Abdominal Wall Reconstruction: An Integrated Approach

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Abstract

Keywords

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- component separation

Abdominal wall reconstruction has undergone substantial evolution over the last few decades. The optimal method of repair should be tailored to each patient's unique condition; however, a general approach that integrates four major factors can be applied as a conceptual framework to most clinical scenarios. Major factors to be considered include selection of mesh material, mesh inset position and technique, selective component separation, and management of soft tissue. These topics are inextricably intertwined in the sense that each can have specific implications, and in some cases, a determinative impact on the other decisions. When the relationship among these four factors is appreciated and applied to patient management, the reconstructive surgeon can achieve consistent outcomes that reflect skill, experience, and understanding.

Although the indications for surgical repair of abdominal wall defects are well established, there have remained some durable controversies in the surgical community about the most appropriate and effective surgical techniques, the need for reinforcement of surgical repairs, mesh selection and position, as well as the need for and approach to component separation. The ongoing debate over the “best” approach to reconstruction of the abdominal wall is fueled by long-standing controversies, innovations in surgical technique, as well as advances in materials science and implantable and robotic device development. In this article, we consider each of these issues and attempt to present an approach which addresses both long-standing debates and emerging considerations.

Mesh Material

In recent years, the emergence of numerous mesh products have caused an increase in the number of options available to surgeons, which further complicates surgical decision making in abdominal wall reconstruction (AWR). In the face of changing technology, there is a need for systematic evaluation of mesh products as they come to market, to clarify the indications for their use and role in the existing material portfolio to inform surgical decisions. In this section, we aim

to summarize the background, literature, and rationale for use of the different mesh choices in AWR.

Primary Suture Repair

The first decision about mesh is whether or not to use any; unless the efficacy of mesh over primary suture repair has been demonstrated, any further discussion about mesh choice is moot. The landmark work by Ramirez et al in 1990 described the use of local tissue transfer for the repair of abdominal wall defects using component separation and myofascial advancement flaps to allow tension-free fascial closure. In the years to come, efforts were made to improve on recurrence rates by reinforcing this repair with synthetic mesh products, but these initial efforts were undertaken without supporting evidence for the efficacy of this practice. In 2000, Luijendijk et al published a prospective randomized controlled trial that still today serves as the best evidence of outcome superiority of mesh repair over primary suture repair. In a cohort of 200 patients with ventral hernias measuring 6 cm or less who were randomized to suture repair or polypropylene mesh repair and followed prospectively for 36 months, the suture repair group had a recurrence rate of 46% at 3 years, as compared with only 23% in the mesh repair group; this discrepancy was even more notable

in the subset of patients who had undergone repair of a recurrent hernia (58% recurrence rate vs. 20%). This convincing data provides an incontrovertible role for mesh reinforcement in hernia repair, and conclusively demonstrates that suture repair alone is inadequate for reconstruction of ventral hernias and most abdominal wall defects. Small umbilical hernias and port site hernias were not considered in this analysis and are probably an exception.

Synthetic versus Biologic Mesh

Mesh products can be categorized into three groups: synthetic, biologic materials, and bioresorbable or biosynthetic meshes. A sound understanding of the mechanical and biochemical properties of these subgroups helps to frame the distinct purposes they are intended to serve. No group of materials is universally superior to another; but, each group of products has a role in AWR. Rather than using a material indiscriminately, it is useful to become familiar with the characteristics, advantages, and disadvantages of each and to use them in the appropriately indicated context.

Synthetic mesh remains the most common repair material for AWR. Historically composed primarily of polypropylene and other rigid, nonresorbable plastics, these materials have the indisputable benefit of low cost. However, in the setting of existing or potential contamination, the use of synthetic mesh poses a substantial risk of infection either through the wound or from abdominal contents. In the setting of wound dehiscence or even translocation of bacteria through the incision or drain sites, mesh can become contaminated directly. When used in immediate proximity to abdominal viscera and vasculature, synthetic meshes may be responsible for mechanical erosion and fistulization, which perpetuate a cycle of contamination and can result in difficult to reverse and, in some cases, life-threatening complications. Even in the setting of limited and contained postoperative infection, synthetic materials develop biofilms—complex molecular “force fields” produced by bacteria that cannot be penetrated by antibiotics—these can complicate treatment of soft tissue infections using conventional means such as percutaneous drainage and intravenous antibiotic administration. In most occasions, infected synthetic mesh must be explanted, resulting in a necessary reoperation and often a larger abdominal wall hernia defect than the original problem it was intended to correct; in the setting of active infection, placement of additional synthetic prosthetic material is contraindicated, presenting a significant clinical dilemma. In 1989, Houck et al published their data and demonstrated that patients with a prior history of wound infection have a greater than threefold increase in additional infection rate following subsequent ventral hernia repairs in comparison to those with no prior infections.

