strong (PFM Medical; titanium coating)
	Multifilament	Surgipro™ (Covidien)
Polyester mesh		Fluorosoft® (SulzerVacutek) Mersilene® (Ethicon) Parietex™ (2D, 3D, lightweight monofilament) (Covidien)
	Pre-shaped	Parietex™ (various pre-shaped and folding meshes) (Covidien)
	Sutureless	ParietexProGrip™ (Covidien)
ePTFE mesh		Bard® Dulex™ Mesh (Two-layered ePTFE mesh with one microporous surface and one macroporous surface) DualMesh® (Gore®) (Two layered ePTFE mesh with one smooth surface and one corduroy surface) Gore Soft Tissue Patch® (Gore) (Two laminar microporous surfaces) MycroMesh® (Gore) (Microporous node and fibril structure with regularly spaced macropores)
	Antimicrobial coating	DualMesh® Plus (Gore) (silver carbonate and chlorhexidine diacetate) MycroMesh® Plus (Gore) (silver carbonate and chlorhexidine diacetate)
cPTFE mesh		MotifMESH® (Proxy Biomedical) Omyra® Mesh (Braun)
PTFE	Monofilament macroporous	INFINIT® Mesh (Gore)
PVDF mesh		Co-PVDF® (Solvay)
Absorbable		
Polyglactin 910		Vicryl® (Ethicon)
Polyglycolic acid		Dexon® (Syneture) Safil® Mesh (Braun)

cPFTE: Condensed polytetrafluoroethylene; ePTFE: Expanded polytetrafluoroethylene; PPM: Polypropylene mesh; PTFE: Polytetrafluoroethylene; PVDF: Polyvinylidenfluoride.

a collagen-coated polyester mesh called Parietex™ Composite (Covidien™) was developed (Tables 1–3). Polyester meshes have not been as widely adopted worldwide as PPM; however, in France, Italy and Belgium they are commonly used, with satisfactory results [22,88,89]. The advantages of polyester meshes are their reported rapid fibroblastic infiltration and fixation to tissues, and less mesh shrinkage compared with PPM [52]. The disadvantages of polyester are higher rates of infection (although there is also

evidence to the contrary) [90], adhesion to viscera if placed in the intra-abdominal position (without collagen coating) [89], and degradation/loss of strength over time [91]. However, many of the studies evaluating the use of polyester mesh are small series and are not scientifically robust [1,89].

ePTFE

ePTFE is a microporous, laminar, hydrophobic prosthetic material with a negative charge. It is composed of compact nodules interlinked by fine fibers. The length of these fibers determines the material's internodal distance and pore size (this is usually a range rather than an exact measurement). PTFE was first used for hernia repair by Harrison in 1957 [92], but after initial promising results, its use was abandoned owing to poor performance [93]. The process of expanding PTFE was refined by Gore® and the first mass-produced ePTFE prosthesis for hernia surgery was the Gore-Tex® Soft Tissue Patch [301]. The material had good biological tolerance and produced a minimal inflammatory reaction compared with PPM or polyester mesh [94–99]. It therefore had advantages when the mesh was in contact with the peritoneum/viscera [100,101]. As a result, ePTFE has been the most commonly used material for laparoscopic/intraperitoneal placement [60]. A disadvantage of ePTFE is the lack of good tissue incorporation and high recurrence rates [102,103]. Modifications have been made to ePTFE in an effort to address this. The first of these was the introduction of multiple perforations in the ePTFE patch in an effort to achieve a prosthesis that, although laminar in structure, would have the properties of a reticular mesh (this was eventually called MycroMesh® [Gore®]) [99]. However, experimental studies showed no biomechanical benefits and greater adhesions on the peritoneal surface over conventional ePTFE mesh [104]. Further modifications included the creation of dual-layered mesh with a corduroy surface (to encourage ingrowth) on one side and a smooth surface on the peritoneal side (DualMesh® [Gore®]). Once again, experimental studies showed little difference compared with conventional ePTFE [105,106]. Copolymerization of ePTFE with other polymers, such as PPM, has produced more promising results [107,108].

Table 2. Commonly used commercially available meshes: composite meshes.

Composite meshes	Aim	Additional component	Mesh and manufacturer
PPM composites	Improved physiological function	Poliglecaprone-25	Ultrapro® (Ethicon)
		Polyglactin 910	Vypro®/ Vypro II® (Ethicon) – Vypro = 69% PPM, 31% Vicryl; Vypro II = 50% PPM, 50% Vicryl
	Improved physiological function/reduced adhesions	Poliglecaprone-25 + polydiaxone	Physiomesh® (Ethicon)
	Reduced adhesions	Collagen-oxidized film	Parietene Composite® (Sofradim)
		ePTFE	Bard® Composix® L/P (Bard)
			Bard® Composix® E/X mesh (Bard)
			Relimesh® (Hernimesh®)
		Hydrogel (polyvinylpyrrolidone + polyethylene glycol)	Intramesh T1 (Cousin)
			Adhesix (Cousin)–sutureless
		Oxidized regenerated cellulose + polydiaxone	Proceed® (Ethicon)
		PVDF	DynaMesh® (DynaMesh)
		Seprafilm® (carboxymethylcellulose + hyaluronic acid)	Sepramesh® (Bard)
Polyester mesh composites	Reduced adhesions	Collagen-oxidized film	Parietex Composite™/Parietex Optimized Composite™ (Covidien™)
		Dimethyl siloxane	Biomesh® A2 (Cousin) – macroporous
			Intramesh® W3 (Cousin) – microporous
Others	Long-term absorbability (up to 60 weeks)	First fiber = glycolide, lactide + trimethylene carbonate Second fiber = lactide + trimethylene carbonate	Tigr® Matrix (Novus Scientific)
	Encourages type 1 collagen	Polyglycolic acid + trimethylene carbonate	Bio-A® (Gore®)

