An Algorithm for Abdominal Wall Reconstruction

Rod J. Rohrich, M.D., James B. Lowe, M.D., Fred L. Hackney, M.D., D.D.S., Julie L. Bowman, M.D., and P. C. Hobar, M.D.

Dallas, Texas

Learning Objectives: After studying this article, the participant should be able to: 1. Describe the anatomy of the anterior abdominal wall, including the neurovasculature and musculofascial layers. 2. List the goals of abdominal wall reconstruction. 3. Discuss the components of the preoperative evaluation of abdominal wall reconstruction. 4. Discuss the considerations in determining immediate versus delayed repair. 5. Be familiar with the following techniques: tissue expansion, vacuum-assisted closure device, abdominal components separation, prosthetic materials, local and distant muscle flaps, free tissue transfer.

Acquired abdominal wall defects result from trauma, previous surgery, infection, and tumor resection. The correction of complex defects is a challenge to both plastic and reconstructive and general surgeons. The anatomy of the abdominal wall, as well as considerations in patient assessment and surgical planning, are discussed. A simple classification of abdominal wall defects based on size, depth, and location is provided. Publications regarding the various abdominal reconstruction techniques are reviewed and summarized to familiarize the reader with the treatment options for each particular defect. Finally, an algorithm is presented to guide the surgeon in selecting the optimal reconstructive technique. (Plast. Reconstr. Surg. 105: 202, 2000.)

Complex abdominal wall defects challenge both general and plastic and reconstructive surgeons. Over the past decade, surgeons have benefited from advancements that have transformed the way we deal with this complex problem. Acquired abdominal wall defects result from previous surgery, trauma, infection, and tumor resection. The reconstructive goals are to protect abdominal contents and provide functional support.

Treatment for an abdominal defect is selected on the basis of several factors, including (1) the medical status of the patient, (2) wound bed preparedness and depth, and (3) size and position of the defect. This article presents a simple classification of abdominal wall defects that will enable the plastic surgeon to develop an algorithmic approach for reconstruction. Previous publications regarding the various techniques of abdominal wall reconstruction are summarized to assist the reader in making treatment decisions.

ANATOMY

An understanding of the surgical anatomy of the abdominal wall is crucial when planning reconstruction. The blood supply, innervation, and complex fascial layers of the abdominal wall are discussed.

Skin and Subcutaneous Tissue

The anatomy of the abdominal skin envelope of an individual is related to body habitus and previous surgery. The obese patient has an excess amount of skin. Patients with previous incisions may have significant disturbances in the cutaneous blood supply. Tissue expansion will change the anatomy of the dermis and epidermis, and the capsule will assist in skin perfusion.

The underlying subcutaneous tissue is divided into the superficial and deep layers, which are separated by Scarpa’s fascia. Whereas the superficial layer covers the entire abdominal wall, the deep layer is limited to the
lower abdomen, below the level of the umbilicus. The continuity of the subcutaneous fascial system should be maintained for an optimal aesthetic outcome.

Musculofascial Layers

The musculofascial layers of the abdominal wall are clearly defined in the literature and anatomy textbooks. An understanding of the layers of the abdominal wall and the anatomic transitions is vital to reconstruction. Fusion of the fascial layers forms three lines on the abdominal wall: the midline linea alba and the two semilunar lines.

The deep fascia is composed of the aponeuroses of the internal and external oblique and transversus abdominis, which fuse at the lateral border of the rectus muscle, forming the semilunar line. Above the arcuate line, the aponeuroses of the internal and external oblique form the anterior fascial layer. The aponeuroses of the internal oblique splits and joins the transversus abdominis to course posterior to the rectus abdominis muscle, forming the posterior layer. The posterior fascial layer lines the abdomen, separating the peritoneum from the abdominal wall. Below the arcuate line, the three aponeuroses are bundled together, forming the anterior layer of the rectus sheath.

The musculature of the abdominal wall can be divided into anterior, anterolateral, and posterior layers. Anteriorly are the rectus abdominis and pyramidalis muscles; anterolaterally, the external oblique, internal oblique, and transversus abdominis muscles; and posteriorly, the quadratus lumborum muscle.

Vascular Supply

Blood is supplied to the abdominal wall both by direct cutaneous vessels and musculocutaneous vessels. Haddad demonstrated the exact locations of these vessels using arteriography. Huger later classified the vascular supply into simple zones for use in abdominal lipectomy. This classification can be applied to abdominal reconstruction.

Zone I, the midabdomen, is supplied primarily by the deep epigastric arcade. The superior epigastric artery arises from the internal thoracic artery and descends with the posterior rectus sheath. The deep inferior epigastric artery arises from the external iliac artery and ascends with the posterior rectus sheath. Each of these vessels supplies branches to the rectus muscle and overlying skin.

Zone II, the lower abdomen, is supplied by branches of the epigastric arcade and the external iliac artery. The superficial epigastric and superficial external pudendal arteries originate from the femoral artery running superficial to the fascia to supply the overlying skin. The inferior epigastric artery on the posterior rectus sheath supplies the underlying muscle in this zone. The deep circumflex iliac artery supplies the muscles in the area of the anterior iliac spine.

Zone III, the flanks and lateral abdomen, are supplied by the intercostal, subcostal, and lumbar arteries. These vessels arise from the aorta and give off perforators to the back and flank. They travel circumferentially on the transversus abdominis, perforating the oblique muscles and supplying the overlying skin.

