Notable Grand Rounds
of the
Michael & Marian Ilitch Department of Surgery

Wayne State University
School of Medicine

Detroit, Michigan, USA

Solhee Lee, MD

ALL ABOUT MESH

July 12, 2023

About Notable Grand Rounds

These assembled papers are edited transcripts of didactic lectures given by mainly senior residents, but also some distinguished attending and guests, at the Grand Rounds of the Michael and Marian Ilitch Department of Surgery at the Wayne State University School of Medicine.

Every week, approximately 50 faculty attending surgeons and surgical residents meet to conduct postmortems on cases that did not go well. That “Mortality and Morbidity” conference is followed immediately by Grand Rounds.

This collection is not intended as a scholarly journal, but in a significant way it is a peer reviewed publication by virtue of the fact that every presentation is examined in great detail by those 50 or so surgeons.

It serves to honor the presenters for their effort, to potentially serve as first draft for an article for submission to a medical journal, to let residents and potential residents see the high standard achieved by their peers and expected of them, and by no means least, to contribute to better patient care.

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All About Mesh

A Notable Grand Rounds Presentation

delivered at
Wayne State University
School of Medicine on
May 31, 2023

by

Solhee Lee, MD

This paper has been adapted from an oral presentation.

Introduction

General surgeons are going to use mesh to fix a hernia at some point in their career, so they must be knowledgeable about the product they are putting into patients. The objectives of this paper are to review the history, types/properties, and clinical applications of surgical mesh.

History

The idea of surgical mesh is credited to Dr. Theodore Billroth, who wrote in 1876 that “If we could artificially produce tissues of the density and toughness of fascia and tendon, the secret of the radical cure of hernia would be discovered.” About 13 years later, surgeons began experimenting with different materials, including metals, silk, and cotton, but they failed due to infections rejection, and recurrence.

The perfect mesh surgeons sought would have these properties:

- long shelf life,
- easy to handle,
- resistant to infection,
- flexible enough to avoid fragmentation,
- long-term tensile strength to prevent recurrence,
- incorporate quickly into host tissue, and
- cost effective.

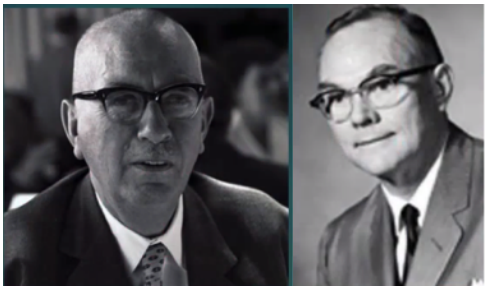

Fig. 1. Dr. Ziegler (L); Dr. Usher ®

In 1952, German biochemists Karl Ziegler (1898–1973) (Fig. 1L) and Giulio Natta (1903–1979) independently developed catalysts that enabled polymerization at room temperature and normal atmospheric pressure, for which they shared the Nobel Prize in Chemistry in 1963. It gave the surgeon a material—polypropylene—for daily practice, which in its properties (nearly) achieved Billroth's initial vision.

In 1955, Dr. Francis Usher (Fig. 1R), a general surgeon, came across an article about a polypropylene material called Marlex that was being used to make hula-hoops and frisbees. Marlex could withstand high temperatures without affecting its form, so it was sterilizable. By 1958, Dr. Usher and colleagues had developed a woven polypropylene mesh and in 1962 published a paper describing its use in surgery.[1]

Polypropylene is a polymer—a plastic—used to make thousands of products from chairs to test tubes to pipette tips to the cap on a Tic Tac tube… and to surgical mesh (Fig. 2). Today, mesh is used in more than 90% of the >1 million hernia repairs in the United States performed yearly and about 80% of the 20 million performed worldwide.

It is now well established that mesh repair reduces recurrence rates. A study published in 2004 demonstrated that recurrence was halved in cases with mesh (1-32% recurrence) versus without mesh (17-67% recurrence).[2] A more recent (2016) study from a nationwide registry in Denmark analyzed elective incisional hernia repairs from 2007 to 2010 in more than 3200 patients, and compared the use of mesh in both open and laparoscopic procedures to just open primary repair. The outcomes studied were five-year risk of reoperation and mesh complications.

