SURGICAL
CLINICS OF
NORTH AMERICA

Prosthetic Material in Ventral Hernia Repair: How Do I Choose?

Sharon Bachman, MD, Bruce Ramshaw, MD*

*Department of General Surgery, One Hospital Drive, DC 075.00,
University of Missouri-Columbia, Columbia, MO 65212, USA*

The evolution of modern ventral hernia repair began in 1958 when Francis Usher [1] published the first of his many papers describing the use of polypropylene mesh for tension-free hernia repairs. This mesh was rightly recognized as a huge leap forward in the reduction of recurrence rates after hernia repairs [2,3]. However, the same properties that led to incorporation of mesh into the abdominal wall also led to adherence of bowel to mesh if the mesh was exposed to the peritoneal cavity. Mesh could then migrate through the bowel wall or incite fistula formation, with potentially disastrous infectious consequences [4–9].

This realization led to the development of "second-generation" mesh, the barrier meshes, which provide a protective layer to prevent intraperitoneal contents from adhering to the prosthetic. With the prevention of adhesions as the goal, these barrier meshes are designed to prevent ingrowth of viscera into the mesh. These meshes have been partly responsible for the popularization of the underlay technique of ventral hernia repair, primarily with the laparoscopic approach.

* Corresponding author.
E-mail address: ramshawb@health.missouri.edu (B. Ramshaw).

surgical.theclinics.com

Acellular collagen scaffolds, which are biologic materials, represent so-called "third-generation" mesh. Although the long-term outcomes for primary hernia repairs with these materials are still being investigated, they have a moderately good success rate for salvaging contaminated and infected fields, especially when placed with wide overlap [10–16].

These technologic advances and the growth of the hernia repair market have led to a proliferation of materials. This article summarizes the similarities and differences of the mesh options and provides surgeons with some guidance in selecting meshes.

A brief description of abdominal wall mechanics

To understand what sort of properties a mesh should have, it is important to look at the tissues it is replacing and/or reinforcing. Klinge and colleagues [17] described a mathematical model that calculated the force of the abdominal wall to be 16 N/cm. This same group also examined the elasticity of the abdominal wall in human cadavers. They described the average male abdominal wall elasticity at 16 N to be 23 ($\pm$ 7%) and 15 ($\pm$ 5%) in the vertical direction and 15 ($\pm$ 5%) in the horizontal direction, while the average female abdominal wall elasticity at 16 N females was 32 ($\pm$ 7%) in the vertical direction and 17 ($\pm$ 5%) in the horizontal direction [18].

Cobb and colleagues [19] actually measured intra-abdominal pressure via intravesicular measurements in healthy volunteers, and documented pressures up to 252 mm Hg over a variety of maneuvers, including lifting, coughing, and jumping. This correlates to forces of up to 27 N/cm [19].

With these numbers in mind, compare a maximum force on the abdominal wall of 27 N/cm with the measured burst force of some of the more common synthetic mesh materials. Marlex has a tensile strength of 59 N/cm, Atrium mesh 56 N/cm, and Vypro (lightweight mesh) 16 N/cm [20]. This same study noted that recurrences in humans invariably occurred at the mesh margin, where the mesh interfaced with tissue [20]. The finding that recurrences occur at the mesh margin is also bolstered by Binnebosel [21] in an experimental model that simulated the abdominal wall and two types of defects. In a pressure-controlled chamber, Ultrapro mesh was place in sublay and overlay positions over two types of simulated fascial defects. As the pressure within the chamber was increased to 200 mm Hg with carbon dioxide insufflation, the mesh dislocated at the edges of the "defect" and slipped into the defect. Increasing the mesh overlap to 4 cm from the defect edges eliminated mesh disruption in three of the four models tested. The lightweight mesh remained intact in all tests [21].

The study by Klinge and colleagues [17] examined the directionality of strength, and measured tensile strength of the vertical and horizontal directions of three meshes. Marlex and Prolene were both over five times stronger than the calculated abdominal wall strength, and Mersilene was at least twice as strong. A similar trend was noted in an animal study conducted

by Cobb. Mesh was implanted into swine for 5 months and then tested for burst strength. Native tissue ruptured at 232 N, lightweight polypropylene mesh burst at 576 N, midweight at 590 N, and heavyweight mesh at 1218 N [22].