ePTFE: Expanded polytetrafluoroethylene; PPM: Polypropylene mesh; PVDF: Polyvinylidene fluoride.

Another disadvantage of ePTFE is it's behavior in the presence of infection. Several studies have shown that ePTFE is more susceptible to infection than other biomaterials [109–113], and that when infection occurs, most ePTFE implants will need to be removed [114,115]. Modified prostheses, pretreated with antimicrobial agents, have been produced to address this issue (DualMesh Plus and MycroMesh Plus [Gore]) and *in vitro* efficiency of these meshes has been demonstrated [116].

In order to combine the reported inertness of ePTFE with the benefit of the tissue ingrowth observed with macroporous PPM and polyester meshes, Gore developed a novel macroporous nonexpanded PTFE mesh, known as INFINIT Mesh (Gore®). Unlike ePTFE prosthesis, the mesh is intended for extraperitoneal use only. In an animal study examining mechanical and histological properties of the mesh, INFINIT Mesh showed similar characteristics to PPM in terms of strength and ingrowth [117]. However, there is currently no clinical trial data to support the use of the mesh ahead of other prosthesis. A Phase IV clinical trial comparing INFINIT Mesh with PPM is currently being conducted.

cPTFE

cPTFE is a macroporous, nonwoven prosthetic material that is created by condensing, rather than expanding, PTFE. The idea is that it combines the open-mesh concept found to be important for tissue integration and *in vivo* implant flexibility, with the inherent property of laminar ePTFE in generating an organised neoperitoneum [118]. Although long-term data on cPTFE are limited, promising results in terms of mesh integration, reduced visceral adhesions and reduced infection risk compared with ePTFE have been reported [118–120]. Two cPTFE base meshes are currently on the market, these are MotifMESH™ (Proxy Biomedical) and Omyra® (Braun).

PVDF

PVDF is a nonabsorbable fluoropolymer. It originated in the semiconductor and chemical processing industries, and PVDF sutures have been used widely in cardiothoracic and orthopedic surgery [121,122]. Although relatively new to the market, *in vitro* and *in vivo* studies have shown promising results [86,123–125]. It has been shown to have similar tensile strength and surface characteristics, but more resistance to hydrolysis, degradation and stiffening compared with PPM and polyester meshes [125]. Moreover, histological analysis of the tissue reaction in a rat model confirmed superior integration compared with PPM [125]. Interestingly, the inflammatory process was less intense with PVDF compared with lightweight/large-pore PPM. The collagenous capsule was limited to the perifilamentary region, rather than producing a scar plate that incorporated the entire mesh. Clinical data from Berger *et al.* evaluated the use of a composite mesh made of PVDF/PPM (DynaMesh®) in laparoscopic (IPOM) incisional hernia repair and parastomal hernia repair in 344 consecutive patients [126–128]. The results were favorable in terms of recurrence and infection (0.3% recurrence in the incisional hernia group; and 2% recurrence in the parastomal hernia group). Conversely, in a small retrospective review of 29 laparoscopic (IPOM) incisional hernia repairs with DynaMesh®, extremely high complication rates were reported [129]. Six patients (20.6%) required reoperation owing to adhesions (five patients) or mesh infection (one patient). Two further patients, who had subsequent surgery for unrelated reasons, were also reported to have adhesions to the mesh. The inability to reproduce the promising results observed by Berger *et al.* suggests that there is currently a lack of clinical and long-term data to support the use of PVDF ahead of other prostheses.

Table 3. Commonly used commercially available meshes: biological meshes.

Biological meshes		Mesh and manufacturer
Porcine small intestine submucosa	Noncrosslinked	Surgisis® (Cook)
	Crosslinked	FortaGen® (Organogenesis)
Human acellular dermis	Noncrosslinked	AlloDerm® (LifeCell) AlloMax (Bard) Flex HD® (Ethicon)
Xenogenic acellular dermis	Noncrosslinked	Strattice™ (LifeCell) Veritas (Synovis) SurgiMend® (TEI Biosciences) Tutomesh® (RTI Bilogics) XenMatrix™ (Brennen)
	Crosslinked	PeriGuard® (Synovis) Permacol® (Covidien™) CollaMend™ (Bard)

Polyglycolic acid

Polyglycolic acid is a popular absorbable suture material. The best-known polyglycolic acid mesh is Dexon® (Synature), which was introduced in 1983. It can be cut to any size without fraying and is completely absorbed within 90 to 180 days [130–132]. However, the mean tensile strength has been shown to decrease by 50% at week 2–10 after implantation [69]. Whether the fibrous ingrowth into the mesh is sufficient to accomplish permanent repair is controversial and as a result it is not a widely used mesh [60,109,131].

