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The 4 Principles of Complex Abdominal Wall Reconstruction

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Summary: Abdominal wall defects are some of the most common and challenging problems encountered by plastic surgeons. A high proportion of patients with abdominal wall defects have significant comorbidities and/or contamination, putting them at high risk for complications. In addition to advanced surgical skills and precise anatomical knowledge, the plastic surgeon needs strict discipline and medical acumen, to optimize patients before and after surgery. In this paper, we discuss the goals of abdominal wall reconstruction, and the 4 steps to successful surgery: preoperative patient selection/optimization, durable and dynamic reconstruction of the musculofascial layer, careful attention to the skin and subcutaneous tissue, and meticulous postoperative management. *(Plast Reconstr Surg Glob Open XXX;XXX:e2549; doi: 10.1097/GOX.0000000000002549; Published online 26 December 2019.)*

GOALS OF ABDOMINAL WALL RECONSTRUCTION

Abdominal wall reconstruction (AWR) may be performed in an obligatory or elective fashion. A patient with a small fascial defect who displays signs of bowel obstruction and/or strangulation usually requires an urgent trip to the operating room for hernia reduction and possible repair. In those patients, there is little time for preoperative optimization, as the risk of delaying the operation is high. The goal of that operation is clearly not complex AWR, but rather relief of symptomatic incarceration and strangulation.

On the other hand, the vast majority of patients presenting for AWR do not display such worrisome symptoms. They may have intermittent discomfort, and inability to perform certain activities of daily living due to a large hernia. In those patients, the surgeon has the opportunity to optimize comorbidities preoperatively, as discussed later in this paper. The ultimate goal is the improvement of the patients' quality of life.[1,2] The means for obtaining this goal are 2-fold: the surgeon must achieve a strong, durable dynamic abdominal wall,[3] which is usually best obtained by mesh-reinforced innervated musculofascial reapproximation. The surgeon must also strive to minimize complications such as hernia recurrence and surgical site occurrences (SSOs).

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PERFORMING SAFE AND EFFECTIVE AWR

Principle 1: Select the Correct Patient and Optimize Their Modifiable Risk Factors

Many of the complications of complex AWR can be minimized with careful patient selection and preoperative optimization (prehabilitation). Complex AWR can have serious, even deadly complications, and it is better to defer elective AWR on a patient who is a poor candidate for surgery, or to delay it until the patients' risk factors are addressed.[4] Complications of AWR fall into 3 categories: SSO (hematoma, seroma, dehiscence, skin necrosis, etc.), hernia recurrence, and medical complications. The 4 most commonly encountered comorbidities that surgeons performing AWR must address preoperatively are tobacco use, malnutrition, obesity, and diabetes mellitus.

The risk of SSOs is significantly higher in patients who use tobacco.[5,6] By decreasing tissue perfusion and oxygenation, tobacco impairs wound healing. It causes platelet aggregation, and this is not mitigated until at least 4 weeks after the last tobacco use. It also causes ciliary dysfunction, which requires at least 6 weeks to improve. In AWR, tobacco use increases the risk of infection 2.5-fold.[5] Smoking cessation for 4 weeks before and after surgery has been shown to significantly decrease the risk of infection and other complications.[6,7]

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The risk of SSOs and other complications is also higher in patients who are malnourished.[8] Protein malnutrition, particularly deficit in arginine and methionine, has been found to be associated with significantly higher mortality.[9–12] In addition, in AWR, low albumin is associated with a 10-fold increase in the risk of infection.[10] This risk is modifiable, as preoperative nutritional repletion (goal serum albumin 3.25 g/dL or higher) has been shown to significantly decrease the risk of infectious and noninfectious complications.[13,14]

Not only does obesity increase the risk of SSOs, especially with a body mass index (BMI) above 31.9 kg/m^2,[15] but it has also been shown to increase the risk of hernia recurrence, with the 2-year risk of recurrence around 8% for BMI between 30 and 39 kg/m^2, 25% for BMI between 40 and 49 kg/m^2, and 45% for BMI above 50 kg/m^2.[16,17] The increasing risk of hernia recurrence with higher BMI has been confirmed by multiple studies,[18] with every unit of BMI leading to a 10% increase in the risk of hernia recurrence.[19] Most surgeons use a BMI cutoff threshold of approximately 40 kg/m^2 before declining elective reconstruction, although this may vary by surgeon/center.