In contrast to synthetic meshes, biologic meshes are resistant to biofilm formation, and when contaminated, can often be salvaged. Further, they are safe when placed against alimentary tract, intra-abdominal organs, or vascular structures. Some early criticism of bioprosthetic mesh products centered on the fear that resorption of the collagen scaffold would ultimately lead to bulging and hernia recurrence, provoking

discussion about the relative cost of higher recurrence rates versus the benefit of lower infection rates. Further investigation suggested a strong correlation between postoperative complications such as infection, seroma, wound dehiscence, and fistula—collectively termed “surgical site occurrence,” or SSO—and hernia recurrence. Infection in particular appears to be a significant contributing cause of future repair failure: in the prospective study by Lujendijk et al in 2000, patients who sustained postoperative infections subsequently developed hernia recurrence in 80% of cases, in contrast to only 34% of patients without infection. In 2007, Iqbal et al evaluated the long-term outcomes of 254 patients that underwent complex ventral hernia repair with the modified Rives–Stoppa technique. They demonstrated that wound infection was predictive of recurrent hernia, with rates of recurrence of 31% compared with 4% in the control group with no signs of infection. The strong correlation between recurrence and SSO suggests that the two endpoints should not be viewed as completely independent. In accordance with this, more recent investigation has focused on SSO as the primary endpoint to be monitored, resulting in many viewing biologic mesh as the safer option. However, the high cost associated with bioprosthetic mesh utilization prohibits indiscriminant, nonselective use of these materials, and requires judgment about when and in whom to use them.

In an effort to mitigate some of the above-mentioned complications of synthetic and expense of biologic mesh, a new generation of biodegradable, resorbable mesh products (TIGR Mesh, Phasix, BioA) has recently emerged as a third category of mesh products marketed for abdominal wall reinforcement. These products are meant to capitalize on strengths of both synthetic and bioprosthetic materials, allowing for relatively low cost while utilizing materials that are rapidly incorporated and degraded, eliminating the need for explantation in the setting of infection. Evidence supporting the use of these newer materials is scarce to date; a recent study by Plymale et al of 31 patients who underwent ventral incisional hernia repair with poly-4-hydroxybutyrate mesh demonstrated no hernia recurrence at a median follow-up of 414 days, with SSO rates comparable to those of bioprosthetic products. However, molecular and biomechanical analysis of these devices also demonstrates that the mesh provides very little inherent strength, relying on reticular collagen remodeling to augment the strength of resultant scar tissue. Even with some interesting and promising results developing, the relative unavailability of robust data to support the use of resorbable synthetic mesh has meant that most discussion about mesh choice continues to be focused on synthetic versus biologic meshes. Recently, in an article by Mike Rosen's group (JACS, 2017), a 3-year review of the American Hernia Society Quality Collaborative reported 3-year results with different mesh groups and found that the SSO rate in bioresorbables was higher than in synthetic mesh (20 vs. 13%, $p = 0.49$), suggesting that perhaps rather than the best of both worlds, we may have the worst of at least one. For the purposes of this review, we will limit the bulk of the discussion to these two principal options and the evolution of the global discussion centered on the development of established indications for their utilization.

Wound Classification and Mesh Choice

Cost analyses promote the use of inexpensive synthetic mesh options whenever it is clinically safe to do so. However, devastating complications such as enterocutaneous fistula, infected, or exposed mesh are substantially more common in AWR with synthetic mesh than with biologics, and the costs and morbidity associated with mesh explantation and subsequent hernia repair far outweigh the cost of a bioprosthetic device. This is particularly relevant in light of the fact that infection rates in ventral hernia are between two and eight times higher than in other sterile procedures, as shown in several studies by Houck et al, Dunne et al, and Finan et al. As such, it is essential to use predictive data to determine when comprehensive risk assessment promotes the use of biologic mesh in spite of higher costs. The arithmetic of this decision takes into account a complex array of factors including the known characteristics of the implants, but more importantly, patient-specific considerations such as comorbid conditions and degree of contamination, both of which act as independent risk factors for complications in hernia repair—and, more specifically, for SSO.

As it pertains to the degree of contamination abdominal wounds, there exists a well-established wound classification system. In 1999, the Centers for Disease Control and Prevention (CDC; available at <https://www.cdc.gov/hicpac/pdf/SSIguidelines.pdf>) developed a system categorizing wounds into four groups ranging from Class I (or “Clean”), representing fresh incisions with no source of contamination, to Class IV (or “Dirty”) used to describe chronically contaminated or infected wounds (►Table 1). Between these classifications was a middle ground characterized by varying degrees of nonsterile contamination including gross but acute spillage of enteric contents. This wound classification system was logical and straightforward, and allowed for classification of all surgical wounds across organ systems and anatomic regions. However, it was not of specific predictive value for assessing risk for development of SSO after hernia repair.