Polyglactin 910

Polyglactin 910 is polyglycolic acid copolymerized with lactic acid and is available as Vicryl® (Ethicon). There is evidence to suggest that Vicryl's rate of absorption is more variable than Dexon's [69]. Early recurrences with Vicryl mesh have been reported at the prosthetic–muscle interface and from 4 weeks on, recurrences have been reported at both the prosthetic–muscle interface and through the mesh site itself [100]. Vicryl appeared to invoke less collagen ingrowth compared with Dexon but also fewer adhesions [69,100]. It was therefore used in the intraperitoneal position, but the subsequent development of improved composite meshes has resulted in its infrequent use today [60].

Composite & hybrid meshes

Biological meshes

Biological tissue grafts from animal (xenogenic) and human (allogenic) sources have been introduced for hernia repair over the last

few years. They are rendered acellular through various methods of preservation and fabrication, and are offered as collagen-rich scaffolding that allows cellular ingrowth, tissue remodeling and neovascularization. However, the specific manufacturing processes that yield modified collagen matrices vary significantly from one product to another [106]. The variations include difference in the type and origin of tissue used, whether the collagen is crosslinked, the decellularization method and the process for sterilization.

Grafts can either be human or animal (porcine or bovine), and are made of one of three types of tissue, namely dermis, small intestine submucosa or pericardium. The various decellularization methods include physical (dissection, agitation, sonication, pressure or freeze-thaw), chemical (detergents, ionic solutions, or acids/bases) and enzymatic methods. The various sterilization methods include γ-irradiation, ethylene oxide gas and hydrogen peroxide plasma [133].

Some materials utilize chemical crosslinking with glutaraldehyde. The purpose of this is to increase the stability to the collagen against the activity of the collagenase, thereby slowing or stopping the degradation of the donor collagen [134,135]. However, it has been suggested that crosslinking leads to nonincorporation of the graft and preclusion of immune cell penetration [133,134]. To date the primary use of biological meshes has been for complex abdominal wall reconstruction and use in infected fields. However, the majority of studies assessing biological meshes have been conducted in clean field cases [136].

Despite encouraging early results, several clinical complications have been reported following the use of biological materials in hernia repair. These include degradation, laxity, lack of integration and recurrence [137,138]. A systematic review reported a failure rate of 8% at 19 months for small intestine submucosa grafts used for incisional hernia repair [136]. By comparison, an aggregate failure rate of 15% at 12 months has been reported for noncrosslinked acellular human dermis grafts and 8% at 15 months for crosslinked porcine dermis [136]. However, these poor results may be related to the nature of the repair and most notably, there have been more reports on acellular dermis grafts used in infected fields compared with small intestine submucosa [136]. It has been suggested that when these grafts are used as a facial bridge, the rates of recurrence are highest (80% recurrence rate compared with 5% recurrence rate when used as an onlay graft) [139,140].

Mesh construction/filament type/coating

Synthetic meshes can be constructed from monofilament or multifilament materials and can be woven, knitted or form flat sheets. Multifilament materials are associated with increased bacterial adhesion *in vitro* and *in vivo* [116,141,142]. This is presumably due to the increased surface area.

Construction of meshes using copolymerization with more than one polymer and the coating of meshes has increased with the increasing popularity of laparoscopic intraperitoneal mesh placement (**Box 2**). The purpose of these modifications is to reduce adhesion formation. These modifications can be classified broadly into two methods [143]. The first method involves treating the prosthesis to create an appropriate interface between the biomaterial and the visceral peritoneum. These treatments are usually absorbable barriers or chemical solutions. Examples include the use of gelatin films [70], Interceed® [144], carboxymethyl–cellulose [145], polyethylene glycol [146] and hyaluronate [146]. The second method involves a physical barrier usually in the form of a nonabsorbable biomaterial (**Table 4**). However, different experimental animal studies show contradictory results – a mesh superior to another in terms of adhesion in one study may be inferior to the same mesh in another study (as summarized in **Table 4**).

Box 2. Amid classification of meshes.

- Type I: totally macroporous
  - Pore size >75 μm, which is the required pore size for admission of macrophages, fibroblasts, blood vessels and collagen fibers
- Type II: totally microporous with multifilament or microporous components
  - Pore size <10 μm in at least one of the surface dimensions
- Type III: macroporous with multifilament or microporous components
- Type IV: biomaterials

Pore size/mesh weight

The weight of the mesh depends on both the weight of the polymer and the amount of material used [147]. However, there are no agreed definitions for 'lightweight' or 'heavyweight' meshes. Most surgeons have had few problems with heavyweight meshes but there is a mismatch between this clinical experience and the published clinical data [55]. The use of heavyweight meshes is associated with increased complications and adverse events, such as fistula formation, adhesion and pain [148]. Although these complications are mainly observed in the intra-abdominal position (**Table 4**), they have also been observed as a result of extraperitoneal placement [60]. Heavyweight meshes have an increased surface area and this produces a more intense inflammatory reaction. They also tend to shrink more than lightweight meshes and are stiffer, which can make normal abdominal movements difficult or unnatural [149].