The lymphatics closely follow the arterial supply but have more overlap in their distribution. Below the umbilicus, in zone II, the drainage is to the inguinal nodes. Deeper drainage occurs by means of the deep epigastric vessels to the external iliac nodes. Zone I both drains to the deep epigastria and follows zone III drainage to the lateral lumbar nodes and superficial inguinal nodes.

Innervation

The intercostal, subcostal, iliohypogastric, and ilioinguinal nerves, which provide motor and sensory innervation to the abdomen, are derived from the roots of nerves T7–L4. These nerves course circumferentially through the abdominal wall, terminating at the midline. The rectus abdominis muscle is innervated by the five lower intercostal nerves as well as the subcostal nerve. The external oblique is innervated by the intercostal, subcostal, and iliohypogastric nerves. The internal oblique and transversus abdominis muscles are supplied by the intercostal, subcostal, iliohypogastric, and the ilioinguinal nerves. The iliohypogastric nerve also supplies the pubis with crossover from the femoral cutaneous nerve. Nerves should be preserved not only for sensation but also to maintain motor function.

Goals

The goals of abdominal reconstruction are threefold: (1) restoration of function and integrity of the musculofascial abdominal wall, (2) prevention of visceral eventration, and (3) provision of dynamic muscle support.
SURGICAL PLANNING

Preoperative Care

When assessing the patient, a complete history, physical, and laboratory workup are essential. The initial assessment may require the involvement of multiple specialties, including general surgery, internal medicine, nutrition, pulmonology, and infectious disease. Coordination of these services is the responsibility of the reconstructive surgeon.

The patient’s medical and social histories are considered. Pulmonary function tests are evaluated, because postoperative loss of domain will decrease total lung capacity, vital capacity, and functional residual capacity. The medication list is reviewed to alert the surgeon about possible complications, such as immunocompromise and slowed wound healing, which are associated with steroid dependency. Finally, social history is important inasmuch as tobacco slows wound healing and alcohol abuse is associated with immunocompromise.

Poor nutritional status negatively affects wound healing. Temple et al. demonstrated that malnutrition was associated with delayed tensile strength in rats. Serum protein levels below 2 g% in humans have been shown to prolong the inflammatory phase and impair fibroplasia. Repair is delayed until nutritional status is optimized.

Weight reduction is encouraged before reconstruction to decrease recurrence and complication rates. Immediately preoperatively, placement of a nasogastric tube is considered, although use is rarely indicated. Bowel preparation, skin preparation, and preoperative intravenous antibiotics are required. Pneumatic compression devices are placed before surgery. Special attention is given to correction of nutritional deficits, pulmonary disorders, and fluid and electrolyte abnormalities.

The desired outcome should achieve both aesthetic and functional goals. The patient’s future expectations, physical activity, and longevity are important considerations. The surgeon and patient should discuss all available alternatives inasmuch as patient compliance will directly affect outcome.

Wound Bed

The wound bed is thoroughly examined at the initial evaluation. The primary issues affecting timing of reconstruction and the specific technique used are inflammation, infection, neoplasms, trauma, and previous surgeries.

A relative tissue deficiency is seen when distended bowel or soft tissue contraction results in the inability to close a defect. In contrast, absolute tissue deficiency involves the quantitative loss of tissue, as from resection. Regardless of the depth of the defect, an absolute tissue loss indicates that anatomic structures may be distorted or lost. Absolute defects are more difficult to correct.

Unfortunately, acute inflammation and edema of the wound bed are often ignored during the reconstructive workup. Even if the contaminated wound bed is converted to clean with debridement, local tissue advancement may be severely limited by inflammation. Repair of patients with fistulas, recent exploration, or significant inflammation from trauma or infection should be delayed until inflammation is minimized. Secondary repairs are associated with significant scar tissue and adhesions, making the operation more difficult.

The infection rate for a clean wound is 1.5 to 3.0 percent, for a clean contaminated wound 3 to 4 percent, for a contaminated wound 8.5 percent, and for a dirty wound as high as 40 percent. Infection rates are higher in the presence of coexisting risk factors such as previous radiation, fistulas, and immune suppression.

Wound infection occurs when pathogenic organisms exceed the combative ability of local tissue defenses. For most bacterial organisms the critical threshold is $10^5$ per gram of tissue; beta-hemolytic streptococcus has a lower threshold. Infection has many harmful consequences, including decrease of the tissue partial pressure of oxygen, prolongation of the inflammatory phase, stimulation of collagenolysis, and inhibition of the immune response. Antibiotic use depends on the clinical status of the patient rather than culture results, because wounds have up to a 40 percent rate of recolonization despite complete healing and absence of clinical signs of infection.

A history of abdominal neoplasm may complicate the reconstructive course inasmuch as chemotherapy impedes wound healing and radiation therapy causes extensive tissue injury and may contribute to abdominal wall defects. Radiation injury following the treatment of intraabdominal disease may present with an associated hernia. Acute radiation in-
jury to a wound bed is manifest by stasis or occlusion of the small vessels and decreased tensile strength. Miller and Rudolph reported that ionizing radiation directly hinders fibroblast proliferation and causes irreversible damage to exposed skin and tissue. During treatment of the previously irradiated patient, the reconstructive surgeon should consider the transfer of nonirradiated tissue by mobilizing distant flaps.