As numerous biologic mesh options emerged in the late 1990s and feasibility of techniques using bioprosthetic

devices was demonstrated, it became apparent that there was an outstanding need for a risk analysis of available mesh options so that an algorithmic approach to mesh choices for ventral hernia repair could be devised. At the end of the last decade, the Ventral Hernia Working Group (VHWG) was assembled for this purpose. In their landmark manuscript published in 2010, a systematic review was performed to categorize patients based on their risk of complications following ventral hernia repair with synthetic mesh. Their protocol categorizes patients by “Grade,” with increasing score representing elevated risk of complication in synthetic mesh abdominal wall repair (►Table 1). Based on their classification system, patients are stratified as relatively low risk—Grade 1—if they have no prior history of wound complications and minimal comorbid conditions. Grade 2 patients exhibit medical risk factors such as tobacco use, diabetes mellitus, and obesity, but no explicit wound-related risk factors. Grade 3 wounds are characterized by elevated potential for contamination due to the presence of a stoma, concomitant bowel resection, enterotomy, or previous wound infection, while Grade 4 patients have gross evidence of infection in the form of infected mesh, fistula, large-scale enteric contamination, or septic dehiscence. In their systematic review of the existing data, the Working Group found that the use of synthetic mesh was appropriate and resulted in acceptable rates of SSO only in the lowest-risk wound category (Grade 1), and they recommended biologic mesh in all other wound classifications.

To that point, however, the utility of these wound classifications was completely theoretical; there had been no prospective analysis, and it was thus unclear whether they had any actual predictive value. As such, in 2012 Rosen and his group published a modified VHWG classification after testing the predictive value of the VHWG grades and its component factors, as well as the CDC wound classification system, in predicting complications. They found that certain Grade 3 patients, such as those with a controlled violation of the gastrointestinal (GI) tract or previous wound infection, had SSO rates more similar to Grade 2 patients, and other Grade 3 patients, such as those with gross spillage, had SSO rates more like Grade 4 patients. Thus, they modified the VHWG to three grades which are more predictive of complications in the clinical setting (►Table 2). Based on this classification system, we consider Grade 1 patients appropriate for synthetic mesh, given the lower rate of SSO, and Grades 3 appropriate for biologic, since incidence of SSO approaches 40% in those cases. In Grade 2 patients, complication rates range between 20 and 30% depending on the risk factor and there is some debate about the use of synthetics versus biologics in this group.

Recently, the traditional dogma that synthetic mesh should not be used in contaminated environments has been challenged. Carbonnel et al presented outcomes after open ventral hernia repair using polypropylene mesh in clean-contaminated and contaminated fields. Incidence of SSO was 26.2 and 34%, respectively, and explantation rate was 4%. The authors comment on the fact that previous literature is based on use of heavier weight, microporous

Table 1 Combined CDC and Ventral Hernia Working Group (VHWG) wound classifications and recommended mesh type

Classification	Definition	Mesh indicated
Class I: Clean VHWG Grade 1	Surgical incision – sterile	Synthetic
Class IIL Clean-contaminated VHWG Grade 3	Controlled entrance to nonsterile material	Biologic/ Synthetic
Class III: Contaminated VHWG Grade 3/4	Gross spillage of nonsterile material	Biologic
Class IV: Dirty VHWG Grade 4	Chronic, infected	Biologic

Abbreviations: CDC, Centers for Disease Control and Prevention; VHWG, Ventral Hernia Working Group.

Table 2 Modified VHWG wound classification and recommended mesh type

Classification	Definition	Mesh indicated
Grade 1	Surgical incision – sterile Few medical comorbidities	Synthetic
Grade 2 Formerly VHWG Grade 2–3 CDC Class 2	Significant medical comorbidities Controlled violation of the GI tract Previous wound infection	Biologic/ Synthetic
Grade 3 Formerly VHWG Grade 3–4 CDC Class 3–4	Gross spillage of GI tract Chronic infection	Biologic

Abbreviations: CDC, Centers for Disease Control and Prevention; GI, gastrointestinal; VHWG, Ventral Hernia Working Group.

mesh rather than contemporary, lightweight mesh. This may indeed provide a relative benefit which translates to lower rates of infection; however, SSO rates are still significantly higher when compared with biologic mesh repair. On the other hand, the use of lightweight mesh limits some of the traditional advantages of heavier weight mesh, including the superior strength characteristics.

In our experience, the incidence of SSO is fairly low with biologic mesh. In 2014, Garvey et al published the outcomes from our institution using biologic material. The explantation rate was 1%, regardless of the grade of contamination. This was the first study to show that there was no statistical difference in the incidences of SSO, 30-day surgical site infection, mesh removal, and hernia recurrence between clean and contaminated wounds when using biologic mesh. These findings are particularly important since it is well known that contaminated cases are universally associated with less favorable outcomes of complications and recurrence with synthetic mesh, highlighting the superior

properties of biologic meshes in clean-contaminated and contaminated wounds.

