Journal of Surgical Oncology

REVIEW

Modern Reconstructive Techniques for Abdominal Wall Defects After Oncologic Resection

IBRAHIM KHANSA, MD AND JEFFREY E. JANIS, MD, FACS*

Department of Plastic Surgery, The Ohio State University Wexner Medical Center, Columbus, Ohio

Resection of abdominal wall tumors often leaves patients with debilitating soft tissue defects. Modern reconstructive techniques can be used to restore abdominal wall integrity. In this article, we present an overview of preoperative patient evaluation, analysis of the defect, surgical planning, and the spectrum of available surgical techniques, ranging from simple to complex. The established clinical evidence in the field of abdominal wall reconstruction is summarized and a case example is provided.

J. Surg. Oncol.

KEY WORDS: abdominal wall reconstruction; desmoid; sarcoma; oncologic; hernia

INTRODUCTION

Reconstructive surgeons are often faced with difficult abdominal wall defects after tumor resection. It is critical to achieve success in abdominal wall reconstruction at the initial stage in order to avoid the morbidity associated with surgical site occurrences, most notably post-operative hernias, surgical site infections, and soft tissue necrosis [1]. A systematic approach to patient evaluation and defect analysis, coupled with a keen knowledge of surgical anatomy, evidence-based medicine, and special oncologic considerations, are essential to perform high-quality abdominal wall reconstruction.

PREOPERATIVE PATIENT EVALUATION AND OPTIMIZATION

The ideal model for the care of patients with abdominal wall tumors is a multidisciplinary team, in which surgical oncologists, reconstructive surgeons, medical oncologists, and radiation oncologists can all evaluate the patient preoperatively. In this model, the reconstructive surgeon can formulate a personalized and individualized reconstructive plan before tumor ablation is undertaken.

Abdominal wall defects can effectively be divided into three types: those involving skin and subcutaneous tissue only, which simply need soft tissue coverage; those involving the musculofascial system only, which require musculofascial reconstruction; and full-thickness defects involving all elements of the abdominal wall, which require musculofascial reconstruction as well as soft tissue coverage in order to restore abdominal wall integrity. The type, size, and location of the tumor can often inform the surgeon preoperatively of what the characteristics of the abdominal wall defect will be after resection. Desmoid tumors and soft tissue sarcomas both tend to be in close proximity to, if not intimately involved in, the musculofascial layer of the abdominal wall [2,3]. In contrast, dermatofibrosarcoma protuberans (DFSPs) are often adherent to the skin and separate from the musculofascial layer [3], and thus can often be resected without disturbing the fascia. Tumors of gastrointestinal origin that have invaded the abdominal wall invariably involve the musculofascial system.

Knowledge of the tumor characteristics and risk of recurrence preoperatively also helps the reconstructive surgeon tailor the surgical plan accordingly. DFSPs tend to have finger-like projections that resemble normal collagen histologically, which may not be seen on frozen sections. As a result, DFSPs often have a high local recurrence rate [3], and the surgeon may choose to use simple reconstructive methods that allow easier surveillance, such as a skin graft or dermal regeneration matrix, rather than a thick flap, which might provide excellent cosmesis and soft tissue contour, but may obscure potential recurrence. Tumor bulk can also be informative to the reconstructive surgeon, as large abdominal wall masses can compress the muscular elements and cause atrophy, which may affect the reconstructive plan [4].

The reconstructive plan and the odds of success both depend intimately on the preoperative characteristics of the patient. Patients with no prior abdominal surgeries, especially those with no prior hernia repairs, transplants, histories of trauma, ostomies, or fistulae, tend to have less scar burden from prior operations, less anatomical distortion of tissue planes, and less loss of abdominal domain. They also tend to have the lowest rate of reconstructive failure and hernia, as inferred from the abdominal hernia literature, which has found a 5-year risk of reoperation of 24% after the first hernia operation, 35% after the second operation, and 39% after the third operation [1]. Patients with prior abdominal surgery, especially those in whom mesh was used, tend to have thick scar usually intimately involving fascia or peritoneum that may need to be resected before repair, thus resulting in a larger defect.

Disclosures: Jeffrey Janis is a consultant for LifeCell, has received a prior honorarium from Pacira, and receives royalties from Quality Medical Publishing. Ibrahim Khansa has no financial interest in any products or techniques mentioned in this article.

*Correspondence to: Jeffrey E. Janis, MD, FACS, Professor and Executive Vice Chairman, Department of Plastic Surgery, The Ohio State University Wexner Medical Center, 915 Olentangy River Rd, Columbus, OH 43212. Fax: 614-293-9024. E-mail: jeffrey.janis@osumc.edu

Received 20 July 2014; Accepted 9 September 2014

DOI 10.1002/jso.23824

Published online in Wiley Online Library (wileyonlinelibrary.com).

Preoperative evaluation also includes risk stratification, to predict the risk of surgical site occurrences, such as infection, seroma, wound dehiscence, and enterocutaneous fistula. One commonly used risk stratification scheme is the Ventral Hernia Working Group (VHWG) grading system [5]. Grade 1 patients have no history of infection, and no risk factors for surgical site occurrence. Grade 2 patients have comorbidities that increase the risk of infection, such as obesity, COPD, smoking, diabetes mellitus, and immunosuppression. Grade 3 patients have a potentially contaminated wound, due to previous infection, presence of an ostomy, or intraoperative violation of the gastrointestinal tract. Grade 4 patients have active infection, including infected mesh. This grading system is useful, since it can be used to risk stratify patients, and has been used to predict the risk of surgical site occurrences in several series [4]. It also helps direct surgical management: synthetic mesh is acceptable for grade 1, and usually simple grade 2 patients, but is usually deemed inappropriate in grade 3 and 4 patients, who may benefit from biologic mesh instead. This grading system is fundamentally based on two large studies that used data from the National Surgical Quality Improvement Program (NSQIP) database to quantify the risk of surgical site occurrences as a function of patient and surgical characteristics. In those studies, patients with operative time greater than 4 hr were 19.3 times more likely to develop a wound infection. Patients with COPD had an 11.5-fold increased risk, and those with low serum albumin had a 10-fold increased risk [6]. Smokers had a 2.04-fold increase in the risk of wound infection [7]. Other risk factors for infection included chronic corticosteroid use, coronary artery disease, use of absorbable synthetic mesh, age, and obesity. Infection has been found to increase the risk of fascial repair breakdown and hernia 4.3-fold [8].

In order to improve the predictive value of the VHWG risk stratification scheme, Kanters et al. modified it by reducing the number of grades to 3, moving patients with a prior history of wound infection from grade 3 to grade 2, and combining patients with a clean-contaminated, contaminated or dirty wound into a single grade (grade 3) using CDC wound class nomenclature [9]. Using data from 332 patients undergoing hernia repair, they validated their modified grading system, and found it to be predictive of surgical site occurrences: the risk of SSO was 14% in grade 1 patients, 27% in grade 2 patients, and 46% in grade 3 patients.

Preoperative evaluation of the patient by the reconstructive surgeon as part of a multidisciplinary team can therefore allow preoperative patient optimization in order to improve outcomes. Firstly, patients should abstain from smoking and all other nicotine sources for at least 4 weeks preoperatively and 4 weeks postoperatively. Indeed, tobacco use has been demonstrated, through a large systematic review [10], to impair wound healing by causing vasoconstriction, vascular endothelial injury and platelet aggregation, leading to a reduction in tissue blood flow by up to 40%, and tissue hypoxia. The same study found that smoking cessation restored normal tissue perfusion and oxygen tension after 1 hr, reduced platelet aggregation after 2 weeks, and reduced endothelial dysfunction after 4 weeks.

Second, in patients with diabetes mellitus, blood glucose levels should be controlled and kept within normal range. Hyperglycemia is known to cause glycosylation of proteins, which then become dysfunctional [11]. It also decreases tissue perfusion and immune cell function. In a prospective cohort study of patients undergoing cardiothoracic surgery, Latham et al. demonstrated that patients with any instance of postoperative hyperglycemia (serum glucose $\geq$ 200 mg/dl) in the 48 hr after surgery had a two-fold increase in the incidence of surgical site infections [12]. Similarly, in a review of 79 patients undergoing surgical closure of difficult wounds, Endara et al. found that patients with any instance of preoperative hyperglycemia (serum glucose $\geq$ 200 mg/dl) had a three-fold increase in the rate of dehiscence, while those with any instance of postoperative hyperglycemia had a 3.5-fold increase in dehiscence [13]. Regarding chronic glucose control, patients with a hemoglobin A1c greater than 6.5% had a 3.5-fold increase in the rate of dehiscence. The deleterious effects of hyperglycemia increase as the degree of hyperglycemia worsens. In a review of 995 patients undergoing general and vascular surgery, Ramos et al. found that the risk of surgical-site infection increased by 30% for every 40 mg/dl increase in serum glucose above 110 mg/dl [14].