Traumatic rupture of the abdominal wall, most commonly supraumbilical, has a 30 percent rate of concurrent intra-abdominal injury. Although immediate reconstruction is recommended in most cases, delay may be required depending on the clinical presentation. Although usually uninvolved in the management of acute penetrating abdominal injury, the plastic surgeon may be called on at a later date for repair of subsequent loss of domain.

The wound bed of the recently postoperative patient requires special attention. Acute wound dehiscence has a 1.8 percent rate of occurrence, developing approximately 7 days after surgery, when the wound is weakest. The reconstructive surgeon may also be called to evaluate wounds that have been left open or temporized. The wound may involve widely separated and contracted musculofascial tissue, exposed viscera, or adherent bowel requiring extensive dissection. Another common defect is the incisional hernia, which has a reported primary occurrence rate of 11 percent, with a recurrence rate as high as 50 percent.

Prosthetic material used in previous operations may present with complications from infection, extrusion, and fistulas. A hernia that recurs despite prosthetic repair is usually the result of tension or insufficient suture technique. Complications vary with the composition of the prosthetic material. Meshed materials integrate into tissues impeding removal, whereas nonmeshed materials such as polytetrafluoroethylene and Silastic are less adherent to surrounding tissues.

Previous incisions indicate interruption of abdominal circulation and therefore are noted on physical examination. Although revascularization has been reported in the literature, caution should be exercised when creating skin islands. Additionally, postoperative abdominal defects are often associated with significant intra-abdominal abnormalities, including vascular interruption and adhesions. Extensive lysis of intra-abdominal adhesions is not indicated in most situations and its routine performance will significantly increase risk to the patient. However, fascial edges must be freed, usually requiring dissection of bowel and resection of the hernia sac.

Immediate versus Delayed Reconstruction

The determination of an immediate versus staged repair depends on the clinical situation. Immediate reconstruction is preferred because it is more cost-effective and less time-consuming in the medically stable patient with a clean wound bed and reliable reconstructive options. Immediate reconstruction may need to be aborted, however, if significant abdominal distention or inflammation is present.

A procedure is delayed if the patient is unstable, reconstructive options are limited or risky, the wound is contaminated, or further procedures are planned. Delayed reconstruction is often performed in the trauma patient with a loss of domain. The wounds of such patients are routinely closed with a temporary substance and subsequently reexplored. A skin graft may be applied as a temporary measure until reconstruction can be performed. A split-tissue skin graft will aid in contracture and has a higher success rate than a full-thickness skin graft. However, a split-tissue skin graft will remain fairly fixed.

A better result with more preservation of tissue may at times be obtained with a staged procedure. The vacuum-assisted closure device may be used in such cases. Using this procedure, a sterile foam dressing is placed in the wound cavity and an evacuation tube exits the wound parallel to the skin surface. The surface of the wound is covered to create an airtight seal, and subatmospheric pressure is applied to the foam dressing. Using animal experiments, Morykwas and colleagues showed that use of the vacuum-assisted closure device results in a fourfold increase in vascularization to the wound, decreased bacterial colonization, increased formation of granulation tissue by 103 percent, and increased flap survival by 21 percent when compared with controls.

If abdominal reconstruction is delayed, surgery should be avoided for 6 months or until the previous abdominal scar has fully matured. This will decrease the number of adhesions and the density of the scar tissue. Abdominal reconstruction after previous surgery has a high rate of enterotomy, which converts a clean case into a clean-contaminated or
contaminated case. Such an event may change the operative plan, thereby requiring autologous reconstruction.\textsuperscript{17}

Unstable or trauma patients with musculofascial defects require fascial support to prevent evisceration. The surgeon may choose to pack the wound, but this will result in significant loss of domain. The abdomen can be closed temporarily with mesh, allowing the surgeon to maintain domain, provide support, and protect the intraabdominal contents. The granulation bed is grafted as soon as possible to prevent continued protein losses.\textsuperscript{4,17,31} Medically unstable patients with chronic fascial defects are managed nonsurgically with abdominal binders and light activity.

**Incision Placement**

The surgical incision must be carefully planned to preserve the neurovascular and muscular structures and allow for future reconstructive options. When possible, previous incisions are used or extended. Otherwise, the midline incision is recommended. Although the midline incision places the wound under tension from the horizontal pull of abdominal wall muscles, it is the least damaging to neurovascular and functional anatomy.\textsuperscript{4} Paramedian incisions are avoided because of the danger of vasculature interruption and skin necrosis when combined with medial retraction.\textsuperscript{4,32} Transverse incisions disrupt vascular arcades and limit the viability of future local or distant flaps.\textsuperscript{32} Subcostal incisions are also discouraged because they interrupt both the deep epigastric arcade and the segmental vessels of the intercostal system.\textsuperscript{8,32} Such recommendations are made to preserve the vasculature; no difference in dehiscence rates has been noted between vertical, horizontal, and oblique incisions.\textsuperscript{4,37}

**Algorithm**

**Tissue Requirements**

**Partial defects.** A partial defect (Fig. 1) involves the loss of either the skin and subcutaneous tissue or the myofascial tissue. Whereas skin and subcutaneous defects are corrected primarily with regard to the size of the defect, partial myofascial defects are corrected primarily on the basis of position. Partial myofascial defects require tension-free closure for success.\textsuperscript{12,38,39} Attempts to close the abdominal cavity under excessive tension can result in fascial dehiscence or “abdominal compartment syndrome.”\textsuperscript{17,30–41} Relative defects of the myofascia can usually be repaired with prosthetics or autologous reconstruction such as abdominal components separation or local flaps. Large absolute defects of the myofascia will likely require a distant flap or free tissue transfer.

