Over the past two decades, the advent of nonoperative management techniques for many solid-organ injuries has led to a significant shift in the care of patients who have sustained abdominal trauma. The ever-improving accuracy of diagnostic modalities (computed tomography in particular) has also contributed to this shift.1-4 Today, fewer patients require operative intervention for treatment of abdominal injuries. Those who do require such intervention make up a select group who continue to pose a significant challenge to surgeons. In our view, these patients are best managed by following a standardized operative approach, the aim of which is to diagnose, prioritize, and treat the injuries in an expeditious fashion so that the patient is not kept in the operating room any longer than necessary [see Figure 1]. Such an approach optimizes patient care by minimizing the risk of missed injuries and ensuring a rapid and efficient response by the members of the surgical team. Naturally, every patient’s care should be individualized as necessary. In general, however, a standardized operative approach, complemented by a solid knowledge of a variety of exposures and techniques, should allow the surgeon to deal with virtually any abdominal injury. In this chapter, we outline our recommended approach to operative intervention in patients with abdominal trauma.

Patient Preparation

The key to success in this setting is advance preparation aimed at covering all eventualities. Such preparation involves both the environment and the patient. The room should be warmed to ensure that the patient does not lose too much heat and become hypothermic. The instruments should be open on the back table, and specific instruments should be available when specific injuries are anticipated (e.g., a vascular set should be available when a vascular injury is suspected). A sufficient number of laparotomy pads should be on hand, and a retracting device with which the surgical team is familiar should be employed. Cell saver systems and rapid infusion systems can be useful adjuncts; if desired and available, they should be requested in advance.  

Patient preparation begins with the insertion of a nasogastric or orogastric tube and a Foley catheter. Invasive monitoring lines may have to be placed, and resuscitation should continue as the patient is being prepared. A broad-spectrum antibiotic should be administered intravenously before the initial incision is made. When the patient is correctly positioned on the operating table, skin preparation should extend from the sternal notch superiorly to include the anterior thorax. Thus, no further preparation will be required if a thoracic injury is identified or vascular control in the thorax is necessary. Thoracostomy, if required, can also be performed without the drapes being changed. Inferiorly, skin preparation should extend to the upper anterior thighs so that the proximal saphenous veins are available if a vascular reconstruction is required and so that distal vascular control can be achieved without undue delay.

All areas of the body that are not included in the skin preparation should be covered so as to prevent excessive heat loss, and warming devices should be placed if available. Sterile draping should be placed so as to allow access to all potential injuries. If the patient is in extremis and in danger of expiring, however, patient preparation should be limited to a rapid skin cleansing and surgery should commence immediately.

Incision and Initial Exploration

CHOICE OF INCISION

A midline celiotomy is the incision of choice. Its advantages are that it allows rapid and easy access to the abdominal cavity, with good exposure of the majority of the intra-abdominal organs and structures, and that it can be extended into a median sternotomy if necessary. Its main disadvantage is that it may not provide adequate exposure of injuries in the deep recesses of the upper quadrants.

Patients with previous midline incisions pose a challenge to the surgeon. If at all possible, an attempt should be made to enter the abdomen above or below the previous incision, in an area less likely to have adhesions. If this is not possible, an alternative incision, such as a chevron (bilateral subcostal) incision, should be considered. A chevron incision provides entry into the abdomen while avoiding any viscera that are adherent to the undersurface of the previous laparotomy scar. However, this incision takes more time, does not provide ideal exposure, and is associated with a higher morbidity; accordingly, it should be considered only when the circumstances are dire. Paramedian, subcostal, retroperitoneal, and flank incisions are not recommended, for much the same reasons.

INITIAL EXPLORATION

Once the peritoneal cavity has been entered, initial exploration proceeds in an orderly fashion so as to minimize hemorrhage and contamination, prevent iatrogenic injury, and facilitate the expeditious identification of injuries. The intestines are eviscerated, and gross blood is rapidly evacuated. Laparotomy pads are then rapidly placed in all four quadrants to pack the abdomen; the right upper quadrant is packed first, then the left upper quadrant, and finally the lower two quadrants. Care should be taken not to tear the falciform ligament or the fibrous capsule of the liver during this maneuver. Blood pressure may drop when the abdomen is decompressed. Anesthesia should be given the opportunity to catch up with resuscitation efforts at this point.