These data have lent scientific support to the theory that synthetic mesh materials, especially traditional "heavyweight" polypropylene mesh, are overengineered for their purpose. This excess prosthetic can lead to more complications, including decreased mesh flexibility, loss of abdominal wall compliance, inflammation, and scarring of surrounding tissues, potentially leading to pain, a sensation of feeling the mesh in the abdominal wall, and mesh contraction and wadding, which in turn may result in a recurrent hernia [23–26]. Meanwhile, new data demonstrate that current materials are not inert. Polypropylene especially is susceptible to degradation via oxidation [27]. The chronic inflammatory response incited by the heavy foreign-body load leads to perpetual exposure of the material to powerful macrophage-produced oxidants. Over time, this markedly alters the surface appearance and properties of the material [27].

The area of heavyweight polypropylene mesh has also been shown to contract up to 54% in experimental models [28], although all mesh types contract to some degree with acute wound-healing [29,30].

Multiple studies in both animals [31] and humans demonstrate that lightweight, macroporous mesh products provide the same benefits of reducing hernia recurrence rates, potentially with fewer undesirable side effects. The overall argument for lightweight mesh is nicely summarized in several papers [31–35]. In a randomized, multicenter study from Europe, patients undergoing a Rives-type preperitoneal sublay ventral hernia repair were randomized among three standard meshes (Atruim, Marlex, and Mersilene) and one lightweight mesh (Vypro) [34]. This study was somewhat limited by some of the material property differences between Mersilene and the two polypropylene standard meshes, as well as by some of the variability in operative technique among the participating medical centers (mesh fixation with absorbable suture at three centers). The recurrence rates were not significantly different and appeared to be technique-specific (absorbable suture fixation) [34].

Another European study of patients undergoing open preperitoneal sublay procedures compared the use of Prolene (heavyweight polypropylene) mesh with Vypro (lightweight polypropylene). This study demonstrated a significant increase in long-term chronic pain and feelings of a "stiff abdomen" in patients who had heavyweight polypropylene used for their hernia repair [35].

A group of 347 explanted mesh specimens were studied for markers of biocompatibility [33]. Inflammatory infiltrate, connective-tissue formation, and immunohistochemical markers for rates of cell proliferation and apoptosis were all reduced in the one lightweight, large-pored mesh (Vypro), compared with traditional polypropylene meshes (Marlex, Prolene, Atrium,

and Surgipro). The lightweight mesh had a lower rate of chronic pain and infection and no fistulization compared with the other meshes [33]. This is the largest collection of explanted mesh reported.

Mesh materials

This section describes the basic mesh materials, as well as the newer products available (Boxes 1, 2, and 3).

Uncoated mesh

The original meshes widely available were woven and knitted from either polypropylene or polyester fibers. Polypropylene consists of a carbon backbone, with alternating methyl and hydrogen groups attached to the carbon chain. These hydrogen–carbon bonds are susceptible to oxidation [27]. Polylpropylene fibers can be manipulated into weaves or knits of differing design and density. Popular variations include monofilament and dual-filament knits. Multifilament variations are also available. The trend toward lightweight mesh has led to the incorporation of absorbable strands into the weave to provide stiffness at implantation. The strands are resorbed, leading to a lighter permanent material. Lightweight mesh can have both thinner fibers and wider mesh pores.