Fig. 2. Polypropylene products — Mesh at right

[1] Usher FC, Allen JE Jr, Crosthwait RW, Cogan JE. Polypropylene monofilament. A new, biologically inert suture for closing contaminated wounds. JAMA. 1962 Mar 10;179:780-2. doi: 10.1001/jama.1962.03050100034006b. PMID: 13923961.

[2] Jacobus W A Burger 1, Roland W Luijendijk, Wim C J Hop, Jens A Halm, Emiel G G Verdaasdonk, Johannes Jeekel. Long-term follow-up of a randomized controlled trial of suture versus mesh repair of incisional hernia. Ann Surg. 2004 Oct;240(4):578-83; discussion 583-5. doi: 10.1097/01.sla.0000141193.08524.7.

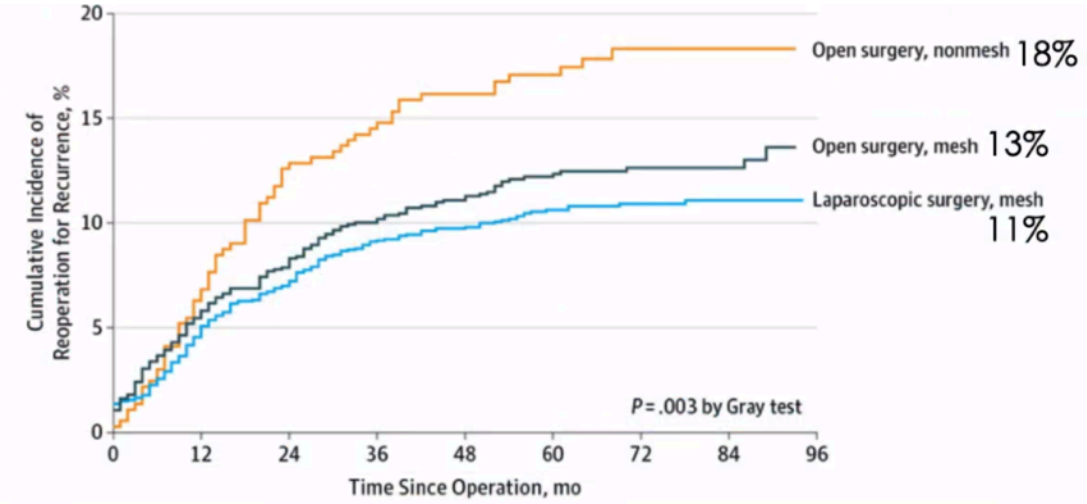

Fig. 3. Risk of reoperation for hernia recurrence after index incisional hernia repair.
Source: Fig. 1 in Kokotovic et al (2016)—see footnote 3.

The study found that with open surgery, without mesh, the recurrence rate was about 18%, compared to 13% in open surgery with mesh and 11% in laparoscopic surgery with mesh (Fig. 3).[3]

How It Works

The implantation of mesh triggers an immune response. It begins with an inflammatory phase in which proteins, albumin/complement, immunoglobulins, platelets, and PMNs are recruited to the area, followed by macrophages and lymphocytes. The chemokines and cytokines in those cells recruit fibroblasts, which start the healing phase ~2–5 days after the injury occurs. The fibroblasts then secrete extracellular matrix and collagen to form scar tissue, with peak levels at ~1–2 weeks.

An inflammatory response is necessary for integration of the mesh to the body with collagen deposition but an excessive response can lead to fibrosis, infection, and mesh rejection. A balance has to be found. The level of the immune response can be mediated through the mesh properties such as porosity, material coatings, and weight.

Properties of Mesh

1. Porosity

Porosity is the space between the fibers that allows for ingrowth and incorporation of the mesh into the abdominal wall. The pores of the mesh on the left in Fig. 4 (next page) are bigger than the pores of the mesh on the right. Pore size influences the ability of bacteria to grow and proliferate: Smaller pores encourage bacterial growth, which is critical in mounting an effective immune response; larger pores allow for more neovascularisation and passage of the macrophages.

Large-pore mesh is more resistant to infection because the bacteria have more places to hide, while microporous meshes, on the other hand, allow for more rapid infiltration of the mesh with scar tissue, which leads to poor mesh integration and a state of chronic inflammation.