Once hemodynamic stability has been achieved, the intraperitoneal portion of the exploration is begun. In cases of blunt trauma, the temporary packs (except for those around the solid viscera) may now be carefully removed and any remaining blood evacuated. In cases of penetrating trauma, it is often easier initially to address the site of ongoing hemorrhage via a direct approach. Vascular injuries are controlled manually until proximal and distal...
control can be achieved. Mesenteric bleeding sites are clamped. Solid organs are initially packed as for blunt trauma, then treated with directed repair. In either scenario, bleeding that remains uncontrolled by packing requires immediate attention.

The enteric viscera are then examined in an orderly fashion. The anterior aspect of the stomach is inspected from the esophagogastroduodenal junction down to the pylorus. If an injury is present or is strongly suspected on the basis of the mechanism of injury or the presence of a hematoma or soilage, the posterior aspect of the stomach is examined by opening the gastrocolic omentum; this measure also permits examination of the anterior surface of the body of the pancreas. The exploration then continues distally along the course of the GI tract. If duodenal or pancreatic injury is a possibility, the duodenum is mobilized fully by means of a Kocher maneuver. The duodenojejunal junction at the ligament of Treitz is then inspected, and the small intestine is inspected all the way to the ileocecal valve. Both sides of the small intestine must be examined, and particular care must be taken not to miss an injury at the mesenteric border. Careful consideration should also be given to the possibility of mesenteric vascular injuries, which may be manifested as mesenteric hematomas.

Next, the colon is inspected from the cecum to the rectum. If injuries are present or missile tracts are noted in proximity to a portion of the ascending or descending colon, the retroperitoneal portion of the colon is inspected by incising the white line of Toldt (the retroperitoneal reflection) so as to allow access to the posterior surface of the colon. Finally, the laparotomy pads around the solid organs are removed, one organ at a time, to permit inspection for hemorrhage or injury.

Once the peritoneal survey is complete, the retroperitoneum is inspected for potential injuries. Retroperitoneal hematomas are classified on an anatomic basis: zone 1 is the central area, bounded laterally by the kidneys and extending from the diaphragmatic hiatus to the bifurcation of the vena cava and the aorta; zone 2

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**Figure 1** Algorithm outlines the approach to initial operative exposure in abdominal trauma patients.
comprises the lateral area of the retroperitoneum, from the kidneys laterally to the paracolic gutters; and zone 3 is the pelvic portion [see Figure 2]. Whether exploration is warranted for a retroperitoneal hematoma depends on the mechanism of injury and the location of the hematoma [see Priorities in Management, Repair of Retroperitoneal Injuries, below, and 7:10 Injuries to the Great Vessels of the Abdomen]. A careful evaluation is performed to identify possible occult injuries to organs (e.g., the pancreas, the duodenum, the retroperitoneal colon, the kidneys, and vascular structures).

The initial exploration concludes with a brief pelvic survey aimed at excluding injuries to the rectum or the distal urogenital tract (including the bladder). At the end of the operation, this initial inspection should be repeated, following the same sequence, to confirm that no injuries have been missed.

Operative Exposure

To expose the various organs that may be injured in patients who have sustained abdominal trauma, the surgeon must be familiar with a number of different techniques. In what follows, we detail the operative exposures that enable the surgeon to perform the necessary repairs. The repairs themselves are described in greater detail elsewhere [see 7:3 Injuries to the Liver, Biliary Tract, Spleen, and Diaphragm; 7:8 Injuries to the Stomach, Small Bowel, Colon, and Rectum; 7:9 Injuries to the Pancreas and Duodenum; 7:10 Injuries to the Great Vessels of the Abdomen; and 7:11 Injuries to the Urogenital Tract].