**Complete defects.** Complete defects (Fig. 2) involve the full-thickness loss of both superficial and musculofascial layers and are almost universally absolute. If the skin loss is less than 15 cm, it can usually be advanced, converting a complete defect to a partial defect. In a complete defect, the surgeon next decides whether reconstruction will be immediate or delayed. Because of the lack of skin and subcutaneous tissues for coverage, components separation and prosthetics are of limited value. Tissue transfer, such as a muscle flap with skin graft or a musculocutaneous flap, may be the only immediate surgical option.\textsuperscript{32,43} The particular flap is selected on the basis of size and position of the defect. In extensive cases, tissue expansion or free tissue transfer may be required. Delayed reconstruction with absorbable mesh and a split-tissue skin graft can be a temporizing solution.

**Position of Defect**

Hurwitz and Hollins\textsuperscript{32} classified abdominal wall defects into specific topographic subunits to aid in a systematic approach to abdominal reconstruction. They described seven anatomic reconstructive subunits with associated priority of reconstruction based on position. The advent of endoscopy, improved prosthetic techniques, and a staged application of components separation has allowed for the development of a new classification that is more simple and clinically useful (Fig. 3). The abdominal wall is subdivided into six subunits using horizontal and vertical planes. The location of the defect is classified as midline or lateral. Next, the defect is classified as belonging to the upper, middle, or lower third of the abdomen.

**Midline defects.** Local flaps are of limited value in the correction of midline defects because of their limited arc of rotation and associated sacrifice of strength of the lower abdominal wall.\textsuperscript{32,44} Because distant flaps are usually harvested from lateral positions, they are difficult to advance to the midline and their use as a first-line option is discouraged.\textsuperscript{44,45}

In midline defects with relative tissue deficiency, tissue can be advanced with fascial re-
Ramirez et al. described "components separation," in which a series of fascial incisions are used for maximal tissue advancement with preservation of the continuity of the internal oblique fascia. A modification of this technique allows for the sequential advancement of tissue with a tension-free closure and provides dynamic abdominal wall support (Fig. 4). Components separation is ideal for midline muscular defects greater than 3 cm in size. Using bilateral relaxing incisions and release, a total of 10 cm, 18 cm, and 6 to 10 cm of advancement can be obtained in the upper, middle, and lower thirds of the abdomen, respectively.

Using components separation in a series of 35 patients, DiBello and Moore reported an 8.5 percent recurrence rate of ventral hernia. Girotto et al. described a series of 37 patients with complicated defects repaired with components separation. In this series, there were two hernia recurrences (5 percent), 11 infections (31 percent), and three recurrent fistulas.

Lowe and colleagues reported on the technique of endoscopic-assisted components separation as a means to preserve midline perforators to the skin during release of the external oblique. Seven patients with midline defects were successfully treated with this technique; there was one recurrence and no incidence of infection, ischemia, or dehiscence.

**Lateral defects.** Components separation is of limited reconstructive use in nonmidline defects or staged pleating of mesh.
Effects. Achievable musculofascial advancement will decrease by one-half if the defect is lateral rather than midline. Additionally, use of components separation in lateral repairs may result in loss of fascial congruity of the abdominal wall. The ribs and iliac crest are also more limiting to tissue advancement in lateral defects.

As opposed to midline defects, most local and distant flaps may be easily rotated to lateral defects.32,44,45 Tissue transfer is selected on the basis of the size of the defect. Nonautologous reconstruction with prosthetics may be hindered by limited laparoscopic accessibility of the lateral abdominal wall.

Size of Defect

Skin and subcutaneous defects of the abdominal wall smaller than 5 cm in size are closed primarily; defects between 5 cm and 15 cm in size are closed with either local advancement or a split tissue skin graft. These defects can also be managed with the vacuum-assisted closure device.46 Defects with a poor vascular bed secondary to radiation, regardless of size, are best managed with cutaneous and fasciocutaneous flaps originating outside of the radiation field.50 For defects greater than 15 cm in size, options include local random flaps, axial skin flaps, and pedicled fasciocutaneous flaps, all of which can be enlarged with tissue expansion.

Tissue expansion is used to close skin and subcutaneous defects greater than 15 cm in size after temporary control is achieved with a skin graft.1 Tissue expansion aids in tissue advancement but often first requires a skin graft for temporary control of the wound.1 Expansion of both sides of a defect accelerates the process of reconstruction. Skin stretch is best over ribs, ilium, or lumbar fascia. Tissue expansi-
sion is a staged procedure that requires a lengthy time period before coverage is achieved. An additional disadvantage is the 20 percent occurrence rate of premature exposure and infection of the tissue expander.32 The advantage of tissue expansion is that reconstruction can be performed with well-vascularized, innervated, autologous tissue.51 Paletta et al.52 reported a series of 11 patients with large defects not amenable to primary closure. The defects were secondary to congenital malformation, necrotizing fasciitis, and traumatic injury. After placing prosthetic mesh to bridge the fascia, the wound bed was allowed to granulate. Tissue expansion was later used to approximate the skin for wound closure. All defects were repaired successfully with the complication of partial exposure of an expander in one patient.

