Synthetic Mesh: Making Educated Choices

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Background

In 1951, Benjamin Pease filed a patent titled, "Nonmetallic Mesh Surgical Insert for Hernia Repair." The patent was awarded in 1954 (Fig. 6.1). In 1958, Usher described the use of this patented material in the form of polypropylene mesh for hernia repair [1]. It was later popularized by the technique outlined by Lichtenstein et al. in 1989 [2]. Today, a mesh hernia repair is the most common technique to repair inguinal and ventral hernias, although there are many technique and mesh variations to choose from. Several studies have demonstrated lower recurrence rates for mesh repair of abdominal wall defects. A meta-analysis of 13 randomized trials comparing open hernia repair with mesh versus without mesh showed a significantly lower incidence of recurrent hernia when mesh was used [3]. The EU Hernia Trialist Collaboration looked at 58 randomized controlled trials and found the use of synthetic mesh was superior with respect to recurrence in both open and laparoscopic hernia operations [4, 5]. Mesh, therefore, potentially results in a more durable hernia repair. At first, the thought process employed by surgeons was that a heavyweight polypropylene material that can withstand maximum intra-abdominal pressure of 170–200 mmHg and that induced significant fibrosis and scar tissue formation was best to buttress a weakened fascia. However, the use of such a mesh and the subsequent fibrotic reaction were later found to be associated with chronic post-hernia repair neuralgia, mesh migration and contraction as well as potential functional restrictions for some patients. The next step in the evolution of polypropylene synthetic mesh was the introduction of mid and lightweight material that had less density of material and wider pores which potentially led to less fibrotic reaction while still providing enough tensile strength to withstand maximum intra-abdominal pressures [6]. Despite the advantage of a less aggressive foreign body response, these newer mesh products continued to have various complications including loss of tensile integrity, erosion, intra-abdominal adhesions, bowel obstruction, and fistula/abscess formation in some patients. Consequently, various medical device companies have joined the quest for the development of the single "ideal" mesh. Other material such as polyester, polytetrafluoroethylene (PTFE), absorbable compounds, and biological meshes have been introduced. While numerous patients have ben-

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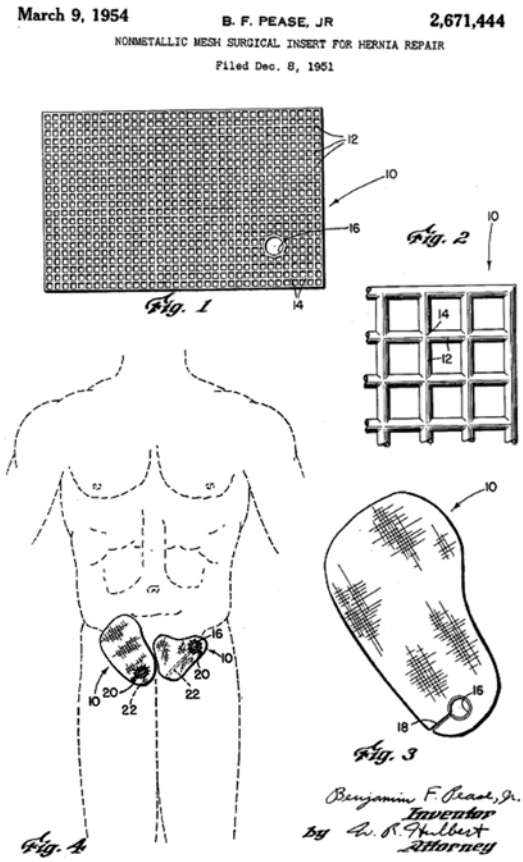

Fig. 6.1 The original plastic hernia mesh patent

efitted from each of these materials, none has yielded a superior outcome for all patients with all types of hernias in all hernia repair techniques all the time. Today, there are hundreds of different meshes manufactured with the above materials. Each addresses some of the concerns related to biocompatibility of synthetic prostheses while posing potential disadvantages. This has created a challenge for many surgeons, particularly in the setting of increasing complexity of hernias seen in everyday practice. Selecting the right mesh for the right patient requires the surgeon to have a relatively thorough understanding of the potential benefits and deficiencies for all types of hernia mesh and the requirements for each specific clinical scenario. With that knowledge, the surgeon is still left with numerous choices and uncertainty in predicting the outcomes for each patient.