Poorly controlled diabetes mellitus is another risk factor for SSOs.[20] Even transient hyperglycemia causes decreased tissue perfusion and impaired immune function. Elective AWR should be delayed until the patient's Hemoglobin A1c (HbA1c) is 7.5% or below.[21] Perioperatively, glucose should be kept below 160 mg/dL,[22] as even a single instance of preoperative or postoperative glucose above 200 mg/dL has been shown to double the risk of infection and triple the risk of dehiscence.[23,24]

The Ventral Hernia Working Group classification scheme combines comorbidities and contamination to classify patients into 4 grades, according to their risk of SSO (Table 1).[25] Grade 1 patients have no comorbidities or history of infection. Grade 2 patients have comorbidities, but no history of infection. Grade 3 patients have a contaminated wound (previous infection, presence of ostomy, entry into the viscera). Grade 4 patients have an infected wound. Although this model has gained popularity, it is not validated. Another widely used model for the prediction of SSOs is the Kanters classification,[26] which is validated (Table 1). Grade 1 patients have no comorbidities or contamination and have an SSO risk of 14%. Grade 2 patients have comorbidities or previous infection and have an SSO risk of 27%. Grade 3 patients have contaminated or dirty wounds and have an SSO risk of 46%.

TABLE 1. Ventral Hernia Working Group and Kanters Classifications

Grading Scheme	Definition
Ventral Hernia Working Group grade[60]	
Grade 1	No comorbidities or contamination
Grade 2	Comorbidities present (tobacco, diabetes, COPD, obesity, immunosuppression)
Grade 3	Contaminated (previous infection, ostomy present, entry into viscera)
Grade 4	Infected
Kanters grade[26]	
Grade 1	No comorbidities or contamination
Grade 2	Comorbidities present and/or previous infection
Grade 3	Infected or ostomy present or entry into viscera

COPD, chronic obstructive pulmonary disease.

Principle 2: Select the Correct Procedure

To minimize the risk of hernia recurrence and bulge, 2 principles should be followed: primary musculofascial closure should be obtained, and most closures in complex patients should be reinforced with mesh.

Repair Good Fascia to Good Fascia

Every effort should be made to achieve primary fascial closure after adequate debridement of any poor quality, attenuated, scarred, damaged, or nonviable musculofascial tissue. This provides a dynamic abdominal wall that can resist stress and strain, leading to much lower rates of hernia recurrence than interpositional bridge mesh repairs.[27–30] If standard maneuvers cannot achieve tension-free primary closure of the fascia, then components separation should be performed. The surgeon can start with unilateral components separation, check the tension on the closure, and if still high, proceed with bilateral components separation. The techniques for anterior and posterior components separation are described in the "Minimize Undermining" section below.

The issue of tension on the closure deserves special attention. Excessive tension can cause "cheese wiring" of the sutures through the fascia, causing fascial dehiscence and hernia recurrence. Excessive tension may also predict a higher risk for postoperative abdominal compartment syndrome (ACS), which can be fatal. The surgeon can usually assess the risk of ACS intraoperatively using objective criteria, by comparing airway pressures before and after the fascial closure. The patient is at higher risk for ACS if the peak airway pressure rises by 12 mm Hg or more above baseline,[31] or if the plateau airway pressure rises by 4.4 mm Hg or more above baseline.[32] If those thresholds are reached despite bilateral components separation, the best course of action is to leave the fascia open, and either place an interpositional bridge mesh, or apply a temporizing dressing and return for fascial closure once swelling has subsided.