Polyester is a carbon-based polymer that forms strong fibers. Hence, it is used in fabrics, but also has multiple other uses. Polyethylene terephthalate (PET or Dacron) is the most common polyester, although there are many other forms. This structure is hydrophilic, whereas polypropylene is

---

Box 1. Examples of nonprotected macroporous mesh for uncontaminated ventral hernia repair without exposure to viscera

Heavyweight polypropylene
    Prolene (Ethicon)
    Marlex (Bard)
Lightweight polypropylene
    Ultrapro (Ethicon)
    ProLite (Atrium)
    TiMesh (GfE)
Polyester
    Parietex: flat and three-dimensional (Covidien)
    Mersilene (Ethicon)
Expanded polyfluorotetraethylene
    MotifMesh (Proxy Biomedical)

Box 2. Examples of mesh for intraperitoneal use or when potential exposure to bowel is suspected

Expanded polyfluorotetraethylene
    DualMesh, DualMesh plus (W.L. Gore)
    Dulex (Bard/Davol)
Polypropylene–expanded polyfluorotetraethylene
    Composix (Bard/Davol)
        E/X: heavyweight polypropylene
        L/P: lightweight polypropylene
Lightweight polypropylene–carboxymethylcellulose-sodium hyaluronate-polyethylene glycol
    Sepramesh (Genzyme)
Lightweight polypropylene–polydioxanone–oxidized regenerated cellulose
    Proceed (Ethicon)
Lightweight polypropylene–omega-3 fatty acid
    C-Qur (Atrium)
Polyester–collagen-polyethylene glycol-glycerol
    Parietex Composite (Covidien)

Box 3. Examples of biologic mesh and prices[a]

Human dermis
    AlloDerm (LifeCell; \$26.08/cm^2)
    AlloMax (Bard/Davol; \$26.00/cm^2)
    FlexHD (MTF)
Porcine dermis
    Permacol (TSL; \$8.33/cm^2)
    Collamend (Bard/Davol; \$16.00/cm^2)
    Strattice (LifeCell)
    XenMatrix (Brennan Medical)
Porcine small intestine submucosa
    Surgisis (Cook; \$3.40/cm^2)
Fetal bovine dermis
    SurgiMend (TEI Bioscience; \$22.00/cm^2)
Bovine pericardium
    Tutopatch (Tutogen Medical)
    Veritas (Synovis; \$8.60/cm^2)

---

[a] *Data from* Bellows CF, Alder A, Helton WS. Abdominal wall reconstruction using biological tissue grafts: present status and future opportunities. Expert Rev Med Devices. 2006;3(5):657–75.

hydrophobic. Polyester is resistant to oxidation, but is susceptible to hydro-lysis. Knitted multifilament polyester has been available for many years (Mersilene). Examples of newer polyester mesh include a flat, screenlike two-dimensional mesh and a multifilament three-dimensional weave. A paper by Leber and colleagues [36] published in 1998 compared the use of Mersilene with Marlex, Prolene, and Gore-Tex for ventral hernia repairs, and found higher rates of infection, small-bowel obstruction, recurrence, and fistula with Mersilene placement. However, this study used a variety of repair techniques and had a high rate of complications overall. Other investigators comparing Mersilene and Prolene using the same Rives-Stoppa technique of hernia repair had a low rate of complications for both meshes, and no difference in complication rate between the two [37]. It is now recommended that bowel be separated from a macroporous mesh of any material.

Coated or barrier mesh

Tissue-separating meshes were developed in response to the challenges of placing mesh intra-abdominally. The ideal intraperitoneal prosthetic would have two sides with opposite functions: The surface exposed to viscera would completely repel any adhesions or ingrowth, while the peritoneal surface would integrate through the peritoneum and preperitoneal fat into the musculo-fascial abdominal wall. Such a mesh does not currently exist.

The first widely used prosthetic for intraperitoneal adhesion reduction was expanded polyfluorotetraethylene (ePTFE). This molecule consists of a long carbon chain with two side fluorine atoms per carbon. The first publications of the original Teflon meshes were by pediatric surgeons looking for a prosthetic they could easily remove from newborns as they grew [38]. The first series of open ePTFE mesh implants in adults was described in 1987 and the first laparoscopic repairs in 1993 [39,40]. The currently available ePTFE materials have microscopic pores on the visceral surface (3 μm wide) that make ingrowth quite difficult. At reoperation, adhesions are usually minimal or easy to lyse [41]. The abdominal wall side is engineered with wider pores (>100 μm) and ridges to encourage ingrowth of mesh into the tissue. Despite this, the ingrowth and incorporation to the peritoneal surface can be relatively easy to disrupt. Therefore, adequate fixation of the mesh is quite important [42].

