Miscellaneous: Meshes and Sutures

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Key Points Summary

- Mesh repair is now standard in most countries and widely accepted as superior to primary suture repair.
- Tissue incorporation of a synthetic mesh is the goal and it depends upon many factors.
- The most important properties of meshes are the type of filament, tensile strength, and porosity.
- The choice of suture is determined by a balance of the various characteristics of suture materials most appropriate for the specific wound closure situation.

Meshes

The concept of using a mesh to repair hernias was introduced over 50 years ago. Until the 1960s, abdominal wall hernias were closed with primary suture repair. In 1958, Usher published his technique using a polypropylene mesh. This led to the Lichtenstein repair some 30 years later which popularized mesh for hernia repair. Mesh repair is now standard in most countries and widely accepted as superior to primary suture repair. Currently, about one million meshes are used per year worldwide [1]. As a result, there has been a rapid growth in the variety of meshes available and choosing the appropriate one can be difficult.

Nylon was the first plastic material used as a suture and was later woven into a mesh prosthesis for hernia repair [2]. Nylon was not suitable in hernia repair because

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it lost strength over time due to hydrolytic digestion and it required explantation if infected. Koontz et al. [3], in 1959, proposed the search for a nonmetallic, synthetic, nonabsorbable material that was resistant to infection. Since the studies of Koontz and the introduction of polypropylene (PP) in 1962, five different material groups have become available for hernia repair and abdominal wall reconstruction: PP, polytetrafluorethylene (PTFE), expanded-polytetrafluorethylene (ePTFE), polyester (POL), and the most recently, polyvinylidene fluoride (PVDF) [4].

Polypropylene is a hydrophobic polymer of carbon atoms with alternating methyl moieties. This material is flexible, strong, easily cut, readily integrated by surrounding tissues, and resists infection. The monofilament nature provides large pores facilitating fibrovascular ingrowth, infection resistance, and improved compliance. PP remains the most popular material in mesh hernia repair [4, 5].

PTFE is a chemically inert synthetic fluoropolymer that has a high negative charge, therefore water and oils do not adhere to it. This material does not incorporate into human tissue and becomes encapsulated. Poor tissue incorporation increases hernia recurrence and an infected PTFE mesh must be explanted. PTFE is microporous, which allows bacteria passage but prevents macrophage passage; therefore the body cannot clear the infection [6, 7]. PTFE was expanded to be improved, and it became a uniform, fibrous, and microporous structure with improved strength called ePTFE. Although it is not incorporated into tissue and has a high incidence of seroma formation, ePTFE remains inert and produces little inflammatory effects, which allows it to be placed directly on viscera.

POL is a carbon polymer of terepthalic acid and can be fashioned into strong fibers suitable to be woven into a prosthetic mesh. It is a hydrophilic material and is degraded by hydrolysis. The latest material developed is a PVDF monofilament, a synthetic yarn made from polyvinylidene fluoride. Its diameter is between 0.085 and 0.165 mm. It is an extremely ageing-resistant, thermoplastic fluoroplastic with suitably adapted elasticity.

The original logic behind using a mesh was very simple: the mesh was a material that could be used to reinforce the abdominal wall with the formation of scar tissue. It was expected that the best meshes would be those made of very strong material and able to induce the most fibrosis. A synthetic mesh should be biocompatible, strong, resistant to infection, nonimmunogenic, minimally bioreactive, and easy to manipulate and cut, particularly for laparoscopic and/or robotics surgery.

Tissue incorporation of a synthetic mesh is the goal and depends upon the material, density, three-dimensional construction, filament type, pore size, compliance, and electric charge [4].

The physical or mechanical properties of mesh materials are (terms and definitions):

The American Society for Testing and Materials specification D4850 defines terminology related to textile fabrics.

Weight: Measurement of the "heaviness" or "heft" of the material, weight/unit area

Shrinkage: Dimensional decrease in length or width of a material

Strain: Deformation of a material in response to an applied force, force/unit area

Tensile strength: Maximum stress that a material subject to a stretching load can withstand without tearing or breaking

Burst strength: The maximum uniformly distributed pressure applied at right angle to its surface that a material will withstand under standardized conditions pressure/unit area.