The modified VHWG classification and rest of nomenclature mentioned earlier are important to identify patients that are at high risk for a complication; however, it is not a complete list of indications for biologic mesh. The previously described classifications fail to identify two basic defect-based indications for biologic mesh. In particular, inadequate soft tissue coverage which can result in exposure or contamination of mesh through the skin, and direct contact with the bowel which can cause enterocutaneous fistulae. In an attempt to create a more comprehensive approach to mesh choice, we suggest five indications for biologic mesh: (1) major comorbidities, (2) controlled or gross contamination from GI track, (3) current or previous wound infections, (4) inadequate soft tissue coverage, and (5) direct contact with bowel. The first three are an aggregate of consensus work from the CDC wound classification and modified VHWG classification. Indications four and five incorporate the defect characteristics and surrounding tissues and together we hope they form a comprehensive set of indications. It is important to mention that direct contact with bowel should be a concern in any case where the mesh is partially or completely intraperitoneal, such as in intraperitoneal onlay mesh (IPOM). But it remains relevant in reconstructive techniques such as the Rives–Stoppa repair and transversus abdominis release (TAR), in which the integrity of the posterior sheath plays a central role and therefore must be reliable and intact.

Clinical examples to operationalize these indications in real patients and clinical scenarios are provided in ►Figs. 1–3.

One of the principle arguments against biologic mesh is the previously reported decreased biomechanical strength and, therefore, the potential higher risk for hernia recurrence. Much of this poor reputation results from the inappropriate use of outdated technology. All early attempts of AWR with biologic material used human acellular dermal matrix (ADM), which is known to have an unacceptable failure rate. Human ADM is too flexible for the high loads exerted by AWR. Xenografts became more popular and, until today, bovine- and porcine-based xenografts are the most commonly used. In 2011, Deeken

Fig. 1 Patient with history of incisional hernia undergoing repair with repositioning of colostomy. In this scenario, there is per se mesh contamination from the ostomy, and risk of parastomal hernia. By using biologic mesh, the colostomy was able to be placed through the mesh without concern of mesh contamination, and additionally, the ostomy site was reinforced without concern for fistula.

Fig. 2 Patient with history of cystoprostatectomy for advanced prostate cancer requiring an ileal conduit for urinary diversion. The ostomy was placed through the mesh without concern of contamination of mesh, fistulization, or parastomal hernia.

and his group evaluated the mechanical strength of several synthetic mesh products and published their results in two different articles. Their data included parallel and perpendicular tensile strength, tear strength, as well as suture retention strength of various mesh products (► **Table 3**). After obtaining the equivalent data for the bovine ADM (BADM) SurgiMend (Integra Lifesciences), it was found to be considerably stronger than all previously measured synthetic and bioresorbable mesh products. The biomechanical strength values for the different thicknesses of SurgiMend are provided in ► **Table 3**. These data provide an insight to the mechanical properties of currently available mesh products, proving that the biomechanical strength of synthetic mesh should not be considered universally superior to biologic mesh.

Biologic Mesh Options

There is certainly a knowledge gap in terms of the ideal xenograft, especially in AWR, and there is a heated debate related to the preferred biologic mesh. Strattice (Lifecell) and to a lesser extent Permacol (Tissue Science Laboratories), both porcine-derived products, have historically been more widely used than bovine mesh due to their first to market status. At MD Anderson Cancer Center, Texas, a group of 21 reconstructive plastic surgeons has been using both bovine and porcine ADMs (PADMs) for many years. In 2013, Selber's research group compared outcomes of AWR based on type of mesh by analyzing prospectively collected data. A total of 120 consecutive patients that underwent nonbridged, underlay (IPOM or retrorectus) AWR for ventral hernia and/or oncologic resection defects were included and divided in two groups, those repaired with PADM, or Strattice, and those repaired with BADM, or SurgiMend. Univariate and multivariate analysis was performed and the two groups were found to have similar patient and defect characteristics. More than half of the patients were VHWG Grade 3 or 4. Overall complication rates were significantly higher in the PADM

Fig. 3 Patient with history of sarcoma who underwent external hemipelvectomy. All the internal organs were exposed after completion of the resection. A 4-mm SurgiMend mesh was placed directly against the bowel and organs, which would be impossible with synthetic mesh. A large soft tissue defect was also present, in which case a medially based thigh flap was used for final coverage.

group, although there was no significant difference in surgical complications. Patient who underwent repair with porcine mesh trended toward higher incidence of postoperative bulge ($p = 0.07$) in a mean follow-up of 2 years. The MD Anderson Cancer Center adverse events database was also queried. This is a voluntary reporting system for intraoperative adverse events, recorded and maintained by operating room (OR) administration. These data were searched and identified seven patients who had intraoperative device failures that were all within the porcine group, constituting a 10.1% device failure rate, compared with 0% device failure

Table 3 Comprehensive table comparing material characteristics and biomechanical properties for different types of synthetic, biodegradable, and biologic mesh