The next innovation was the merging of heavyweight polypropylene mesh with a layer of ePTFE. This composite graft allows for a macroporous mesh to be exposed to the anterior abdominal wall, while the undersurface resists ingrowth. This mesh has been popular for many years. Some problems can occur when there is a differential in contraction between the polypropylene and the ePTFE layers, which leads to rolling of the mesh edges and thus exposure of the polypropylene to bowel [23,43].

A number of available meshes form a temporary composite with an absorbable material, providing a barrier between the mesh and the viscera. The mesh needs to be protected for 7 to 14 days until a neoperitoneum is created.

Polypropylene meshes that are impregnated with Seprafilm (Sepramesh), oxidized regenerated cellulose (Proceed), and omega-3 fatty acids (C-Qur) form a hydrogel barrier, which is resorbed over time. Polyester mesh coated with a collagen layer is also available (Parietex Composite). These materials are all designed for intra-abdominal use. Numerous animal studies document the antiadhesive properties of these meshes compared with bare macroporous polypropylene [30,42,44–51]. The documented literature on observations of mesh during reoperation of human subjects remains scanty [41], although we have noted in our clinical practice that adhesions to ePTFE are easily disrupted with blunt dissection. Also, on several reoperations in cases where collagen-coated polyester mesh or oxidized regenerated cellulose–coated midweight polypropylene mesh had been implanted, there were also minimal adhesions. The point fixation devices used during laparoscopic repairs serve as the nidus of the most tenacious adhesions [52–55].

Biologic mesh

Biologic mesh materials are based on collagen scaffolds derived from a donor source. Dermis from human, porcine, and fetal bovine sources are decellularized to leave only the highly organized collagen architecture with the surrounding extracellular ground tissue. Other natural collagen sources in additional to the dermal products include porcine small intestine submucosa (which is layered for strength) and bovine pericardium.

The collagen in these materials can be left in its natural state or chemically crosslinked to be more resistant to the collagenase produced in wounds. By increasing crosslinking, the persistence of the mesh is also increased. Uncrosslinked mesh can be totally incorporated and reabsorbed within 3 months, whereas a highly crosslinked mesh can persist for years. It is not yet known if outcomes are affected based on the type of biologic mesh used in various clinical scenarios.

Most of the human studies published on biologic materials are from difficult clinical situations. Because angiogenesis is a part of the remodeling of the mesh, these materials can potentially resist infection. Other findings demonstrate some resistance to adhesion formation. There are some early reports on the use of biologic mesh in humans for primary hernia repairs in the inguinal region [56–58] as well as intraperitoneally for hiatal hernia repairs [59]. There are no current published reports on the use of biologics for primary repairs of ventral hernias. Long-term studies will be necessary before these materials are widely and routinely used as a primary mesh. Genetic studies of collagen formation will also be necessary help to determine if patients who form hernias are able to lay down normal collagen as they remodel biologic mesh.

How do I choose?

A frequent question from surgeons is: "With the wide variety of mesh products to choose from, which mesh is best?" At this point, there is no

"best" mesh, so the decision of which mesh to use is based on several factors: the type of procedure being done, the clinical situation, the desired handling characteristics, and the products available to the surgeon based upon hospital materials contracts and costs.

Although heavyweight polypropylene mesh is currently the most frequently used mesh in the world, no situation mandates its use. Surgeon comfort level with these thick, stiff materials is high. Heavyweight polypropylene mesh is easy to handle and gives a feeling that a satisfactorily "strong" repair will ensue. However, as discussed previously, it is clear that these materials are mechanically overengineered for their function, and the potential complications are significant [20,23]. The body of literature against the use of these materials will continue to grow. It is clear that most "lightweight" materials, whether polypropylene or polyester, are sufficiently stronger than the anterior abdominal wall tissue, while inciting less inflammation, shrinking less, and offering more compliant characteristics than "heavyweight" polypropylene.