Elasticity: Property of a material whereby it changes its shape and size under the action of opposing forces, but recovers its original configuration when the forces are removed.

Stiffness: Ratio of steadily increasing or decreasing force acting on a deformable elastic material to the resulting displacement or deformation.

Compliance: Unit displacement or deformation of a material as the result of application of a unit force.

Isotropy: When a material does not exhibit differences in properties based on the direction of the applied load, the material is said to be isotropic.

These same terms are also used in description, testing and performance of mesh materials [8].

The most important properties of meshes were found to be the type of filament, tensile strength, and porosity. These determine the weight of the mesh and its biocompatibility. The tensile strength required is much less than originally presumed and lightweight meshes are thought to be superior due to their increased flexibility and reduction in discomfort. Large pores are also associated with a reduced risk of infection and shrinkage.

Calculations of intra-abdominal pressures proved that this would be possible without compromising mesh function. In fact, the tensile strength of a mesh required to withstand the maximum abdominal pressure is only a tenth of that of most meshes (Fig. 1). This realization led to the concept of lightweight meshes.

Lightweight meshes were first introduced in 1998 (Vypro) and their superiority over the heavyweight meshes is now widely accepted. These meshes have large pores (normally 3–5 mm) and a small surface area. They stimulate a reduced

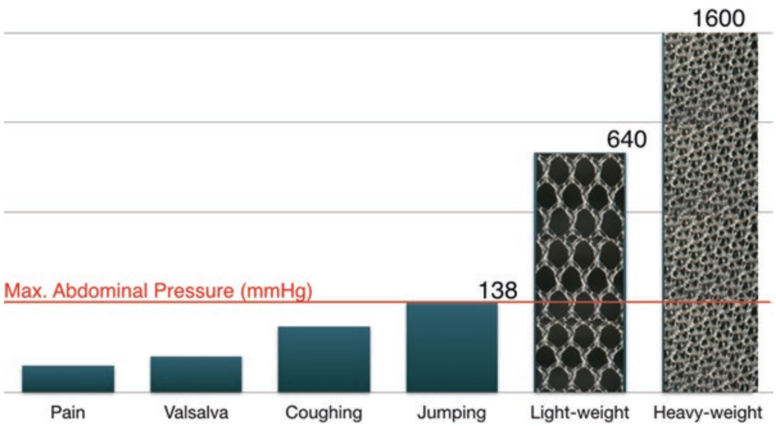


Fig. 1 Comparison of mesh (light- and heavyweight) strength with abdominal wall pressures

inflammatory reaction and, therefore, have greater elasticity and flexibility [9]. They also shrink less and have been shown to decrease pain after Lichtenstein inguinal hernia repair. Unfortunately, despite these improvements, they continue to have complications such as recurrence, infection, and adhesion formation.

The maximum intra-abdominal pressures generated in healthy adults occur while coughing and jumping (Fig. 1). These are estimated to be about 170 mmHg [10]. Meshes used to repair large hernias therefore need to withstand at least 180 mmHg before bursting (tensile strength up to 32 N/cm). This is easily achieved as even the lightest meshes will withstand twice this pressure without bursting (e.g., burst pressure of Vypro = 360 mmHg [11]. This illustrates that the tensile strengths of 100 N/cm of the original meshes were vastly overestimated.

Porosity is the main determinant of tissue reaction. Pores must be more than 75 μm in order to allow infiltration by macrophages, fibroblasts, blood vessels, and collagen. Meshes with larger pores allow increased soft tissue ingrowth and are more flexible because of the avoidance of granuloma bridging. Granulomas normally form around individual mesh fibers as part of the foreign body reaction. Bridging describes the process whereby individual granulomas become confluent with each other and encapsulate the entire mesh. This leads to a stiff scar plate and reduced flexibility. It occurs in meshes with small pores of less than 800 μm.

The weight of the mesh depends on both the weight of the polymer and the amount of material used (pore size) [12].

Heavyweight meshes use thick polymers, have small pore sizes, and high tensile strength. These meshes typically weigh 100 g/m^2 (1.5 g for a 10 × 15 cm mesh). The strength is derived from a large mass of material, which activates a profound tissue reaction and dense scarring.