Partial myofascial defects smaller than 3 cm in size are closed primarily. Prosthetic materials are ideal for use in midline repair of larger myofascial defects because of technical accessibility. Use of prosthetics in defect closure requires the presence of adequate skin and subcutaneous coverage as well as an adequate wound bed.53 Attempts should be made to protect the intraabdominal contents with omentum, if possible. Failure of prosthetic material occurs with excessive wound tension, poor wound status, and a history of infection.16

A variety of prosthetic materials are available to surgeons for abdominal reconstruction. They are classified as meshed or nonmeshed, and absorbable or nonabsorbable. Most nonmeshed materials restrict bacterial egress and inhibit collagen formation.54 Mesh is advantageous because it allows septic drainage, provides easy access to the abdominal cavity, and allows granulation tissue to grow within its interstices for added strength.17 Polypropylene mesh has been shown to be fairly resistant to bacterial contamination both experimentally and clinically.54–56

In a series of 15 patients with large wounds associated with massive infection or trauma, Voyles et al.55 reported using polypropylene mesh to gain initial control of the wound. The wound was then allowed to form granulation, with a subsequent split tissue skin graft for coverage as needed. However, Voyles noted that long-term success was compromised by extrusion of mesh and/or fistulas in 14 of the 15 patients.

In contaminated wounds, most authors recommend temporary repair using absorbable mesh and delayed skin grafting as needed.4,17,31 Absorbable mesh, made from polyglycolic acid, remains in place for approximately 4 to 6 weeks, providing support while granulation tissue forms in the wound. The use of absorbable mesh is limited because of its association with ulceration, fistulas, and late hernia formation.32 Ulceration is believed to occur secondary to ischemia resulting from the restricted vascular perfusion of granulation tissue growing through mesh. As the wound contracts, wrinkles occur with resultant loss of coverage, extrusion, and erosion.4,17,42

Several different techniques have been used to place mesh material. Stoppa describes a
method in which mesh is placed in an extensive area of preperitoneum; a limited number of tacking sutures are needed, because intraabdominal pressure will hold the mesh in place.\textsuperscript{57} Larson and Vandertoll reported a technique of intraperitoneal placement of mesh, again relying on intraabdominal pressure for support and limiting associated complications.\textsuperscript{58} Finally, the advent of laparoscopy has allowed for placement of mesh using a stapling device.\textsuperscript{59}

Other materials may be used in the reconstruction of partial defects of the myofascial layers. Fascial grafts harvested from the tensor fasciae latae have been used for abdominal reconstruction in contaminated wounds. Williams et al.\textsuperscript{60} reported success after using 12 tensor fasciae latae grafts for myofascial repairs. Complications included two cases of dehiscence, two cases of graft breakdown, one fistula and one recurrence. Disa and colleagues\textsuperscript{61} report on a series of 32 patients with large, contaminated defects treated with tensor fasciae latae tissue transfer. Initially, all repairs were successful; however, long-term complications of recurrence in three patients and dehiscence in seven—two requiring further repair with split-tissue skin grafts—are reported. However, the lack of tensile strength and contractility make fascia inferior to muscle flaps.

Omentum, when available, has the advantages of being highly vascularized and of providing plentiful fat for contouring. However, omentum requires skin grafting for coverage and lacks fascial support, requiring prosthetic material for strengthening.\textsuperscript{62} Free skin grafting, deepithelialized skin flaps, and fascial cutaneous flaps have been described for partial and full-thickness abdominal defects of a large size, but they provide no support when the fascia is deficient.\textsuperscript{17,42,63}

Myofascial defects not amenable to components separation have been reconstructed by using tissue expansion between the internal and external oblique muscles, as well as between the internal oblique and transversus abdominis.\textsuperscript{64} Byrd and Hobar reported successful repair by using this method in a case series of two patients with congenital defects involving more than 50 percent of the abdominal surface.\textsuperscript{51} Hobar et al. reported the successful repair of a large, complicated posttraumatic defect by using tissue expansion.\textsuperscript{64} Jacobsen et al. described a series of four patients who achieved primary closure of middle or lower abdominal wall hernias with expanders positioned between the external oblique and the internal oblique/transversalis muscles.\textsuperscript{65}

Large fascial defects not amenable to components separation may also be reconstructed by using autologous tissue from a local or distant source. Local and distant flaps tend to be more tedious and limited and are also associated with donor morbidity. However, flaps provide dynamic support with contraction of the muscle that simulates the normal action of the abdominal wall.\textsuperscript{42} In the heavily contaminated or infected wound with a tissue deficiency, flaps are contraindicated because they allow spread of infection to harvested sites. In this situation, the skin should be left open, with fascia supported by absorbable mesh to prevent eversion.

**Cutaneous flaps.** Cutaneous flaps, which include fasciocutaneous and musculocutaneous flaps (Table I), are used primarily to repair partial defects of the skin and subcutaneous tissues. Some authors have reported using cutaneous flaps with fascial grafts for the repair of complete defects, although this is not advocated.