AORTA AND BRANCHES

Control of the aorta can be gained at several different levels, depending on the site of injury. The supraceliac aorta can be exposed by incising the gastrohepatic ligament, retracting the left hemiliver laterally and cephalad, and retracting the stomach caudally. The esophagus and periesophageal fat pad are then mobilized laterally to permit identification of the abdominal aorta at the diaphragmatic hiatus, at which point the aorta can be encircled, clamped, or compressed. This exposure allows control of the aorta, but it is inadequate in terms of providing vascular access for definitive repair. Better exposure of the supraceliac aorta and its branches can be obtained by means of a left medial visceral rotation [see Figure 3]. To perform this maneuver, the splenorenal ligament is mobilized with a combination of sharp and blunt dissection. The left peritoneal reflection is incised from the splenocolic flexure down the paracolic gutter to the level of the distal sigmoid colon. The left-side viscera are then gently mobilized to the midline (mostly with blunt dissection) in a plane anterior to Gerota’s fascia. This technique allows exploration of the entire length of the abdominal aorta, the origin of the celiac axis, the origin of the superior mesenteric artery, the left iliac system, and the origin of the right common iliac artery. In addition, it facilitates control of the left renal vascular pedicle before exploration of a left-side zone 2 retroperitoneal hematoma. Alternatively, a variation on the standard left medial visceral rotation (the Mattox maneuver6) may be employed, in which the left kidney is also included in the organs that are rotated (the plane being anterior only to the muscles of the posterior abdominal wall). This variant may afford better access to the origin of the left renal artery.

If the injury is more distal, the aorta may be approached in a transperitoneal fashion. The small intestine is retracted to the right, the transverse colon is retracted cephalad, and the descending colon is retracted laterally. The peritoneum is then incised directly over the aorta, and the third and fourth portions of the duodenum are mobilized cephalad. The proximal limit of this dissection extends to the left renal vein, which may be divided if necessary to provide more cephalad access to the aorta. If ligation of the left renal vein is called for, it should be done at a point where the gonadal vein will be left intact to drain the kidney. A more limited dissection may suffice to expose the distal infrarenal aorta. Depending on the injury, distal control may or may not be required. Control may be achieved at the level of the distal infrarenal aorta, above the bifurcation.

Once again, if the patient is in extremis, formal dissection may be curtailed and proximal control achieved either by manually compressing the aorta against the spine at the level of the esophagogastroduodenal junction or by using an aortic occluder [see 7:10 Injuries to the Great Vessels of the Abdomen].

VENA CAVA AND BRANCHES

Access to the suprahepatic inferior vena cava can be gained only by either incising the central tendon of the diaphragm or by performing a median sternotomy and opening the pericardium. The infrahepatic inferior vena cava is exposed by performing a right medial visceral rotation (the Cattell-Braasch maneuver) [see Figure

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**Figure 2** Shown are the anatomic zones of the retroperitoneum: zone 1 (central), zone 2 (flank), and zone 3 (pelvic).
The right colon is mobilized by taking down the hepatic flexure and then incising the right peritoneal reflection along the paracolic gutter. The colon is once again reflected medially toward the aorta in a plane anterior to Gerota’s fascia with careful blunt dissection. If additional exposure is necessary, the inferior margin of the peritoneal incision may be extended to the root of the mesentery—and even beyond, if the inferior mesenteric vein is sacrificed. This exposure permits visualization of both the aorta below the origin of the superior mesenteric artery and the vena cava below the third portion of the duodenum. Exposure of the portion of the vena cava directly below the liver alone can be achieved by performing a Kocher maneuver [see Figure 5] with medial mobilization of the duodenum and the head of the pancreas.

**LIVER**

Mobilization of the liver begins with division of the round ligament (ligamentum teres), followed by takedown of the falciform ligament (to prevent iatrogenic trauma to the liver capsule during exposure and identification of other intraperitoneal injuries). This mobilization may be extended as far cephalad as is necessary. Further mobilization can be achieved by incising the left triangular ligament, with care taken not to injure the suprahepatic inferior vena cava at the diaphragmatic hiatus during the dissection. When visualization of the right hemiliver is required, the falciform ligament should be incised to its most superior extent, and the right triangular ligament should then be carefully divided. This step is challenging and may have to be performed partly by palpation, with care taken not to injure the inferior vena cava, the hepatic veins, or the phrenic vessels [see 7:7 Injuries to the Liver, Biliary Tract, Spleen, and Diaphragm].

**SPLEEN**

The spleen can be mobilized into the midline by dividing the phrenosplenic and splenorenal ligaments with a mixture of sharp and blunt dissection. In cases where the spleen has been injured by blunt trauma, these ligaments often are already disrupted, and this disruption facilitates the dissection. The splenocolic ligament often contains sizeable blood vessels that must be controlled, and the gastrosplenic ligament contains the short gastric arteries. Once the spleen is mobilized into the midline, control of the vascular pedicle can be achieved, the splenic injury can be assessed, and splenorrhaphy or splenectomy can be performed as appropriate [see 7:7 Injuries to the Liver, Biliary Tract, Spleen, and Diaphragm and 5:25 Splenectomy].