Reinforce the Fascial Repair with Mesh

The effectiveness of mesh reinforcement of primary fascial closure has been demonstrated in several studies,[33–36] which have shown that both short-term and long-term recurrence rates decrease by up to 50% when the fascial closure is reinforced with mesh.[33] Moreover, those studies demonstrate that the fascial closure should be reinforced with mesh regardless of the defect size. Although most studies suggest at least 5 cm of overlap or underlap, this requires further study, as there is some evidence that the amount of under/overlap depends on the size of the defect itself.[37]

Ensure Proper Mesh Placement and Fixation

In general, mesh should be placed under adequate tension to avoid ripples or folds in the mesh. It should be taut, flat, and planar to promote increased contact with vascularized tissue and promote better integration.[38] The ideal mesh location would insulate the viscera from the mesh, while protecting the mesh from exposure in case of wound-healing complications. The retrorectus/retromuscular plane (Rives-Stoppa technique) satisfies these criteria, because the mesh is located in a well-vascularized plane between the underlying posterior rectus sheath and the overlying rectus abdominis muscle. Indeed, mesh placement in the retrorectus plane has been shown to have excellent outcomes.[30] Another excellent option for mesh placement is the wide intraperitoneal underlay position, although synthetic mesh used in this position should be coated with a barrier layer to protect the viscera, and should be appropriately fixated so as to prevent internal herniation.

Use of mesh as an overlay requires wide subcutaneous undermining to accommodate the mesh, and this decreases skin vascularity while creating a large dead space, resulting in higher rates of SSOs[30,39] and hernia recurrence.[40,41] However, there are recent data that suggest that, in low-risk patients, overlay macroporous midweight polypropylene mesh fixated with both staples and fibrin glue has acceptable complication rates and yields a durable repair.[42–47]

The highest rate of hernia recurrence, bulge, and SSOs occurs with interpositional bridge mesh placement, where the fascia cannot be closed primarily.[30] This is most pronounced when biologic mesh is used, as it tends to stretch and attenuate with time.[28,45]

Choose the Correct Mesh Type

When deciding which type of mesh to use, the surgeon must weigh each patient's risk of infection against the risk of hernia recurrence and bulge. Meshes can be broadly divided into synthetic and biologic. Synthetic meshes are more durable. However, biologic meshes tend to incorporate better and be more resistant to infection. Recent data suggest that the porosity and weight of the synthetic mesh are important factors when it comes to integration and ability to clear infection, with macroporous midweight meshes achieving the best combination of strength and integration. Lightweight meshes tend to suffer from central mesh failure more,[46,47] and heavyweight microporous meshes form scar plates and do not resist infection well.[48,49]

Biologic meshes vary by source animal and processing technique. Most abdominal wall biologic meshes are xenografts (with the majority of those being noncrosslinked porcine, although there are others). None are approved by the United States Food and Drug Administration to be placed in infected fields despite the fact that many surgeons do so. More recent data suggest that, in challenging contaminated environments, staged repairs have lower complication rates than single-stage repairs.[50]

Principle 3: Pay Special Attention to the Skin and Subcutaneous Tissue

Minimize Undermining

The preservation of skin and soft tissue vascularity is essential to reducing the risk of SSOs. This vascularity is derived, on each side, largely from 2 rows of perforators, which themselves originate from the superior and deep inferior epigastric vessels.[51] Techniques that preserve as many of those vessels as possible have been shown to result in significantly fewer SSOs than techniques that involve wide undermining.[31,52–55]