Lightweight meshes are composed of thinner filaments and have larger pores (>1 mm). Their weight is typically 33 g/m^2 (0.5 g for a 10 × 15 cm mesh). They initiate a less pronounced foreign body reaction and are more elastic. Despite a reduced tensile strength, they can still withstand pressures above the maximum abdominal pressure of 170 mmHg (minimum tensile strength 16 N/cm).

A new generation of even lighter meshes includes the titanium/propylene composite meshes. These have been shown to be associated with a more rapid recovery in a recent, randomized controlled trial (RCT) [13]. The lightest of these (Extralight TiMesh) may have insufficient tensile strength in some situations (maximum tensile strength 12 N/cm).

Numerous randomized prospective trials have evaluated lightweight versus heavyweight mesh in ventral hernia repair with equal outcomes in ventral hernia repair recurrence [14–16]. The choice between a lightweight and heavyweight mesh is multifactorial and superiority has yet to be proven.

Shrinkage occurs due to contraction of the scar tissue formed around the mesh. Scar tissue shrinks to about 60% of the former surface area of the wound [11]. The smaller pores of heavyweight meshes lead to more shrinkage due to the formation of a scar plate.

The popularization of laparoscopic intraperitoneal mesh placement has led to increasing concern regarding mesh-related adhesions. Adhesions result from the fibrin exudates that follow any kind of trauma. These exudates form temporary adhesions until the fibrinolytic system absorbs the fibrin. Absorption is delayed in the presence of ischemia, inflammation, or foreign bodies (e.g., meshes). In these situations, they mature into tissue adhesions.

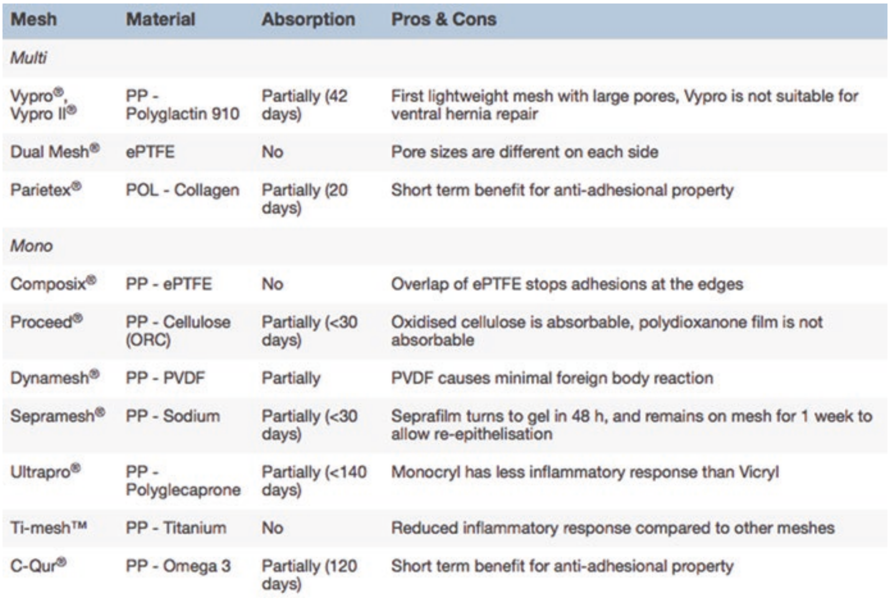
All meshes produce adhesions when placed adjacent to bowel, but their extent is determined by pore size, filament structure, and surface area. Heavyweight meshes induce an intense fibrotic reaction that ensures strong adherence to the abdominal wall but also causes dense adhesions. In contrast, microporous ePTFE does not allow tissue ingrowth. It has a very low risk of adhesion formation, but is unable to adhere strongly to the abdominal wall.

These two extremes illustrate the difficulty of producing a mesh that will adhere well to the abdominal wall but not to the bowel. Composite meshes aim to do this by providing an additional surface that can be safely placed in contact with bowel while peritoneal mesothelial cells grow over the mesh. These combine more than one material and are the basis of most new mesh designs. The main advantage of the composite meshes is that they can be used in the intraperitoneal space with minimal adhesion formation. They require a specific orientation: the visceral side has a microporous surface to prevent visceral adhesions, whereas the nonvisceral side is often macroporous to allow parietal tissue ingrowth. Despite the vast selection of brands available, nearly all these meshes continue to use one or another of three basic materials; PP, POL, and ePTFE, which are used in combination with each other or with additional materials such as titanium, omega 3, monocryl, polyvinylidene fluoride (PVDF), and hyaluronate. However, all of them come with some disadvantages, contrary to the manufacturers' literature [4, 17].