Mesh name	Mesh type	Porosity	Parallel strength (MPa)	Perpendicular tensile strength (MPa)	Tear resistance (N)	Suture retention strength (N)	Reference
BardMesh	Permanent synthetic	Medium pore	11.64 ± 1.68	0.16 ± 0.02	46.84 ± 1.7	66.80 ± 4.2	¹
Prolene	Permanent synthetic	Medium pore	16.06 ± 1.44	0.76 ± 0.20	39.33 ± 1.1	70.49 ± 2.6	¹
Ultrapro	Permanent synthetic	Macroporous	13.52 ± 0.92	0.08 ± 0.02	10.47 ± 0.7	16.74 ± 1.0	¹
Pariatex	Permanent synthetic	Macroporous	15.51 ± 0.37	6.63 ± 0.69	32.66 ± 0.7	58.38 ± 3.2	¹
Proceed	Permanent synthetic	Macroporous	4.44 ± 0.25	4.78 ± 0.64	20.19 ± 1.7	41.62 ± 1.0	¹
Composix E/X	Permanent synthetic	Medium pore	10.74 ± 1.11	1.44 ± 0.23	48.75 ± 2.3	70.47 ± 4.4	¹
Composix L/P	Permanent synthetic	Macroporous	6.10 ± 0.27	1.48 ± 0.13	32.76 ± 2.8	48.58 ± 1.3	¹
Dualmesh	Permanent synthetic	Nonporous	7.52 ± 0.25	5.52 ± 0.06	41.28 ± 1.5	72.95 ± 2.5	¹
Seri Scaffold	Silk	Macroporous	10.50 ± 0.62	6.21 ± 0.65	26.03 ± 2.04	45.19 ± 4.83	¹
Phasix	Degradable synthetic	Macroporous	6.06 ± 2.33	1.53 ± 0.06	30.3	59.2	¹
Bio-A	Degradable synthetic	Microporous	3.73 ± 0.38	3.51 ± 0.18	16.6	~45	¹
SurgiMend 1.0	Biologic	Microporous	28.54 ± 1.99	19.64 ± 6.56	27.86 ± 1.0	87.85 ± 4.9	¹
SurgiMend 2, 3, 4	Biologic	Microporous	14.61 ± 5.26	27.10 ± 7.74	79.28 ± 25.01	144.91 ± 39.15	²

rate for the bovine group (none of the device failures were reported by surgeons who had or have a financial relationship with SurgiMend). Device failures consisted of one porcine mesh of irregular thickness and six device tears; three tears were small and could be repaired with mesh pledgets, the other three were larger and required replacement of the mesh (►Fig. 4). Two out of seven patients (28.6%) with device failures developed hernia or bulge, compared with 5.6% in the group without intraoperative device failure (p -value = 0.02).

The increased intraoperative device failure rates of the PADM lead to a series of experiments in the laboratory where the strength of PADM versus BADM, directly “out of the package” was investigated. Dye-cut samples of both mesh materials were subjected to several biomechanical tests, assessing uniaxial tensile strength, suture retention strength, and tear resistance strength. In 2014, Adelman et al published the results demonstrating that in all parameters, BADM performed superiorly to PADM of similar thickness. For SurgiMend, the strength

increased linearly with increased thickness. When the samples were tested for suture tear-through resistance, the 4-mm SurgiMend never failed because each sample broke the 24-gauge steel wire used to test it (►Fig. 5). This has potential clinical implications and corroborates the findings of previous data with increased intraoperative failure rates of Strattice as presented above.

In addition to the inherent material strength and intraoperative performance of biologic materials, the authors were also interested in the long-term recurrence rates of PADM versus BADM. In 2013, Booth et al published data in the Journal of the American College of Surgeons looking at bridge repairs versus complete myofascial closure. Human ADM, PADM, and BADM for mesh repair of complex abdominal wall defects were compared as a subanalysis. When assessing 3-year hernia rates, the human ADM had a very high rate of recurrence at 32%, as expected (use was discontinued early in this series when other ADMs became available). The porcine group had a hernia recurrence rate of 15%,

Fig. 4 Cases of intraoperative device failures in the porcine mesh group.

Fig. 5 Images of suture retention testing failure mechanism for bovine (BADM) and porcine (PADM) acellular dermal matrix. BADM failed at higher forces of pull and the suture cut through at a linear fashion, compared with PADM, which failed consistently and repeatedly at lower forces and following an oblique, fracture pattern. For thicker BADM, the stainless steel wire needle failed before damaging the material.

compared with 6% in the bovine group, suggesting better persistence of repair in BADM.

To conclude the discussion on mesh selection, based on published literature and our extensive experience with AWR at MD Anderson Cancer Center, primary suture repair should be avoided in extensive abdominal wall defects. Synthetic mesh is effective and is often preferred in low morbidity patients with noncontaminated wounds (VHWG/CDC Grade 1), in whom use of biologic mesh is not cost effective. Biologic mesh is preferred in patients with inadequate soft tissue coverage, direct contact with bowel, significant comorbidities, and contaminated or infected wounds (VHWG 2, 3/CDC 2, 3, 4). Bovine mesh appears to have superior intrinsic

biomechanical strength, fewer intraoperative failure rates, and lower hernia recurrence rates than porcine mesh. For these reasons, BADM has become the material of choice by many in our institution when the use of biologic mesh is indicated.