Risk of exposure

The first step of the mesh decision tree is to consider risk of exposure of mesh to intraperitoneal contents, which is directly related to the repair technique. If there is no risk of mesh–bowel interaction (overlay technique, retro-rectus position with little tension on the posterior closure), then a lightweight, macroporous mesh made of polypropylene or polyester is appropriate.

If there is concern that the mesh may become exposed to bowel, such as in the breakdown of a posterior closure of a retro-rectus repair under great tension, or if the mesh is being placed as an underlay open or laparoscopically, then a barrier mesh that rebuffs ingrowth of adherent viscera is appropriate. ePTFE has been safely used for this purpose for many years. It is very strong and possibly more inert compared with other available prosthetic materials. However, it is hydrophobic and presents a large foreign-material load to the patient. It is also more difficult to handle compared with other tissue-separating meshes because of the lack of memory in ePTFE. There are many composite meshes available. Some of the older materials have encountered some complications, especially when heavyweight polypropylene has been combined with ePTFE (Fig. 1) [43]. Now available is a newer variation of this material that is a composite of lightweight polypropylene and ePTFE. Other newer composite barrier meshes coat lightweight mesh with substances forming a barrier that allows for regrowth of the peritoneal epithelium before absorption of the barrier material.

Clinical scenario

The choice of mesh may be directed by the clinical scenario, such as when there is contamination or infection at the site of repair. Although products
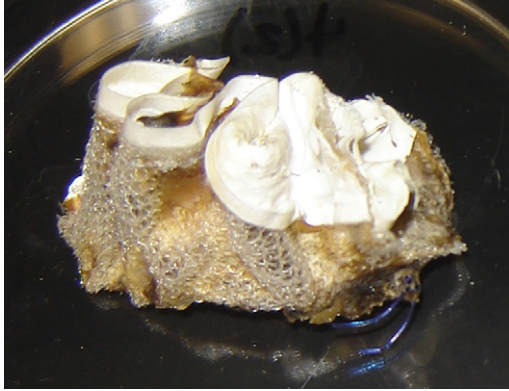
Fig. 1. An explanted mesh consisting of a heavyweight polypropylene–ePTFE composite, after cleaning. This specimen is notable for the contraction of the mesh, which led to exposure of the polypropylene to the viscera.

that contain antibacterial agents exist, the implantation of permanent synthetic mesh in infected fields is still not recommended. Absorbable synthetic mesh, such as Vicryl, does not prevent formation of future hernias [60] and, when placed in the peritoneal cavity in proximity to viscera, can result in significant adhesions and fistula formation [61,62]. We have reoperated on patients who had received Vicryl meshes for open abdomens and experienced an inflammatory reaction produced by the resorption of the Vicryl, leading to a frozen abdomen due to the extent of the adhesion formation. Biologic mesh has been touted as the solution for infected fields. Even so, certain rules still apply: The source of infection must be controlled and well drained, and the technique must be similar to a synthetic mesh repair. Wide overlap of mesh edges and placement in a retro-rectus position rather than inlay help decrease recurrence rates [10]. It is unclear how potential collagen deposition alterations in patients disposed toward hernia formation will influence long-term remodeling of these materials.

Cost

Another consideration is the cost of the material. It is difficult to obtain the true price of any mesh, as the cost to each hospital differs significantly depending on the materials contracts at that institution. Many surgeons are limited to specific brands because of these contractual arrangements, and such arrangements make it almost impossible to compare mesh costs head to head between companies. However, more highly engineered mesh is more expensive and barrier meshes are up to ten times more expensive than uncoated, macroporous mesh. Biologics are up to ten times more expensive than barrier meshes.

References

[1] Usher FC, Ochsner J, Tuttle LL Jr. Use of Marlex mesh in the repair of incisional hernias. Am Surg 1958;24(12):969–74.

[2] Burger JW, Luijendijk RW, Hop WC, et al. Long-term follow-up of a randomized controlled trial of suture versus mesh repair of incisional hernia. Ann Surg 2004;240(4):578–83 [discussion: 583–5].