[3] Dunja Kokotovic, MB'; The Bisgaard, MD, DMSc; Frederik Helgstrand, MD, DMSc. Long-term Recurrence and Complications Associated With Elective Incisional Hernia Repair. JAMA. 2016;316(15):1575-1582. doi:10.1001/jama.2016.15217

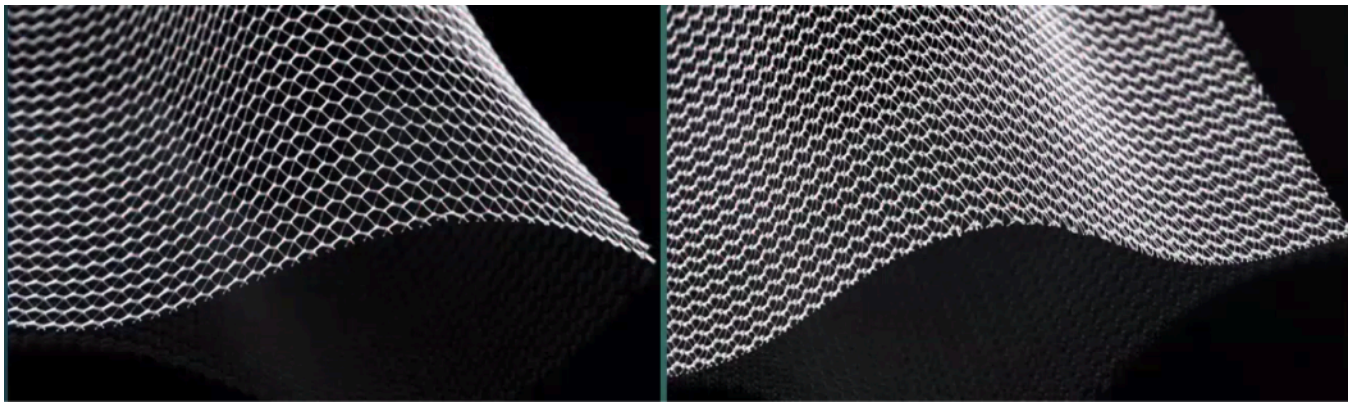

Fig. 4. Mesh porosity

Macroporous meshes have pores measuring 1–2 mm. Medium pore mesh measures 0.6–1 mm. Small pore mesh measures 0.1–0.6 mm. The pores should ideally be greater than 0.8 millimeters to avoid granuloma bridging, which occurs when inflamed tissues on the scaffolding of the mesh bridge with each other and create a stiff scar plate.

2. Weight
Weight affects the intensity of the foreign body immune reaction. Heavy mesh is less flexible, which can decrease incorporation of the mesh with the tissue, and can contract to a greater degree. The extent of inflammation can cause shrinkage by as much as 50% recurrence as the mesh pulls away from the rest of the repair. Less foreign body reaction leading to better absorption can also lead to a denser scar with less flexibility.

Mesh is classified as heavy (>80 g/m^2), medium (50-80 g/m^2, light (35-50 g/m^2), and ultra light (<35 g/m^2).

3. Strength
Tensile strength is a measure of axial stress and is defined as the maximum force that can be placed on the mesh before it fails. Early meshes had a vastly overestimated tensile strength of 100 N/cm. The tension placed on the abdominal wall can be calculated by the Law of Laplace:
Tension = (diameter *x* pressure)/4 *x* wall thickness). Mesh needs to be able to withstand at least 180 mmHg or 32 N/cm. Ball-burst strength is the maximum tension that can be placed on the mesh, measured by compressing it with a steel ball until the point of rupture. (Fig. 5)

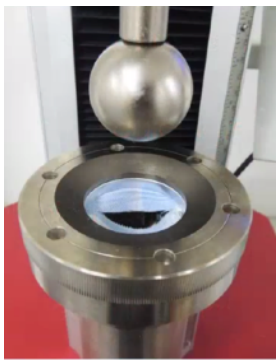

Fig. 5. Ball-burst strength

Types of Mesh

1. Monofilament vs. Multifilament
Mesh may be monofilament or multifilament. Monofilament mesh is more rigid, while the surface area of multifilament mesh is about 157% greater so it accommodates more

Bard Ventralight ®			Progrip ®		
Size 11.4cm-30x35cm			Size 30cmx15cm		
Physical Properties			**Physical Properties**		
Base Material	Polypropylene		Base Material	Polyester	
Barrier	PGA		Barrier	None	
Pore Size	0.66mm		Pore Size	1.1mm	
Weight	54g/m2		Weight	73 g/m2	
Biomechanical Properties			**Biomechanical Properties**		
Tensile Strength	↔ 50.8 N/mm	↕ 123 N/mm	Tensile Strength	↔ ND N/mm	↕ ND N/mm
Tear Strength	↔ ND N/mm	↕ ND N/mm	Tear Strength	↔ ND N/mm	↕ ND N/mm
Ball Burst Strength	380	N	Ball Burst Strength	ND N/cm	

Fig. 6. Mesh comparison chart (source: SAGES website)

bacterial adhesion. Phasix monofilament mesh is advertised as resistant to bacteria. It is also somewhat resistant to stitches, the filaments being very tough.

