Mesh Sutured Repairs of the Abdominal Wall

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Introduction

When the ultimate tensile strength of newly apposed tissue remains above the level of the forces applied, the repair will remain intact. However, when distracting forces are greater than strength of a repair, the closure begins to gap as sutures tear through tissue at the suture/tissue interface (STI). Dehiscence represents an acute loss of integrity of the closure, often due to a large force applied over a short amount of time. Incisional hernia formation represents a slower deformation of the repair site due to the repetitive application of stress over time resulting in chronic suture pull-through and ultimately repair failure.

Larger suture filaments resist tearing through tissue in comparison to finer suture of the same tensile strength, for the same reason that large nails better support hanging pictures on drywall than do slender nails. Large suture filaments distribute forces at the STI over a broader surface area than does a thinner suture. However, drawbacks of large filament sutures are high-profile knots that are poorly tolerated by overlying tissues, potentially becoming infected and requiring removal.

In order to utilize a large-sized suture (for force distribution) with a relatively small knot, a mesh suture was conceptualized. The mesh suture is mostly air so that the filaments collapse at the tied knots for low profile and improved biocompatibility. Tissue ingrowth into the suture may magnify collagen deposition and the foreign body response at the repair site. Experimental mesh sutures have been shown to resist suture pull-through in comparison in vitro to clinically used solid sutures in cadaver human finger tendon [1] and dog cadaver rotator cuff models [2]. In vivo rat

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hernia [3] and porcine laparotomy models [4] have shown resistance to suture pull-through and double the ultimate tensile strength of closure at 8 days.

Based on these concepts and preclinical data, the mesh suture technique for approximating the abdominal wall was developed. Uncoated macroporous polypropylene hernia mesh is cut into strips and used as sutures—passing them through either side of the abdominal wall and approximating the tissue with tied knots. Surgical technique and outcomes are presented below.

Surgical Technique

To create mesh sutures, strips 20 mm wide are cut along the blue lines of a single piece of PROLENE Soft Prolene Mesh (Ethicon, Somerville NJ, 12 × 14 in. or 30.5 × 35.6 cm in size). This uncoated, macroporous, lightweight polypropylene mesh, when cut along the blue lines, generates strips that have higher ultimate tensile strength than a number one polypropylene suture [5]. Other macroporous uncoated meshes in the high lightweight to low mid-weight range could potentially be utilized for a mesh suture technique; however, the surgeon needs to understand a particular mesh's anisotropic properties in order to cut strips in the appropriate direction to maintain sufficient tensile strength. For example, Bard Soft Mesh (Davol, Warwick RI) is comprised of diamonds with relatively equal sides that are bisected with two fine filaments to create two smaller triangles. The surgeon should cut strips parallel to the two fine filaments. Composite partially absorbable meshes such as Ultrapro have not been tried. At present we have only gathered experimental data on the tensile strength of our preferred mesh for the technique, PROLENE Soft Prolene Mesh, and thus cannot endorse the adequacy of repairs using mesh strips of other brands and manufacturers.

In order to pass the strips through the abdominal wall, a number one polypropylene suture is tied to the end of the mesh strip. The needle of the number one polypropylene suture is then passed through the abdominal wall with a standard needle driver and simply used to pull the strip through the tissues. The mesh suture is tied with a square knot and an additional throw for security. The sutures are placed with 1 cm bites, spaced 10–12 mm from each other. (The reader can visit https://youtu.be/OuMp3EXAxzw for an illustration of the technique.)

Mesh sutures can be used as the sole closure device of the abdominal wall or can be used in combination with planar meshes. Standard surgical techniques of excision of scar, removal of old mesh, avoidance of subcutaneous fat in the suture loop, and incorporation of the posterior sheath are all important and not specific to a mesh suture closure.

Mesh sutured repairs achieve a high-tension closure with improved force distribution and less pull-through than a standard suture repair but with less total foreign material and less opening of tissue planes than required for a planar mesh.

Indications

Sutures alone are not sufficient for hernia repair due to an unacceptable chance of recurrence. At Northwestern, even with the addition of an anterior components release, suture closure alone yielded a recurrence rate of 23% at 14 months [6]. Use of a macroporous, uncoated, lightweight polypropylene mesh placed in the retrorectus space can decrease the hernia recurrence rate down to zero at over 2 years of follow-up for clean cases [7]. However, not all hernia cases can or should have a full retrorectus mesh placement, particularly cases with gross contamination or a compromised posterior sheath.