Third, patients with malnutrition should have their nutrition improved preoperatively and postoperatively. In a large cohort study conducted across 44 Veterans Affairs Medical Centers, analyzing patients who underwent 87,078 noncardiac operations over a period of 27 months, Khuri et al. identified 34 preoperative variables that predicted 30-day postoperative mortality [15]. The most powerful predictor of postoperative mortality was low-serum albumin, underscoring the danger of malnutrition in surgical patients. Similarly, Kudsk et al. retrospectively reviewed 526 patients undergoing intraabdominal surgery [16], and found that major complication rates increased significantly with decreasing preoperative albumin levels. They also found that the mortality rate was significantly higher when the preoperative serum albumin was lower than 3.25 g/dl. Improvement of nutritional status has been shown to improve outcomes and reduce mortality with surgery. Mullen et al. have shown that adequate preoperative nutritional repletion of malnourished surgical patients reduced the risk of postoperative complications 2.5-fold, postoperative sepsis six-fold, and postoperative mortality five-fold [17]. In a prospective cohort study of 1,085 patients undergoing intraabdominal surgery, Jie et al. demonstrated that in patients with severe malnutrition, preoperative nutritional repletion with enteral nutrition or total parenteral nutrition for a mean duration of 9.7 days reduced the risk of postoperative complications from 50.6% to 25.6%, including a reduction in the rate of infection from 33.8% to 16.3% [18].

GOALS OF ABDOMINAL WALL RECONSTRUCTION

The most important goal of abdominal wall reconstruction in patients in whom a fascial defect is present is the prevention of bowel herniation, which may lead to incarceration, strangulation, bowel necrosis and/or obstruction, perforation, peritonitis, and death [19]. In order to achieve this goal, the repair should be strong, stable, and dynamic. Dynamic abdominal wall repairs have been shown to resist stress and strain better than a dynamic repairs [20]. This is because non-innervated muscle or fascia eventually atrophies, which leads to a weak point through which abdominal contents can bulge or herniate. A dynamic repair may also improve bowel function by strengthening expulsive forces and may improve respiratory function by providing more optimal breathing mechanics [20].

In order to obtain a dynamic abdominal wall repair, the ideal repair material is innervated muscle and fascia, rather than a "bridge" of prosthetic material. Reinforcing the importance of a dynamic abdominal wall repair, Booth et al. have shown that fascial reapproximation with mesh reinforcement has a much lower recurrence rate (8%) than bridged mesh repair (56%) at 31 months [21].

Another goal of abdominal wall repair is soft tissue coverage in order to obtain a healed wound, and cover any prosthetic reinforcement material, if present. In general, it is preferable to place prosthetic material, especially if synthetic, in an underlay or retrorectus position, in order to avoid exposure in cases where soft tissue coverage fails. This is discussed in more detail later in this article.

Ultimately, the main goal of abdominal wall reconstruction is to improve patients' health-related quality of life. Successful abdominal wall reconstruction has been shown to positively impact patients' pain, physical functioning, social functioning, and ability to return to work. Those are negatively impacted by hernia recurrence and surgical site occurrences, such as infection, seroma, wound dehiscence, and enterocutaneous fistulas [22,23].

ABDOMINAL WALL ANATOMY AND IMPLICATIONS FOR RECONSTRUCTION

The abdominal wall is a complex, dynamic structure, and knowledge of its detailed anatomy allows for advanced reconstructive techniques that do not denervate or devitalize the abdominal wall. In particular, knowledge of the innervation and vascular supply patterns to the abdominal wall are critical in order to obtain a repair with a dynamic abdominal musculature and well-perfused skin (Fig. 1).

Vascular perforators to the abdominal wall skin emerge from the deep epigastric vessels through the rectus abdominis muscle. They are usually grouped into a medial and lateral row, with the medial row being dominant. The periumbilical perforators are usually the largest and most dominant perforators, and usually come off the medial row and are typically located within 3 cm of the umbilicus [24,25]. Preservation of these perforators is the underlying principle behind the Perforator-Sparing approach as originally described by Saulis and Dumanian [26], as well as the Minimally-Invasive Component Separation with Inlay Bioprosthetic (MICSIB) mesh technique [27]. Both of these techniques are described in more detail later in this article.

Innervation of the abdominal wall is derived from segmental intercostal nerves that travel in the plane between the internal oblique and the transversus abdominis muscle. They enter the rectus abdominis muscle just medial to the linea semilunaris. Preservation of these segmental intercostal nerves (and their accompanying blood vessels) to the rectus abdominis muscle is the underlying anatomic principle behind the component separation technique.

RECONSTRUCTIVE LADDER IN ABDOMINAL WALL RECONSTRUCTION

Abdominal wall defects can be classified into three types: 1) Those involving skin and subcutaneous tissue only; 2) Those involving muscle and fascia only; and 3) Full thickness defects involving skin, subcutaneous tissue, muscle, and fascia [28]. The reconstructive ladder is different depending on the type of defect, as well as the size of the defect, the presence of contamination, and the type of tumor.

Type 1 Defects: Skin and Subcutaneous Tissue Only

Defects involving the skin and subcutaneous tissue only tend to be the simplest to reconstruct. At the bottom of the reconstructive ladder is healing by secondary intention, with frequent dressing changes or negative-pressure wound therapy. This can be used as a definitive reconstruction method in patients in whom no critical structures are exposed, and those in whom further surgery is contraindicated. It can also be used as a temporary coverage method in patients in whom margins are uncertain, while awaiting permanent pathology results, before definitive reconstruction is undertaken. Complex primary closure is the second rung on the reconstructive ladder, and the most commonly used closure technique. Skin grafts can be placed over well-perfused wound beds at the time of tumor excision, or in a delayed fashion. While they may have the disadvantage of color mismatch and contour deformity, split-thickness skin grafts have the advantage of obtaining a healed wound while allowing clinical surveillance for tumor recurrence, owing to their thin nature. If no evidence of recurrence is seen, the skin graft can be excised, and another closure method with improved aesthetics can be performed.

Local flaps recruit abdominal skin in order to close defects that are not amenable to primary closure. The most common local flaps are advancement flaps, in which undermining of the skin and subcutaneous tissue is performed, appropriate back-cuts performed, and the skin advanced so as to close the incision in tension-free fashion. Another local flap option is to take advantage of perforators from the deep epigastric system to the skin and subcutaneous tissue, by designing local "propeller" flaps based on one or two perforators [29].

Regional flaps most commonly use tissue from the thigh or from the back to cover abdominal wall defects. The rectus femoris musculofascial flap can be useful in patients with massive loss of abdominal wall domain. It has been described to reach the costal margin, and the muscle been shown to respond to changes in intraabdominal pressure by contracting [20]. Other regional flaps include the pedicled tensor fascia lata musculofascial flap. However the distal ¼ of the flap tends to have unreliable vascularity [20,30,31]. The anterolateral thigh fasciocutaneous flap, based on the descending branch of the lateral circumflex femoral artery, is also commonly used for abdominal wall reconstruction [32,33]. Large flaps encompassing most of the anterior thigh, and including variable amounts of vastus lateralis, rectus femoris. and tensor fascia lata muscles, have been successfully used for very large defects of the abdominal wall [32,34,35]. Another commonly used regional flap is the latissimus dorsi musculocutaneous flap [36]. Anterolateral thigh flaps and subtotal thigh flaps can usually be left attached to their blood supply and tunneled to the defect. However, in cases where this does not allow them to reach the full extent of the defect with no tension or kinking of the pedicle, they can be either transposed underneath the rectus femoris to gain additional pedicle length or moved to the abdominal wall as free flaps. Free flaps lie at the top of the reconstructive ladder, and require ligation of the flap's original blood supply and the use of microsurgical techniques to reanastomose the blood vessels near the recipient site. Potential recipient vessels for free flaps to the abdominal walls include the superficial femoral artery (usually requires a vein graft), or the deep epigastric vessels.

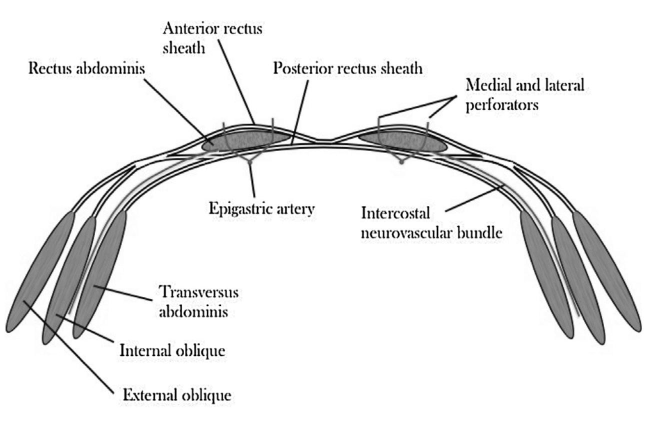

Fig. 1. Schematic anatomy of the anterior abdominal wall.

Type 2 Defects: Muscle and Fascia Only

For patients with defects of the abdominal musculofascial system, healing by secondary intention is generally not an option. Temporizing measures may be employed, however, in the event of patient instability or questionable margins requiring permanent pathology. In this case, multiple dressing options are available. These generally consist of a nonadherent protective layer that covers the bowel, followed by a layer of foam connected to a negative pressure source [37]. Polyglactin absorbable mesh can also be applied over bowel, as part of a staged reconstruction. This therapy can be continued until granulation tissue has formed over the bowel. At that point, a split-thickness skin graft can be applied, and a healed wound can be obtained. Fabian et al. have applied this staged reconstructive technique to 88 patients as a temporizing measure before definitive abdominal wall reconstruction, and demonstrated a low morbidity rate [38]. However, neither granulation nor skin grafting can provide fascial continuity, and both treatment options result in a weak, adynamic abdominal wall, and are therefore typically used as a temporizing measure.