Surgeons most often perform wide undermining to obtain access for anterior components separation or to place mesh. Both of these maneuvers, however, can be performed with minimal skin undermining. As described by Butler and Campbell, minimally invasive anterior components separation can be performed through a horizontal 3 cm wide tunnel just below the costal margin,[31] thereby preserving the periumbilical perforators (**See Video 1 [online]**, which displays the technique for minimally invasive anterior components separation). This tunnel is then used to access the linea semilunaris.[38] A vertical subcutaneous tunnel is dissected along the linea semilunaris from 5 cm above the costal margin to the inguinal ligament. The external oblique aponeurosis and muscle are then incised 1 cm lateral to the linea semilunaris. The loose areolar plane between the internal and external oblique muscles is entered. This plane is verified by observing the orientation of the underlying internal oblique muscle fibers. After placing a plastic suction tip as a dissection aid deep to the external oblique muscle and along the planned aponeurotomy, the external oblique aponeurosis is incised along its entire length. The cut edges of the external oblique muscle are then held with Allis clamps, and medial to lateral dissection is performed in the areolar plane just deep to the external oblique, until the mid- or posterior axillary line is reached.[55]

Another technique for components separation, known as "posterior components separation" or transversus abdominis release, can also be performed with virtually no skin undermining [**See Video 2 [online]**, which displays the technique for posterior components separation (transversus abdominis release)].[56,57] The rectus abdominis muscle is first palpated, and its medial and lateral borders are identified. An incision through the reflection of the rectus sheath along the medial border of the rectus abdominis muscle is made, and the retrorectus plane is entered. Medial to lateral dissection is performed in this plane with a combination of cautery and blunt dissection, making sure to elevate the muscle and the underlying fat fully to protect the deep inferior epigastric vessels from injury [**See Video 2 [online]**, which displays the technique for posterior component separation (transversus abdominis release)]. Special care must be taken inferior to the arcuate line, as the posterior rectus sheath only consists of transversalis fascia there, and is quite thin. As the linea semilunaris is reached, the segmental intercostal nerves to the muscle must be protected as they pierce the posterior rectus sheath. About 5 mm medial to those nerves, the posterior lamella of the internal oblique aponeurosis is incised. The underlying transversus abdominis muscle fibers are also incised. This muscle is thickest cranially, so it is easiest to start there. It should also be noted that the medial edge of the transversus abdominis muscle is deep to the rectus abdominis muscle cranially, but becomes more lateral as one travels caudally.[58]

Incising the transversus abdominis muscle fibers allows entry into the plane between the transversus abdominis muscle and the underlying transversalis fascia, although it can also be transitioned to the plane between the transversalis fascia and peritoneum, if needed. Blunt dissection is performed from medial to lateral in this plane. Extreme care must be taken during this dissection not to perforate the transversalis fascia/peritoneum, as they are exceedingly fragile. Cranially, this plane goes above the dome of the diaphragm. Caudally, it reaches the pubic bone and Cooper's ligament. Laterally, it reaches the psoas muscle.

Another step that has traditionally required skin undermining is mesh fixation with sutures. However, percutaneous transfascial suture fixation allows secure mesh fixation without any skin undermining (**See Video 3 [online]**, which displays the technique for transfascial percutaneous mesh fixation without skin undermining).[55] This technique can be used with retrorectus or wide intraperitoneal underlay mesh placement. 1-polyglyconate sutures are preplaced into the mesh, taking 1 cm bites 1 cm away from the edge, and spacing the sutures 1 cm apart (if intraperitoneal underlay) or at 8 cardinal points (if retromuscular). Each transfascial fixation point is selected to be as lateral as possible, to keep the mesh under maximal tension. A small skin stab incision is made overlying each planned fixation point, and a Carter-Thomason laparoscopic suture passer (CooperSurgical, Inc, Trumbull, CT) is inserted under direct visualization through the skin stab incision and through the fascia. Each tail of the suture is passed through a separate fascial stab but through the same skin stab. After all the sutures are passed, they are tied. This results in transfascial sutures whose knots lie on the anterior rectus sheath.