Defining Hernia Mesh

Table 6.1 describes types of hernia mesh available in the US market by the plastic polymer used and divided be those which are macroporous (not used in the abdominal cavity) and those that have microporous surfaces (potentially used in the abdominal cavity).

Polypropylene (Figs. 6.2, 6.3, 6.4, 6.5, and 6.6) is synthesized from the monomer propylene via addition reaction. It is a hydrophobic compound and theoretically resistant to many chemical

Table 6.1 Description of available hernia meshes based on type of polymer, pore size and location for use

Basic polymer	Macroporous (used in abdominal wall)	Microporous (potential for use in abdominal cavity)
Polypropylene	Lightweight Mid-weight Heavyweight Coated polypropylene	Polypropylene with absorbable microporous barrier Polypropylene with permanent microporous barrier Microporous PTFE and Polypropylene composite
Polyester	Multifilamented polyester Monofilamented polyester	Polyester with absorbable microporous barrier
PTFE	Macroporous PTFE	Microporous PTFE Dual-sided PTFE (smooth and textured) Microporous PTFE and Polypropylene composite
Absorbable synthetic	Macroporous absorbable synthetic	Microporous absorbable synthetic

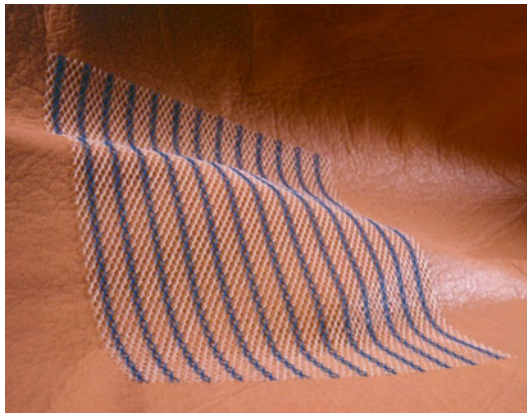

Fig. 6.2 Lightweight Polypropylene (macroporous)

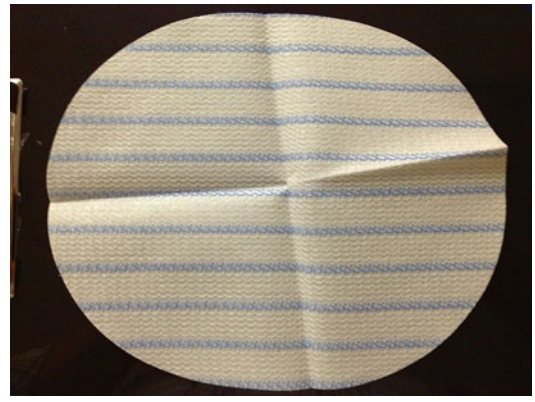

Fig. 6.5 Polypropylene with a microporous absorbable cellulose surface

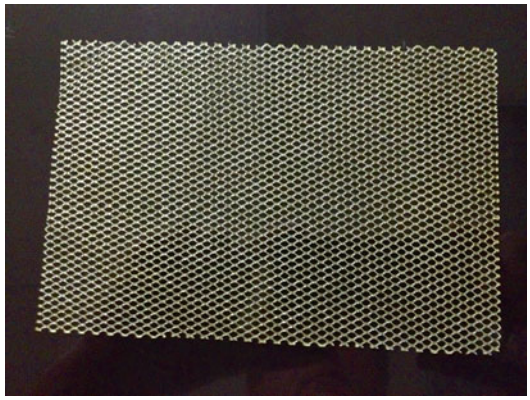

Fig. 6.3 Polyurethane-coated polypropylene (macroporous)