Primary repair of the fascia, when feasible, is the simplest method of obtaining fascial continuity. Even in cases where the fascia can be reapproximated easily, multiple studies have shown that reinforcement with mesh should be performed. In a multicenter, randomized-controlled trial, Luijendijk et al. compared primary repair with sutures to repair with additional reinforcement using a synthetic mesh underlay [8]. After a 3-year follow-up, the rate of hernia recurrence in the mesh reinforcement group was half the rate of recurrence in the primary suture group (23% vs. 46%, $P = 0.005$). Interestingly, in the mesh reinforcement group, many of the recurrences were attributed to technical errors, namely insufficient overlap between the mesh and the fascia (<4 cm), and excessive distance between tacking sutures (>1 cm). The importance of mesh reinforcement has been confirmed by several other authors [4,39,40], and the VHWG has recommended using mesh reinforcement in most hernia repairs in order to reduce the risk of recurrence [5].

In cases where the fascia cannot be reapproximated primarily, four options exist: leaving a fascial defect to heal by staged approach with temporizing mesh interposition (as discussed above), using mesh as an definitive interposition bridge (as discussed in the next section), recruiting abdominal fascia through the use of local musculofascial flaps (such as component separation), and the use of regional or free flaps.

Component separation. In order to repair a large midline or paramedian fascial defect, the fascia needs to be mobilized to gain primary reapproximation, which is the gold standard for a durable result. Of the three lateral muscular elements, the external oblique muscle has the most limited capacity to be advanced medially, due to its low elasticity, and its tethering to the rib cage, iliac crest, and inguinal ligament. As a result, it can usually only be advanced 2 cm in the epigastrium, 4 cm at the umbilicus, and 4 cm in the suprapubic area. The plane between the external oblique and internal oblique muscles is relatively avascular [30]. By making a parasagittal incision in the external oblique aponeurosis about 2 cm lateral to the linea semilunaris, and delaminating the external from the internal oblique out to as far as the posterior axillary line, the rectus abdominis-internal oblique-transversus abdominis unit can be freed from the tight external oblique [41] (Fig. 2). Using this technique, Ramirez et al. were able to obtain advancements of 5, 10, and 3 cm in the epigastric, waistline and suprapubic areas respectively, on each side [30]. This concept has become known as component separation, since the components of the abdominal wall are separated in order to extend its capacity to be advanced medially. Some authors have modified the technique by separating the rectus muscle from the posterior rectus sheath, a technique that provides an additional 2 cm of advancement on each side [42].

In its traditional form, component separation requires wide undermining of the skin flaps to a level lateral to the linea semilunaris. As such, the perforators from the deep epigastric vessels, including the robust periumbilical perforators, are usually divided. This led to high rates of midline wound complications in the early years of component separation [43]. Since then, several authors have devised methods to incise the external oblique aponeurosis without devascularizing the overlying skin. Saulis et al. performed external oblique release by only elevating the skin flaps inferior and superior to the periumbilical perforators, without disturbing them [26]. Butler et al. modified this technique in order to preserve the majority of the blood supply to the anterior abdominal wall, and devised a technique known as MICSIB [27]. They proposed dissecting a 3 cm-wide tunnel superficial to the anterior rectus sheath, 2 cm below the costal margin, laterally to just beyond the linea semilunaris. Then, using this tunnel for access, they incised the external oblique aponeurosis, and dissected the plane between the external and internal oblique muscles bluntly. Underlay biologic mesh was used. This technique spares most of the perforators from the deep epigastric vessels. They compared this technique to traditional component separation, and found significantly lower rates of skin dehiscence (11% vs. 28%), seroma (2% vs. 6%), abdominal bulge (4% vs. 14%), and hernia recurrence (4% vs. 8%) [44]. Other techniques for minimally-invasive component separation have been described. One such technique was proposed by Lowe et al. [45]. Through a small skin incision 5 cm medial to the anterior superior iliac spine, an endoscopic balloon is inserted over the midaxillary line and inflated, thus creating a lateral subcutaneous pocket that does not disturb the perforators. Using laparoscopic instruments inserted into that subcutaneous pocket, the external oblique aponeurosis is then released endoscopically along a parasagittal line 1 cm lateral to the linea semilunaris. Dissection of the plane between the external and internal oblique is then performed. They compared this technique to traditional open component separation, and found a decrease in wound related complications (infection 0% vs. 40%; dehiscence 0% vs. 43%). A similar technique was described by Rosen et al. [46], who also demonstrated a significant decrease in wound-related complications (27% vs. 52%) [47].

Another technique for component separation, known as "posterior component separation", involves release of the transversus abdominis muscle, as described by Novitsky et al. [48]. The posterior rectus sheath is first incised 1 cm lateral to its medial edge. The retrorectus space is developed until the linea semilunaris, taking care to preserve the segmental nerves to the rectus muscle. The transversus abdominis fascia and muscle are then incised 5 mm medial to the linea semilunaris, and a plane between the transversus abdominis muscle and the transversalis fascia is developed and can be dissected laterally as far as the psoas muscle. They found that posterior component separation allowed up to 8–12cm of additional medial advancement of the posterior rectus sheath per side.

Regional flaps. The anterolateral thigh and subtotal thigh flaps have the potential to include a sizable amount of vascularized iliotibial tract, which can be used for musculofascial repair in full-thickness defects, with the skin paddle of the flap used for skin coverage [49]. However, the thin fascia outside of the iliotibial tract is weaker. Consequently, many authors usually recommended performing underlay or interposition fascial repair with mesh, and covering that with the flap [32].

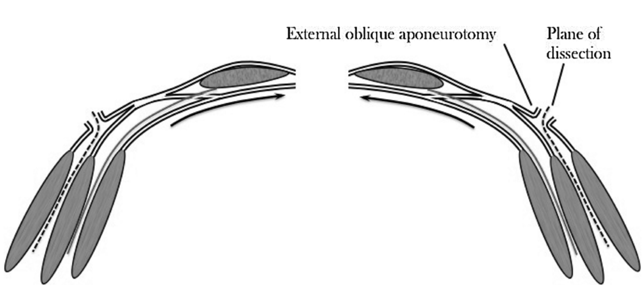

Fig. 2. Dissection in anterior component separation.

Type 3 Defects: Skin, Subcutaneous Tissue, Muscle, and Fascia

Full thickness defects of the abdominal wall usually require a combination of the techniques described for type 1 and type 2 defects described above. Fasciocutaneous flaps from the thigh, which include both fascia and skin, can be especially useful in those situations [49]. Lannon et al. have studied the anterolateral thigh flap in abdominal wall and pelvic reconstruction in 27 patients [33]. The mean size of their anterolateral flaps was 152.1 cm^2, and the flaps were able to reach as cranial as the costal margin. The vascularized fascia lata included in the flap was used as a fascial repair material in eight patients. In those patients, the fascia lata was sutured to the native abdominal fascia using interrupted #1-polypropylene sutures, and was anchored to the pubis via drill holes. In two additional patients, the fascia lata became devascularized during flap harvest, and the authors used it as a non-vascularized fascial graft. Both of these patients developed a hernia or bulge. In patients in whom the fascia was vascularized, no hernias developed. In all cases, if mesh is used, the authors caution against allowing the mesh to contact the vascular pedicle to the flap, in order to avoid erosion into the pedicle.

For larger defects, Lin and Butler have reported their experience with the subtotal thigh flap [32]. In their study of eight flaps in seven patients with large, full-thickness abdominal wall defects, the mean flap size was 514 cm^2. They define the subtotal thigh flap as a chimeric flap measuring at least 400 cm^2, and containing multiple elements supplied by one or more of the major branches of the lateral circumflex femoral vessels, including the thigh skin, vastus lateralis, rectus femoris, and tensor fascia lata. When using pedicled flaps, the flap was tunneled under the sartorius, and under the rectus femoris (if not included in the flap), which afforded them an additional 5 cm of reach. In all cases, they used human acellular dermal matrix in a bridged interposition fashion, sutured to the surrounding fascia using interrupted #1-polypropylene and anchored to the ribs, lumbosacral spine, and/or pelvis. Unlike Lannon et al., they did not use the fascial component of the thigh flap for fascial repair, believing that the sutures would tear through the fascia in the direction of its fibers. Over long-term follow-up, one patient developed a hernia, and one patient developed a fascial laxity, neither of which required reoperation. Kimata et al. verified the utility of the anterolateral thigh flap in abdominal wall reconstruction [35]. In their experience, its main advantages over the tensor fascia lata flap included larger size, and more reliable blood supply to the distal flap tip, which can be extended all the way to the knee. Although they found that the pedicled anterolateral thigh flap can reach as cranial as 8 cm above the umbilicus, they found that converting to a free anterolateral thigh flap became necessary in certain situations: when there was a large epigastric abdominal defect that could not be covered by a pedicled flap, and when the defect orientation was horizontal, which would require a sharp arc of rotation if a pedicled flap were used.

MESH USE IN ABDOMINAL WALL RECONSTRUCTION

Types of Mesh

It has been demonstrated that mesh should be used as reinforcement of primary fascial repair in most cases [8]. The choice of the type of mesh to be used depends on several factors, including degree of contamination and patient comorbidities. The VHWG grading system [5] and the modification by Kanters [9], can help guide the surgeon's choice of the type of mesh to use.

