REVIEW

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Synthetic Meshes in Hernia Surgery

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Abstract

Hernia surgery is among the most common surgical procedures, and more than 80% of them are mesh repairs. Since the introduction of synthetic mesh materials in the 1890s, studies have continued the search for the ideal mesh material with physical, mechanical, structural properties and biocompatibility. It is crucial for surgeons to know the basic structural properties such as the textile fundamentals, porosity, mesh weight, mesh shrinkage and mechanical properties such as mesh bursting strength, elasticity and the anisotropic behavior of the mesh materials in order to make a proper mesh choice. First generation meshes, which are produced from single non-absorbable material are classified as macro-porous, micro-porous or macro-porous with multifilament or microporous components. Second generation meshes are produced from more than one synthetic material. Polypropylene, polyester and polytetrafluoroethylene are the materials used, as in the first generation meshes. As a composite system, other materials such as polyvinylidene fluoride, titanium, poliglecaprone 25 and omega 3 are also combined with these synthetic materials. If the selected mesh is to be used for intra-peritoneal placement, it should be one with a barrier in order to reduce the risk of intestinal adhesions. If the selected mesh material has anisotropic properties, the orientation of the mesh is necessary in the proper direction to match the physiological stretchability, and hence to reduce recurrence.

Keywords: Synthetic surgical meshes, mesh materials, physical properties, mechanical properties

INTRODUCTION

A hernia is described as the protrusion of an organ or tissue through the wall of the physiological cavity. Hernias are classified according to their anatomical locations. The main types of anterior abdominal wall hernias are; inguinal (the most common, accounting for about 75-80% of all types), femoral, umbilical-paraumbilical, epigastric, spigelian, parastomal and incisional hernias.[1] It is well known that the occurrence of hernia is a multifactorial problem incorporating anatomical weakness and many predisposing factors, such as genetic factors and connective tissue disorders.[2] Hernia repair is among the most frequently performed surgical procedures in general surgery. More than 20 million inguinal hernia surgeries are performed annually worldwide, and in the United States, more than 80% of them are mesh repairs.[3] It is obvious that, after the acceptance of mesh implants for hernia repair in both open and laparoscopic repairs, there has been an evident decrease in recurrence rates. Before the introduction of mesh techniques, the expected recurrence rates for primary inguinal hernia repairs and recurrent hernia repairs were 10-30% and 35%, respectively.[4] The recurrence rates after mesh implants were 0-1.7% for tension-free repairs and 0-0.4% for totally extra peritoneal repairs.[5] Although the recurrence rates dropped markedly with the use of prosthetic materials, they still produce some undesired outcomes such as contraction, infection and adhesion between the visceral side and adjacent organs. The prosthetic material used should allow healthy tissue in-growth for incorporation, retaining enough strength to resist abdominal pressure, and sufficient elasticity under physiological pressure and corresponding anisotropy.[6] Since the introduction of prosthetic materials in hernia surgery, many studies have been conducted to find the ideal material in terms of its physical structure and biological responses. The majority of studies have focused on the physical and mechanical properties of mesh materials, such as their weight, pore size and filament type. The aim of this article was to review the main prosthetic materials, structural and mechanical properties of meshes, types of meshes, and currently available surgical synthetic meshes in hernia surgery.

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History

The first proposal to use a prosthetic material in hernia surgery was put forward by Billroth[7] in 1890. He suggested that finding such material would greatly reduce the recurrence rate after hernia repair.[7] The first prosthetic material used for hernia repair were silver wire coils which were used by Phelps in 1894.[8] Until the 1940s, several surgeons used handmade silver wire filigrees, which became the first prosthetic mesh. Due to various disadvantages such as its inertness in human tissues, fluid accumulation, sinus tract formation, and high infection rates, the use of silver filigrees was abandoned. The second material which was introduced as a prosthetic material in 1940 by Burke was tantalum. It was used until the 1950s with promising study reports and clinical outcomes. However, longer follow-up studies revealed some important disadvantages of this material, where the most undesired outcomes were fragmentation and fracture of the tantalum gauze, which made it unpopular in hernia surgery.[9] Stainless steel was another metallic material which was used in the 1980s and it produced much better outcomes than silver filigrees and tantalum gauze. However, the increasing popularity of other synthetic materials and the use of magnetic resonance imaging reduced its popularity and led to its very limited use in hernia repair. Nylon was the first synthetic prosthetic material used for hernia repair, but due to hydrolytic digestion, it was reported to lose strength and also had to be removed in cases of infection. These undesirable properties made nylon inappropriate for hernia repair.[2] Dr. Francis Usher, started to use other materials such as Teflon, Orlon, Dacron and Propylene in 1955. In 1958, he published a study on hernia repair using polypropylene (PP) mesh, and after 30 years, the Lichtenstein repair, which is now regarded as the "tension-free" mesh technique, became popular for inguinal hernia repair.[10] Although the advantages of meshes were recognized, long-term evidence-based recollection of cases was required to statistically quantify their advantages. In 2002, the European Union Hernia Trialists Collaboration participated in randomized trials of mesh repair, analyzed many randomized controlled trials and concluded that the use of surgical meshes was superior to other techniques.[11]