Another option for mesh fixation without skin undermining is the use of self-adhering mesh in the retrorectus plane (**See Video 4 [online]**, which displays the technique for the placement of self-adhering mesh in the retrorectus plane).[59] This mesh is a macroporous polyester mesh with polylactic acid micrgrips. It is best reserved for patients with no contamination. Full closure of the posterior rectus sheath must be achieved. The mesh can then be applied against the posterior rectus sheath and adheres with great strength without sutures. Of note, studies show this technique can reduce postoperative pain and narcotic requirements by 50% due to elimination of fascial tacks or sutures.[58]

Excise Undermined and Marginal Skin

The presence of skin undermining greater than 2 cm has been found to more than double the risk of SSO.[25,60] If possible, marginal and undermined skin and subcutaneous tissue should be excised before closure. Care must be taken to avoid overexcision, which would place undue tension on the closure. Precise estimation of the amount of skin that can be safely excised can be achieved with tailor tacking (**See Video 5 [online]**, which displays the technique for the use of tailor tacking to precisely estimate the amount of skin that can be safely excised).[61]

In obese patients who have lost significant weight, there may be redundant skin. Excision of this redundant skin has been shown to reduce complications,[62–64] and improve patient satisfaction.[65] In contrast, the addition of panniculectomy to hernia repair in patients who are obese and have not lost significant weight increases complication rates.[66,67]

In patients who need excision of excess skin, this may take the form of a vertical panniculectomy, a horizontal panniculectomy, or a combination of both. The combination of a vertical and horizontal panniculectomy results in a fleur-de-lis pattern. The Mercedes modification of the fleur-de-lis pattern results in improved wound healing, due to the upper triangular flaps having more obtuse angles, and therefore improved perfusion to the tips (Fig. 1).[68]

Obliterate Dead Space

One of the enemies of the reconstructive surgeon is dead space, which can result in seroma/abscess formation, leading to wound breakdown. Every effort must be made to obliterate any potential dead space. Closed suction drains should be used wherever dead space is present and should be maintained until the output is less than 20 mL a day for 2 consecutive days with the patient ambulatory.[69] The drain bulb should be squeezed side to side and emptied whenever 25% full.[70,71] The drain tubing should be stripped frequently to prevent clotting.[69] Another technique that has been shown to decrease the risk of subcutaneous seroma is progressive tension sutures.[72] These sutures are placed between the underside of the Scarpa's fascia and the anterior rectus sheath. With every suture, the skin flap is advanced toward the midline to offload tension off the closure. Another effective tool is incisional negative pressure wound therapy, which has been shown to decrease the risk of seroma, dehiscence, and infection in AWR,[73] cardiac surgery,[74] groin vascular surgery,[75] and orthopedic surgery.[76]

In cases of retrorectus or intraperitoneal mesh, a seroma may form between the mesh and the rectus sheath. In addition to ensuring the mesh is taut, central suspension sutures may be placed.[55] These sutures are analogous to the progressive tension sutures used in the subcutaneous plane. They consist of 3-point sutures that include the 2 sides of the fascia, as well as the midline of the mesh. When tied, these sutures appose the mesh against the underside of the fascia, minimizing dead space.

Principle 4: Carefully Manage the Patient Postoperatively

For the patient undergoing complex AWR, the postoperative management is at least as important to the ultimate outcome as the surgery itself.[4]

The increased intraabdominal pressure after repair puts the patient at high risk for venous thromboembolism, atelectasis, and pneumonia. To minimize the risk of venous thromboembolism, early ambulation (as early as the evening of surgery) is extremely important. In addition, sequential compression devices should be on and functional whenever the patient is in bed, as this has been shown to reduce the risk of venous thromboembolism significantly.[77] To minimize the risk of atelectasis, incentive spirometry should start in the recovery unit, as soon as