In 2010, an expert review stated that the term 'lightweight' is not simply descriptive of the product being low in weight, nor can it be simply be defined by a cut-off value of weight per square meter, filament or specific pore size [55]. Lightweight typically refers more to meshes with a larger pore size, resulting in smaller surface area. The lower amount of material present in lightweight material should lead to decreased foreign-body reaction and fibrosis [150,151]. It has been suggested that the increased flexibility of lightweight meshes should result in a better activity profile following surgery [152]. However, concerns have been raised over the strength of lightweight meshes in the repair of large hernia defects and the risk of sutures tearing out of the mesh [147].

Porosity also appears to be important in resistance to infection. If pore sizes are less than 10 nm, macrophages and neutrophilic granulocytes are unable to pass through the pores [153].

Table 4. Experimental studies comparing adhesion formation of different prosthetic materials.

Author (year)	Animal	n	Meshes	Open/ laparoscopic	Fewer adhesions	More adhesions	Timescale	Ref.
Jenkins *et al.* (1983)	Rats	41	PPM (Marlex®) Vicryl® ePTFE Silastic PPM (Marlex) + Gelfilm®	Open	Vicryl	PPM (Marlex) PPM (Marlex) + Gelfilm	1, 2, 4, 8 weeks	[70]
Naim *et al.* (1993)	Rats	–	PPM + ePTFE PPM + Interceed® PPM + Poloxamer	Open	PPM + Interceed	–	–	[144]
Bellón *et al.* (1996)	Rabbits	24	PPM (Marlex) ePTFE (MycroMesh®)	Open	ePTFE (MycroMesh)	PPM (Marlex)	14, 30, 60, 90 days	[104]
Baykal *et al.* (1997)	Mice	72	PGA PPM	Open	PGA	PPM	5, 14 days	[172]
Dasika and Widmann (1998)	Rats	47	PPM Vicryl PPM + Vicryl	Open	Vicryl PPM + Vicryl	PPM	1, 2, 3 months	[173]
Bellón *et al.* (1999)	Rabbits	48	ePTFE (STP®) PPM (Marlex) PPM (Prolene®) Lyodura®	Open	ePTFE (STP) Lyodura	–	14, 30, 60, 90 days	[174]
Vrijland *et al.* (2000)	Rats	44	PPM PPM + Vicryl PPM + Fluorosoft®	Open	PPM + Fluorosoft	PPM + Vicryl	60 days	[49]
Bellón *et al.* (2000)	Rabbits	8	ePTFE (MycroMesh) ePTFE (DualMesh®) ePTFE (STP) PPM (Marlex)	Open	–	PPM (Marlex)	3, 7 days	[175]
Bellón *et al.* (2002)	Rabbits	14	ePTFE (DualMesh) ePTFE (CV-4®)	Open	ePTFE (DualMesh)	ePTFE (CV-4)	14 days	[176]
Zieren *et al.* (2002)	Rats	40	ePTFE (DualMesh) Polyester Composite	Open	No difference	No difference	14, 90 days	[177]
van't Riet *et al.* (2003)	Rats	91	PPM PPM + Icodextrin Sepramesh® Parietex™	Open	Sepramesh Parietex™	PPM PPM+ Icodextrin	7, 30 days	[178]
Matthews *et al.* (2003)	Rabbits	20	ePTFE (DualMesh) PPM (Marlex)	Open	ePTFE (DualMesh)	PPM (Marlex)	1, 3, 9, 16 weeks	[179]

Table 4. Experimental studies comparing adhesion formation of different prosthetic materials (cont.).

Author (year)	Animal	n	Meshes	Open/lap	Fewer adhesions	More adhesions	Timescale	Ref.
Borrazzo *et al.* (2004)	Pigs	21	PPM ePTFE (DualMesh) Sepramesh	Lap	Sepramesh	–	28 days	[180]
González *et al.* (2004)	Rats	80	PPM (Parietene®) Parietex Composite™ Parietene Composite® Composix® E/X Sepramesh ePTFE (DualMesh)	Open	Parietex Composite Parietene Composite Composix E/X ePTFE (DualMesh)	PPM (Parietene) Sepramesh	21 days	[84]
Butler and Prieto (2004)	Guinea pigs	19	PPM (Prolene) PPM (Prolene) + AlloDerm®	Open	PPM (Prolene) + AlloDerm	–	4 weeks	[181]
Kayaoglu *et al.* (2005)	Rats	60	PPM (Surgipro™) ePTFE (DualMesh) Sepramesh Vypro II® Parietex Composite	Open	ePTFE (DualMesh) Sepramesh	–	4 weeks	[182]
Matthews *et al.* (2005)	Rabbits	30	ePTFE (DualMesh) Composix E/X Sepramesh	Open	ePTFE (DualMesh)	–	1, 3 , 9, 16 weeks	[183]
Demir *et al.* (2005)	Rats	30	PPM (Bard® Mesh) Composix E/X PPM (Bard Mesh) + Interceed	Open	PPM (Bard Mesh) + Interceed		14 days	[184]
McGinty *et al.* (2005)	Pigs	8	PPM (Prolene) ePTFE (DualMesh) Parietex Composite	Lap	Parietex Composite	–	28 days	[185]
Konstantinovic *et al.* (2005)	Rats	48	PPM (Marlex) Surgisis®	Open	PPM (Marlex) (30 days) Surgisis (90 days)	–	30, 90 days	[186]
Sikkink *et al.* (2006)	Rats	60	PPM (Prolene) PPM (Prolene) + Hyalobarrier® gel PPM (Prolene) + Tissucol® ePTFE (DualMesh) Sepramesh Parietene Composite	Open	Sepramesh	PPM (Prolene)	2 months	[87]
Dilege *et al.* (2006)	Rats	30	PPM (Prolene) PPM + Interceed Sepramesh	Open	PPM + Interceed Sepramesh	PPM (Prolene)	28 days	[83]

Table 4. Experimental studies comparing adhesion formation of different prosthetic materials (cont.).