Mesh Inset Technique

There are several different positions in which to place mesh in AWR, including overlay (top of the fascia), interpositional (otherwise known as a bridged repair), retrorectus (eponymously known as a Rives–Stoppa repair), and intraperitoneal or underlay (also known as IPOM). There is literature that has demonstrated that both overlay and bridged repairs result in more SSOs and hernia recurrence rates compared with intraperitoneal or retrorectus repairs, which appear to have similar SSO and recurrence rates. In 2013, Albino et al published a systematic review in *Plastic and Reconstructive Surgery* confirming these findings after analyzing 62 relevant articles including 5,824 patients.

Mesh inset technique determines the ability to achieve primary repair of the fascial defect, which is always the goal for optimal long-term outcomes (► **Fig. 6**). In bridged repairs, the mesh is a single closure layer of avascular material which bears all of the load, compared with primary fascial closure with mesh reinforcement, which provides a double-layer closure in which one layer is vascularized. Several studies have confirmed the superiority of primary fascial closure combined with mesh reinforcement. In 2013, Booth et al published the MD Anderson experience of bridged versus primary autologous closure. In that study, all patients who underwent bridged repairs developed recurrent hernia or bulge within 4 years. Multivariate analysis demonstrated that the only independent factors for recurrence were bridged repair, with hazard ratio of 7.3, and defect width > 15 cm, with hazard ratio of 2.5, which reflects the clinical significance of primary fascial closure when feasible.

When primary autologous closure is not possible, a bridged repair can be considered. Some authors believe that staged closure is preferable in these situations; however, there are certain patients that require a definitive single-stage repair, because of either defect characteristics or other comorbid conditions. In those cases, a thick, strong xenograft

Fig. 6 Bridged versus primary autologous fascial closure in abdominal wall reconstruction.

is optimal. By definition, bridging bears two of the five previously presented indications for biologic mesh, including inadequate soft tissue coverage since the mesh is subcutaneous, and direct contact with bowel since it is intraperitoneal. Regarding the concerns about strength of repair, based on data presented earlier, thick bovine xenograft provides high biomechanical strength, exceeding both porcine and most synthetic material. Combining the high strength with the indications for biologic mesh, thick bovine xenograft is our mesh of choice to bear the load and avoid complications in a bridged repair when a single stage is planned.

Fixation Principles

In our group practice, the gold standard repair is considered underlay, intraperitoneal, or retrorectus with primary autologous fascial closure (►Fig. 7). Surgical technique is certainly an important factor with regards to hernia recurrence. In mesh fixation, we abide the concept of “pillars of strength” in the abdominal wall. These comprise the linea alba in the midline and the 2 linea semilunares one on each side, which are the musculotendinous junctions of the lateral and midline abdominal wall musculature. These are the locations of fascial confluence and represent the strongest zones for suture retention,

analogous to the conjoined tendon in inguinal hernia repair, or a tendon repair in the extremity. Suturing through muscle-only should be avoided as it is prone to failure and loosening. In setting mesh at the “pillars of strength” dictates mesh dimensions. The goal is always a tension-free, autologous midline closure. The mesh width can be estimated as twice the width of the rectus complex, or the distance between the linea semilunaris on each side (this can vary based on anatomy and missing portions of the rectus muscle). The suture line on the mesh should be slightly narrower, by approximately 1 to 2 cm, than the suture line at the level of the fascia, to create a taught mesh inset with tension-free autologous midline approximation (►Fig. 8). If suture placement is too wide on the mesh, then the mesh will be redundant and fold when the fascia is closed. This miscalculation results in the fascia bearing all the load instead of the mesh. If suture placement is too narrow, the abdominal compartment is pulled too tight, the mesh bears more load than necessary, and the fascia is excessively redundant. The mesh is secured with sutures placed 1 cm apart to avoid bowel herniation between the sutures when IPOM is performed. For retrorectus repairs, suture placement can be less rigorous. By placing the sutures along the proposed line at regular intervals, force distribution is achieved, which is critical

Fig. 7 Gold standard abdominal wall repair: underlay, intraperitoneal with primary autologous fascial closure.

Fig. 8 “Pillars of strength” of the abdominal wall and mesh fixation. Mesh width = linea semilunaris to linea semilunaris distance.

Fig. 9 Mesh inset with optimal force distribution by placing horizontal mattress sutures 1 cm apart through the “pillars of strength.”

in maintaining abdominal wall balance. This particular technique results in a tightly placed, narrow mesh, which is different than what many synthetic mesh users are currently advocating, which is wide placement of mesh with relatively little fixation (► **Fig. 9**). We recommend avoiding a large patulous piece of mesh, since we rely on the “pillars of strength” and load-bearing principles. Additionally, using smaller size mesh reduces overall cost when considering biologic.