[3] Luijendijk RW, Hop WC, van den Tol MP, et al. A comparison of suture repair with mesh repair for incisional hernia. N Engl J Med 2000;343(6):392–8.

[4] Amid PK, Shulman AG, Lichtenstein IL, et al. Biomaterials for abdominal wall hernia surgery and principles of their applications. Langenbecks Arch Chir 1994;379(3):168–71.

[5] Costa D, Tomas A, Lacueva J, et al. Late enterocutaneous fistula as a complication after umbilical hernioplasty. Hernia 2004;8(3):271–2.

[6] DeGuzman LJ, Nyhus LM, Yared G, et al. Colocutaneous fistula formation following polypropylene mesh placement for repair of a ventral hernia: diagnosis by colonoscopy. Endoscopy 1995;27(6):459–61.

[7] Fernandez Lobato R, Martinez Santos C, Ortega Deballon P, et al. Colocutaneous fistula due to polypropylene mesh. Hernia 2001;5(2):107–9.

[8] Losanoff JE, Richman BW, Jones JW. Entero-colocutaneous fistula: a late consequence of polypropylene mesh abdominal wall repair: case report and review of the literature. Hernia 2002;6(3):144–7.

[9] Ott V, Groebli Y, Schneider R. Late intestinal fistula formation after incisional hernia using intraperitoneal mesh. Hernia 2005;9(1):103–4.

[10] Franklin ME Jr, Gonzalez JJ Jr, Glass JL. Use of porcine small intestinal submucosa as a prosthetic device for laparoscopic repair of hernias in contaminated fields: 2-year follow-up. Hernia 2004;8(3):186–9.

[11] Franklin ME Jr, Gonzalez JJ Jr, Michaelson RP, et al. Preliminary experience with new bioactive prosthetic material for repair of hernias in infected fields. Hernia 2002;6(4): 171–4.

[12] Helton WS, Fisichella PM, Berger R, et al. Short-term outcomes with small intestinal submucosa for ventral abdominal hernia. Arch Surg 2005;140(6):549–60 [discussion: 560–2].

[13] Ueno T, Pickett LC, de la Fuente SG, et al. Clinical application of porcine small intestinal submucosa in the management of infected or potentially contaminated abdominal defects. J Gastrointest Surg 2004;8(1):109–12.

[14] Catena F, Ansaloni L, Gazzotti F, et al. Use of porcine dermal collagen graft (Permacol) for hernia repair in contaminated fields. Hernia 2007;11(1):57–60.

[15] Schuster R, Singh J, Safadi BY, et al. The use of acellular dermal matrix for contaminated abdominal wall defects: Wound status predicts success. Am J Surg 2006;192(5):594–7.

[16] Diaz JJ Jr, Guy J, Berkes MB, et al. Acellular dermal allograft for ventral hernia repair in the compromised surgical field. Am Surg 2006;72(12):1181–7 [discussion: 1187–8].

[17] Klinge U, Klosterhalfen B, Conze J, 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.

[18] Junge K, Klinge U, Prescher A, et al. Elasticity of the anterior abdominal wall and impact for reparation of incisional hernias using mesh implants. Hernia 2001;5(3):113–8.

[19] Cobb WS, Burns JM, Kercher KW, et al. Normal intraabdominal pressure in healthy adults. J Surg Res 2005;129(2):231–5.

[20] Welty G, Klinge U, Klosterhalfen B, et al. Functional impairment and complaints following incisional hernia repair with different polypropylene meshes. Hernia 2001;5(3):142–7.

[21] Binnebosel M, Rosch R, Junge K, et al. Biomechanical analyses of overlap and mesh dislocation in an incisional hernia model in vitro. Surgery 2007;142(3):365–71.

[22] Cobb WS, Burns JM, Peindl RD, 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.

[23] Klinge U, Klosterhalfen B, Muller M, et al. Foreign body reaction to meshes used for the repair of abdominal wall hernias. Eur J Surg 1999;165(7):665–73.

[24] LeBlanc KA, Whitaker JM. Management of chronic postoperative pain following incisional hernia repair with Composix mesh: a report of two cases. Hernia 2002;6(4):194–7.