Synthetic mesh. Synthetic meshes are usually composed of a man-made polymer, interwoven into a matrix. The size of the gaps in the matrix defines the porosity of the mesh, which in turn drives the body's response to the mesh. Porous meshes, such as polypropylene meshes, allow tissue ingrowth, which leads to incorporation and adhesion to the recipient tissue. This can be advantageous in situations where incorporation is desired. A downside of those meshes is that they develop adhesions to bowel if directly placed on it [50,51], which can lead to obstruction and enterocutaneous fistula formation. Using these meshes in direct contact with bowel without intervening peritoneum or without barrier-coating is, therefore, discouraged. In contrast, less porous meshes, such as polytetrafluoroethylene (PTFE), undergo encapsulation rather than ingrowth, but if infected, require complete removal [52].

Synthetic meshes are unable to resist infection, and using them in contaminated environments is contraindicated. In addition, exposure of synthetic meshes (as in cases of wound breakdown) usually necessitates removal of the mesh. For that reason, use of synthetic meshes in an overlay position is not recommended, especially where the vascularity of the overlying skin is questionable. In controlled situations, such as elective tumor resections under sterile conditions, synthetic meshes can be a useful, strong, and inexpensive reinforcement method when placed in an underlay or retrorectus position.

Biologic meshes. Surgeons are often faced with an abdominal wall defect in the setting of contaminated field. This can be due to infection of previously placed mesh, presence of an ostomy, or presence of an enterocutaneous fistula. In such patients, the use of synthetic mesh can have higher rates of complications [53]. One option is to stage the procedure. The initial stage would consist of removal of infected mesh, reversal of the ostomy, or takedown of the enterocutaneous fistula with reestablishment of gastrointestinal continuity. The patient would then have to wait to undergo definitive abdominal wall reconstruction at a second stage. In the time period between the two stages of the procedure, the abdominal musculature could contract laterally, resulting in further loss of abdominal domain, depending on the time between stages [54]. Another option is to use biologic mesh, which consists of human or animal tissue that has been treated to remove the cellular and immunologic elements, leaving only an acellular scaffold [54].

The advent of biologic meshes has added a valuable option to the field of abdominal wall reconstruction in potentially contaminated fields. Biologic meshes are repopulated by recipient fibroblasts and new blood vessels as early as 2 weeks after implantation, and can therefore resist infection [55]. This has been demonstrated in an animal model by Milburn et al., who inoculated acellular dermal matrices and PTFE meshes implanted in rabbits with various amounts of Staphylococcus aureus, and found the ADMs to have much a lower number of colony-forming units at 7 and 21 days postimplantation [56]. Similarly, Harth et al. inoculated polyester mesh and four types of biologic meshes implanted in rats with Staphylococcus aureus [57]. They demonstrated complete bacterial clearance in 92% of Strattice mesh, 75% of XenMatrix mesh, 67% of Permacol mesh, 58% of Surgisis mesh, and 0% of polyester mesh. In addition to lowering the risk of surgical site occurrences, biologic meshes also make the management of such occurrences easier when they occur. In cases of skin healing complications leading to exposure of the biologic mesh, the wound can usually be treated with local wound care until the mesh granulates. This is in contrast to most synthetic meshes, which usually require explantation when exposed. The issue with biologic meshes, however, center around cost and durability—both of which need to be taken into account when selecting this as the mesh option for reconstruction.

Techniques of Mesh Placement

Meshes act as reinforcement to the primary fascial repair, by taking some tension off the repair in the early postoperative period. In general, when placing mesh, overlap between the mesh and the fascia should be at least 4 cm on each side [58]. Sutures should be placed at least 1 cm from the edge of the mesh to avoid tearing through. Biologic mesh should be placed in near maximal tension in order to place it in maximal contact with well-vascularized tissue.

Mesh can be placed in one of four positions, each with advantages and disadvantages. Overlay placement is the easiest, but also has the highest seroma rate due to the required wide undermining of the skin [59], although placing progressive tension sutures from the skin flaps to the fascia in order to obliterate dead space has been shown to significantly lower drain outputs, and may in fact lower the risk of seroma [60]. Nevertheless, synthetic mesh placed in an overlay fashion is at risk of exposure and infection if wound-healing problems occur

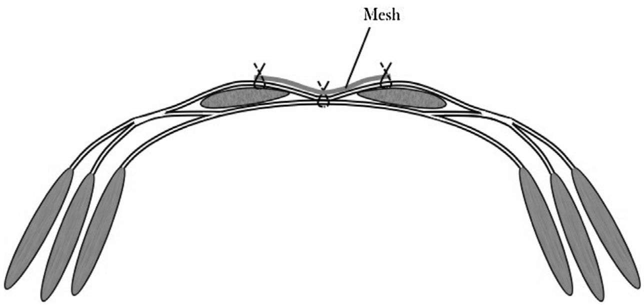

Fig. 3. Overlay placement of mesh.

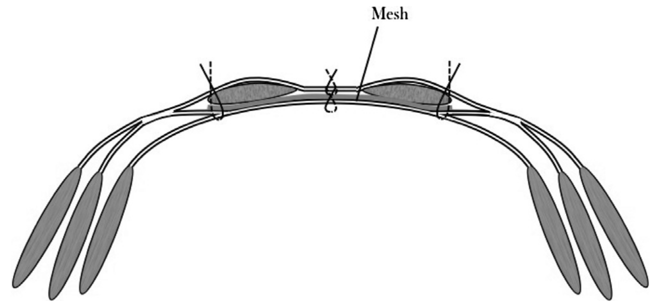

Fig. 5. Retrorectus placement of mesh.

(Fig. 3). Wide intraperitoneal underlay placement (Fig. 4) is a preferred technique as it distributes tension across a wide area and provides robust reinforcement, and is naturally forced to adhere to the undersurface of the abdominal wall through intraabdominal pressure (Law of LaPlace). Retrorectus mesh placement (the Rives-Stoppa technique) is also a preferred technique, whereby mesh is placed between the well vascularized rectus abdominis muscle and the posterior rectus sheath [61]. Dissection is performed between the posterior sheath and the rectus muscle from medial to lateral until the intercostal perforators are encountered and preserved (Fig. 5). The posterior sheath is closed primarily, and mesh is placed atop this closure. The mesh is secured to the overlying rectus muscle and anterior rectus sheath laterally using transfascial sutures [62].

Finally, in cases where the fascia cannot be approximated primarily, mesh can be placed in a bridging interposition fashion (Fig. 6). This technique has the highest rate of hernia and bulge. In the case of biologic mesh, interposition does not place it in close contact with well-vascularized tissue, and therefore does not allow revascularization and incorporation. This often leads to biologic mesh attenuation, herniation, and bulge [63,64]. Interposition mesh should be avoided whenever possible, through the use of advanced techniques such as component separation and regional fasciocutaneous flaps.

The rates of hernia recurrence and surgical-site occurrences across the various types of mesh placement have been compared extensively in the literature. In a systematic review of 62 peer-reviewed articles including 5,824 patients, Albino et al. [65] found that the rate of hernia recurrence was highest with overlay (17%) and interposition (17%) mesh placement, and lowest with underlay (7.5%) and retrorectus (5%). The hernia recurrence rate with overlay or interposition mesh placement was significantly higher than with underlay or retrorectus mesh placement. For biologic mesh, the recurrence rate was 20% when used as an overlay, 56% when used as an interposition bridge, 8% in the retrorectus position, and 16% when used as an underlay. In comparison, for synthetic mesh, the recurrence rate was 10% when used as an overlay, 11% when used as an interposition bridge, 6% in the retrorectus position, and 5% when used as an underlay.

Overall, infection rates were highest with interposition mesh placement (25%), while there were no differences in infection rates between onlay (4%), underlay (7%) and retrorectus (4%) placement. Interestingly, biologic meshes tended to have more infections than synthetic meshes, although this likely reflects the fact that biologic meshes were used more often in contaminated or dirty wounds in the studies analyzed.

Overall, underlay and retrorectus mesh placement provide the lowest rates of hernia recurrence and surgical-site occurrences, but it is unclear which of the two techniques is best.

ONCOLOGIC CONSIDERATIONS

Management of Positive Margins

Obtaining widely negative margins during the initial resection of an abdominal wall tumor is essential to avoid positive margins on final permanent pathology and the need for re-resection. The presence of a reconstructive surgeon with a firm grasp of advanced reconstructive techniques within the multidisciplinary team, may increase the success of a reconstruction, even if it is of significant size due to the primary goal of obtaining negative margins.

In the case of tumors that have a high recurrence rate, or a high rate of positive margins on final permanent pathology, the simplest reconstructive option that does not compromise quality of life should be performed first [66]. In fact, National Comprehensive Cancer Network guidelines recommend minimizing undermining and rearrangement of adjacent tissues in any case where the risk of recurrence or persistence is high [67]. In cases where persistent disease is found on permanent pathology, every attempt should be made to re-excise the tumor to clear margins, and re-excision is significantly easier in cases where a simple reconstructive method was used. DuBay

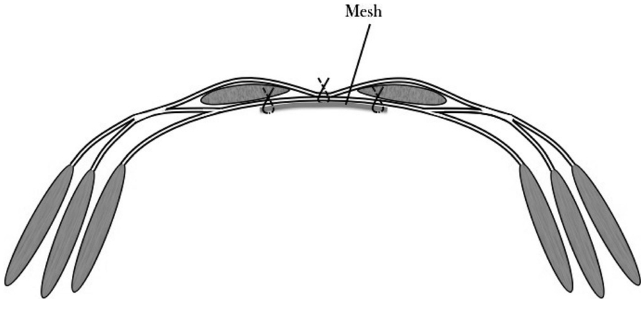

Fig. 4. Underlay placement of mesh.