The Properties of Synthetic Mesh Materials

The ideal mesh should be resistant to infection, chemically inert, non-carcinogenic, inert to the body and its fluids, robust to sterilization, and able to limit hypersensitivity allergic or foreign body reactions.[12] After the implantation of meshes, there are two pathways: Integration or degradation. The expected outcome is tissue incorporation, which is related with the material, pore size, filament type, density, three-dimensional structure, compliance and electric charge.[13] The synthetic materials are mainly classified into two groups: Non-absorbable and absorbable. The non-absorbable synthetic materials are: PP, polytetrafluorethylene (PTFE), expanded polytetrafluoroethylene (ePTFE) and polyester (PET).[2,14] The absorbable materials are: Polylactide, polyglycolic acid, polycaprolactone and polydioxanone. The most common reason for the use an absorbable mesh material is to prevent abdominal compartment syndrome with distended bowels and intra-abdominal infections.[15] By allowing fibrous and connective tissue regeneration, absorbable materials give transient support to the wall of the abdomen and dissolve slowly by hydrolysis.[16]

Currently Used Non-absorbable Materials and Their Properties

Polypropylene: PP is a non-absorbable polymer and it is the most popular mesh material used in hernia surgery with several advantages compared to the other materials. PP is synthesized by the polymerization of propylene.[16] Along with good mechanical stability and strength, it is resistant to biological degradation and it is electrostatically neutral, highly hydrophobic and non-polar.[16] Despite all these advantages, reduced flexibility, shrinkage and local cracks have been observed after the explantation of PP meshes.[17] In spite of these disadvantages, because of its easy fiber manufacturing, durable strength, low cost and ease of handling, PP remains the most commonly used mesh material. Depending on the weight of the mesh, PP meshes may be classified as either light-weight (LW) or heavyweight (HW). The density of a mesh is mainly dependent on its textile structure and pore size along with the molecular weight of the polymer and the diameter of the fiber.[16] The flexibility of LW meshes are generally better than HW meshes and also they mimic human tissues better.[18] PP meshes are manufactured in both coated forms for intra-peritoneal use, and uncoated forms, for extra-peritoneal use.

Polyester: Polyester is composed of polyethylene-terephthalate (PET). It is a soft and compliant material suitable for mesh construction. It is slightly polar, more hydrophilic and hydroscopic than homochain hydrocarbon polymers.[9] The fibers of polyester are very strong, tough and can resist most chemicals.[16] Its textile structure may be mono- or multi-flament. PET surgical meshes were first used for inguinal and abdominal hernias in the 1960s.[19] Meshes now have different configurations for different types of hernia repairs, such as incisional, inguinal and hiatal hernia repair. PET has similarities to PP in biological responses, such as scar formation, complications and side effects.[20] However, degradation after long term is the most undesired complication as shown in some studies. Due to hydrolytic degradation, reduced mechanical strength up to 30% was observed in PET vascular grafts after 10 years, and complete implant failure was observed after 25 to 40 years.[21]

Expanded polytetrafluoroethylene: PTFE is a synthetic polymer consisting of carbon and fluorine with strong bonds between them.[14] Due to its chemical stability, it is inert in nature and resistant to degradation in the body.[11] It has smaller pores sizes than PP, with large pores on one side and smaller pores on the other. Due to this property, it inhibits intestinal adhesion and also does not facilitate tissue in-growth in the abdominal wall, which ultimately results in encapsulation and weaker hernia repair.[22] With the advantages of minimal inflammatory reaction and lower scar density for intraperitoneal use, correct fixation is very important, because ePTFE can be broken easily.[23] The other important feature of this material is its porosity. Due to the microporous structure of its mesh, it is not possible for macrophages to penetrate this material in cases of infection, and the mesh must be removed, particularly if placed during an open ventral hernia repair.[24]

Polyvinylidene fluoride: Polyvinylidene fluoride (PVDF) is manufactured by the polymerization of vinylidene difluoride and is highly inert in nature. It is resistance to degradation and its hydrolysis is better than PET, with high durability and bio-stability.[25] It was demonstrated that the mechanical properties of PVDF are highly stable, as it retains 92.5% of its original strength after 9 years of implantation.[26]

It is crucial for surgeons to understand the basic physical structures and mechanical properties of mesh materials in order to make an informed choice.