[25] Klosterhalfen B, Klinge U, Hermanns B, et al. [Pathology of traditional surgical nets for hernia repair after long-term implantation in humans]. Chirurg 2000;71(1):43–51 [German].

[26] Coda A, Bendavid R, Botto-Micca F, et al. Structural alterations of prosthetic meshes in humans. Hernia 2003;7(1):29–34.

[27] Costello CR, Bachman SL, Ramshaw BJ, et al. Materials characterization of explanted polypropylene hernia meshes. J Biomed Mater Res B Appl Biomater 2007;83B(1):44–9.

[28] Klinge U, Klosterhalfen B, Muller M, et al. Shrinking of polypropylene mesh in vivo: an experimental study in dogs. Eur J Surg 1998;164(12):965–9.

[29] Gonzalez R, Ramshaw BJ. Comparison of tissue integration between polyester and polypropylene prostheses in the preperitoneal space. Am Surg 2003;69(6):471–6 [discussion: 476–7].

[30] Harrell AG, Novitsky YW, Peindl RD, et al. Prospective evaluation of adhesion formation and shrinkage of intra-abdominal prosthetics in a rabbit model. Am Surg 2006;72(9):808–13 [discussion: 813–4].

[31] Junge K, Klinge U, Rosch R, et al. Functional and morphologic properties of a modified mesh for inguinal hernia repair. World J Surg 2002;26(12):1472–80.

[32] Cobb WS, Kercher KW, Heniford BT. The argument for lightweight polypropylene mesh in hernia repair. Surg Innov 2005;12(1):63–9.

[33] Klosterhalfen B, Junge K, Klinge U. The lightweight and large porous mesh concept for hernia repair. Expert Rev Med Devices 2005;2(1):103–17.

[34] Conze J, Kingsnorth AN, Flament JB, et al. Randomized clinical trial comparing lightweight composite mesh with polyester or polypropylene mesh for incisional hernia repair. Br J Surg 2005;92(12):1488–93.

[35] Schmidbauer S, Ladurner R, Hallfeldt KK, et al. Heavy-weight versus low-weight polypropylene meshes for open sublay mesh repair of incisional hernia. Eur J Med Res 2005;10(6):247–53.

[36] Leber GE, Garb JL, Alexander AI, et al. Long-term complications associated with prosthetic repair of incisional hernias. Arch Surg 1998;133(4):378–82.

[37] Yaghoobi Notash A, Notash AY, Farshi JS, et al. Outcomes of the Rives-Stoppa technique in incisional hernia repair: ten years of experience. Hernia 2007;11(1):25–9.

[38] Talbert JL, Rodgers BM, Moazam F. Surgical management of massive ventral hernias in children. J Pediatr Surg 1977;12(1):63–7.

[39] Bauer JJ, Salky BA, Gelernt IM, et al. Repair of large abdominal wall defects with expanded polytetrafluoroethylene (PTFE). Ann Surg 1987;206(6):765–9.

[40] LeBlanc KA, Booth WV. Laparoscopic repair of incisional abdominal hernias using expanded polytetrafluoroethylene: preliminary findings. Surg Laparosc Endosc 1993;3(1):39–41.

[41] Koehler RH, Begos D, Berger D, et al. Minimal adhesions to ePTFE mesh after laparoscopic ventral incisional hernia repair: reoperative findings in 65 cases. JSLS 2003;7(4):335–40.

[42] McGinty JJ, Hogle NJ, McCarthy H, et al. A comparative study of adhesion formation and abdominal wall ingrowth after laparoscopic ventral hernia repair in a porcine model using multiple types of mesh. Surg Endosc 2005;19(6):786–90.

[43] Saettele TM, Bachman SL, Costello CR, et al. Use of porcine dermal collagen as a prosthetic mesh in a contaminated field for ventral hernia repair: a case report. Hernia 2007;11(3):279–85.

[44] Bellon JM, Garcia-Honduvilla N, Serrano N, et al. Composite prostheses for the repair of abdominal wall defects: effect of the structure of the adhesion barrier component. Hernia 2005;9(4):338–43.