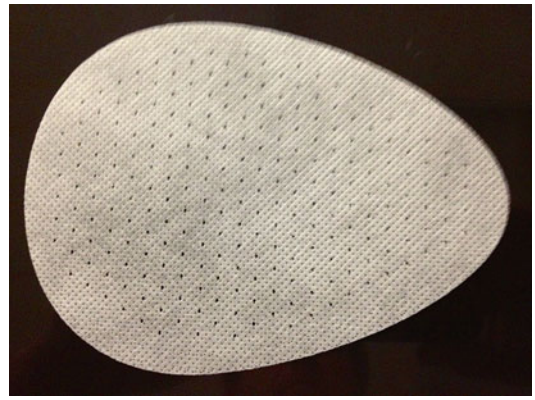

Fig. 6.6 Non-woven polypropylene

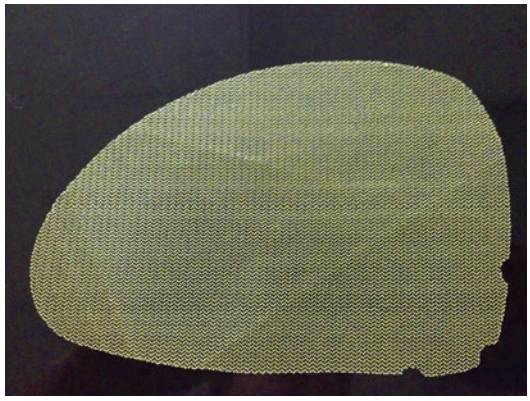

Fig. 6.4 Omega-3 fatty acid-coated polypropylene (macroporous)

solvents, bases, and acids. It is, however, thermoplastic and can be remelted and reformed. Hernia mesh is made with semicrystalline polypropylene fibers extruded and then woven into monofilament or multifilament structures. Recently, nonwoven and coated polypropylene fibers have also been made available to the growing list of hernia mesh choices. In vivo, polypropylene mesh has been shown to degrade by undergoing oxidation. It occurs when C–H bonds are compromised, creating free radicals that will bind oxygen. If chain scission or cross-linking occurs, the mesh may change its property and become stiff and/or contract. Heavy-weight polypropylene mesh, defined as having greater than 90 g/m^2 area of material and pore size <3–5 mm, has been shown,

in some patients and animal studies, to induce an intense foreign body reaction. Examples of polypropylene mesh are in Figs. 6.2, 6.3, 6.4, 6.5, and 6.6.

Polyethylene Terephthalate (PET) is a member of the polyester family (Figs. 6.7 and 6.8). It is synthesized from the monomer bis-β-hydroxyterephthalate via condensation reaction by either esterification (water as a by-product) or transesterification (methanol as a by-product). It is less hydrophobic than polypropylene. Yet its thermoplastic property is similar to polypropylene. The degradation mechanism of concern is hydrolysis. The physiochemical changes that occur during degradation of PET include discoloration, chain scissions resulting in reduced molecular weight, formation of acetaldehyde, and formation of cross-links. Because of its macroporous design, a significant inflammatory reaction with tissue ingrowth occurs that results in variable degree of scar formation. Polyester mesh can be constructed in monofilament or multifilament forms. Recent data, however, suggest that monofilament polyester may be too fragile with resultant frequent central mesh failures.

Polytetrafluoroethylene (PTFE) (Fig. 6.9) is a fluorocarbon-based polymer that is synthesized via a free-radical polymerization of tetrafluoroethylene. PTFE is highly crystalline, significantly hydrophobic, and one of the most chemically inert polymers in the market. The high strength of the fluoro-carbon bind is mostly responsible for the inertness of this polymer. Expanded PTFE (ePTFE), commonly used in hernia mesh, is produced when PTFE is heated and then stretched, creating micropores. The hydrophobic, microporous nature of this material can lead to fibrous encapsulation and mesh contraction in some patients. There have also been rare reports of chronic, active seromas. This material was used in one of the first meshes designed for placement against the viscera (primarily using a laparoscopic approach for ventral/incisional hernia repair). In this type of PTFE product, one side of the material is rough to induce tissue ingrowth, while the other side is smooth to reduce tissue ingrowth from the viscera. Monofilament PTFE mesh with an open macroporous design is another PTFE-based product that may allow better tissue integration.