Our indications for a mesh sutured repair alone, without a concurrent planar mesh underlay, include:

- Umbilical hernias and small defects that do not warrant a full retrorectus mesh.
- Open abdomens and acute dehiscences.
- Non-midline defects or defects with altered anatomy (such as abdominal wall resection or flap harvest) in which defect geometry is not favorable for an planar mesh placement.
- Parastomal hernia repair with bowel obstruction.
- Hernia repair in high-risk patients with medical comorbidities that may not tolerate the additional operating room time required to perform a planar mesh repair and contaminated defects where utilizing a planar mesh risks mesh infection requiring removal. While both Carbonell [8] and Slater [9] have shown excellent outcomes with acceptable complication rates with the use of planar meshes in contaminated fields, both series still had an approximately 5% incidence of full mesh removal.

Umbilical Hernias and Small Defects

Umbilical hernias are common clinical entities with wide variations in treatment. Suture repairs are generally simple and with less surgical site occurrence (SSO), while mesh repairs have less hernia recurrence [10] but with higher surgical site infection (SSI) [11]. Mesh sutured repairs have the benefits of simplicity and force distribution, but without the need for a preperitoneal mesh. Typically, three to four strips are used for a 1–2 cm diameter defect. A video of a mesh sutured repair of an umbilical hernia can be found at https://www.youtube.com/watch?v=dbezjvIlUyQ. The surgeon should exercise caution for repair of umbilical hernias with coexisting rectus diastasis, as the superior-most mesh strip will be placed in tissues that are already stretched and potential susceptibility to pull-through. The same is true for epigastric hernias located in the center of rectus diastasis. At least 20 umbilical hernias have been repaired using this mesh suture technique with only one recurrence.

Open Abdomen and Dehiscence

Repair of the open abdomen is difficult, as tissues are swollen, inflamed, and potentially contaminated. For fascial dehiscence, there has already been one failure at the suture/tissue interface. The goals of closure are to limit the chance of a recurrent dehiscence, avoid development of an enterocutaneous fistula, and to achieve a long-term intact abdominal wall. Sheets of prosthetic mesh are avoided due to the required tissue dissection in an already inflamed field and the potential for contamination. Sutures have already failed. Bioprosthetic meshes used for force distribution are associated with high SSO in these cases. Polyglactin meshes to contain viscera and then skin grafts 2 weeks later are safe and effective at avoiding a recurrent dehiscence but require a complex second-stage hernia repair [12]. Mesh sutured repairs solve many of these considerations, as they can be placed in an inflamed field without significant concern for infection or sinus tracts as will be described in "Repair of Contaminated Incisional Hernias" section. They achieve improved force distribution in comparison to sutures, and they do not require opening of new tissue planes. An illustrative case of a massive open abdomen after a liver transplant taken back to the operating room three times is provided (Fig. 23.1). Sequential closure

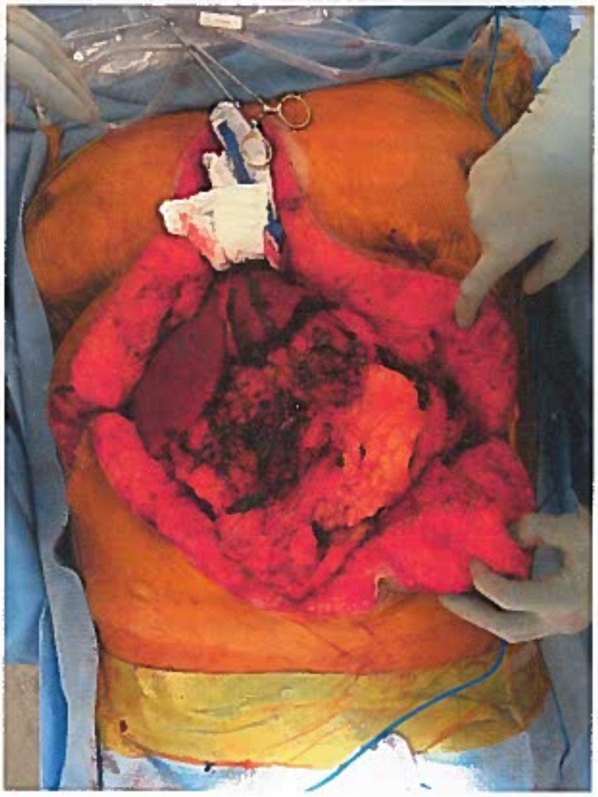

Fig. 23.1 Liver transplant patient 3 days after initial Mercedes incision with median sternotomy for vascular control