There are two categories of composite meshes: absorbable and permanent. Barrier coatings in absorbable composite meshes require hydration prior to usage, and they are not amenable to modification, so they cannot be cut. However, they allow for neoepithelialization of the mesh before visceral adhesion, which mitigates viscera–mesh-related complications, and can aid in tissue ingrowth. Parietex® composite mesh was the first to offer a resorbable collagen barrier on one side to limit visceral attachments and a three-dimensional polyester knit structure on the other to promote tissue ingrowth and ease of use. The collagen film is composed of glycerol, polyethylene glycol, and porcine collagen. This balance of material properties produces superior cellular proliferation when compared to PP mesh in vitro and works with the body's natural systems to provide rapid fibrous ingrowth, minimal shrinkage, and strong tissue integration [18, 19].

Permanently combined meshes take advantage of the properties of both macro- and microporous meshes. A microporous mesh permits placement adjacent to viscera, whereas macroporous mesh promotes parietal tissue ingrowth. These meshes can be modified and are easily cut to fit specific applications. They have also been demonstrated in animal models to lessen visceral adhesions and complications [20]. These properties permit intraperitoneal placement (e.g., Dual Mesh®, Dulex®, and Composix®).

There are also absorbable synthetic meshes that are used in contaminated cases where primary abdominal closure is not feasible. These absorbable materials provide a lattice for new collagen formation and then become absorbed, thus they are not suitable for permanent hernia repair. The recurrence rate is >50%, but whatever



Mesh	Material	Absorption	Pros & Cons
Multi			
Vypro®, Vypro II®	PP - Polyglactin 910	Partially (42 days)	First lightweight mesh with large pores, Vypro is not suitable for ventral hernia repair
Dual Mesh®	ePTFE	No	Pore sizes are different on each side
Parietex®	POL - Collagen	Partially (20 days)	Short term benefit for anti-adhesional property
Mono			
Composix®	PP - ePTFE	No	Overlap of ePTFE stops adhesions at the edges
Proceed®	PP - Cellulose (ORC)	Partially (<30 days)	Oxidised cellulose is absorbable, polydioxanone film is not absorbable
Dynamesh®	PP - PVDF	Partially	PVDF causes minimal foreign body reaction
Sepramesh®	PP - Sodium	Partially (<30 days)	Seprafilm turns to gel in 48 h, and remains on mesh for 1 week to allow re-epithelisation
Ultrapro®	PP - Polyglecaprone	Partially (<140 days)	Monocryl has less inflammatory response than Vicryl
Ti-mesh™	PP - Titanium	No	Reduced inflammatory response compared to other meshes
C-Qur®	PP - Omega 3	Partially (120 days)	Short term benefit for anti-adhesional property

Fig. 2 A list of composite meshes (for intraperitoneal use) and their characteristics

recurrences develop could be repaired at a later date with a nonabsorbable mesh. Dexon® (polyglycolic acid) and Vicryl® (polyglactin 910) are examples of such meshes (Fig. 2).

Laparoscopic and Robotic Suture Materials

Suturing and knot tying in laparoscopic and da Vinci robotic surgery constitute advanced minimally invasive surgery skills. Developing proficiency in the standard methods with needle drivers is often an arduous process because of loss of tactile feedback. In laparoscopic surgery limited tactile feedback is present but in robotic surgery tactile feedback is replaced by haptic feedback. Recent advances in laparoscopic and robotic instrumentations have presented surgeons and gynecologists with easier methods of suturing and tying. The evolution of laparoscopic and da Vinci robotic surgery has expanded to more advanced and complex general surgery, and urological and gynecological procedures. For patients to get benefit from minimal access surgery surgeons must first develop and become expert in those laparoscopic surgery skills necessary for these advanced operations. Suturing and knot tying are among these advanced minimally invasive surgery skills required for many complex procedures. Developing proficiency in the standard methods of minimal access surgical suturing and knot tying with needle drivers may often be an arduous process [21].