Limited studies are available that discuss the use of cutaneous flaps for repair of the upper two-thirds of the abdominal wall. The thoracoepigastric flap has been described for repair of the upper third of the abdomen, but its use is limited by its arc of rotation.\textsuperscript{32,44,45} The iliolumbar bipedicled flap is ideal for the middle third of the abdominal wall. Ohtsuka et al. described the iliolumbar bipedicled flap with a tensor fasciae latae graft for the repair of defects of the lateral abdominal wall.\textsuperscript{66}

The lower third of the abdomen may be reconstructed by using direct cutaneous flaps that originate from the femoral vessels. One such flap is the groin flap, which has a large arc of rotation allowing mobilization to the umbilicus.\textsuperscript{45} The groin flap provides fat for contouring, does not necessitate skin grafting for coverage, and leaves negligible donor defects. Terasi et al. reported a case in which the groin flap was used in conjunction with a thigh adipofascial graft for the successful repair of a large defect secondary to tumor resection.\textsuperscript{67} Finally, Earle and Blackburn reported the successful repair of an abdominal defect secondary to a gunshot wound by using a groin flap lined with a dermal graft.\textsuperscript{68}

Also available is the superficial inferior epigastric artery flap, which provides a large soft tissue island. Stern and Nahai noted that the
superficial inferior epigastric artery flap was easily accessible in a case series of 27 patients who were successfully treated with this flap; however, none of the reported repairs were abdominal.69 This flap is suboptimal because of the anatomic unreliability of the donor vessel.45 Finally, the extended deep inferior epigastric flap, a musculocutaneous flap, may be used to repair defects of the lower abdomen and groin. Koshima and Soeda described using the extended deep inferior epigastric flap to repair a defect secondary to resection of a malignant lymphoma.70 Classen reported a case series of seven oncology patients who had defects repaired with the extended deep inferior epigastric flap.71 Three in this series required lower abdominal repairs; all of which were successful with a single complication of infection. Finally, Gottlieb et al. reported on four patients with lower abdominal and groin defects that were successfully repaired with extended deep inferior epigastric flaps.72

Local muscle flaps. Local flaps (Table II) are the optimal choice for partial musculofascial defects of the lateral abdominal wall greater than 3 cm in size. The rectus abdominis, when available, is the flap of choice for such lateral defects.44 This flap offers the option of a superior or inferior pedicle base. The superiorly based pedicle flap is used for defects of the upper two-thirds of the abdomen; the inferiorly based flap for defects of the lower one-third.

Mathes and Bostwick73 first described the use of the rectus abdominis flap in a case of a shotgun injury primarily repaired with mesh but complicated by long-term mesh extrusion. The defect was successfully repaired by removing the mesh and employing a superior-pedicled rectus abdominis flap. Parkash and Palepu74 reported 15 cases of chest, abdomen, and groin defects repaired with seven superior-based and eight inferior-based rectus abdominis flaps. Fourteen of the 15 patients achieved primary wound healing and long-term success. Successful repair in one case was compromised by wound infection and septicemia.

DeFranzo and colleagues75 described the rectus abdominis turnover for repair in 15 cases of large midline hernia defects. There were four serious complications requiring reoperation, two hernias, and two cases of midline skin loss requiring a split tissue skin graft for coverage.

The external oblique is used to correct defects of the entire abdominal wall, but it is preferred for the upper two-thirds because of a limited arc of rotation and tenuous blood supply. Spear and Walker76 reported successful repair with the external oblique flap in 32 of 33 patients with abdominal wall defects following a transverse rectus abdominis myocutaneous procedure. Seven patients required prosthetic reinforcement because of excessive tension.

The internal oblique flap reaches the lower third of the abdomen and the groin. Use of this flap is hindered by the technical difficulty of dissection and unreliability of the donor vessel.72 Ramasastry et al. reported that an in-

### TABLE I
Cutaneous Flaps Used in Abdominal Wall Reconstruction44,65,71

<table>
<thead>
<tr>
<th>Flap</th>
<th>Size</th>
<th>Vasculature</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracoepigastric</td>
<td>25 × 7 cm</td>
<td>Musculocutaneous perforators of the superior epigastric artery</td>
<td>Upper third</td>
</tr>
<tr>
<td>Iliolumbar</td>
<td></td>
<td>Superior circumflex iliac artery and lumbar artery</td>
<td>Middle third, lateral</td>
</tr>
<tr>
<td>Groin</td>
<td>25 × 10 cm</td>
<td>Superior circumflex iliac artery</td>
<td>Lower third</td>
</tr>
<tr>
<td>Superficial inferior epigastric</td>
<td>15 × 30 cm</td>
<td>Superficial inferior epigastric artery</td>
<td>Lower third</td>
</tr>
<tr>
<td>Extended deep inferior epigastric</td>
<td></td>
<td>Deep inferior epigastric artery</td>
<td>Lower third</td>
</tr>
</tbody>
</table>