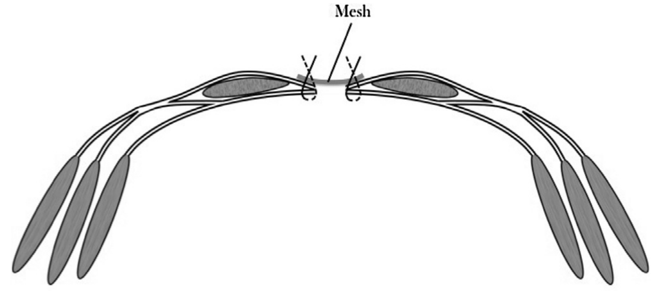

Fig. 6. Interposition bridge placement of mesh.

et al. report on a patient who underwent immediate rotation flap closure after excision of a DFSP, but was then found to have residual disease on permanent pathology [68]. During re-excision, there was extensive tumor infiltration along the undermined plane beneath the rotation flap, requiring a much larger re-excision.

Effect of Radiation

Patients who have had radiation to the abdominal wall prior to reconstruction are at increased risk for wound healing complications and subsequent mesh exposure [69]. For that reason, Butler et al. recommend avoiding synthetic meshes in patients with radiated abdominal walls [69]. They also note that many of those patients require soft tissue reconstruction with healthy, vascularized tissue from a regional or distant source to replace the radiated local tissues. In their series of six patients with prior radiation undergoing abdominal wall reconstruction using AlloDerm in an inlay position, four patients required regional or distant flap transfer. There was one incidence of enterocutaneous fistula, and no instances of hernia or bulge. In an animal study, Dubin et al. showed that placing human acellular dermal matrix in an irradiated field did not impede neovascularization compared to placing it in a non-irradiated field [70].

Chest Wall and Diaphragm Reconstruction

In cases where the resection extends to the chest wall, the latissimus dorsi muscle flap, as well as the pectoralis major flap, serve as workhorse flaps, as they allow obliteration of dead space, and provide a watertight closure that prevents respiratory compromise [71]. Criteria for rigid reconstruction of the chest wall have been described [72]. Most surgeons agree that rigid reconstruction is indicated for bony defects larger than 5 cm or four adjacent ribs. Patients who have had radiation can tolerate larger defects, owing to their stiff chest wall from radiation-induced fibrosis [72]. Rigid reconstruction of the chest wall may be accomplished using bone flaps or grafts, synthetic mesh, or biologic mesh [73].

Patients in whom partial or total resection of a hemidiaphragm is required in order to obtain negative margins represent an added level of complexity to the reconstructive plan. The goals of diaphragm reconstruction are to prevent diaphragmatic hernias, and to provide an airtight closure for improved respiratory mechanics. The major reconstructive options available are primary closure, synthetic meshes, biologic meshes, and autologous flaps. Avella et al. report on five patients with retroperitoneal tumors requiring partial diaphragmatic resection [74]. In patients in whom primary repair of the diaphragm was feasible, human acellular dermal matrix (HADM) was used as an overlay to buttress the primary repair. In patients with larger defects, the HADM was used as an interposition bridge. In all cases, omentum was mobilized and placed against the HADM in order to provide it with a vascularized environment conducive to revascularization. All patients healed without diaphragmatic hernias or respiratory compromise. Barua et al. similarly report on 35 patients with partial hemidiaphragmatic defects, who underwent reconstruction with crosslinked porcine dermal matrix or bovine pericardium [75]. They favor the use of bioprosthetic mesh over synthetic mesh due to the propensity of the latter to cause bowel adhesions, fistulas, and infection. Finley et al. caution that repair of the diaphragm should be performed under some tension, as a loose repair can lead to billowing and paradoxical diaphragmatic motion [76]. When there is concern that biologic mesh may not be able to revascularize due to lack of adjacent vascularized tissue, the latissimus dorsi musculocutaneous flap provides an excellent option that achieves the goals of diaphragmatic reconstruction. McConkey et al. report on the use of this flap, based on its primary thoracodorsal blood supply, with good results [77]. If the patient has had a posterolateral thoracotomy transecting the insertion of the muscle and its thoracodorsal pedicle, a reverse flap, based on its segmental paravertebral blood supply, can be raised and passed through the chest after resection of the tenth rib [78–80].

Bony Pelvic Reconstruction

Patients in whom the bony pelvis is involved with tumor, and who are candidates for limb-sparing resection, may require bony reconstruction in order to preserve ambulation. The major indication for bony reconstruction of the pelvis is disruption of stable bony continuity between the spine and the lower extremities. This can be due to total or partial sacrectomy with disruption of more than 50% of the sacroiliac joints [81] or periacetabular resection with loss of the hip joint [82].

In sacroiliac defects, small defects may be amenable to reconstruction with spinal instrumentation alone [82]. However, multiple studies have shown that reconstruction with a fibula free flap in combination with metallic rods provides superior long-term stability to instrumentation alone [83,84]. Choudry et al. report on the use of bilateral fibula free flaps stabilized to the last remaining vertebral body and to the remaining pelvis in a patient undergoing total sacrectomy, with excellent long-term results [85].

Periacetabular tumor resection usually requires reconstruction, in order to allow ambulation and minimize limb shortening [86]. One option is to use a joint replacement prosthesis, such as the saddle prosthesis used by Cottias et al. [87]. However, most patients in this series had limited ability to ambulate postoperatively. Yu et al. have reported on the use of the fibula free flap to reconstruct periacetabular defects [88]. The fibula was stabilized to the femoral stump, as well as the remaining ilium. Bony union and full weight bearing were obtained in all patients at an average of 13.6 weeks postoperatively.

ALGORITHMIC APPROACH TO ABDOMINAL WALL RECONSTRUCTION

The senior author's (J.E.J) approach to abdominal wall reconstruction is personalized to each patient's specific clinical situation, and informed by published evidence.

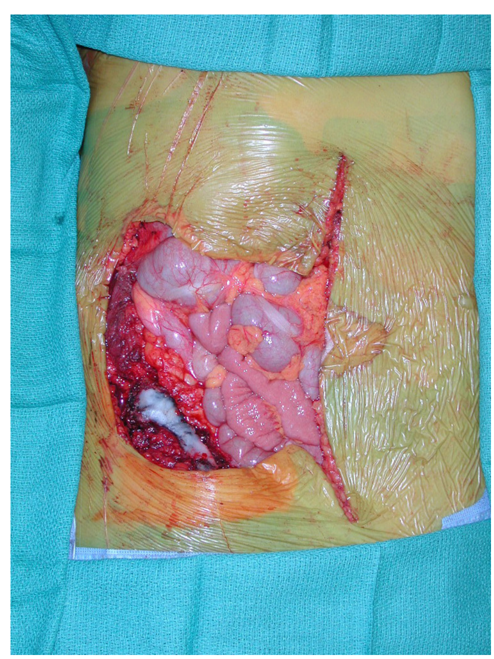

Fig. 7. Case example: Full-thickness defect encompassing most of the right-sided abdominal wall.

Every attempt is made to maximally optimize the patient preoperatively, as outlined above. The patient's best chance at obtaining a stable, long-term abdominal wall reconstruction is at the time of the first operation.

Musculofascial reapproximation is always attempted. The key is to have the fascia under physiologic tension (i.e., the same tension under which it would be in an unoperated abdominal wall). Too little tension can lead to fluid collections. Excessive tension can lead to attenuation and dehiscence. If primary fascial closure does not allow fascial reapproximation under physiologic tension, unilateral minimally-invasive component separation, using the technique described by Butler et al. [27], is used. Bilateral component separation is performed if necessary.

In general, most hernias and abdominal wall reconstructions are reinforced with mesh, in order to decrease the risk hernia formation/recurrence. Synthetic mesh is favored due to its strength, durability, and cost. However, biologics are used more in patients with significant comorbidities or contaminated/infected fields. The mesh is usually placed as a wide intraperitoneal underlay, or in a retrorectus position. The mesh should be under tension, and there should be no wrinkles or folds in it, or fluid will accumulate. Peak inspiratory pressure is always checked after fascial closure, and compared to the value before closure, in order to assess for risk of abdominal compartment syndrome.

Closed-suction drains are placed in the component separation donor site, between mesh and fascia, and in the subcutaneous plane (if necessary). Postoperatively, it is imperative for patients to use incentive spirometry starting in recovery, and to ambulate multiple times a day starting the morning after surgery. The senior author has found that this significantly decreases postoperative medical complications. Antibiotics are not routinely used past the immediate postoperative period.

Case Example

A 61-year-old female with a history of a right abdominal wall desmoid tumor, status post two prior resections and radiation therapy, presented with a recurrence. She underwent a wide local excision of the tumor, resulting in a massive full-thickness defect of her right

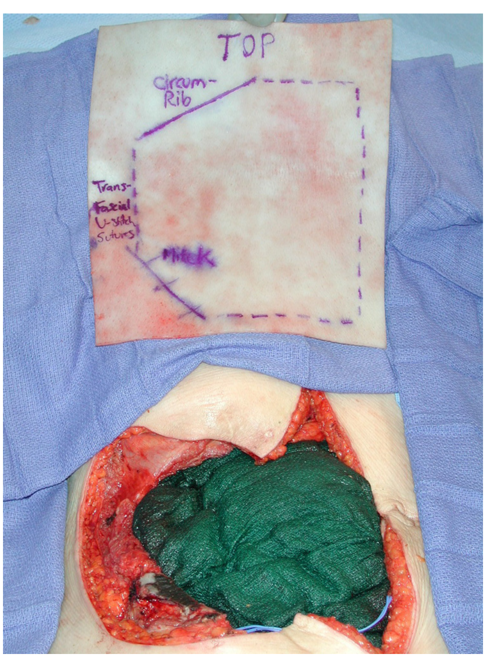

Fig. 8. Case example: XenMatrix porcine acellular dermal matrix fashioned to the fascial defect, with 4 cm overlap in all directions.