Author (year)	Animal	n	Meshes	Open/lap	Fewer adhesions	More adhesions	Timescale	Ref.
Burger *et al.* (2006)	Rats	200	PPM (Prolene) ePTFE (DualMesh) Ultrapro® Timesh® Sepramesh Parietex Composite Proceed® Tutomesh®	Open	Sepramesh Parietex Composite	–	7, 30 days	[187]
Harrell *et al.* (2006)	Rabbits	60	ePTFE (DualMesh) Composix E/X Proceed PPM (Marlex)	Sequential lap	ePTFE (DualMesh)	PPM (Marlex)	16 weeks	[188]
Kiudelis *et al.* (2007)	Rabbits	42	PPM (Prolene) Mersilene® PPM + Vicryl ePTFE Bard Proceed	Open	ePTFE Bard Proceed	PPM (Prolene) Mersilene PPM + Vicryl	30 days	[189]
Jacob *et al.* (2007)	Pigs	10	Proceed Parietex Composite PPM	Lap	Parietex Composite	PPM	28 days	[85]
Voskerician *et al.* (2007)	Rats	–	cPTFE (MotifMESH™) ePTFE (DualMesh) Composix PPM (Marlex) Proceed	Open	cPTFE (MotifMESH) Composix	PPM (Marlex)	1, 3 months	[119]
Novitsky *et al.* (2007)	Rabbits	20	PPM (Marlex) ePTFE (DualMesh) Composix E/X Proceed	Open	ePTFE (DualMesh)	PPM (Marlex)	1 year	[47]
Bellón *et al.* (2007)	Rabbits	24	Parietex Composite Sepramesh PPM–PU 99	Sequential lap	Parietex Composite PPM-PU 99	Sepramesh	3, 7, 14 days	[190]
Miwa *et al.* (2007)	Rats	20	PPM Composix E/X	Open	Composix E/X	PPM	3 months	[191]
Marcondes *et al.* (2008)	Rabbits	24	PPM (Surgipro) Sepramesh Composix E/X	Lap	Sepramesh	PPM (Surgipro)	28 days	[192]

Table 4. Experimental studies comparing adhesion formation of different prosthetic materials (cont.).

Author (year)	Animal	n	Meshes	Open/lap	Fewer adhesions	More adhesions	Timescale	Ref.
Matin-Cartes *et al.* (2008)	Pigs	10	PPM ePTFE (DualMesh Plus®) PPM + fibrin glue ePTFE (DualMesh Plus) + fibrin glue	Open	PPM + fibrin glue ePTFE (DualMesh Plus) + fibrin glue	PPM ePTFE (DualMesh Plus)	5 weeks	[193]
Junge *et al.* (2009)	Rats	40	PVDF + PPM (DynaMesh) Parietene Composite ePTFE (DualMesh) PPM	Open	Parietene Composite®	PPM	30 days	[86]
Conze *et al.* (2008)	Rabbits	–	Co-PVDF® PPM (Prolene)	Lap	No difference	No difference	7, 21, 90 days	[123]
Schug-Pass *et al.* (2008)	Pigs	6	PPM (TiMesh® Light) PPM (TiMesh) + SurgiWrap®	Lap	No difference	No difference	3 months	[194]
Prieto-Diaz-Chavez *et al.* (2008)	Rats	40	PPM + fibrin glue PPM	Open	PPM + fibrin glue	PPM	–	[195]
Junge *et al.* (2009)	Rats	40	PVDF + PPM PPM + Col ePTFE (DualMesh) PPM	Lap	PVDF + PPM PPM + Col	PPM ePTFE (DualMesh)	30 days	[86]
Emans *et al.* (2009)	Rats	–	PPM (Prolene) Proceed PPM + NVP/BMA	Open	Proceed (7 days) PPM + NVP/BMA (30 days)	PPM (Prolene)	7, 30 days	[72]
Pierce *et al.* (2009)	Rabbits	41	C-Qur™ PPM (Prolite Ultra™) Composix Parietex Proceed Sepramesh ePTFE (DualMesh)	Open	C-Qur	Proceed Composix	120 days	[196]
Schreinemacher *et al.* (2009)	Rats	–	PPM (Prolene\0 TiMesh PPM (Ultrapro®) Proceed Parietex Composite c-Qur	Lap	Parietex Composite (7 days) C-Qur (7 days) No difference (30 days)	–	7, 30 days	[197]

Table 4. Experimental studies comparing adhesion formation of different prosthetic materials (cont.).