The Structural Properties of Mesh

Textile Fundamentals

The manufacturing structure of a mesh may be woven, non-woven or knitted with mono- or multi-filament fibers as its textile structure (Figure 1). Due to the tightness and packed structure of woven meshes, they have a smaller pore size, and hence have the disadvantage of poor fibrous tissue ingrowth.[12] Non-woven mesh structures are produced by the interlocking or bonding of fibers. Due to their micro-porous structure, they allow better fibrous tissue ingrowth and reduced adhesion than woven mesh.[27] Most meshes are warp knitted as textile structures, have larger pore size and greater elasticity. The mechanical characteristics of knitted and woven fabrics are extremely anisotropic.[28]

Pore Size (Porosity)

Pore size is the main factor in the reaction of tissue to the mesh. Porosity simply is the ratio of the volume of voids in the mesh to the total volume of the mesh.[29] Cell proliferation and bacterial growth are highly dependent on porosity. Pores must be larger than 75 μm for the infiltration of blood vessels, fibroblasts, collagen and macrophages. Large pores allow tissue integration without filling with scar tissue, which makes the mesh more flexible since there will be no granuloma bridging (Figure 2). As a part of the foreign body reaction, granulomas normally form around mesh fibers, and bridging is the start of the confluence of individual granulomas with each other. This causes the encapsulation of the entire mesh, which leads to a tough scar plate which reduces flexibility.[30] The encapsulation and bridging of granulomas are more likely to occur in meshes with pores of less than 800 μm. Meshes are classified according to pore size as: Very large pore: >2,000 μm; large pore: 1,000-2,000 μm; medium pore: 600-1,000 μm; small pore: 100-600 μm and microporous (solid): <100 μm.[31]

Mesh Weight and Tensile Strength

The weight of the mesh is directly proportional to the weight and amount of the material used.[32] According to weight, meshes are classified as: heavy-weight (HW), if they are above 80 g/m^2; medium-weight (MW) for 50-80 g/m^2; LW for 35-50 g/m^2; and ultra-lightweight, below 35 g/m^2.[33] HW meshes are known to have a tensile strength up to 100 N/cm^2. It was shown by Klinge at al.[34] that the maximum force on the abdominal wall is about 16 N/cm^2. In an *in vivo* study, Cobb et al.[35] measured bladder pressures on humans while performing different activities, and the maximum tensile strength was determined to be between 11 N/cm^2 and 27 N/cm^2. It is clear that the tensile strength of the HW meshes far exceeds the strength of the abdominal wall. In a porcine model, Cobb at al.[35] tested the burst strength of meshes with different weights, namely HW, MW and lightweight meshes, 5 months after implantation and found that all meshes, regardless of their weight, had significantly greater strength than that of the abdominal wall. Due to less foreign body reaction and inflammatory response, the LW meshes had better tissue integration and improved mesh compliance, which caused less pain and discomfort.

Mesh Shrinkage

Shrinkage is the name given to the contraction in dimensions in the length and/or width of the mesh material post implantation. It is caused by the contraction of the scar tissue formed at the site of the mesh. Due to its smaller pores, HW mesh shrinks more due to greater scar plate formation. Different types of mesh materials show significant variations

Figure 1. (a-c) Schematic view of the manufactured structure of a mesh. Woven (a) warp knitted (b) and non-woven (c).

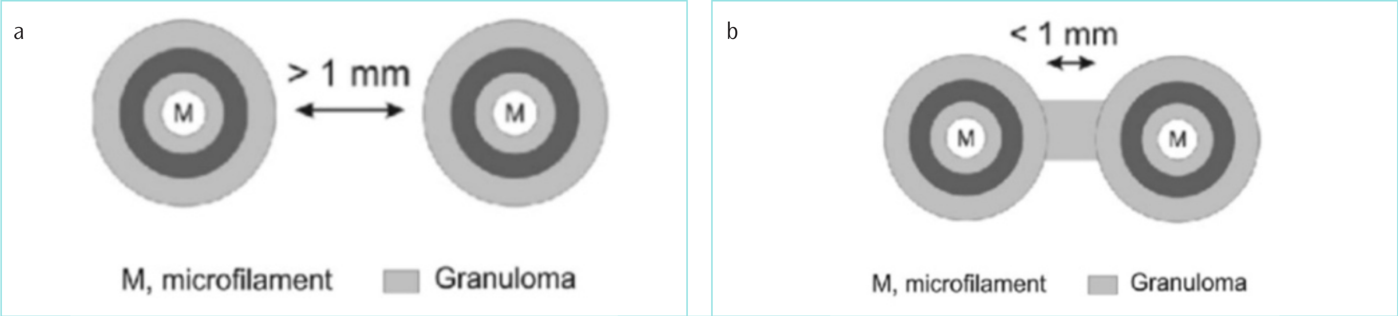

Figure 2. (a,b) Granulomas forming around individual mesh fibers (a) and bridging where individual granulomas become confluent with each other and encapsulate the entire mesh (b).

in their degrees of shrinkage. Synthetic meshes show a minimum and maximum degree of shrinkage as follows: polyester (PET): 6.1% to 33.6%, PTFE: 4% to 51%, and PP: 3.6% to 25.4% (Figure 3).[36]