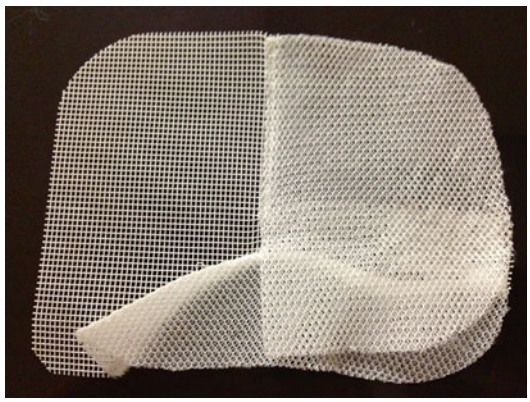

Fig. 6.7 Multifilamented polyester (macroporous)

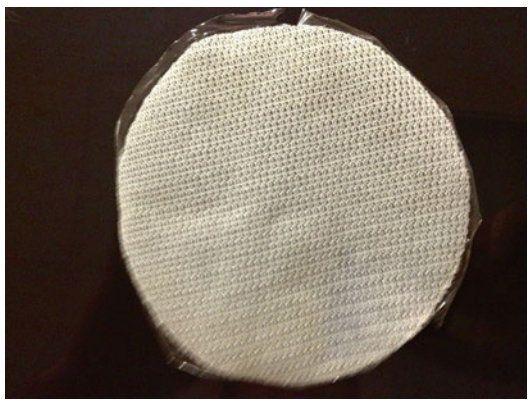

Fig. 6.8 Multifilamented polyester with a microporous absorbable collagen barrier

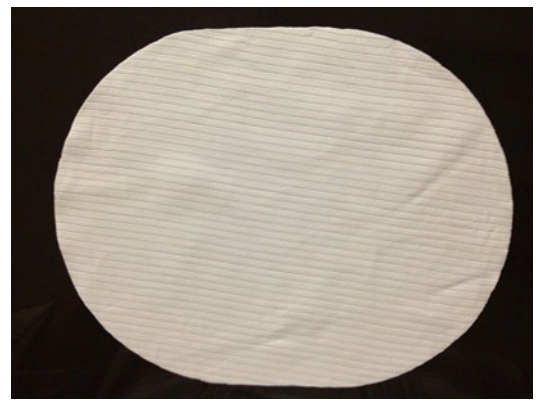

Fig. 6.9 Dual-sided PTFE mesh (microporous)

Mesh design is an important factor that needs to be taken into consideration before selecting a mesh. Unfortunately, despite recent advances, all meshes incite variable degrees of foreign body response. In order to improve this response, the mesh design could be better optimized. The parameters influencing the mesh design are weight, pore size, and the weave. Heavy-weight meshes with small pores were initially thought to be the best to withstand maximum intra-abdominal pressure of 170–200 mmHg. However, they were later found to be over-engineered for most people. In addition, they formed a rigid scar plate and granuloma bridging in many patients due to their small pores. The introduction of mid and lightweight meshes with larger pores (>1 mm) reduced the foreign body response and granuloma bridging [7] Despite this reduction, the foreign body response has not been eliminated and lower ratio of type I/III collagen continues to occur, highlighting the need for additional research. The weave design will dictate the overall mechanical properties, pore size, and the foreign body response. Isotropic and anisotropic qualities of the mesh are also determined by the weave design. Isotropic mesh design displays equal mechanical properties in any direction of applied force, while anisotropic mesh exhibits different mechanical properties depending on the direction of the force.