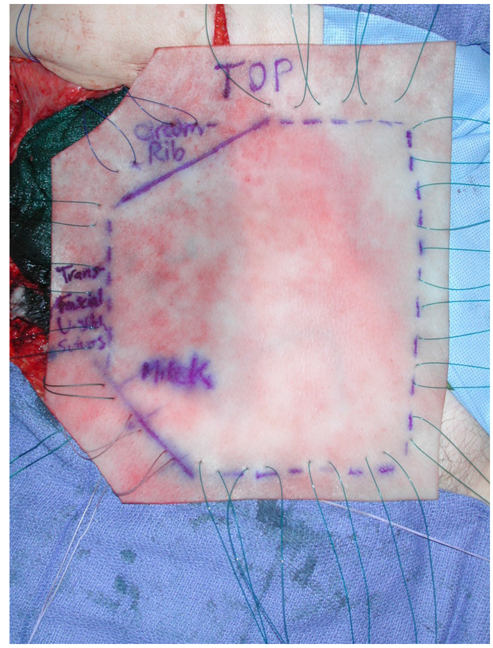

Fig. 9. Case example: XenMatrix mesh with U-stitches that would be placed transfascially in order to place the mesh in a wide intraperitoneal underlay position.

abdominal wall measuring 450 cm^2, and extending from the costal margin to the pelvis, including the entire right-sided rectus muscle, portions of the internal oblique, external oblique and transversus abdominis muscles, the superior epigastric vessels and the deep inferior epigastric vessels (Fig. 7). The patient thus had a type 3 abdominal wall defect, encompassing both soft tissue and fascia. Due to the massive size of her fascial defect, it was deemed that primary fascial reapproximation could not be achieved. The next best alternative would be to perform contralateral minimally-invasive component separation in order to minimize the size of the fascial defect, and to place mesh in a wide intraperitoneal underlay position, as described by Butler et al. [27].

Due to her history of radiation therapy, it was deemed that healthy, well-vascularized regional or distant soft tissue would need to be used to

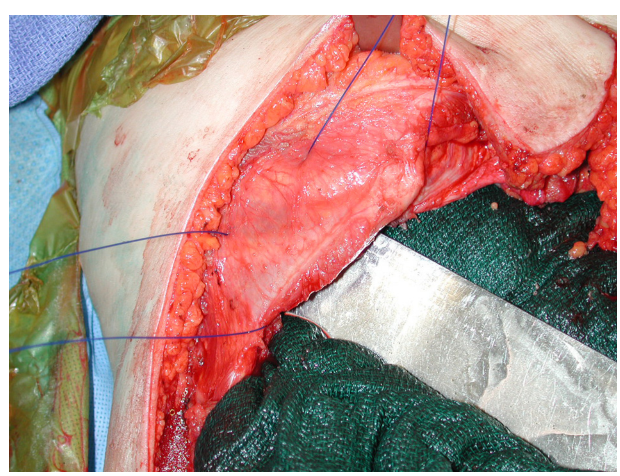

Fig. 10. Case example: Circum-costal sutures in place.

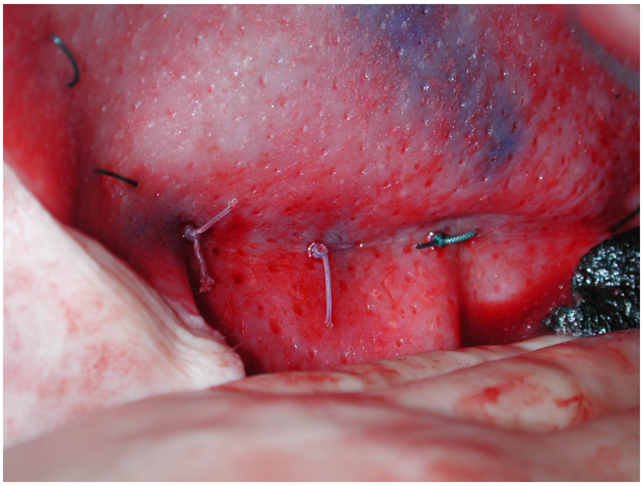

Fig. 11. Case example: Mitek suture anchors used to anchor the mesh to the iliac crest.

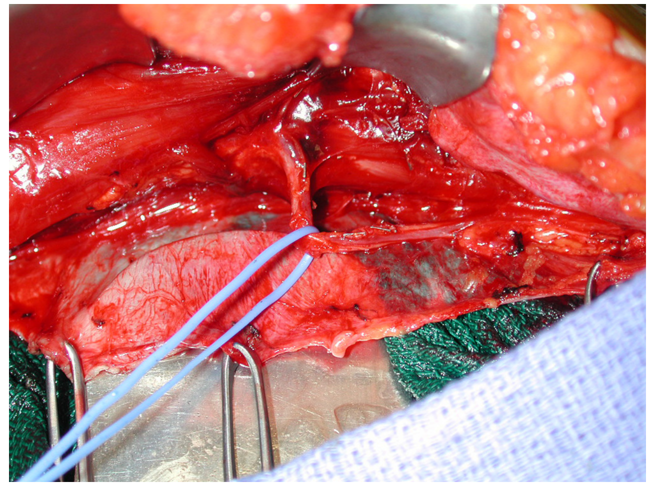

Fig. 13. Case example: The descending branch of the lateral circumflex femoral artery, dissected to its origin.

replace her radiated local tissue. It was also deemed that biologic mesh would be safest to use in the setting of radiation therapy [69], as it has been shown to incorporate well in the face of radiation [70], and could be treated with local wound care if exposed due to dehiscence or partial flap necrosis. Noncrosslinked porcine acellular dermal matrix was fashioned to the fascial defect, with 4 cm overlap in all directions (Fig. 8). The mesh was secured to the underside of the remaining abdominal musculature using transfascial U-stitches (Fig. 9), to a fixed rib using circum-costal sutures (Fig. 10), and to the iliac crest using Mitek (DePuy Mitek Inc., Raynham, MA) suture anchors (Fig. 11).

An anterolateral thigh flap was designed, based on the descending branch of the lateral circumflex femoral vessels (Fig. 12). The flap was raised as described by Lin and Butler [32], including a large portion of the tensor fascia lata, and a cuff of vastus lateralis muscle in order to promote neovascularization of the underlying biologic mesh. Even after the pedicle had been skeletonized and dissected all the way to its origin from the profunda femoris vasculature (Fig. 13), the flap could not be transposed as a pedicled flap to reach the most superior aspect of the defect (Fig. 14). Instead, it was transferred as a free flap, with microsurgical anastomosis of the flap's descending branch of the lateral circumflex femoral vessels to the patient's left deep inferior epigastric vessels. The fascia of the flap was approximated to the edges of the remaining abdominal musculature, completely covering the biologic mesh. This was followed by skin repair (Fig. 15). The thigh donor site was skin grafted (Fig. 16).

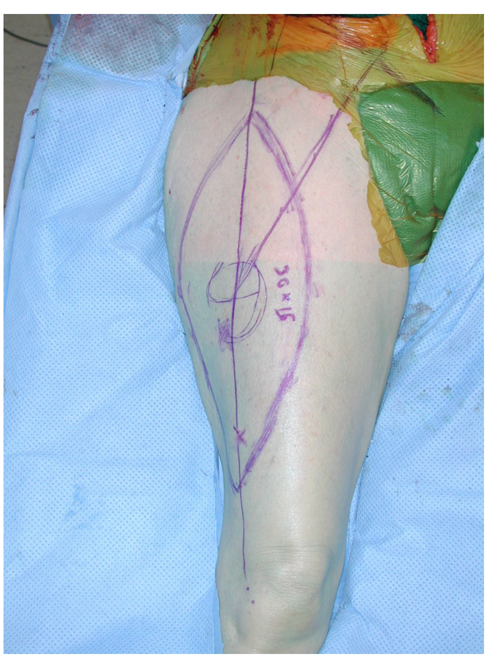

Fig. 12. Case example: Design of the anterolateral thigh flap.

Fig. 14. Case example: Cranial reach of the fully dissected pedicled anterolateral thigh flap.

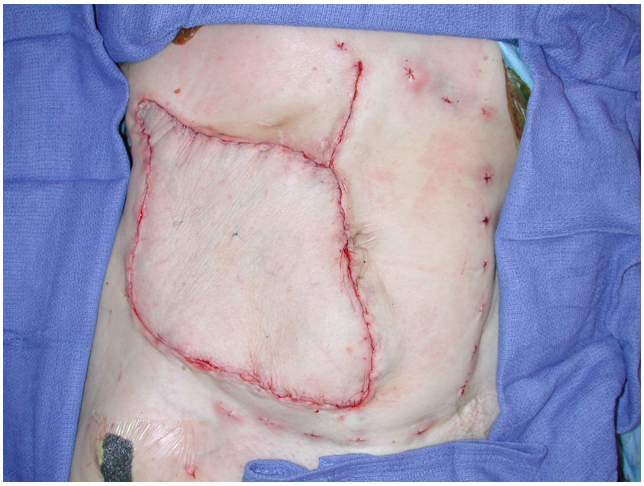

Fig. 15. Case example: Appearance of the completed free flap inset.