Mechanical Properties of Mesh

Mesh Bursting Strength

Bursting strength defines the maximum point of exerted uniform pressure, under standardized testing conditions, at the correct angle in relation to the plane of the mesh material at which it ruptures.[37] This strength is related with the mechanical properties, shape, structure density and weight of the mesh. After hernia surgery, the accepted maximum applied forces to the abdominal wall are as follows: 22 N/cm^2 in the craniocaudal and 32 N/cm^2 in the lateral directions.[38] The accepted groin load maximum is 16 N/cm^2.[39] In a study by Deeken et al.[40-43], seven composite meshes were tested by ball bursting (C-QUR, Bard Supramesh, PROCEED, Parietex, BardComposix E/X, Bard Composix L/P, and Dual Mesh) revealing that they had a burst strength higher than 32 N/cm^2. Different studies have shown that the human abdominal wall has a lower burst strength than all knitted synthetic meshes.[41]

Mesh Elasticity and Strength

A materials property in how it changes its dimensions and form when exposed to opposite acting forces, however regains its original dimensions and form when said forces diminish is called elasticity.[42] The abdominal wall has a natural elasticity of 38% at 32 N/cm^2 and it shows a lower resilience in the longitudinal direction than in the horizontal direction. Mesh materials with knitted structures are more elasticity than those with woven structures, and they also have the ability to stretch in all directions.[43] The elasticity exhibited by lightweight meshes at 16 N/cm^2 is approximately 20-35%. On the other hand, HW meshes, at 16 N/cm^2, exhibit an elasticity of 4-15%, which might lead to a restriction in abdominal distension[30]. An appropriate mesh tensile strength along with a suitable stretch capability of the material leads to less pain, less prolapse or recurrence and overall more functional and better results. The elongation rate of the native human abdominal wall is approximately 30%. Meshes with a higher elongation rate than 30% may stretch more than the abdominal wall, which may result in bulging and recurrence.[40]

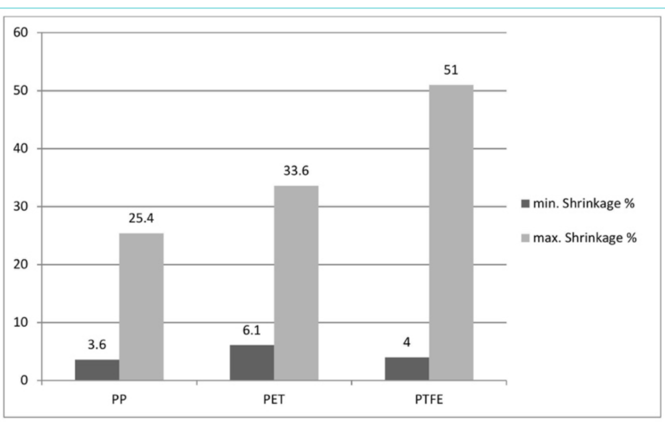

Figure 3. Minimum and maximum shrinkage of synthetic meshes in percentages.

Anisotropic Behavior of Mesh

An anisotropic material is the name given to a material that, if stretched in different directions, responds in different ways. Saberski et al.[6] studied the anisotropic properties of the six most commonly used meshes: PP (Trelex®, Pro-Lite™, Ultrapro™), polyester (Parietex™), and PTFE-based (Dualmesh®, Infinit) meshes, and found that five out of these six meshes presented considerable anisotropic behavior. Ifinit approximately exhibited 20-fold, Ultrapro™ 12-fold, Trelex®, ProLite™, and Parietex™ 2.3-2.4 fold differences between their perpendicular axes. Dualmesh® had the least anisotropic behavior, with an indiscernible difference between the axes.[6] If the selected mesh material has anisotropic properties, the appropriate orientation of the mesh is necessary to comply with the physiological stretchability in order to reduce recurrence.

Classification of Synthetic Surgical Meshes

1. First Generation Meshes

First-generation meshes are classified into three categories according to their structural properties as follows: 1) macro-porous meshes, 2) micro-porous meshes, and 3) macro-porous meshes with multi-filament or micro-porous components. Macro-porous prostheses have a pore size greater than 75 µm and the material of choice is PP. Micro-porous prostheses are commonly made from e-PTFE and have smaller pores, usually less than 10 µm. Macro-porous prostheses containing microporous or multifilament components incorporate plaited multi-filamentary threads in their architecture. They have pore sizes larger than 75 µm, and less than 10 µm of space between their threads.[44]

2. Second Generation Meshes

Due to a number of complications, such as infection, adhesions and recurrence, there is a continuous need to improve surgical meshes. The combination of more than a single synthetic material was used in the development of second generation meshes in order to reduce these complications. Almost the entirety of these meshes consist of PP, e-PTFE or PET combined with one another or different materials such as PVDF, titanium (Ti), omega-3 fatty acids, poliglecaprone 25 (PGC-25), collagen or beta-glucan. Second-generation meshes may be classified as:

2.1. Non-absorbable and synthetic with a barrier: To prevent bowel adhesion when placed intraperitoneally, absorbable or non-absorbable barriers are used in these prostheses. The barrier minimizes the biological response, limiting initial adhesion opportunity to the material. Therefore, it reduces the activation of cells and inflammatory cytokines. Therefore, the onset of an inflammatory cascade is inhibited. Omega-3 fatty acids, ePTFE, collagen, polyurethane, oxidized regenerated cellulose or beta-glucan are possible barriers.[2] The anti-adhesive characteristics of these meshes with non-absorbable or absorbable barriers have been shown in different experimental studies.[45]

2.2. Partially-absorbable and synthetic meshes: Maintaining long-term wound strength and intraoperative handling characteristics by reducing the density of the biomaterial and its subsequent inflammatory reaction is the main goal of constructing a partially absorbable mesh.[2] Recently developed meshes have been improved with the fusion of non-absorbable PP and absorbable materials such as polyglactin 910 and PGC-25.[46] Polyglycolide (L-lactide-co-glycolide) and PP are the most frequently studied materials. These meshes cause less fibrosis, structural changes and chronic inflammation. Some studies have concluded that the use of these prostheses causes less pain and discomfort.[2]

2.3. Combined meshes: The major aim of these meshes is to prevent complications, especially the occurrence of intestinal adhesion, by incorporating the advantages of two different meshes. Polyester and PTFE combined meshes are designed in such a way that the polyester allows for the abdominal wall tissue in-growth and PTFE, which is the surface which comes into contact with the intestines, prevents the occurrence of intestinal adhesion, which is achieved through the different (small) pore size of the mesh. A recent design using a combination of synthetic meshes involves the construction of a mesh which consists of a PET or PP foundation covered with polymers which are absorbable. The adhesion of the intestine with the mesh typically occurs within 7 days of surgery.[47] Therefore, it is thought that only a temporary barrier for adhesion is required for synthetic meshes.

3. Third Generation Meshes (Biological Prosthesis)

The basis of biological mesh materials are scaffolds of collagen acquired from donor sources. Fetal bovine, porcine and human dermis sources are processed by decellularization resulting in highly organized collagen sources exclusively, to remain with the dermal products included in bovine pericardium and porcine small intestine submucosa. The main goal is to provide a matrix of native cells in order to complete healing and synthesize connective tissue which may restore the mechanical and functional integrity of the abdominal wall. Since the aim of this article is to review synthetic meshes, we will not discuss third-generation meshes further.

Discussion

Since the properties of the mesh material play an important role in successful surgical repair, it is important to understand the properties of the mesh material before selecting the most suitable one for the patient. Recent progress has produced a significant number of variations of the mesh materials being used in the repair of hernias. First-generation meshes were mainly based on PP systems. They are classified as macro-porous, micro-porous and macro-porous meshes with multifilament or micro-porous components. Second-generation meshes are composed of a combination multiple synthetic materials. All of them continue to use PP, PET or e-PTFE. They are also systemically combined with different materials such as PVDF Ti, PGC-25 and omega 3.[44] When these composite meshes are applied to intraperitoneal spaces, they form minimal adhesions with the adjacent surfaces provided that each individual side of said mesh is modified to the exact requirements, so they need a specific orientation during implantation. For repairs of hernias where the mesh will contact the bowel, a composite or non-absorbable composite mesh is recommended.[2] To inhibit bowel adhesions, intra-abdominal placement of the prosthesis incorporating a barrier needs to be used. The size of the mesh used is also an important factor.[45-47] Regarding the shrinkage character of the chosen mesh, Elango et al.[2] reported that a minimum of 15x15 cm for the repair of inguinal hernia, and a minimum of 4 cm wider mesh than the defect for umbilical, ventral and incisional repair is required. As we continue to learn more information about the physical and mechanical properties of meshes, mesh selection becomes more important. For inguinal hernia repair, there is little argument about the mesh selection. Although the recurrence rates are similar between HW and LW meshes, for Lichtenstein repairs, it was reported that there were fewer foreign body sensations and less chronic pain reported by those patients who received a LW mesh.[48] However, a longer-term follow-up study with 5-year results revealed a higher recurrence rate for those patients receiving LW meshes in totally extra-peritoneal laparoscopic inguinal repairs, with recurrence rates of 3.8% and 1.1% for patients receiving LW and HW meshes, respectively. A more significant difference with the LW mesh for direct inguinal hernia was seen.[49] Compared with the maximum exerted forces to the abdominal wall, the groin region has a relatively lower force value. Also, the flexibility of the groin region is less than the upper abdominal wall. Therefore, an important mechanical property of the mesh is its elasticity. Based on the knowledge that, at 16 N/cm^2, lightweight meshes have an elasticity range of between 20 to 35%, and they may cause bulging above 30%, the use of such meshes may increase recurrence rates, especially in cases of direct inguinal hernia.[43] Among the mesh materials, PP meshes are the most popular ones for inguinal hernia repair. Decision making in mesh selection for ventral or incisional hernias can often be a confusing problem. There are two important factors in such decisions, namely the patient and the mesh. Factors related with the patient include: The type of abdominal hernia, the size of the defect, the physical capacity and status of the patient, the type of the planned surgery (onlay- inlay placement of the mesh), and the risk of surgical site infection. The factors related with the mesh type are: The material of the mesh, the composition of the mesh, and the physical and mechanical properties of the mesh. For intra-abdominal placements, the mesh must be able to prevent bowel adhesions; this can include an ePTFE surgical mesh or a mesh with an absorbable or non-absorbable barrier. In cases of an increased risk of surgical site infection, a micro-porous (solid) surgical mesh may not be a suitable choice. Due to the micro-porous structure of the mesh, it is not possible for macrophages to penetrate the material in cases of infections, and the mesh must be removed, especially if the placement was carried out in the course of an open ventral hernia repair. In ventral hernia repairs, LW meshes have poorer outcomes compared with MW meshes. In a study of the open retro-muscular placement of meshes for incisional hernia, it was found that use of LW meshes showed a follow-up recurrence of 22.9%, whereas the use of MW meshes showed a follow-up recurrence of 10.6%, where central mesh fracture was the mechanism of recurrence in 46.5% of cases.[50]