There Is no standardized nomogram for meshes. Mesh manufacturers are not required to put them on their labels so it is difficult to compare one with another. Fig. 6 is an attempt to compare physical properties—base material, pore size, weight, and barrier—as well as tensile and ball burst strength, of two meshes.

2. Synthetic vs. Composite

First generation meshes came in permanent and absorbable ((bioresorbable/biodegradable) synthetic versions. Permanent synthetic mesh is made from polypropylene, polyester, or expanded polytetrafluoroethylene. Absorbable synthetic mesh is made by Vicryl and Phasix. Second generation meshes, designed to improve adhesion, are composites of a smooth resorbable collagen barrier on the bowel side and a sticky polyester knit on the abdominal wall side. It is obviously vital to orient the mesh correctly during placement.

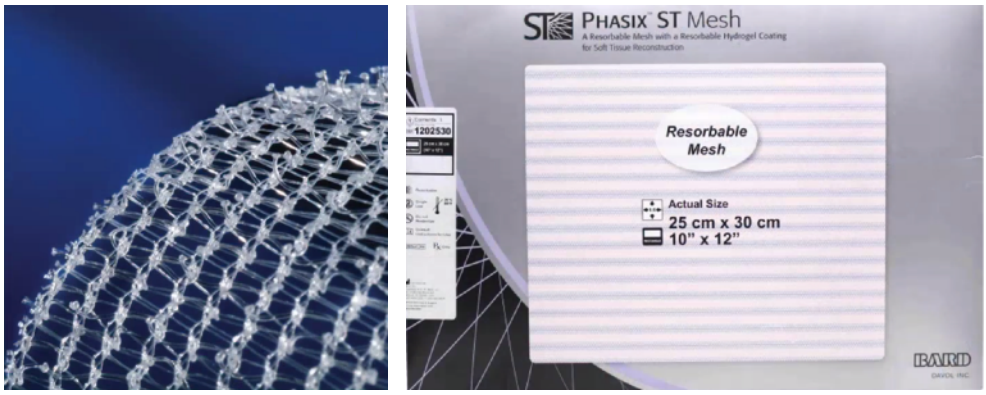

Fig 7. Two second-generation meshes

Commercial examples include ProGrip (Fig. 7L), a monofilament polyester with a resorbable polylactic acid microgrip technology that adheres to tissue. Phasix ST (Fig. 7R) is more rigid but more resistant to bacteria. It is a composite knitted monofilament made from polyhydroxybutyrate (P4HB), biologically derived material fully re-

sorbable through hydrolysis. Its byproducts are CO_2 and H_2O. The hydrogel barrier is placed on the bowel side.

Dr. Alisa Coker illustrated the resorption of Phasix ST mesh at a presentation in 2019. Fig. 8) shows complete resorption by about 12 to 18 months, enough time for the native tissue to build its own scaffold.

A 2022 phase 1 (safety) clinical study of single-stage abdominal wall reconstruction in contaminated and dirty wounds was conducted using Phasix mesh. The study involved 34 patients, of whom 12 were contaminated and 22 were dirty or infected. In follow-up at about 37 months it was found that surgical site occurrence, defined as anything requiring procedural intervention (*i.e.,* hematoma, seroma, surgical site infection), was about 12%. The midline hernia recurrence at 37 months was zero.[4]

A longitudinal, nine-center prospective study conducted from 2011–2014 in the United States and the Netherlands looked at the use of a specific biosynthetic absorbable mesh in clean-contaminated or contaminated[5] cases.[6] The mesh was Bio-A, a biosynthetic web scaffold made of 67% polyglycolic acid (polymer) and 33% trimethylene carbonate (absorbs in 6–7 months). The study's endpoint was hernia recurrence at two years. About 77% of the cases were contaminated and 23% were clean-contaminated (Fig. 9, next page).