The Rives–Stoppa or retrorectus repair was designed to sequester synthetic mesh. In these cases, the synthetic mesh must be placed in a privileged environment to avoid complications resulting from mesh being placed in direct contact with the bowel or skin. Additionally, intact posterior sheath is a requirement for successful execution of this technique. Unfortunately, the posterior sheath can be an unreliable layer, particularly in the presence of significant adhesions, a history of multiple laparotomies, radiation, or soft tissue resection. In these cases, biologic mesh allows intraperitoneal placement or at least incomplete coverage, a technique with greater versatility that can be used in any situation. Familiarity with both retrorectus and IPOM techniques is important for the herniologist.

Component Separation

The traditional component separation procedure was described by Oscar Ramirez in the early 1990s. This refers to the anterior component separation, performed by dividing the

internal and external oblique muscles. Many variations have been described since then. An external oblique aponeurotomy can be performed extending from the arcuate line to the costal margin. The fascia of the external oblique becomes muscular in the cephalad direction and reflects normal anatomy. An important technical point is that the external and internal oblique layers must be separated to achieve an increase in domain (► **Fig. 10**). The dissection is extended until lateral intercostal perforators are encountered, which provide blood supply to the muscle. If this dissection is not performed to that extent, the excursion of the abdominal wall is limited and the gain in domain for fascial closure is marginal.

Posterior component separation, or TAR is a technique that has become more popular recently. It refers to a separation between the transversalis muscle and the internal oblique. This technique facilitates posterior sheath closure by continuing the retrorectus dissection over the transversalis muscle and increases the space for mesh placement. It enables synthetic mesh use by extending the posterior sheath and it can be used effectively with minimally invasive approaches such as lap or robotic hernia repair. Relatively little fixation is generally provided in these approaches and it should be understood that most gains are in posterior sheath excursion rather than true abdominal domain. In complex hernias and abdominal wall defects that require significant domain acquisition, wide exposure and load-bearing mesh inset with primary fascial closure is preferable. It is important to understand that both anterior and posterior component separation should not be performed in the same patient as it excessively weakens the abdominal wall. As a final point, TAR or posterior component separation does not offload tension from the midline to facilitate a tension-free autologous fascial closure as the posterior sheath is not a strength layer. The minimally invasive TAR approach has its place in smaller hernias where domain and fascial tension are less critical and when significant overlying soft tissue manipulation is undesirable.

Integrated Approach—Mesh Type, Mesh Location, and Component Separation

Combining the knowledge of mesh material options, mesh inset, and component separation techniques, the surgeon can develop an integrated approach to achieve the optimal AWR, which is especially critical in complex defects. Mesh position and component separation techniques are affected by choice of mesh. Most synthetic mesh requires a privileged environment to prevent contact with visceral structures, so

Fig. 10 External oblique aponeurotomy and separation of external and internal oblique during anterior component separation to provide maximum excursion of the abdominal wall.

the retrorectus position becomes important. If the dissection is being carried in the retrorectus space, a TAR is reasonable since the plane is already being developed. If a biological mesh is selected, there is no concern to protect the mesh in the retrorectus space and, therefore, the anterior components separation is more practical and often preferred. These are philosophically different approaches, but either one may be appropriate in AWR, as long as the approach remains holistic and internally consistent with respect to mesh type, position, size, and components technique.

Minimally Invasive Components Separation

There is a variety of minimally invasive component separation techniques, including endoscopic or use of counter incisions (→Fig. 11). In 2012, Ghali et al published the outcomes of minimally invasive component separation with inlay bioprosthetic mesh (MICSIB) in the *Journal of American College of Surgeons*. The incidences of SSO, abdominal wall bulge, and recurrent hernia were lower in the MICSIB group compared with the open component separation group. Regardless of the selected components technique, it is imperative to preserve blood supply to the skin and soft tissue. Abdominal wall devascularization is rare, but the consequences are so disastrous and the measures to recover are so extreme that measures of prevention are essential in every case.

The predominant blood supply to the anterior abdominal wall is based on the deep inferior epigastric artery perforators (DIEPs), with contributions from the superior epigastric, superficial inferior epigastric, circumflex iliac, superficial external pudendal, as well as intercostal arteries and perforators. It is now well known that the entire abdominal wall can survive based only on a single DIEP, similar to a single perforator DIEP flap.

Despite the obvious benefits from preserving the DIEPs, in case of inlay mesh repair in addition to component separation, placement of the sutures to secure the mesh on the fascia can be very challenging. Especially if the surgeon

attempts to secure the mesh along the linea semilunaris as described earlier, this necessitates either transcutaneous suture placement or suturing through narrow tunnel between the preserved soft tissues. Transcutaneous suture placement may cause injury to the dermal vascular and lymphatic vascular system, limits soft tissue excursion, and can be associated with poor aesthetic outcome. To address this problem, perforator sparing techniques have evolved, maintaining the benefits of minimally invasive techniques but also allowing increased flexibility in mesh fixation. These techniques suggest, instead of preserving all the intervening tissue, sparing only the tissue containing the perforators, providing wider exposure for the release as well as mesh fixation. In 2002, Saulis and Dumanian published the outcomes of their technique sparing the periumbilical rectus abdominis perforators. Their results confirmed decreased rates of wound healing complications and dehiscence. To avoid creation of dead space and damage to blood supply, a tunnel can be developed between perforators as they emerge through the anterior rectus sheath and the component separation can be performed through the tunnel (MICSIB). Alternatively, counter incisions can be performed laterally to assist with exposure, or the procedure can be performed endoscopically. For a less technically demanding approach, the majority of the perforators have been consistently found to be within 6 cm from the umbilicus. The authors' preferred technique is preserving the periumbilical tissue that contains these perforators and performing component separation after dissecting cephalad and caudal. The spared soft tissue does not interfere with placing or tying sutures and provides wide exposure without compromising blood supply.