Despite all the above mentioned knowledge about meshes and their materials, there are still several points which need clarification. Due to a lack of standardization in test protocols and terminology, material mechanical investigations and clinical study results are mostly confusing. Our knowledge about the mechanical properties of mesh materials may be quite satisfactory. However, considering the structural and mechanical properties of meshes, surgeons still have a lack of knowledge about the exact behaviors of the mesh implanted and the biologic host's responses.

CONCLUSION

This article briefly reviews the properties of mesh materials and discusses which one might be most appropriate. Although there are several studies on this topic, there are currently no standardized test procedures. Although there are more than 70 types of commercially available meshes, it is clear that the ideal mesh has yet to be discovered. The fact that meshes still suffer from infection and/or contraction post implantation is well known. Nevertheless, adhesion amongst the visceral side and neighboring organs still occurs. These mentioned complications might lead to bowel erosion, chronic pain, hernia recurrence or intestinal obstruction. Most of the investigations which were recently published still claim that PP is the "gold standard" mesh. Although the properties of mesh materials are well known, the physical and mechanical properties of the meshes used need to be clarified and must be listed on the packaging of meshes on the market. This is because without knowing the physical and mechanical characteristics of meshes, such as their elasticity, bursting strength and anisotropic behavior, it is not possible for surgeons to decide which mesh is the right one for their patient. Additionally, the correct orientation of the mesh is necessary according to these characteristics. Regarding the properties of mesh materials, the site of the hernia, the strength of the part of the abdominal hernia site and the physical condition of the patient must also be taken into consideration while selecting the proper mesh. Understanding the properties of the mesh material is an important factor which will help surgeons and will thus reduce complications through the application of the proper mesh material.

MAIN POINTS

- It is crucial for surgeons to know the basic structural and mechanical properties of mesh materials in order to make a proper choice.
- First generation meshes, which are produced from single non-absorbable materials are classified as macro-porous, micro-porous and macro-porous with multifilament or micro-porous components.
- Second generation meshes are produced from more than one synthetic material. PP, Polyester (PET) and ePTFE are the materials used, as in first generation meshes.
- With regards to the properties of the mesh material, the site of hernia, the strength of the part of the abdominal hernia site and the physical condition of the patient must also be taken into consideration while selecting the proper mesh.