### TABLE II
Local Flaps Used in Abdominal Wall Reconstruction

<table>
<thead>
<tr>
<th>Size</th>
<th>Pedicle Base</th>
<th>Pattern of Circulation</th>
<th>Dominant Vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus abdominis</td>
<td>25 × 6 cm</td>
<td>Superior and inferior</td>
<td>Type III Superior and inferior epigastric arteries</td>
</tr>
<tr>
<td>External oblique</td>
<td>20 × 40 cm</td>
<td>Superior</td>
<td>Type IV Lateral cutaneous branches of the inferior posterior intercostal arteries</td>
</tr>
<tr>
<td>Internal oblique</td>
<td>10 × 20 cm</td>
<td>Inferior</td>
<td>Type V Ascending branch of the deep circumflex iliac artery</td>
</tr>
</tbody>
</table>

ternal oblique flap was used to repair a large posttumor resection defect of the groin without complication.77

**Distant muscle flaps.** Larger partial musculo-fascial and complete defects not amenable to components separation or local flaps are corrected with distant flaps (Table III). Distant flaps can be used to correct midline defects larger than 10 cm, 18 cm, and 5 to 6 cm of the upper, middle, and lower abdomen, respectively. Additionally, lateral defects greater than 5 cm, 9 cm, and 2 to 3 cm of the upper, middle, and lower thirds, respectively, are repaired with distant flaps.

The tensor fasciae latae is one of the distant flaps and is used to repair defects of the lower two-thirds of the abdomen. The tensor fasciae latae has the advantage of being an expandable flap with a large arc of rotation that can reach the upper third of the abdominal wall.44,45 It is the flap of choice for repairs of the midline and lower abdominal wall. The tensor fasciae latae is limited by donor morbidity because harvesting more than 8 cm requires a skin graft for closure.

Williams and colleagues78 reported a series of nine patients successfully treated with pedicled tensor fasciae latae flaps. Complications included one seroma, greater than 50 percent loss in two patients, and tip necrosis in one patient. Nahai et al.79 described 60 tensor fasciae latae flaps, 15 used for repair of the abdominal wall and groin. The defects were due to trauma, radiation, tumor, and herniation. All 15 repairs were successful without report of complication or donor morbidity. Gruen et al.80 reported a series of 10 oncologic patients with large abdominal wall defects, five of which were successfully repaired with pedicled tensor fasciae latae flaps.

The rectus femoris flap is another of the smaller flaps used for repair of the lower two-thirds of the abdomen. The rectus femoris is a strong muscle, is expandable, and has a large arc of rotation. This flap is recommended for use in chronically infected wounds or in cases associated with pelvic osteomyelitis.44 The rectus femoris flap is associated with some donor morbidity, particularly weakening of quadriceps function.32 Caulfield et al. noted an average 24 to 28 percent loss of strength in a series of seven patients following a rectus femoris tissue transfer.81 Finally, the tissue available from this flap is variable depending on body habitus; the cutaneous portion of the rectus femoris flap may be unreliable.43,82

The extended rectus femoris or “mutton chop” flap has been used successfully in the epigastric region for massive defects.82–84 Dibbell et al. reported a series of 15 patients with large defects repaired with the extended rectus femoris either alone or in conjunction with the tensor fasciae latae, without the use of adjuvant mesh, with long-term complications limited to abdominal herniation in one patient.83 Brown et al. reported success with two patients treated with extended rectus femoris flaps, when used with adjuvant local skin coverage.82 Bilateral rectus femoris flaps mobilized for repair of the entire abdominal wall also have been described.84 The facility and expandability of the rectus femoris has been questioned by some authors, leaving this technique in some disrepute.43

The latissimus dorsi is ideal for the repair of large lateral wall defects of the upper third of the abdomen. Transfer of the latissimus dorsi flap requires harvesting of the pregluteal fascia to reach the abdominal midline.35 Neilsen et al.86 reported a series of 62 repairs using the latissimus dorsi flap, 22 of which were cases of abdominal reconstruction. With the exception of cosmetic defects, there were no complications associated with this procedure. Houston et al. reported long-term success in six patients treated with the extended latissimus dorsi flap.85 The extended latissimus dorsi flap is primarily limited by donor morbidity.

**TABLE III**

Distant Flaps Used in Abdominal Wall Reconstruction

<table>
<thead>
<tr>
<th>Flap Size</th>
<th>Size of Skin Island</th>
<th>Pattern of Circulation</th>
<th>Dominant Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensor fasciae latae</td>
<td>5 × 15 cm</td>
<td>40 × 10 cm</td>
<td>Type I</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>20 × 8 cm</td>
<td>12 × 20 cm</td>
<td>Type II</td>
</tr>
<tr>
<td>Latissimus dorsi</td>
<td>25 × 35 cm</td>
<td>30 × 40 cm</td>
<td>Type V</td>
</tr>
<tr>
<td>Gracilis</td>
<td>6 × 24 cm</td>
<td>16 × 18 cm</td>
<td>Type II</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>10 × 26 cm</td>
<td>10 × 15 cm</td>
<td>Type I</td>
</tr>
</tbody>
</table>

The gracilis flap is one of the smaller flaps used to repair defects of the lower third of the abdomen. Venugopalen reported a series of 20 patients with ventral incisional hernias repaired with gracilis flaps, without recurrence at 5-year follow-up. This flap is suboptimal in extensive repairs because of the unreliability of the distal skin island.\(^4,62\)

The vastus lateralis flap, also used in the lower third of the abdomen, has limited donor morbidity. However, this flap lacks a significant fascial component and is thus limited.\(^4\) Dowdell and McCraw described a series of three patients with defects complicated by infection or radiation that were successfully repaired with the vastus.\(^88\) It was noted that, when using the vastus lateralis, the donor site should be closed primarily to avoid exposure of the shaft of the femur.\(^45\)