In summary, anterior and posterior component separation (TAR) is possible. TAR enables synthetic mesh and Rives–Stoppa repair and is more effective for reconstructing and reinforcing the posterior sheath than the anterior fascia. Anterior component separation favors an open approach

Fig. 11 Minimally invasive component separation preserving the deep inferior epigastric perforators.

and is more effective in reconstructing the anterior fascia. Perforator sparing is critical for soft tissue viability and can be achieved by preserving the periumbilical soft tissue. This can be done safely, without interfering with mesh inset.

Soft Tissue Coverage

Soft tissue coverage is the fourth factor that must be considered in an integrated approach to AWR. Excess tissue can be addressed in a variety of ways, including vertical panniculectomy, horizontal panniculectomy, or fleur-de-lis excision. These techniques should always be approached with an emphasis on previous scars (chevrons, midlines, pfannenstiels, etc.) and blood supply. As long as general plastic surgical principles are obeyed, these techniques are reliable. A more challenging problem than tissue excess is inadequate soft tissue coverage. As discussed in the section on mesh choice, in the case of inadequate soft tissue coverage, risk of mesh exposure must be factored into mesh choice. Occasionally, vacuum-assisted closure (VAC) with delayed primary closure is the best option. In this setting, use of a biologic mesh may be more appropriate because of the contamination risk and the ability to manage exposed mesh and VAC changes in a contaminated setting. This allows

dressings changes at bedside rather than in the OR and does not necessitate the removal of exposed mesh, which may be untenable in sicker patients or anytime it is preferable to leave the abdominal wall/mesh repair intact (►Fig. 12).

In case the defect is too large for local tissue rearrangement, or the patient is not a candidate for staged closure, pedicled or free flaps can be utilized depending on the size and location of the wound. The anterior lateral thigh (ALT) flap is very useful and can be used as a pedicled flap for suprapubic and lower abdominal defects. It is based on the descending branch of the lateral circumflex femoral vessels (►Fig. 13). In defects located more cephalad on the abdominal wall, especially when involving the epigastrium, the traditional pedicled ALT flap usually will not reach. In this situation, the pedicle can be extended using an arteriovenous loop. The saphenous vein is dissected long, the proximal end is left intact, the distal end is anastomosed to the femoral artery, and the loop is transferred into the abdominal defect. The microvascular anastomosis can be performed closer to the defect and convert a complicated, multistaged repair to a single-stage solution (►Fig. 14). In 2013, Baumann and Butler published a comprehensive algorithm of abdominal wall flap reconstruction, including regional and distant options for epigastric, periumbilical, and hypogastric defects.

Fig. 12 Patient with a history of multiple bowel resections, enterocutaneous fistula, and loss of domain with a large ventral hernia. Patient underwent bridged repair with biologic mesh and had insufficient soft tissue and skin for closure, so he required vacuum-assisted closure (VAC) coverage for several weeks prior to delayed primary closure.

Fig. 13 Patient who underwent abdominal wall resection and bridged repair with biologic mesh. Due to the inadequate soft tissue, an anterior lateral thigh (ALT) flap was harvested axially and transferred under the rectus femoris and sartorius muscles for inset.

Fig. 14 Patient with large abdominal wall resection extending to the epigastrium. Repair was performed utilizing a biologic mesh and a free anterior lateral thigh (ALT) flap using an arteriovenous (AV) loop for extension of the vascular pedicle (Courtesy of Charles Butler).

In summary, perforator sparing technique is critical for soft tissue viability of the abdominal wall. In complex defects where there is inadequate soft tissue for closure, biologic mesh is indicated due to inadequate tissue coverage and risk of mesh exposure. For small defects, delayed primary closure after VAC is possible. For larger defects, the ALT and other fasciocutaneous or myocutaneous flaps can be utilized either pedicled or free, depending on the size and location of the defect.

Conclusion

Abdominal wall reconstruction requires a truly integrated approach, taking into consideration the four factors described in this article—mesh choice, mesh position and inset technique, component separation, and soft tissue management. As we have seen, the choice of mesh has direct implications for

mesh positioning and inset, and both affect the approach to component separation technique. The condition of the overlying soft tissue will affect mesh choice and position, and component separation technique, as well. None of these decisions stand in isolation of the others. When performing AWR, a holistic approach that considers the complex interplay of these factors will reduce complications and improve outcomes in AWR.

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