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References

1. Dabbas N, Adams K, Pearson K, Royle GT. Frequency of abdominal wall hernias: Is classical teaching out of date? JRSM Short Rep. 2011; 2(1): 5.
2. Elango S, Perumalsamy S, Ramachandran K, Vadodaria K. Mesh materials and hernia repair. Biomedicine. 2017; 7(3): 16.
3. Wahba M. Evaluation of lightweight polypropylene mesh in Stoppa pre-peritoneal repair of bilateral inguinal hernias. J Am Sci. 2014; 10(5): 116-24.
4. Gilbert AI. Inguinal herniorrhaphy: reduced morbidity, recurrences, and costs. South Med J. 1979; 72(7): 831-4.
5. Bendavid R. Expectations of hernia surgery (inguinal and femoral). In: Principles and Practice of Surgical Laparoscopy, Paterson-Brown S, Garden J, (editors). W.B. Saunders, 1994; 387-414.
6. Saberski ER, Orenstein SB, Novitsky YW. Anisotropic evaluation of synthetic surgical meshes. Hernia. 2011; 15(1): 47-52.
7. Billroth T. The Medical Sciences in the German Universities: A Study in the History of Civilization; Welch WH. Ed. Macmillan: New York, NY, USA; 1924.
8. DeBord JR. The historical development of prosthetics in hernia surgery. Surg Clin North Am. 1998; 78(6): 974.
9. DeBord JR. The historical development of prosthetics in hernia surgery. Surgical Clin North Am. 1998; 78(6): 973-1006.
10. Klinge U, Klosterhalfen B, Birkenhauer V, Junge K, Conze J, Schumpelick VJ. Impact of polymer pore size on the interface scar formation in a rat model. J Surg Res. 2002; 103(2): 208-14.
11. EU Hernia Trialists Collaboration. Repair of groin hernia with synthetic mesh: Meta-analysis of randomized controlled trials. Ann Surg. 2002; 235(3): 322-32.
12. Shankaran V, Weber DJ, Reed RL 2nd, Luchette FA. A review of available prosthetics for ventral hernia repair. Ann Surg. 2011; 253(1): 16-26.
13. Procter L, Falco EE, Fisher JP, Roth JS. Abdominal wall hernias and biomaterials A. Gefen (Ed.), Bioengineering research of chronic wounds (1st ed). Springer Verlag: Berlin Heidelberg; 2009.p.425-47.
14. Cobb WS. A Current Review of Synthetic Meshes in Abdominal Wall Reconstruction. Plast Reconstr Surg. 2018; 142(3 Suppl): 64S-71.
15. Dayton MT, Buchele BA, Shirazi SS, Hunt LB. Use of an absorbable mesh to repair contaminated abdominal-wall defects. Arch Surg. 1986; 121(8): 954-60.
16. Todros S, Pavan PG, Natali AN. Synthetic surgical meshes used in abdominal wall surgery: Part I-materials and structural conformation. J Biomed Mater Res B Appl Biomater. 2017; 105(3): 689-99.
17. Costello CR, Bachman SL, Grant SA, Cleveland DS, Loy TS, Ramshaw BJ. Characterization of heavyweight and ligtweight polypropylene prosthetic mesh explants from a single patient. Surg Innov. 2007; 14(3): 168-76.
18. Hollinsky C, Sandberg S, Koch T, Sedler S. Biomechanical properties of lightweight versus heavyweight meshes for laparoscopic inguinal hernia repair and their impact on recurrence rates. Surg Endosc. 2008; 22(12): 2679-85.
19. Wolstenholme JT. Use of commercial Dacron fabric in the repair of inguinal hernias and abdominal wall defects. Arch Surg. 1956; 73: 1004-8.
20. Leber GE, Garb JL, Alexander AI, Reed WP. Long-term complications associated with prosthetic repair of incisional hernias. Arch Surg. 1998; 133(4): 378-82.
21. Maarek JM, Guidoin R, Aubin M, Prud'homme RE. Molecular weight characterization of virgin and explanted polyester arterial prostheses. J Biomed Mater Res. 1984; 18(8): 881-94.
22. Woloson SK, Greisler HP. Biochemistry, immunology, and tissue response to prosthetic material. In: Bendavid R, Abrahamson J, Arregui ME, Flament JB, Phillips EH, et al., editors Abdominal wall hernias. Principles and management. New York: Springer-Verlag; 2001; 201-7.
23. Koehler RH, Begos D, Berger D, Carey S, LeBlanc K, Park A, et al. Minimal adhesions to ePTFE mesh after laparoscopic ventral incisional hernia repair: reoperative findings in 65 cases. Zentralbl Chir. 2003;128(8): 625-30.
24. Hawn MT, Gray SH, Snyder CW, Graham LA, Finan KR, Vick CC. Predictors of mesh explantation after incisional hernia repair. Am J Surg. 2011; 202(1): 28-33.
25. Klinge U, Klosterhalfen B, Ottinger AP, Junge K, Schumpelick V. PVDF as a new polymer for the construction of surgical meshes. Biomaterials. 2002; 23(16): 3487-93.
26. Laroche G, Marois Y, Schwarz E, Guidoin R, King MW, Pâris E, et al. Polyvinylidene fluoride monofilament sutures: can they be used safely for

long-term anastomoses in the thoracic aorta? Artif Organs. 1995; 19(11): 1190-9.