Fig. 23.2 Lateral incisions closed with mesh sutures. Midline temporarily closed with polyglactin mesh

over three separate operating room procedures was required (Figs. 23.2, 23.3, 23.4 and 23.5). Nine dehiscence and open abdomen cases have been closed in this manner over the last several years, with two patients returning to the operating room for a formal mesh repair in a well-nourished patient without wounds. No patient developed a sinus or chronic infection from this closure technique.

Non-midline Hernias

There are several difficulties with non-midline hernia repairs. Thin muscle fascia and the muscle itself away from the midline do not hold sutures well, often resulting in tissue tearing at the STI. In addition, intercostal segmental nerves are sizeable and located in the area of these lateral defects, increasing the potential to be ensnared by multiple sutures required to hold a planar mesh in place. For these reasons, flank hernias are regarded as extremely challenging to repair and in many hands are treated with giant prosthetic meshes with wide overlays and with minimal transfascial sutures for fixation [13]. Diametrically opposed to this approach is to simply repair the abdominal wall with a mesh suture that resists pull-through and is quickly incorporated into the tissues to decrease the chance of infection. By keeping the mesh sutures at the site of muscle division, these are anatomic repairs that may better avoid intercostal nerve injury.

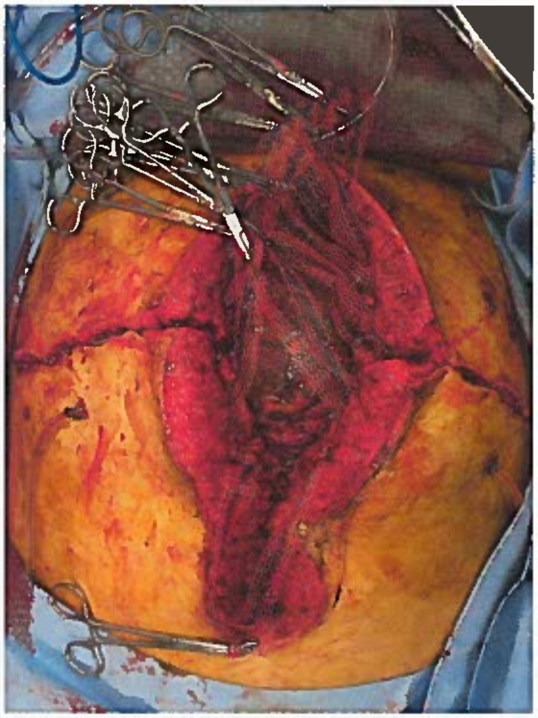

Fig. 23.3 Sequential polyglactin mesh tightening, abdominal wall closure with mesh strips

Fig. 23.4 Midline allowed to close with negative pressure wound treatment assistance

Fig. 23.5 Patient has remained hernia-free with over 1-year follow-up

A common misunderstanding regarding flank defects is that there is an element of denervation or a zone of muscle atrophy. Flank defects lateral to the semilunar lines are typically hernias of the internal oblique and transverse abdominis, with an intact external oblique. That is why the hernias often do *not* seem classic and do *not* have bowel palpable underneath the skin. In our recent study, 55% of patients had this hernia pattern of defects of the deeper two layers of the abdominal wall, 32% had hernias of all three layers, and only 13% had denervation injuries (often identifiable with an injury to the spine) [14].