**Free flaps.** Free flaps are considered when local tissues have been previously destroyed or when a pedicled flap cannot reach or is insufficient in size to cover a defect. In the case of free tissue transfer for abdominal reconstruction, a suitable recipient vessel is required. The most popular recipient vessels include the inferior epigastric, deep circumflex iliac, superior epigastric, internal thoracic, and saphenous vein loop grafts. Most of these are external peritoneal vessels; however, internal peritoneal vessels may also be used.\(^85\) A variety of free flaps are discussed in the literature, but the tensor fascia lata is reported most commonly.\(^60,89,90\)

Cooper et al.\(^91\) reported on their experience using the free groin flap in a series of 130 patients, four of whom required abdominal repair. Successful repair was achieved in each of these four patients without reported complications. Disadvantages of the free groin flap include inadequate myofascial support for abdominal reconstruction and an unreliable pedicle.

In their series on 10 oncologic patients, Gruen et al. described successful repair in five patients by using free tensor fasciae latae flaps, without reported complication.\(^80\) Finally, Williams et al. reported six cases of abdominal reconstruction using the tensor fasciae latae free flap.\(^78\) One case was complicated by infection and three cases by distal tip necrosis, two of which subsequently dehisced.

The free innervated latissimus dorsi flap has also been described as a means to reestablish the contractile force and strength of the lost abdominal wall. Ninkovic et al.\(^92\) reported success by using the free latissimus dorsi flap without significant complication in four patients with full thickness defects; two were staged procedures and two were immediate repairs.

**Conclusions**

Correction of complex abdominal wall defects is a challenge to general and plastic and reconstructive surgeons. The goal of reconstruction is to protect the abdominal contents while providing functional support. A review of the literature is presented emphasizing the success rates of various surgical options for abdominal reconstruction. We present a simple classification system based on the depth, size, and position of a defect. The algorithm for abdominal reconstruction is based on this classification system and, when combined with the literature review, will guide the surgeon in selecting the most appropriate reconstructive option.

**Acknowledgment**

The authors thank Elizabeth Fletcher for her medical illustrations.

**References**


**Self-Assessment Examination follows on page 217.**
An Algorithm for Abdominal Wall Reconstruction
by Rod J. Rohrich, M.D., James B. Lowe, M.D., Fred L. Hackney, M.D., D.D.S., Julie L. Bowman, M.D., and P. C. Hobar, M.D.

1. WHICH OF THE FOLLOWING MUSCLES IS NOT CONSIDERED TO BE A COMPONENT OF THE ANTEROLATERAL ABDOMINAL WALL?
   A) The external oblique
   B) The internal oblique
   C) The rectus abdominis
   D) The transversus abdominis

2. WHAT ARE THE GOALS OF ABDOMINAL WALL RECONSTRUCTION?4,12
   A) Restoration of abdominal wall function and integrity
   B) Prevention of visceral eventration
   C) Provision of dynamic muscular support
   D) All of the above

3. WHICH OF THE FOLLOWING IS NOT AN INDICATION FOR DELAYED ABDOMINAL WALL REPAIR?
   A) The patient is medically unstable
   B) A contaminated or infected wound bed
   C) Desire to reduce the cost of repair
   D) Significant wound bed inflammation with loss of domain

4. IF ABDOMINAL REPAIR IS DELAYED, WHICH OF THE FOLLOWING MAY BE USED TO ASSIST IN TEMPORARY WOUND CLOSURE?
   A) Prosthetic material
   B) Split thickness skin graft
   C) Full thickness skin graft
   D) Vacuum assisted closure device
   E) All of the above

5. WHICH OF THE FOLLOWING ARE ADVANTAGES OF VACUUM ASSISTED CLOSURE?
   A) Promotion of wound vascularization
   B) Minimization of surrounding tissue edema
   C) Increased granulation tissue formation
   D) All of the above

6. WHICH OF THE FOLLOWING STATEMENTS IS INCORRECT?
   A) In terms of preserving neurovascular structures, the least damaging abdominal incision is the midline incision.
   B) Because absorbable mesh allows for septic drainage and the formation of granulation tissue within its interstices, its use is preferable to autologous tissue.
   C) Skin and subcutaneous defects greater than 15 cm in size are closed with a fasciocutaneous flap or with tissue expansion.
   D) Closure of a fascial defect with significant wound tension is avoided because this may result in the “abdominal compartment syndrome” of respiratory and renal failure.17,39–41
   E) The lack of tensile strength and contractility makes fascial grafts inferior to muscle flaps.

7. WHICH OF THE FOLLOWING IS INCORRECT?
   A) Partial defects of the skin and subcutaneous tissue less than 3 cm in size are corrected using primary closure.
   B) A midline fascial defect greater than 3 cm in size is repaired using components separation, if possible.
   C) Large midline defects not amenable to components separation can be repaired with a distant muscle flap.
   D) Muscle flaps are ideally suited for repair of lateral myofascial defects.
   E) Complete abdominal wall defects are repaired either with a combined skin graft/muscle flap or with a musculocutaneous flap.
   F) For aesthetic results, free tissue transfer is always preferable to local and distant muscle flaps.

To complete the examination for CME credit, turn to page 483 for instructions and the response form.