27. Raptis DA, Vichova B, Breza J, Skipworth J, Barker S. A comparison of woven versus nonwoven polypropylene (PP) and expanded versus condensed polytetrafluoroethylene (PTFE) on their intraperitoneal incorporation and adhesion formation. J Surg Res. 2011; 169(1): 1-6.
28. Zhu LM, Schuster P, Klinge U. Mesh implants: An overview of crucial mesh parameters. World J Gastrointest Surg. 2015; 7(10): 226-36.
29. Karageorgiou V, Kaplan D. Porosity of 3D biomaterial scaffolds and osteogenesis. Biomaterials. 2005; 26(27): 5474-91.
30. Klosterhalfen B, Junge K, Klinge U. The lightweight and large porous mesh concept for hernia repair. Expert Rev Med Devices. 2005; 2(1): 103-117.
31. Earle DB, Mark LA. Prosthetic Material in Inguinal Hernia Repair: how do I choose? Surg Clin North Am. 2008; 88(1): 179-201.
32. Procter L, Falco EE, Fisher JP, Roth JS. Abdominal wall hernias and biomaterials. Gefen A, (editor), Bioengineering research of chronic wounds (1st ed), Springer Verlag: Berlin Heidelberg; 2009.p.425-47.
33. Zogbi L. The Use of Biomaterials to Treat Abdominal Hernias. In: Pignatello R., editor. Biomaterials Applications for Nanomedicine. 1st ed. Volume 18. InTech; Rijeka, Croatia: 2008.p.359-82.
34. Klinge U, Klosterhalfen B, Conze J, Limberg W, Obolenski B, Ottinger AP, et al. Modified mesh for hernia repair that is adapted to the physiology of the abdominal wall. Eur J Surg. 1998; 164(12): 951-60.
35. Cobb WS, Burns JM, Peindl RD, Carbonell AM, Matthews BD, Kercher KW, et al. Textile analysis of heavy weight, mid-weight, and light weight polypropylene mesh in a porcine ventral hernia model. J Surg Res. 2006; 136(1): 1-7.
36. Slater, NJ, Knaapen, L, van Goor, H. Abdominal wall defects: Pathogenesis, prevention and repair. Surgery (Oxford). 2015; 33: 206-13.
37. Zhu, LM, Schuster, P, Klinge, U. Mesh implants: An overview of crucial mesh parameters. World J Gastrointest Surg. 2015; 7(10): 226-36.
38. Pott PP, Schwarz ML, Gundling R, Nowak K, Hohenberger P, Roessner ED. Mechanical properties of mesh materials used for hernia repair and soft tissue augmentation. PLoS One. 2012; 7(10): e46978.
39. Klinge U, Klosterhalfen B, Conze J, Limberg W, Obolenski B, Ottinger AP, et al. Modified mesh for hernia repair that is adapted to the physiology of the abdominal wall. Eur J Surg. 1998; 164(12): 951-60.
40. Deeken CR, Abdo MS, Frisella MM, Matthews BD. Physicomechanical evaluation of polypropylene, polyester, and polytetrafluoroethylene meshes for inguinal hernia repair. J Am Coll Surg. 2011; 212(1): 68-79.
41. Cobb, WS Kercher KW, Heniford BT. The argument for lightweight polypropylene mesh in hernia repair. Surg Innov. 2005; 12(1): 63-9.
42. Hollinsky C, Sandberg S. Measurement of the tensile strength of the ventral abdominal wall in comparison with scar tissue. Clin Biomech (Bristol, Avon). 2007; 22(1): 88-92.
43. Bilsel Y, Abci I. The search for ideal hernia repair; mesh materials and types. Int J Surg. 2012; 10(6): 317-21.
44. Baylón K, Rodríguez-Camarillo P, Elías-Zúñiga A, Díaz-Elizondo JA, Gilkerson R, Lozano K. Past, Present and Future of Surgical Meshes: A Review. Membranes. 2017; 7(3): 47.
45. Bellon JM, Garcia-Honduvilla N, Serrano N, Rodriguez M, Pascual G, Bujan J. Composite prostheses for the repair of abdominal wall defects: effect of the structure of the adhesion barrier component. Hernia. 2005; 9(4): 338-43.
46. Bellon JM, Rodriguez M, Garcia-Honduvilla N, Pascual G, Buján J. Partially absorbable meshes for hernia repair offer advantages over nonabsorbable meshes. Am J Surg. 2007; 194(1): 68-74.
47. Robinson TN, Clarke JH, Schoen J, Walsh MD. Surg Endosc. 2005; 19(12): 1556-60.
48. Uzzaman MM, Ratnasingham K, Ashraf N. Meta-analysis of randomized controlled trials comparing lightweight and heavyweight mesh for Lichtenstein inguinal hernia repair. Hernia. 2012; 16(5): 505-18.
49. Roos MM, Bakker WJ, Schouten N, Voorbrood CEH, Clevers GJ, Verleisdonk EJ, et al. Higher Recurrence Rate After Endoscopic Totally Extraperitoneal (TEP) Inguinal Hernia Repair with Ultrapro Lightweight Mesh: 5-Year Results of a Randomized Controlled Trial (TULP-trial). Ann Surg. 2018; 268(2): 241-6.
50. Cobb WS, Warren JA, Ewing JA, Burnikel A, Merchant M, Carbonell AM. Open retromuscular mesh repair of complex incisional hernia: predictors of wound events and recurrence. J Am Coll Surg. 2015; 220(4): 606-13.