Author (year)	Animal	n	Meshes	Open/lap	Fewer adhesions	More adhesions	Timescale	Ref.
Costa *et al.* (2009)	Rats	55	PPM PPM + PAF SIS	Open	SIS	PPM PPM + PAF	–	[198]
Ansaloni *et al.* (2009)	Rats	60	PPM PPM–PU 99 PPM + SIS PPM + ePTFE No mesh (control)	Open	PP–PU 99 PPM + SIS	PPM + ePTFE	21, 90, 180 days	[199]
Jin *et al.* (2009)	Pigs	9	cPTFE cPTFE + HPM Polyester–collagen composite HPM	Open	HPM Polyester–collagen composite	–	90 days	[200]
Voskerician *et al.* (2010)	Rats	20	cPTFE cPTFE + HPM cPTFE + HFL	Open	cPTFE + HPM	cPTFE cPTFE + HFL	30 days	[201]
Zinther *et al.* (2010)	Sheep	16	Parietex Composite PVDF + PPM (DynaMesh)	Lap	Parietex Composite	PVDF + PPM (DynaMesh)	3, 6 ,12, 18 months	[202]
Gaertner *et al.* (2010)	Rats	–	PPM (Marlex) PPM (Surgipro) Composix E/X ePTFE (STP) MycroMesh ePTFE (DualMesh) Vicryl Mesh Vypro II® Parietex Composite Sepramesh AlloDerm Permacol™ Peri-Guard® Veritas®	Open	Parietex Composite Sepramesh®	–	7 days	[203]
Gruber–Blum *et al.* (2011)	Rats	32	SurgiWrap Prevadh® Seprafilm®	Lap	SurgiWrap Prevadh	SurgiWrap	30 days	[204]
Rodriguez *et al.* (2011)	Rabbits	18	Parietex Composite Sepramesh Proceed	Open	Parietex Composite	Sepramesh Proceed	3, 7, 14 days	[54]

Table 4. Experimental studies comparing adhesion formation of different prosthetic materials (cont.).

Author (year)	Animal	n	Meshes	Open/lap	Fewer adhesions	More adhesions	Timescale	Ref.
Fujino *et al.* (2011)	Rabbits	–	PPM + PLLA PPM + Seprafilm	Open	PPM + PLLA	–	4 weeks	[206]
Yao *et al.* (2011)	Rats	93	PPM + PLC PPM + HA + PLC PPM + Collagen + PLC	Open	PPM + Collagen + PLC	PPM + PLC PPM + HA + PLC	30, 60, 90 days	[207]

AlloDerm®: Decellularized human dermis (LifeCell™); Co-PVDF®: Auto manufactured mesh woven with PVDF polymer (Solvay); Composix®: Nonwoven ePTFE (Bard®); Composix® E/X: PPM mesh sewn with polypropylene stitching to a thin sheet of ePTFE (Bard®); cPTFE (MotifMESH®): Nonwoven macroporous condensed PTFE (Proxy Biomedical); C-Qur™: PPM with a Omega 3 fatty acid bioabsorbable coating (Atrium); ePTFE (CV-4®): Auto manufactured mesh woven out of ePTFE suture thread CV-4 (Gore®); ePTFE (DualMesh®): Two layered ePTFE mesh with one smooth surface and one corduroy surface (Gore®); ePTFE (STP®): Gore-Tex® Soft Tissue Patch; ePTFE with two laminar microporous surfaces (Gore®); Fluorosoft®: Fluoropassivated polyester (SulzerVacutek®); Gelfilm®: Absorbable gelatin film (Pharmacia and Upjohn); Hyalobarrier® Gel: Sterile transparent and highly viscous gel obtained by condensation of hyaluronic acid (Fidia Advanced Biopolymers SRL); HFL: Human fascia lata; HPM: Human peritoneal membrane; Icodextrin: Iso-osmolar biodegradable – 1,4-linked glucose polymer solution (Baxter); Interceed: Oxidized regenerated cellulose (Ethicon); Lyodura®: Lyophilized dura mater (Braun®); Mersilene: Polyester mesh (Ethicon); MycroMesh®: ePTFE (Gore®); Parietene Composite®: PPM mesh bonded on one side to a collagen-oxidized film (Sofradim); Parietex Composite™: Collagen-oxidized film treated polyester mesh (Covidien™); Permacol™: Porcine dermal collagen implant (Covidien™); Peri-Guard®: Patch made from bovine pericardium (Synovis®); PGA: Polyglycolic acid; Poloxamer: Triblock copolymers consisting of central hydrophobic block of polyethylene glycol flanked by two hydrophilic blocks of polyethylene glycol; Polyester Composite: Polyurethane-covered Dacron mesh (Braun); PPM (Marlex®): Monofilament PPM mesh (Bard®); PGA: Polyglycolic acid; Poloxamer: Triblock copolymers consisting of central hydrophobic block of polyethylene glycol flanked by two hydrophilic blocks of polyethylene glycol; PGA: Polyglycolic acid; Poloxamer: Triblock copolymers consisting of central hydrophobic block of polyethylene glycol flanked by two hydrophilic blocks of polyethylene glycol; Polyester Composite: Polyurethane covered Dacron® mesh (Braun); PPM (Marlex®): Monofilament PPM mesh (Bard®); PPM (Prolene®): Monofilament PPM mesh (Ethicon); PPM (Prolite Ultra™): PPM (Atrium); PPM + PAF : PPM with a coating of polylactic acid film; PPM + PLC: PPM with a polyactide-co-caprolactone coating; PPM + PLLA: PPM with Poly L: lactic acid film; PPM + HA + PLC: PPM with a hyaluronic acid and polyactide-co-caprolactone coatings; PPM + Collagen + PLC: PPM/collagen composite with a polyactide-co-caprolactone coating; PPM + NVP/BMA: PPM with N-vinyl pyrrolidon and n-butylmethacrylate coating; PPM-PU 99: Auto designed prosthesis composed of reticular PPM mesh and a nonabsorbable polyurethane film; PPM (Surgipro™): monofilament PPM mesh (Covidien™); Prevadh®: Biological antiadhesive barrier (Sofradim); Proceed® – PPM: Polydiaxanone composite with oxidized cellulose coating (Ethicon); PVDF + PPM (DynaMesh®): Two-component (PPM + PVDF) monofilament mesh (DynaMesh); Seprafilm® – Bio absorbable translucent membrane composed of carboxymethylcellulose and hyaluronic acid (Genzyme); Sepramesh®: PPM mesh coated on one side with a Seprafilm® (Bard®); Silastic: Polydimethylsiloxone prosthesis (Dow Corning); SIS: Porcine small intestine submucosa mesh; SurgiWrap®: Bioresorbable adhesion barrier film (Mast); Surgisis®: Derived from porcine small intestine submucosa (Cook); TiMesh®: PPM with titanium coating (PFM Medical); Tissucol®: Fibrin glue (Baxter); Tutomesh®: Acellular collagen matric form bovine pericardium (RTI Biologics); Ultrapro®: Partially absorbable composite PPM/Poliglecaprone-25 monofilament mesh (Ethicon); Veritas®: Acellular bovine pericardium (collagen not crosslinked); (Synovis); Vicryl® (Mesh): Polyglactin 910 (Ethicon); Vypro II®: PPM/polyglactin 910 composite mesh (Ethicon).
Modified from Morales-Conde *et al.* [106,207]