Flank hernias exist in several common patterns. Defects lateral to the semilunar line after urology or other retroperitoneal access procedures are located along dermatome lines and do not have any denervation component. Kocher, reverse Kocher, and Mercedes incisions for hepatobiliary, spleen, and pancreas procedures involve the rectus muscles and can extend past the semilunar lines. These three incisions create a variable zone of denervation of the rectus muscle inferomedial to the incision. "Hockey stick" incisions are oriented typically along the dermatome lines and do not create large denervation zones, though they do cross the semilunar line. Finally, flank hernias associated with trauma often are located near or involve the pelvic brim and may require a reinsertion of the abdominal muscles to bone with anchors or trans-osseous sutures.

Mesh sutured repairs can be performed quickly due a lack of requirement for opening of large tissue planes. With the patient in lateral decubitus position, the abdomen is entered through the hernia defect, and the retracted internal oblique and transversus abdominis muscles can be located by palpation. The interval between these two muscles and the overlying external oblique is developed. The only difficulty in this dissection is if the semilunar line is involved, as the planes are relatively fused at this site. After locating the layers, the operating room table is put into the reflexed position, and the mesh strips are passed through the internal oblique and transversus abdominis musculature (or even around a rib if that is required). The importance of reflexing the operating room table to bring the lateral tissues into better apposition greatly facilitates this repair technique. If there is significant tension, multiple strips can be placed and then tied down all at once, so as to avoid a single mesh strip/tissue interface bearing the entirety of the repair force, even for a short period. Following repair of the internal oblique and transversus abdominis as a single unit, the attenuated external oblique is resected to healthy muscle and approximated with mesh sutures as a second layer. If desired, a hybrid type of procedure with a narrow well-fixed planar mesh immediately under the external oblique can be employed. A mesh sutured repair of a patient after rib resection for abdominal aortic aneurysm access demonstrates the retracted internal oblique/transverse abdominis muscles which can be viewed at https://www.youtube.com/watch?v=Fx_vM0Ra90c. A right-angled clamp as opposed to a number one polypropylene suture for passage of the mesh sutures is used in this relatively early case that is still without a recurrence.

Parastomal Hernia Repairs

As mesh sutures seem relatively resistant to contamination as will be described in "Repair of Contaminated Incisional Hernias" section, it seemed natural to use them to tighten the musculature around a functioning ostomy at the time of a parastomal hernia reconstruction. Unfortunately, three or four patients treated in this manner went on to have their parastomal hernia recur as described below. Mesh sutured repairs have been performed expeditiously in parastomal hernias with an associated bowel obstruction, where a formal repair with a planar may be quite challenging.

Repair of Contaminated Incisional Hernias

Treatment of the patient with a pre-existing hernia in need of a bowel procedure or patients with hernias and infected mesh is hotly debated. Suture closure of the abdominal wall is simple, does not require the opening of tissue planes, and is associated with at least a 23% recurrence rate even if an anterior components release is performed [6]. Delayed primary closure to decrease the chance of infection requires a second trip to the operating room. Prosthetic planar mesh placement is controversial and could require the removal of the mesh if the bowel surgery requires revision or the mesh were to become infected [8]. Bioprosthetic mesh, touted for its resistance to infection, is still associated with high SSO and does not obviate the development of a recurrent incisional hernia [15].

We recently reported the outcomes of 48 patients treated with contaminated incisional hernias with mesh sutured repairs [16]. All patients were clean-contaminated, contaminated, or infected by Centers for Disease Control and Prevention definition.

All had pre-existing hernias greater than 5 cm wide by CT scan (range 5–25 cm), and the average separation of the medial border of the rectus muscles by CT scan was 10.5 cm. The average age was 62, and the average BMI was 29.8. Anterior components release performed through lateral incisions for perforator preservation was performed in 69% of the patients to decrease tension at the repair site and to have the ability to debride scarred or infected midline tissue.