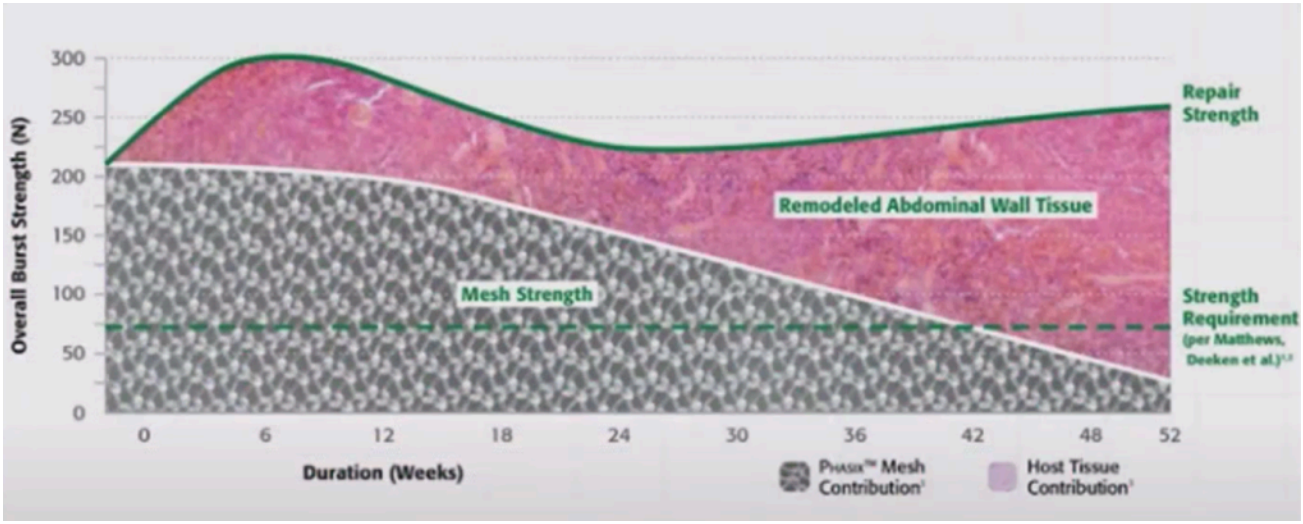

Fig. 8. Phasix ST mesh repair strength over time in a 52-week preclinical model. *Source*: Alisa M. Coker, MD.

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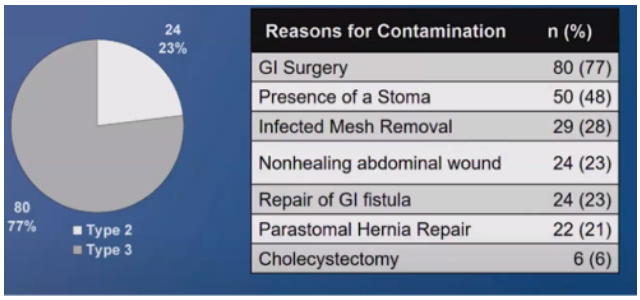
[4] Samuel C Schecter, Laurel Imhoff, Michael V Lasker, Shana Hornbeck, Henry C Flores. Single-stage abdominal wall reconstruction in contaminated and dirty wounds is safe: a single center experience. Surg Endosc. 2022 Aug;36(8):5766-5771. doi: 10.1007/s00464-022-09058-4. Epub 2022 Feb 7.

[5] "Clean contaminated" means that there is an incision through which the respiratory or GI tract or GU tract has been entered under controlled conditions but no obvious contamination was encountered. A contaminated case means a major break in sterility, or gross spillage from the GI tract, or any incision where acute inflammation is encountered.

[6] Rosen MJ, Bauer JJ, Harmaty M, Carbonell AM, Cobb WS, Matthews B, Goldblatt MI, Selzer DJ, Poulose BK, Hansson BM, Rosman C, Chao JJ, Jacobsen GR. Multicenter, Prospective, Longitudinal Study of the Recurrence, Surgical Site Infection, and Quality of Life After Contaminated Ventral Hernia Repair Using Biosynthetic Absorbable Mesh: The COBRA Study. Ann Surg. 2017 Jan;265(1):205-211. doi: 10.1097/SLA.0000000000001601. PMID: 28009747; PMCID: PMC5181129.