Hernia Mesh for Specific Clinical Scenarios

Direct *viscus exposure* to the synthetic hernia mesh can lead to adhesions or the ingrowth of bowel and other visceral organs causing erosion, fistula, abscess, and/or obstruction. A variety of mesh options for intra-abdominal placement have been designed to address this issue. A solid permanent (PTFE or silicone) or absorbable (many types) barrier is used on a variety of polypropylene or polyester meshes. This combination is referred to as "composite" mesh (Fig. 6.10). There are also PTFE meshes with a rough surface that is intended to promote ingrowth into the abdominal wall and a smooth surface that faces the intra-abdominal visceral organs and is designed to prevent ingrowth. (More recent mesh options include non-woven microfibers of polypropylene.)

The use of synthetic hernia mesh in a *contaminated or potentially contaminated field* has been controversial. Contamination has long been regarded as a relative contraindication to the use of permanent synthetic mesh. As a result, in such a setting, a multi-stage operation with delayed definitive hernia repair has been advocated [8, 9] More recently, a single-stage repair with the use of biologic mesh has become widely popular in the USA. Despite its relatively safe profile, higher wound complications and higher 3-year recur-

Fig. 6.10 Microporous PTFE and macroporous Polypropylene composite mesh

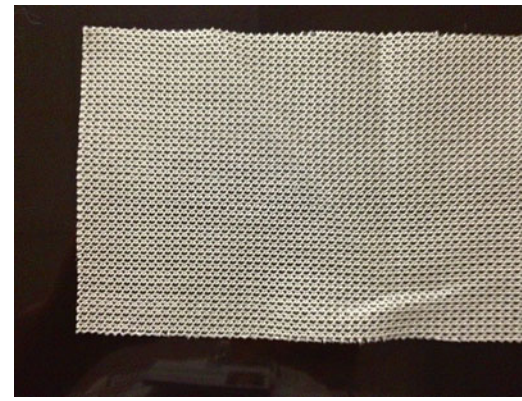

Fig. 6.11 Macroporous long-term resorbable synthetic mesh

rence (about 50%) have been associated with this technique [10]. Furthermore, a systematic review of 32 studies comparing the use of biologic mesh to synthetic non-absorbable mesh in contaminated fields during single-stage repairs did not find any advantage favoring the use of biologic material. While wound infection rates were similar, the recurrent hernia rate was significantly higher with biologic mesh [11]. The value of biologic mesh and other options will need to be measured. The use of long-term absorbable synthetic material has also been documented for both multi-staged and single-stage hernia repairs in contaminated fields (Fig. 6.11).

New Concepts in Improving Mesh Biocompatibility

Animal studies have demonstrated that *randomly generated fibers*, or non-woven material, such as non-woven polypropylene, may be beneficial for biocompatibility when compared to woven or knitted fibers [12]. Based on this principle, hernia meshes made with non-woven fibers have been introduced. Long-term outcomes have yet to be demonstrated.

Another relatively new concept in mesh design, aimed at minimizing fibrotic tissue, ingrowth, and/or scar tissue formation, are *coated polypropylene or polyester prostheses*. Most coated products are designed to prevent ingrowth to the viscera by coating the visceral side of the mesh with a microporous coating. Different types of coatings that are currently available in the market for this purpose include collagen, omega 3 fatty acid, hyaluronic acid, and other degradable polymers. Coatings can also be applied to individual mesh fibers to mask the bodies' foreign body response to polypropylene. Coatings available for this purpose include titanium and polyurethane. Because these mesh products are macroporous, they are not designed to prevent ingrowth and may not be the best choice for placement against the viscera. However, they may be beneficial in decreasing the foreign body response.