[45] Matthews BD, Pratt BL, Pollinger HS, et al. Assessment of adhesion formation to intra-abdominal polypropylene mesh and polytetrafluoroethylene mesh. J Surg Res 2003;114(2):126–32.

[46] Matthews BD, Pratt BL, Backus CL, et al. Comparison of adhesion formation to intra-abdominal mesh after laparoscopic adhesiolysis in the New Zealand white rabbit. Am Surg 2002;68(11):936–40 [discussion: 941].

[47] Matthews BD, Mostafa G, Carbonell AM, et al. Evaluation of adhesion formation and host tissue response to intra-abdominal polytetrafluoroethylene mesh and composite prosthetic mesh. J Surg Res 2005;123(2):227–34.

[48] Baptista ML, Bonsack ME, Felemovicius I, et al. Abdominal adhesions to prosthetic mesh evaluated by laparoscopy and electron microscopy. J Am Coll Surg 2000;190(3):271–80.

[49] Kayaoglu HA, Ozkan N, Hazinedaroglu SM, et al. Comparison of adhesive properties of five different prosthetic materials used in hernioplasty. J Invest Surg 2005;18(2):89–95.

[50] Bellon JM, Serrano N, Rodriguez M, et al. Composite prostheses used to repair abdominal wall defects: physical or chemical adhesion barriers? J Biomed Mater Res B Appl Biomater 2005;74(2):718–24.

[51] Borrazzo EC, Belmont MF, Boffa D, et al. Effect of prosthetic material on adhesion formation after laparoscopic ventral hernia repair in a porcine model. Hernia 2004;8(2):108–12.

[52] Karahasanoglu T, Onur E, Baca B, et al. Spiral tacks may contribute to intra-abdominal adhesion formation. Surg Today 2004;34(10):860–4.

[53] Joels CS, Matthews BD, Kercher KW, et al. Evaluation of adhesion formation, mesh fixation strength, and hydroxyproline content after intraabdominal placement of polytetrafluoroethylene mesh secured using titanium spiral tacks, nitinol anchors, and polypropylene suture or polyglactin 910 suture. Surg Endosc 2005;19(6):780–5.

[54] Duffy AJ, Hogle NJ, LaPerle KM, et al. Comparison of two composite meshes using two fixation devices in a porcine laparoscopic ventral hernia repair model. Hernia 2004;8(4):358–64.

[55] LeBlanc KA, Stout RW, Kearney MT, et al. Comparison of adhesion formation associated with Pro-Tack (US Surgical) versus a new mesh fixation device, Salute (ONUX Medical). Surg Endosc 2003;17(9):1409–17.

[56] Ridgway DM, Mahmood F, Moore L, et al. A blinded randomised controlled trial comparing porcine dermal collagen with polypropylene for primary inguinal hernia repair. J Am Coll Surg 2007;205(3s):A15.

[57] Edelman DS, Selesnick H. "Sports" hernia: treatment with biologic mesh (Surgisis): a preliminary study. Surg Endosc 2006;20(6):971–3.

[58] Edelman DS. Laparoscopic herniorrhaphy with porcine small intestinal submucosa: a preliminary study. JSLS 2002;6(3):203–5.

[59] Oelschlager BK, Carlos AP, John H, et al. Biologic prosthesis reduces recurrence after laparoscopic paraesophageal hernia repair: a multicenter, prospective, randomized trial. Ann Surg 2006;244(4):481–90.

[60] Pans A, Elen P, Dewé W, et al. Long-term results of polyglactin mesh for the prevention of incisional hernias in obese patients. World J Surg 1998;22(5):479–82 [discussion: 482–3].

[61] de Vries Reilingh TS, van Goor H, Koppe MJ, et al. Interposition of polyglactin mesh does not prevent adhesion formation between viscera and polypropylene mesh. J Surg Res 2007;140(1):27–30.

[62] Vrijland WW, Bonthuis F, Steyerberg EW, et al. Peritoneal adhesions to prosthetic materials: choice of mesh for incisional hernia repair. Surg Endosc 2000;14(10):960–3.