Reasons for Contamination	n (%)
GI Surgery	80 (77)
Presence of a Stoma	50 (48)
Infected Mesh Removal	29 (28)
Nonhealing abdominal wound	24 (23)
Repair of GI fistula	24 (23)
Parastomal Hernia Repair	22 (21)
Cholecystectomy	6 (6)

Fig. 9. Surgical filed characteristics from the COBRA Trial (see footnote 5). *Source*: Courtesy Alisa M. Coker, MD

The GI surgeries were mostly ostomy creations or takedowns or bowel resections. The study found ~16% hernia recurrence using Bio-A bioresorbable mesh in clean-contaminated or contaminated cases (the recurrence for biologic mesh, on the other hand, would be about 28%). Surgical site infection was about 18%, much higher than the clean case recurrence rate of 0.1 to 3%. Midline hernia recurrence (Fig. 10) was 14%[7] and was more likely in patients with a BMI >30, or if the defect was longer and more than 11 centimeters, or if there was a post-op superficial

Description	Total (% of subjects)
Hernia Recurrence	16 (17%)
SSI	21 (18%*)
Seroma	6 (6%)
Recurrent Fistula	2 (2%)
Bowel Obstruction	2 (2%)
Dehiscence	1 (1%)
Hematoma	1 (1%)

Fig, 10.Midline hernia recurrence

wound infection. In comparison, midline hernia recurrence in laparoscopic surgery was about 11%.

Biologic vs. Bio-resorbable and Synthetic Mesh.

A randomized clinical trial involving 253 patients of whom 126 received synthetic meshes and 127 received biologic meshes found a ~20% recurrence with biologic mesh and ~5% recurrence with synthetic mesh after 24 months. There was no significant difference in overall 2-year risk of surgical site occurrence that required a procedural intervention.[8] However, the biologic mesh cost $21,539 versus $105 for the synthetic.

An analysis of 100 midline ventral hernia cases (50 clean-contaminated and 50 contaminated) where permanent synthetic mesh was placed in the retrorectus space found no association with increased risks of infection, fistula formation, or clinically significant adhesions at 23-month follow-up. The 30-day surgical site infection rate was ~7% for the clean-contaminated and ~19% for contaminated cases.[9]

Given enough experience and controlled low contamination, permanent synthetic mesh seems to be acceptable, but studies that have found no significantly increased risk of infection tend to be anecdotal, and I personally would not use permanent synthetic mesh with a bowel injury.

A 3rd generation biologic mesh (Strattice and XenMatrix are examples) would be better but the cost is great and the recurrence rate, especially

[7] It says 17% in Fig. 10, but that was counting the peristomal at hernia recurrences, but just Medline alone was 14%.

[8] Rosen MJ, Krpata DM, Petro CC, Carbonell A, Warren J, Poulose BK, Costanzo A, Tu C, Blatnik J, Prabhu AS. Biologic vs Synthetic Mesh for Single-stage Repair of Contaminated Ventral Hernias: A Randomized Clinical Trial. JAMA Surg. 2022 Apr 1;157(4):293-301. doi: 10.1001/jamasurg.2021.6902. PMID: 35044431; PMCID: PMC8771431.

[9] Souza JM, Dumanian GA. Routine use of bioprosthetic mesh is not necessary: a retrospective review of 100 consecutive cases of intra-abdominal midweight polypropylene mesh for ventral hernia repair. Surgery. 2013 Mar;153(3):393-9. doi: 10.1016/j.surg.2012.08.003. Epub 2012 Oct 13. PMID: 23068089.

if the mesh is used in a bridging fashion, is going to be high—about 80%, though that can reduced to 20% by applying component separation first. These meshes are so costly that hospitals may end up thousands of dollars out of pocket per case. The mesh is essentially a collagen scaffold from human, porcine, or bovine dermis. It causes no inflammatory response from the body but the high cost and higher recurrence rate are counter factors.

Maxwell *et al* (2019) reported a recurrence rate of only 11%[10] but the cost of biologic mesh at 180 days was $31,000, versus $15,000 for synthetic mesh. The study involved 415 open ventral hernia repair cases over a 3-year period at a tertiary care center. The median direct cost of cases performed without mesh was $5,432, compared with $7,590 for synthetic mesh and $16,970 for biologic mesh. The average cost of a hernia repair using 587 cm^2 pieces of mesh was ~$20,000-–$26,000 with biologics versus $13,000 with synthetics (resorbable and permanent).