The Medical and Legal Aspects of Synthetic Mesh Manufacturing and Marketing

Most hernia meshes fall in the class II medical device category of FDA and enter the market with a 510K application process. Class II devices are subject to general controls and special controls. Special controls include safety measures such as postmarket surveillance and premarket data requirements. However, no clinical study or premarket approval is generally necessary as long as a predicate device is identified. Therefore, biocompatibility defined as "the ability of a material to perform with an appropriate host response in a specific application" [13] is not typically tested in humans prior to use in patients. With respect to postmarket surveillance, there are currently two mechanisms in place. The Safe medical Devices Act of 1990 requires user facilities to report device-related deaths to the FDA and the manufacturer and report serious injuries to the manufacturer, who then reports to the FDA. This law does not address whether or not the device responsible for death or serious injury needs to be returned to the manufacturer and/or studied [14]. The second mechanism for postmarket surveillance is a voluntary web-based program known as MedWatch. This program allows health care professionals and consumers to report adverse events directly to the FDA [15].

Is There an "Ideal" Mesh?

Since the introduction of the synthetic material to the hernia world, there has been a quest to find the "ideal" mesh. Various attempts have been made to either manufacture or describe the qualities of an "ideal" prosthesis. Clinical studies have not yet found a single hernia mesh that has ideal tensile strength which also behaves as the most biocompatible in all patients with all types of hernias all the time. While the "ideal" mesh may not exist when looking at the hernia patient population as a whole, there are individuals whose hernias have been repaired with what they would con-

sider "ideal" mesh for that particular patient, or a sub-population of patients. Unfortunately, traditional clinical research tools, such as prospective randomized controlled trials, are inadequate to help us identify those individuals and sub-populations. Identifying sub-populations of patients that would do best, or worst, with various mesh options is a future challenge for hernia researchers.

Shared Decision-Making Process

The general public awareness about hernia mesh is on the rise. Whether it is due to increased conversation on social media or the negative advertisements by various legal firms, or both, more and more patients today expect to play an active role in the technique and mesh selection process. Surgeons are often able to narrow down the options based on the understanding of the potential benefits and deficiencies of different hernia mesh choices and their application to any specific clinical scenario. But, for a growing number of patients, a shared-decision process for the choice of mesh and technique for hernia repair is preferred.

Applying Complexity Science and Nonlinear Data Analytics: A Novel Approach

As mentioned earlier, traditional research methodologies are insufficient to best identify the subpopulation of patients who may benefit from or be harmed by a certain type of mesh. This is due to the fact that hernia disease (as with other medical phenomenon) is a complex entity while traditional clinical research tools are designed for simple (or isolated) systems. Recently, the principles of complexity science have been introduced into the health care. Complexity science tools can potentially categorize patients into subpopulations that are more likely to demonstrate biocompatibility with one type of hernia mesh versus others. One tool that can be used to better determine appropriate mesh choice is the use of clinical quality improvement (CQI) principles. CQI includes defining a dynamic care process, preferably based on the entire cycle of care, for patients with hernia disease. It also involves defining outcome measures that ultimately determine the value of care. The data can be gathered from multiple sources during real patient care, including from the patient. Many institutions that have begun CQI projects have also introduced disease-specific multidisciplinary teams. These teams tend to maintain a better contact with the patient throughout the entire cycle of care and, therefore, collect a great deal of information pertaining to the process and outcome measures. As more data are collected, certain patterns begin to emerge. These patterns can potentially be quantified using nonlinear data analytics. Identifying the factors (variables) that matter in determining outcomes can generate predictive algorithms that can assist surgeons and patients in determining the appropriate mesh (and technique) choice for each patient group [16]. Although the application of complexity science to patient care is in its infancy, the potential to improve outcomes through predictive analytics using data generated by real-world patient care is significant.

Summary

Mesh selection for patients undergoing hernia repair can be a challenging process. Due to the complexity of the hernia patient population and the vast choices of hernia mesh, traditional research mechanisms to determine the best, and worst, mesh for each technique, patient, and patient sub-populations are inadequate. Currently, a shared decision process allows the surgeon and patient to make choices that include each perspective. In the future, the use of complexity science tools such as CQI will facilitate predictive analytics that will allow for more informed choices that will benefit both the surgeon and the patient.

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