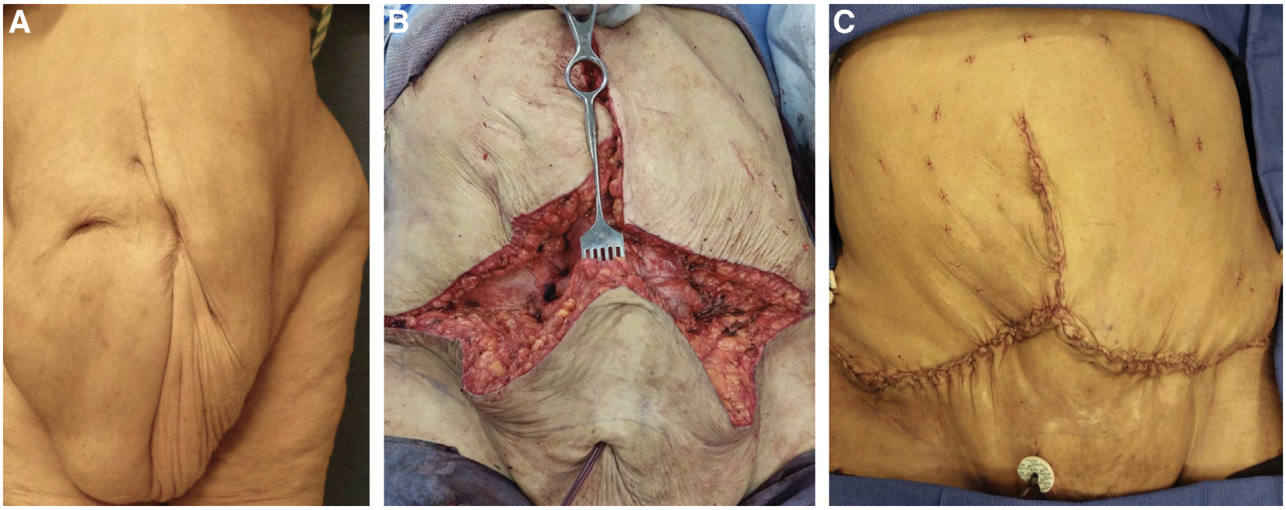

Fig. 1. Technique for Mercedes modification of the fleur-de-lis panniculectomy. A, In a patient with a large overhanging pannus and a hernia, skin excision in a vertical and a horizontal direction is needed to eliminate poorly vascularized and undermined skin. B, The Mercedes modification of the fleur-de-lis pattern improves outcomes by making the tips of the upper triangular flaps obtuse with improved perfusion. C, The T-junction is located more cranial than a classic fleur-de-lis panniculectomy, outside the pubic area, allowing for a more hygienic healing environment.

the patient is awake enough to participate.[78] This has been shown to reduce the risk of postoperative pneumonia.[79]

Adequate pain control is essential to achieving early mobility and good respiratory effort. In addition, poorly controlled pain has been associated with sympathetic hyperactivity, leading to relative tissue ischemia and wound complications.[80] Narcotics should be minimized, as they carry the risk of somnolence, confusion, respiratory depression, and ileus.[81] Opioid-sparing pain control begins preoperatively: the placement of epidural catheters preoperatively has been shown to significantly decrease narcotic requirements.[82] Intraoperatively, infiltration with local anesthetic should be performed as a transversus abdominis plane block. Long-acting formulations, such as liposomal bupivacaine, achieve longer relief of pain.[83] Another procedure which has been shown to decrease postoperative pain and narcotic requirements is the use of self-adhering mesh in the retrorectus plane.[58] Postoperatively, multimodal nonopioid analgesics such as acetaminophen, nonsteroidal anti-inflammatory drugs (celecoxib, ketorolac), and gabapentin should be used as first-line drugs.[84,85]

PEARLS AND PITFALLS

- A large proportion of patients with complex abdominal defects have had many mediocre operations before. They only have 1 good chance at a "gold standard" operation. In an elective situation, do not operate on those patients until they are absolutely ready (all comorbidities optimized, and contamination minimized).
- The entire reconstruction can be lost due to skin necrosis/dehiscence, or a seroma around the mesh that becomes an abscess. The importance of careful skin management and dead space obliteration cannot be emphasized enough.

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