Onlay vs. Sublay

A systematic review from India looked at six randomized controlled trials total of 986 patients, about half onlay and half sublay. The study found no statistically significant difference between the two methods of placement in hernia recurrence, surgical site infection, or length of stay, but did find that seroma formation was higher in onlay cases.[11] This review had limitations in that only two of the six studies mentioned hernia size and not all studies mentioned the type of mesh used and the type of drain (if used).

Bridging vs. Component Separation

In cases where fascia cannot be primarily reapproximated, then rather than bridging a defect with mesh alone and covering with subcutaneous tissue and skin, component separation should be considered. Reduced hernia recurrence falls from ~80% in bridged procedures to ~20% in component separation plus biologic mesh and ~10% in component separation plus permanent mesh.

Weightlifting Restrictions

In clinic I counsel patients not to lift more than 10 pounds for six weeks, a guesstimate based on knowing that the wound repair process takes about 12 weeks—so they should wait until the halfway point before lifting things. However, a European survey of 400 surgeons[12] found no conclusive data on post-operative weightlifting after hernia surgery. There was wide variation in responses and fewer than 10% justified their recommendations with supporting data.

After laparoscopic abdominal surgery, 50% recommended weightlifting based on the patient's comfort level alone: If they could handle the pain, then they could lift what they could. About a third recommended lifting 10 to 20 pounds after a laparotomy and about 75% agreed on <2 weeks post-operative weightlifting restrictions after laparoscopic repair (*vs*. the 6 weeks I tell my patients).

With respect to midline or transverse laparotomies, about 50% recommended <4 weeks and the other half recommended >4 weeks—essentially, there was no consensus.

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[10] Maxwell DW, Hart AM, Keifer OP Jr, Halani SH, Losken A. A Comparison of Acellular Dermal Matrices in Abdominal Wall Reconstruction. Ann Plast Surg. 2019 Apr;82(4):435-440. doi: 10.1097/SAP.0000000000001692. PMID: 30562207.

[11] Pereira C, Gururaj S. Onlay Versus Sublay Mesh Repair for Incisional Hernias: A Systematic Review. Cureus. 2023 Jan 24;15(1):e34156. doi: 10.7759/cureus.34156. PMID: 36713818; PMCID: PMC9879281.

[12] Schaaf S, Willms A, Schwab R, Güsgen C. Recommendations on postoperative strain and physical labor after abdominal and hernia surgery: an expert survey of attendants of the 41st EHS Annual International Congress of the European Hernia Society. Hernia. 2022 Jun;26(3):727-734. doi: 10.1007/s10029-021-02377-w. Epub 2021 Feb 24. PMID: 33629178; PMCID: PMC9200870.

Patient Perspective
But perceptions and understanding about mesh and hernia surgery are changing.

Elhage *et al* (2021)[13] gave a 16 question survey to patients in pre-op for elective hernia surgery. Of 222 patients, about 45% believed that mesh caused complications and 38% reported concerns about mesh. Patients who performed their own research, women, and patients with recurrent hernias were more likely to have concerns about mesh ($P \leq 0.03$).

Ads such as that shown at Fig. 11 are thus to be expected. The fact that the practice that posted the ad has an attorney dedicated to hernia mesh is a strong pointer to the importance of pre-operative counseling of the patient. Surgeons should discuss with them mesh infection incidence (which is 0.1 to 3% in clean cases) and the risks related to BMI, smoking, age, and COPD. The type of mesh to be used should also be discussed. If a patient is averse to using mesh then even costly bio-resorbable mesh should be discussed

Fig. 11. The importance of pre-op counseling

Take-home Points
- Mesh has been shown to decrease hernia recurrence.
- The mesh most resistant to infection is light weight, macroporous, and monofilament.
- Bio-resorbable mesh (Vicryl, Phasix, Bio-A, TIGR) should be considered in clean-contaminated/contaminated fields.
- There is no consensus and minimal data regarding weight restriction recommendations post-hernia surgery.
- Pre-operative counseling is very important, especially given increasing societal mesh aversion.

* * *

[13] Elhage SA, Thielen ON, Otero J, Huber AT, Grigg TM, Suddreth CE, Monjimbo GA, Prasad T, Augenstein VA, Heniford BT. Perceptions and understanding about mesh and hernia surgery: What do patients really think? Surgery. 2021 Jun;169(6):1400-1406. doi: 10.1016/j.surg.2020.12.001. Epub 2021 Jan 15. PMID: 33461777.