With an average follow-up of 12 months, 3 patients had failure of the 48 midline incisions closed with mesh sutures, for a 6% hernia recurrence rate for ventral hernia repair. In four patients a parastomal defect was tightened around a functioning ostomy loop, and three of these repairs failed, yielding an *overall* failure rate of 13%. The overall SSO rate was 27% with an SSI rate of 19%, the majority of which were managed conservatively with antibiotics. Two patients with infected subcutaneous fluid collections returned to the OR for a washout, but the strips were left in place. These two patients have remained hernia-free. No patient had a delayed removal of mesh strips due to chronic sinus formation. When compared to similar cohorts reported for other techniques [16], a mesh suture repair had similar SSO and SSI, but is technically more straightforward and quicker, with the same or lower hernia recurrence rate. As all of the foreign material is located immediately under the surgical incision, removal of the sutures for re-exploration for infection would not be particularly challenging. While longer-term follow-up is needed for hernia recurrence rates, it is emphasized that this is a "get-out-of-Dodge" strategy for difficult clinical situations that is fast, does not require the opening of tissue planes (thus not compromising tissue vascularity), and still permits a planar mesh repair in a clean field at a later time. Perforator-sparing anterior components releases are an excellent adjunct to the procedure to reduce tension at the closure line.

Mesh Suture Closure as an Adjunct to Planar Mesh Repairs

As mentioned above, for clean midline ventral hernia defects, a planar mesh repair remains our primary technique of choice and has not had a recurrence in 100 patients with 2-year follow-up [7]. However, even for retrorectus mesh repairs, we perform the final tissue approximation of the medial border of the rectus muscles over the mesh with mesh strips rather than standard suture. Over and above decreased suture pull-through, we believe that mesh strips have improved biocompatibility in comparison to sutures as will be discussed below.

Drawbacks/Pitfalls

All of the procedures described are open surgeries with lengthier hospitalizations than achieved for minimally invasive surgeries. Incisions and resulting scars are long, often requiring the excision of skin made redundant by the abdominal wall approximation. Drains and soft tissue handling are necessities of all but the smallest mesh sutured repairs, as is a working knowledge of perforator preserving anterior components releases. Attaching the introducing needle to the mesh strip is clumsy, though these procedures are still quicker in duration to alternatives using large planar meshes. Our relatively unsuccessful outcomes in the few parastomal hernias closed with mesh sutures are found in "Parastomal Hernia Repairs" section. There are no contraindications to the performance of a mesh sutured closure, though alternate strategies are typically used for truly infected cases. The greatest potential issue is draining suture sinuses from the increased surface area and amount of permanent foreign material located particularly at the knot. The amount of foreign material is far less than a planar mesh, though still more than an absorbable suture. As is discussed below, this has not been a clinical problem (Figs. 23.6, 23.7, 23.8, 23.9, 23.10 and 23.11).

Fig. 23.6 A 60-year-old female with left rectus removal for breast reconstruction. Underwent a repair using a transversus abdominis release (TAR) with mesh and then had a postoperative mesh infection that required mesh removal. Presented with this open granulated wound

Fig. 23.7 One year after skin graft closure of wound, she developed new wounds on the left side of the hernia. Due to the prior TAR release, she could not have a components procedure, so she received botulinum toxin into the abdominal wall to improve compliance 1 month before surgery

Fig. 23.8 CT scan demonstrates 15.9 cm separation between abdominal wall edges

Fig. 23.9 Upper mesh sutures in place between left semilunar line and right rectus muscle