Fig. 16. Case example: Right thigh flap donor site with skin graft in place.

FUTURE DIRECTION

As reconstructive surgeons devise new, more advanced techniques, larger, and more complex abdominal wall defects are becoming more amenable to reconstruction. Tissue expansion has been used successfully to generate soft tissues to allow closure of complex abdominal defects [89]. Newer, stronger acellular dermal matrices have been manufactured, and have allowed for a more durable abdominal wall repair [90]. As the fields of abdominal wall reconstruction and of reconstructive surgery advance, the number of rungs on the traditional reconstructive ladder is expanding [91], providing reconstructive surgeons with new and improved reconstructive tools.

SUMMARY

Abdominal wall reconstruction after oncologic resection can be performed with excellent outcomes by preoperative patient optimization, careful analysis of the defect, and application of evidence-based medicine and sound oncologic principles.

REFERENCES

1. Flum DR, Horvath K, Koepsell T: Have outcomes of incisional hernia repair improved with time? A population-based analysis. Ann Surg 2003;237:129–135.
2. Williams KJ, Hayes AJ: A guide to oncological management of soft tissue tumors of the abdominal wall. Hernia 2014;18:91–97.
3. Stojadinovic A, Hoos A, Karpoff HM, et al.: Soft tissue tumors of the abdominal wall: Analysis of disease patterns and treatment. Arch Surg 2001;136:70–79.
4. Yezhelyev MV, Deigni O, Losken A: Management of full-thickness abdominal wall defects following tumor resection. Ann Plast Surg 2012;69:186–191.
5. Breuing K, Butler CE, Ferzoco S, et al.: Incisional ventral hernias: Review of the literature and recommendations regarding the grading and technique of repair. Surgery 2010;148:544–558.
6. Dunne JR, Malone DL, Tracy JK, et al.: Abdominal wall hernias: Risk factors for infection and resource utilization. J Surg Res 2003;111:78–84.
7. Finan KR, Vick CC, Kiefe CI, et al.: Predictors of wound infection in ventral hernia repair. Am J Surg 2005;190:676–681.
8. Luijendijk RW, Hop WC, van den Tol MP, et al.: A comparison of suture repair with mesh repair for incisional hernia. N Engl J Med 2000;343:392–398.
9. Kanters AE, Krpatafor DM, Blatnik JA, et al.: Modified hernia grading scale to stratify surgical site occurrence after open ventral hernia repairs. J Am Coll Surg 2012;215:787–793.
10. Sorensen LT: Wound healing and infection in surgery: The pathophysiological impact of smoking, smoking cessation, and nicotine replacement therapy: A systematic review. Ann Surg 2012;255:1069–1079.
11. Janis JE: Discussion: The role of chronic and perioperative glucose management in high-risk surgical closures: A case for tighter glycemic control. Plast Reconstr Surg 2013;132:1005–1007.
12. Latham R, Lancaster AD, Covington JF, et al.: The association of diabetes and glucose control with surgical-site infections among cardiothoracic surgery patients. Infect Cont Hosp Epidem 2001;22:607–612.
13. Endara M, Masden D, Goldstein J, et al.: The role of chronic and perioperative glucose management in high-risk surgical closures: A case for tighter glycemic control. Plast Reconstr Surg 2013; 132:996–1004.
14. Ramos M, Khalpey Z, Lipsitz S, et al.: Relationship of perioperative hyperglycemia and postoperative infections in patients who undergo general and vascular surgery. Ann Surg 2008;248:585–591.
15. Khuri SF, Daley J, Henderson W, et al.: Risk adjustment of the postoperative mortality rate for the comparative assessment of the quality of surgical care: Results of the national veterans affairs surgical risk study. J Am Coll Surg 1997;185:315–327.
16. Kudsk KA, Tolley EA, DeWitt RC, et al.: Preoperative albumin and surgical site identify surgical risk for major postoperative complications. J Parenter Enteral Nutr 2003;27:1–9.
17. Mullen JL, Buzby GP, Matthews DC, et al.: Reduction of operative morbidity and mortality by combined preoperative and postoperative nutritional support. Ann Surg 1980;192:604–613.
18. Jie B, Jiang ZM, Nolan MT, et al.: Impact of preoperative nutritional support on clinical outcome in abdominal surgical patients at nutritional risk. Nutrition 2012;28:1022–1027.
19. Read RC, Yoder G: Recent trends in the management of incisional herniation. Arch Surg 1989;124:485–488.
20. Ger R, Duboys E: The prevention and repair of large abdominal-wall defects by muscle transposition: A preliminary communication. Plast Reconstr Surg 1983;72:170–175.

21. Booth JH, Garvey PB, Baumann DP, et al.: Primary fascial closure with mesh reinforcement is superior to bridged mesh repair for abdominal wall reconstruction. J Am Coll Surg 2013;217:999–1009.
22. Sosin M, Patel KM, Albino FP, et al.: A patient-centered appraisal of outcomes following abdominal wall reconstruction: A systematic review of the current literature. Plast Reconstr Surg 2014; 133:408–418.
23. Zarzaur BL, DiCocco JM, Shahan CP, et al.: Quality of life after abdominal wall reconstruction following open abdomen. J Trauma 2011;70:285–291.
24. Patel KM, Bhanot P: Complications of acellular dermal matrices in abdominal wall reconstruction. Plast Reconstr Surg 2012;130: 216S–224S.
25. Schaverien M, Saint-Cyr M, Arbique G, et al.: Arterial and venous anatomies of the deep inferior epigastric perforator and superficial inferior epigastric artery flaps. Plast Reconstr Surg 2008;121:1909–1919.
26. Saulis AS, Dumanian GA: Periumbilical rectus abdominis perforator preservation significantly reduces superficial wound complications in "separation of parts" hernia repairs. Plast Reconstr Surg 2002;109:2275–2280.
27. Butler CE, Campbell KT: Minimally invasive component separation with inlay bioprosthetic mesh (MICSIB) for complex abdominal wall reconstruction. Plast Reconstr Surg 2011;128: 698–709.
28. Tang R, Gu Y, Gong DQ, et al.: Immediate repair of major abdominal wall defect after extensive tumor excision in patients with abdominal wall neoplasm: A prospective review of 27 cases. Ann Surg Oncol 2009;16:2895–2907.
29. Scaglioni MF, Di Giuseppe A, Chang EI: Propeller flap reconstruction of abdominal defects: Review of the literature and case report. Microsurgery 2014;Epub ahead of print.
30. Ramirez OM, Ruas E, Dellon AL: "Components separation" method for closure of abdominal-wall defects: An anatomic and clinical study. Plast Reconstr Surg 1990;86:519–526.
31. Dorai AA, Halim AS: Extended double pedicle free tensor fascia latae myocutaneous flap for abdominal wall reconstruction. Singapore Med J 2007;48:e141–e145.
32. Lin SJ, Butler CE: Subtotal thigh flap and bioprosthetic mesh reconstruction for large, composite abdominal wall defects. Plast Reconstr Surg 2010;125:1146–1156.
33. Lannon DA, Ross GL, Addison PD, et al.: Versatility of the proximally pedicled anterolateral thigh flap and its use in complex abdominal and pelvic reconstruction. Plast Reconstr Surg 2011;127:677–688.
34. Sarabahi S, Bajaj SP, Bhatnagar A, et al.: Reconstruction of abdominal wall by whole thigh flap. JPRAS 2006;59:1429–1432.
35. Kimata Y, Uchiyama Y, Sekido M, et al.: Anterolateral thigh flap for abdominal wall reconstruction. Plast Reconstr Surg 1999; 103:1191–1197.
36. Ninkovic M, Kronberger P, Harpf C, et al.: Free innervated latissimus dorsi muscle flap for reconstruction of full-thickness abdominal wall defects. Plast Reconstr Surg 1998;101:971–978.
37. Cheatham ML, Demetriades D, Fabiar TC, et al.: Prospective study examining clinical outcomes associated with a negative pressure wound therapy system and Barker's vacuum packing technique. World J Surg 2013;37:2018–2030.
38. Fabian TC, Croce MA, Pristchard E, et al.: Planned ventral hernia: Staged management for acute abdominal wall defects. Ann Surg 1994;219:643–653.
39. Burger JW, Luijendijk RW, Hop WC, et al.: Long-term follow-up of a randomized controlled trial of suture versus mesh repair of incisional hernia. Ann Surg 2004;240:578–583.
40. Stabillini C, Stella M, Frascio M, et al.: Mesh versus direct suture for the repair of umbilical and epigastric hernias. Ten-year experience. Ann Ital Chir 2009;80:183–187.
41. Dibello JN, Moore JH: Sliding myofascial flap of the rectus abdominis muscle for the closure of recurrent ventral hernias. Plast Reconstr Surg 1996;98:461–469.
42. Shestak KC, Edington HJD, Johnson RR: The separation of anatomic components technique for the reconstruction of massive abdominal wall defects: Anatomy, surgical technique, applications and limitations revisited. Plast Reconstr Surg 2000;105:731–738.
43. Girotto JA, Ko MJ, Redett R, et al.: Closure of chronic abdominal wall defects: A long-term evaluation of the components separation method. Ann Plast Surg 1999;42:385–394.
44. Ghali S, Turza KC, Baumann DP, et al.: Minimally invasive component separation results in fewer wound-healing complications than open component separation for large ventral hernia repairs. J Am Coll Surg 2012;214:981–989.
45. Lowe JB, Garza JR, Bowman JL, et al.: Endoscopically assisted "components separation" for closure of abdominal wall defects. Plast Reconstr Surg 2000;105:720–729.
46. Rosen MJ, Jin J, McGee MF, et al.: Laparoscopic component separation in the single-stage treatment of infected abdominal wall prosthetic removal. Hernia 2007;11:435–440.
47. Harth KC, Rosen MJ: Endoscopic versus open component separation in complex abdominal wall reconstruction. Am J Surg 2010;199:342–347.
48. Novistky YW, Elliott HL, Orenstein SB, et al.: Transversus abdominis muscle release: A novel approach to posterior component separation during complex abdominal wall reconstruction. Am J Surg 2012;204:709–716.
49. Nthumba P, Barasa J, Cavadas PC, et al.: Pedicled fasciocutaneous anterolateral thigh flap for the reconstruction of a large postoncologic abdominal wall resection defect: A case report. Ann Plast Surg 2012;68:188–189.
50. Yang F: Radical tumor excision and immediate abdominal wall reconstruction in patients with aggressive neoplasm compromised full-thickness lower abdominal wall. Am J Surg 2013;205:15–21.
51. Butler CE, Prieto VG: Reduction of adhesions with composite AlloDerm/polypropylene mesh implants for abdominal wall reconstruction. Plast Reconstr Surg 2004;114:464–473.
52. Danino AM, Malka G, Revol M, et al.: A scanning electron microscopical study of the two sides of polypropylene mesh (Marlex) and PTFE (GoreTex) mesh 2 years after complete abdominal wall reconstruction: A study of 15 cases. Br Assoc Plast Surg 2005;58:384–388.
53. Stone HH, Fabian TC, Turkleson ML, et al.: Management of acute full-thickness losses of the abdominal wall. Ann Surg 1981; 193:612–617.
54. Diaz JJ, Conquest AM, Ferzoco SJ, et al.: Multi-institutional experience using human acellular dermal matrix for ventral hernia repair in a compromised surgical field. Arch Surg 2009;144: 209–215.
55. Connor J, McQuillan D, Sandor M, et al.: Retention of structural and biochemical integrity in a biological mesh supports tissue remodeling in a primate abdominal wall model. Regen Med 2009;4:185–195.
56. Milburn ML, Holton LH, Chung TL, et al.: Acellular dermal matrix compared with synthetic implant material for repair of ventral hernia in the setting of peri-operative Staphylococcus aureus implant contamination: A rabbit model. Surg Inf 2008;9: 433–442.
57. Harth KC, Broome AM, Jacobs MR, et al.: Bacterial clearance of biologic grafts used in hernia repair: An experimental study. Surg Endosc 2011;25:2224–2229.
58. Butler CE, Baumann DP, Janis JE, et al.: Abdominal wall reconstruction. Curr Probl Surg 2013;50:557–586.
59. Lin HJ, Spoerke N, Deveney C, et al.: Reconstruction of complex abdominal wall hernias using acellular human dermal matrix: A single institution experience. Am J Surg 2009;197:599–603.
60. Janis JE: Utilization of progressive tension sutures in components separation: Merging cosmetic surgery techniques with reconstructive surgery outcomes. Plast Reconstr Surg 2012;130:851–855.
61. Bauer JJ, Harris MT, Gorfine SR, et al.: Rives-Stoppa procedure for repair of large incisional hernias: Experience with 57 patients. Hernia 2002;6:120–123.
62. Flament JB: Retro rectus approach to ventral hernia repair. Op Tech Gen Surg 2004;6:165–178.
63. Patton JH, Berry S, Kralovich KA: Use of human acellular dermal matrix in complex and contaminated abdominal wall reconstructions. Am J Surg 2007;193:360–363.