Tensile strength & elasticity

The maximum intra-abdominal pressures generated in healthy adults occur while coughing and jumping. These are estimated to be approximately 170 mmHg [154]. Meshes used to repair hernias therefore need to withstand at least 180 mmHg before bursting (tensile strength up to 32 N/cm). Moreover, it is important that the strength of meshes is tested in a biaxial fashion. Virtually all meshes tested *in vitro* are able to withstand this pressure, even the lightweight meshes (e.g., Vypro burst pressure: 360 mmHg [155]). Exceptions are 'ultra-lightweight' meshes, such a TiMesh® Extralight (16 g/m^2), which has a tensile strength of only 12 N/cm [156]. However, in a clinical trial assessing its performance in groin hernia repair, it performed favorably [156].

The natural elasticity of the abdominal wall at 32 N/cm is approximately 38%. More compliant lightweight meshes have been shown to have an elasticity of approximately 20–35% at 16 N/cm [155]. Less compliant heavyweight meshes have only half this elasticity (4–16% at 16 N/cm) and therefore may restrict abdominal movement and distension in some patients.

What mesh classification systems exist?

Classifications systems are important in order to improve the possibility of comparing different studies and their results. By describing meshes in a standardized way, meshes with the same characteristics produced by different manufacturers can be compared. The secondary purpose of a classification would be to develop evidence-based therapeutic guidelines of which type of mesh to use for different clinical scenarios.

The best-documented mesh classification system was devised by Amid in 1997 [157]. The classification was based on pore size of the meshes and is shown in Box 2.

More recently, a research group from Aachen, Germany, in conjunction with mesh manufacturers have begun the process of devising a new classification system [158]. This system differentiates 'major' differences (objectified through randomized controlled trials) and 'minor' differences (not significantly different in randomized controlled trials) between available meshes. The classification is intended to be used for analysis of the data from the registry of hernia repairs, as well as implant failures to detect major mesh material-related problems.

These classification systems provide useful comparative groups for research purposes; however, none of the current classification systems give a concise hernia-specific overview of which mesh/group of meshes is best for a particular scenario.

What different types of meshes are available?

The commercially available meshes are shown in Tables 1–3. For clarity they are divided into synthetic

noncomposite meshes, composite meshes and biological meshes. The list is not exhaustive but rather includes the most commonly used meshes in each category. In addition to the meshes listed, many manufacturers produce plugs/hernia systems made of the same material as the fast meshes for hernia-specific repairs.

Mosquito net as a hernia prosthetic in low-income countries

Although the use of alloplastic mesh is common place in more economically developed countries, in developing countries the cost of mesh often prohibits its use. In situations where commercial material is not available or affordable, nylon mosquito net has been used as an alternative [159–166]. In two clinical trials assessing the use of mosquito net compared with a commercial hernia mesh, there was no significant difference in the clinical short-term outcome or in the surgeons' comfort in handling the two different materials [159,161]. The price of the locally bought nylon mesh was US$0.0043 as compared with US$108 for the commercial mesh [161]. However, some surgeons have raised concern over the use of nylon mosquito net and the risk of infection and recurrence [167,168].