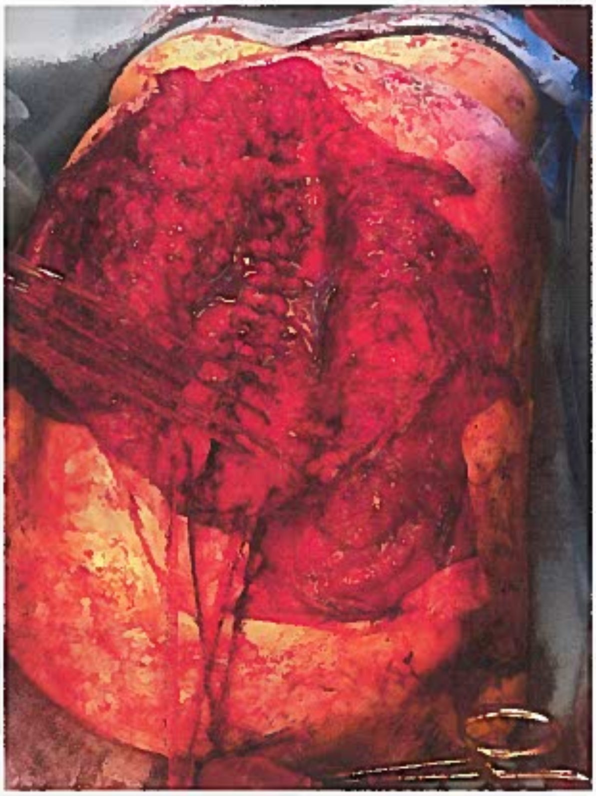

Fig. 23.10 Continued primary closure with mesh sutured technique

Fig. 23.11 Six-month outcome with intact closure and without wound issues

Discussion

The key to all high-tension tissue repairs (including the linea alba, rotator cuffs, Achilles, finger tendons, etc.) is for the strength of the repair to remain high. At the time of surgery, the strength of the repair is a complex mixture of the strength of the sutures, the number of sutures applied, knot integrity, and the resistance of the tissues to tear at the suture/tissue interface (STI). Soon after suture repair of tissues, and over the next several days, there is loosening of the suture tension by up to 50% [17], perhaps due to a "softening" STI from local ischemia, inflammation, or collagenases. The postoperative weakening of the physical construct of tendon repairs was first shown in 1941 and was determined to last approximately 5 days before biologic healing becomes additive to the total repair strength [18]. Early tearing of sutures through tendons is referred to as "gap formation" in the orthopedics literature and is due to the forces applied at the STI being greater than tissue tolerance. In hand surgery, early gap formation of a repaired finger flexor tendon of 1–3 mm is associated with either rupture or scar formation [19]. Analogously, early separation of the midline abdominal closure at 30 days of 15 mm or more as shown by migration of metal clips placed at the time of laparotomy or by CT scan demonstrates that early failure of the abdominal wall closure construct is predictive of incisional hernia formation [20–22].

Sutures concentrate forces at the STI, and for high-tension closures a zone of ischemia of variable size and dimensions is created. This zone of ischemia causes an internal pressure sore, though its size is small enough to permit remodeling over time through the creation of scar. Humans scar more than other animals and regenerate less [23]. Scar is not normal tissue, and it lacks pulsatile blood flow that accompanies normal wound healing [24]. It does not respond to tensile forces with hypertrophy as described by Wolff's law. Instead, scar deforms in response to normal tensile stresses, elongates, and weakens over time. If the strength of the scar falls below the outward forces applied to the abdominal wall by the viscera, an incisional hernia will develop. Scar is also not as strong as the native tissue it replaces, gaining only 70% of the strength of the native linea alba [25]. It is the replacement of the linea alba with scar that could be the cause of "late" incisional hernias over time [26].

It has been shown in preclinical animal models that mesh sutured repairs have a greater early tensile strength than suture closures, but the tissue tolerance of the mesh strips, especially in a contaminated field, then becomes important for clinical usage. Classic teaching is to limit permanent materials to a minimum and possibly to only use absorbable sutures and absorbable meshes (synthetic or bioprosthetic). In our reported series [16], several patients had their midline skin incisions left open with exposure of 0-polypropylene sutures (diameter 0.4 mm) and mesh strips (filament diameter 0.15 mm for Soft Prolene). Over time, the sutures required removal to permit healing, whereas we observed the deposition of granulation tissue over and around mesh strips during the course of secondary wound healing. Several other patients with seromas and exposed mesh strip knots had their skin opened in the office, and the wounds were allowed to close with local wound care. This clinical experience is consistent with animal data that the foreign body reaction quantitatively differs depending on the filament diameter [27]. We propose that a high surface area/low filament size closure with mesh strips is more biocompatible than a low surface area/high filament diameter device such as a large monofilament suture. In addition, the high surface area conditions of a permanent suture will result in a magnified foreign body reaction that persists and is located immediately at the repair site. This compares well conceptually to large planar meshes that create scar burden far from the abdominal wall closure.

Mesh sutured repairs have simplified our abdominal wall paradigm. Clean midline cases that require either a long repair or associated treatment of rectus diastasis receive a narrow well-fixed retrorectus mesh. Almost every other clinical situation (other than parastomal hernias) have been treated successfully and simply with mesh sutures.

Conflict of Interest Statement Dr. Dumanian has financial interest in the Advanced Suture Co and the Mesh Suture Co. He could potentially benefit from the outcomes of this research. There are no additional conflicts to report for Drs. Dumanian or Lanier.

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