The choice of suture is determined by a balance of the various characteristics of suture materials most appropriate for the specific wound closure situation.

Absorbable Versus Nonabsorbable

The major subdivision of sutures is important to understand. Sutures that lose the majority of their tensile strength within 60 days are considered absorbable sutures. The absorbable sutures are degraded by tissue enzymes or hydrolysis.

- The absorbable sutures in laparoscopic surgery are generally used as deep sutures; they do not need to be removed postoperatively, such as in myomectomy or intestinal anastomosis.
- The nonabsorbable sutures in laparoscopic surgery are used for reconstructive surgery and where manual removal of sutures postoperatively is not required, because it is not possible in minimal access surgery.

Tensile Strength

Depending on size (thickness) laparoscopic surgeons prefer to use the smallest size that will provide adequate strength. It is important to have less foreign body load on the tissue. The strength increases as the first digit decreases.

- 3-0 is a thick strong suture used for fine surgery in laparoscopic surgery.
- 6-0 is a thin comparatively weak suture used for ultrafine surgery such as tubal recanalization surgery.

Plasticity and Elasticity

In laparoscopic surgery the ability to retain length and strength after stretch and the ability to regain its original length after stretch, respectively, are very important. Laparoscopic instruments are always insulting the tissue because of tactile feedback. The laparoscopic surgeon should try to respect sutures as much as possible. This is important:

- To accommodate postoperative edema without cutting into the tissue
- To maintain epidermal approximation once the edema has resolved.

Ease of Handling and Knot Security

It is important for laparoscopic surgeons to keep in mind the coefficient friction of sutures. Ease of handling and knot security are determined by a number of related characteristics.

- A suture with a low coefficient of friction generally slides through tissue well but the knot will unravel more easily.
- A suture with a high memory will spring back to its original position and it is difficult to use this type of suture in laparoscopic surgery. Although nonabsorbable sutures such as Prolene sutures tend to be strong, they may be difficult to handle and have decreased knot security.
- A suture with high pliability can be easily bent, and will therefore handle well in laparoscopic surgery with good knot security.

Multifilament Versus Monofilament

In laparoscopic surgery the multifilament braided sutures handle more easily and tie well, but can potentially harbor organisms between fibers leading to increased infection risk. Although in laparoscopic surgery the chance of infection is less compared to open surgery because the interior milieu is maintained, if possible the multifilament should be avoided in contaminated wounds. They also tend to have higher capillarity therefore they can absorb and transfer fluid more easily increasing the potential for bacteria to enter from the skin surface.

- Monofilament sutures have a lower infection risk and a lower coefficient of friction, but with a lower ease of handling and knot security.

Tissue Reactivity

This refers to the degree of inflammatory response to the suture.

- Higher for natural products such as silk and gut
- Lower for synthetic fibers such as nylon

Concluding Remarks

- The choice between a lightweight and heavyweight mesh is multifactorial and superiority has yet to be proven.
- The main advantage of the composite meshes is that they can be used in the intraperitoneal space with minimal adhesion formation.
- There are two categories of composite meshes: absorbable and permanent. Each of them has its peculiarities.
- It is important for laparoscopic surgeons to keep in mind all the characteristics of the suture material such as: absorbance, tensile strength, tissue reactivity, plasticity, elasticity, number of filaments, ease of handling, and knot security.

Glossary

Expanded-polytetrafluorethylene (E-PTFE). PTFE was expanded to be improved, and it became a uniform, fibrous, and microporous structure with improved strength.

Polyester (POL) A carbon polymer of terepthalic acid that can be fashioned into strong fibers suitable to be woven into a prosthetic mesh.

Polypropylene (PP) Hydrophobic polymer of carbon atoms with alternating methyl moieties.

Polytetrafluorethylene (PTFE) Chemically inert synthetic fluoropolymer that has a high negative charge, therefore water and oils do not adhere to it.

Polyvinylidene fluoride (PVDF) A synthetic yarn made from polyvinylidene fluoride. Its diameter is between 0.085 and 0.165 mm.

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