Is there one mesh suited to use in all hernia repairs or should the mesh be tailored to the repair?

There are several acceptable methods of repair for each type of abdominal wall hernia [60]. It is clear that not all hernias are equal. The position of the hernia and proximity to bony prominences, the size of the defect, the normal function of the patient and their comorbidities are just a few of the variables that exist. Moreover, the expertise and preference of the surgeon, the mesh fixation technique, the available resources and the cost, are further variables that complicate the process. It seems clear that there is no easy scientific answer that offers one golden solution for all hernia repairs. The choice is usually based upon surgeon preference, surgeon experience, the available resources and to some extent, but by no means principally, evidence-based practice. Given this and the characteristics of the currently available meshes, there cannot currently be one mesh for all repairs. Rather, we should be aiming towards an evidence-based decision tree of the most appropriate repairs for particular types of scenarios, taking into account both the hernia and the patient [169]. This should extend to recommending the most appropriate meshes for each of these scenarios.

It has repeatedly been shown that the prosthetic only plays a small part in the overall outcome of hernia repair. The type of repair, surgical technique and skill of the operating surgeon (often referred to as expertise) are also of key importance [170,171].

Expert commentary

The contradictory evidence supporting one mesh prosthetic ahead of another is in part due to the diverse nature of hernia disease. Surgeons must consider the context of the repair that is being performed when choosing the most suitable prosthetic. For extraperitoneal placement in younger or functionally active individuals, the evidence supports the use of a lightweight/large-pore polypropylene or polyester prosthetic [55,68,147,155,156]. For patients with poor tissue constitution who are at high risk of recurrence, heavyweight meshes may be the more appropriate choice.

For ventral hernia repair there is a trade off between increased adhesions from open surgery (more adhesions but with the advantage of extraperitoneal mesh placement) versus laparoscopic surgery (fewer adhesions but with the disadvantage of intraperitoneal mesh placement). Again, the most appropriate repair must be tailored to the hernia and the needs of the patient. If the mesh is to be placed in the intraperitoneal position, a composite mesh should be used. The contradictory nature of the data regarding composite meshes makes it difficult to suggest one mesh ahead of another. The promising early data from composite meshes containing either PVDF or cPTFE suggest that meshes including these polymers may be of benefit [119,125,126].

Poor results from repair in contaminated fields once again makes it difficult to recommend one prosthetic ahead of another. Certainly it seems that ePTFE should be avoided in these circumstances. Biological meshes may yet prove beneficial in the repair of such hernias but the current data do not provide sufficient evidence to support their use.

We must not forget that the prosthetic of choice, while important, is only part of the repair process. Patient selection, method of repair and surgical skill also have a large part to play in producing the best outcomes, both in terms of recurrence and functionality.

Five-year view

The modern era of mesh continues to evolve. In the next 5 years there are two key areas of research that need to be addressed in prosthetic development. The first is related to the current meshes on the market. We need better evidence supporting the use of one prosthetic ahead of another. Research should be directed to particular patient/hernia scenarios (e.g., infected fields and active patients with small primary defects, among others). Randomized controlled trials need to ensure long-term follow-up. The responsibility of implanting a lifelong device must not be underestimated and, as surgeons, we must ensure that there is sufficient evidence to support the choice of prosthetic. Particular emphasis needs to be placed on the use of various meshes including biological materials in infected fields. A classification system, which guides surgeons on the most appropriate prosthetics for a particular patient and hernia scenario, can then be created.

Second, the biological basis of hernia disease/recurrence needs to be further evaluated. The ideal prosthetic would allow a hernia defect to 'heal' and restore normal anatomy. The use of biological treatments/stem-cell treatments, perhaps impregnated on absorbable meshes, may make this ideal a real possibility.

Financial & competing interests disclosure

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

No writing assistance was utilized in the production of this manuscript.

Key issues

- There is a vast array of prosthetic material available for hernia repair.
- The history of prosthetic use in hernia surgery dates back to 1900.
- Wound healing and the foreign-body reaction to prosthetic materials is a complex process that is influenced by the type of prosthetic material.
- Prosthetic materials aim to encourage enough ingrowth (preferentially of type 1 collagen) to allow sufficient mechanical strength to prevent recurrence, but not so much as to reduce abdominal wall compliance, cause pain, adhesion formation or unpredicted mesh shrinkage.
- The most commonly used synthetic polymers are polypropylene, expanded polytetrafluoroethylene and polyester.
- New polymers with promising initial results are condensed polytetrafluoroethylene and polyvinylidene fluoride.
- Biological meshes vary in material source, type of tissue, presence or absence of collagen crosslinking, decellularization methods and sterilization methods.
- Composite meshes have been developed in an effort to minimize adhesion formation while producing desired biomechanical support.
- The evidence promoting one composite mesh ahead of another is contradictory.
- The term 'lightweight' mesh refers to the total amount of prosthetic material and pore size rather than the actual mesh weight.
- A tailored approach to hernia repair and prosthetic choice is advisable.
- In the future, we need better randomized controlled trials comparing different meshes for particular patient and hernia scenarios.

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