64. Bluebond-Langner R, Keifa ES, Mithani S, et al.: Recurrent abdominal laxity following interpositional human acellular dermal matrix. Ann Plast Surg 2008;60:76–80.
65. Albino FP, Patel KM, Nahabedian MY, et al.: Does mesh location matter in abdominal wall reconstruction? A systematic review of the literature and a summary of recommendations. Plast Reconstr Surg 2013;132:1295–1304.
66. Goldberg C, Hoang D, McRae M, et al.: A strategy for the successful management of dermatofibrosarcoma protuberans. Ann Plast Surg 2013Epub ahead of print.
67. National Comprehensive Cancer Network. Clinical practice guidelines in oncology: Dermatofibrosarcoma protuberans. 2012. Available at http://www.nccn.org/professionals/physicians_gls/PDF/dfsp.pdf Accessed August 24, 2014.
68. DuBay D, Cimmino V, Lowe L, et al.: Low recurrence rate after surgery for dermatofibrosarcoma protuberans. Cancer 2004;100: 1008–1016.
69. Butler CE, Langstein HN, Kronowitz SJ: Pelvic, abdominal, and chest wall reconstruction with AlloDerm in patients at increased risk for mesh-related complications. Plast Reconstr Surg 2005;116: 1263–1275.
70. Dubin MG, Feldman M, Ibrahim HZ, et al.: Allograft dermal implant (AlloDerm) in a previously irradiated field. Laryngoscope 2000;110:934–937.
71. Bakri K, Mardini S, Evans KK, et al.: Workhorse flaps in chest wall reconstruction: The pectoralis major, latissimus dorsi, and rectus abdominis flaps. Semin Plast Surg 2011;25:43–54.
72. Mahabir RC, Butler CE: Stabilization of the chest wall: Autologous and alloplastic reconstructions. Semin Plast Surg 2011;25: 34–42.
73. Jonsson P, Gyllstedt E, Hambraeus GR, et al.: Chest wall sarcoma: Outcome in 22 patients after resection requiring thoracic cage reconstruction. Sarcoma 1998;2:143–147.
74. Avella D, Garcia LJ, Gusani NJ, et al.: Human acellular dermal matrix: An innovative tool for diaphragmatic reconstruction in patients with large intra-abdominal tumors. Am J Surg 2010;199: e12–e16.
75. Barua A, Catton JA, Socci L, et al.: Initial experience with the use of biological implants for soft tissue and chest wall reconstruction in thoracic surgery. Ann Thorac Surg 2012;94:1701–1705.
76. Finley DJ, Abu-Rustum NR, Chi DS, et al.: Reconstructive techniques after diaphragm resection. Thorac Surg Clin 2009;19: 531–535.
77. McConkey MO, Temple CLF, McFadden S, et al.: Autologous diaphragm reconstruction with the pedicled latissimus dorsi flap. J Surg Oncol 2006;94:248–251.
78. Bedini AV, Andreani SM, Muscolino G: Latissimus dorsi reverse flap to substitute the diaphragm after extrapleural pneumonectomy. Ann Thorac Surg 2000;69:986–988.
79. Sinna R, De Dominicis F, Quassemyar Q, et al.: Diaphragmatic reconstruction using combined reversed extended latissimus dorsi and serratus anterior fascia flaps. Ann Thorac Surg 2011;91: 922–924.
80. Yoshioka M, Nomori H, Mori T, et al.: Extrapleural pneumonectomy via a lower door open thoracotomy with reconstruction of the diaphragm and pericardium using autologous materials for mesothelioma. Surg Today 2006;36:1036–1038.
81. Gunterberg B, Romanus B, Stener B: Pelvic strength after major amputation of the sacrum: An experimental study. Acta Orthop Scand 1976;47:635–642.
82. Niemeyer P, Ludwig K, Werner M, et al.: Reconstruction of the pelvic ring using an autologous free non-vascularized fibula graft in a patient with benign fibrous histiocytoma. World J Surg Oncol 2004;2:38–43.
83. Zhu R, Cheng LM, Yu Y, et al.: Comparison of four reconstruction methods after total sacrectomy: A finite element study. Clin Biomech 2012;27:771–776.
84. Cheng L, Yu Y, Zhu R, et al.: Structural stability of different reconstruction techniques following total sacrectomy: A biomechanical study. Clin Biomech 2011;26:977–981.
85. Choudry UH, Moran SL, Karacor Z: Functional reconstruction of the pelvic ring with simultaneous bilateral free fibular flaps following total sacral resection. Ann Plast Surg 2006;57: 673–676.
86. Satcher RL, O'Donnell RJ, Johnston JO: Reconstruction of the pelvis after resection of tumors about the acetabulum. Clin Orthop Relat Res 2003;409:209–217.
87. Cottias P, Jeanrot C, Vinh TS, et al.: Complications and functional evaluation of 17 saddle prostheses for resection of periacetabular tumors. J Surg Oncol 2001;78:90–100.
88. Yu G, Zhang F, Zhou J, et al.: Microsurgical fibular flap for pelvic ring reconstruction after periacetabular tumor resection. J Reconstr Microsurg 2007;23:137–142.
89. Carlson GW, Elwood E, Losken A, et al.: The role of tissue expansion in abdominal wall reconstruction. Ann Plast Surg 2000; 44:147–153.
90. Janis JE, O'Neill AC, Ahmad J, et al.: Acellular dermal matrices in abdominal wall reconstruction: A systematic review of the current evidence. Plast Reconstr Surg 2012;130:183S–193S.
91. Janis JE, Kwon RK, Attinger CE: The new reconstructive ladder: Modifications to the traditional model. Plast Reconstr Surg 2011;127:205S–212S.