**PANCREAS**

Intraoperative evidence of a central hematoma, peripancreatic edema, or bile staining in the retroperitoneum or the lesser sac raises the possibility of pancreatic injury. The contents of the lesser sac can be visualized by performing a direct inspection through the gastrohepatic ligament or by dividing the ligament. Alternatively, access can be gained by dividing and ligating two or three gas-
troepiploic arcades of the gastrocolic ligament. If it proves necessary to explore the pancreas, the stomach is separated from the transverse colon by completing the division of the gastrocolic ligament, and a Kocher maneuver is performed to reflect all portions of the duodenum medially, along with the head of the pancreas. The peritoneum lateral to the duodenum is incised, and careful blunt dissection is employed to mobilize the duodenal loop from the common bile duct superiorly to the superior mesenteric vein inferiorly. This mobilization allows inspection of the anterior and posterior surfaces of the head of the pancreas, as well as the uncinate process. If injury to the body or tail of the pancreas is suspected, the splenorenal and splenocolic ligaments are incised. At this point, the spleen and then the pancreas can be mobilized medially to a position near the level of the superior mesenteric vessels, and the anterior and posterior aspects of the body and tail of the pancreas can be examined [see 7:9 Injuries to the Pancreas and Duodenum].

**KIDNEYS**

Operative exposure of the kidneys starts with either a left or a right medial visceral rotation, depending on which kidney is involved. The renal vascular pedicle should be controlled before any hematoma in Gerota’s fascia is opened [see 7:11 Injuries to the Urogenital Tract]. Repair of the kidney may be facilitated by mobilizing the organ out of Gerota’s fascia and retracting it medially.

**DUODENUM, BILIARY TRACT, AND SMALL INTESTINE**

Exposure of the posterior surface of the duodenum is achieved by means of a Kocher maneuver [see Pancreas, above, and Figure 5]. This technique is also used when injury to the distal extrahepatic biliary system is suspected. The proximal extrahepatic biliary tree is visualized by using a Kocher maneuver in conjunction with local exploration of the porta hepatis. In patients with injuries to the distal duodenum or the proximal jejunum, division of the ligament of Treitz may also be necessary for accurate identification of the site of injury. Because of the mobility of the small intestine, injuries to this structure generally are readily identified and repaired without additional mobilization.

**COLON AND RECTUM**

Evidence of staining, pneumatosis, or hematoma in proximity to a portion of the ascending or descending colon, particularly in the setting of related injuries or missile tracts, should prompt a full evaluation of the colon. Because the colon is a partially retroperitoneal structure, the retroperitoneal reflection must be incised to allow inspection of the posterior surface of the colon. Sometimes, rectal injuries are not accessible via an intraperitoneal approach; in this situation, consideration should be given to a diverting colostomy and presacral drainage [see 7:8 Injuries to the Stomach, Small Bowel, Colon, and Rectum].

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*Figure 4* Right medial visceral rotation is performed to provide exposure of the inferior vena cava, the infrarenal abdominal aorta and iliac vessels, and the right renal vascular pedicle.
Priorities in Management

CONTROL OF HEMORRHAGE

In the event that the patient remains hemodynamically unstable because of persistent uncontrolled hemorrhage, the primary focus of the initial exploration is control of bleeding. As noted (see above), the approach to hemorrhage control differs depending on whether the patient sustained blunt trauma or penetrating trauma. In cases of blunt trauma with bleeding from a solid organ, the first thing that should be done is to attempt repeat packing of the specific bleeding site with a sufficient number of laparotomy pads. This is an important skill to master and can be effective as a temporizing measure until either more definitive vascular control can be achieved or coagulopathy can be corrected. In cases of penetrating trauma, bleeding is more effectively managed by means of either vascular control just proximal and distal to the site of injury or direct control at the bleeding site.

When significant hemorrhage is anticipated, control of the injured vessel should be obtained by the operative techniques discussed previously [see Operative Exposure, above]. Given the possibility of exsanguinating hemorrhage, the surgeon must be prepared to gain proximal aortic control at the diaphragmatic hiatus or even within the chest via a left lateral thoracotomy. For immediate control, the aorta can be manually compressed at the hiatus; a padded Richardson retractor, an aortic compressor, or an assistant’s hand can then take over this function to allow the surgeon to continue the exploration. If a need for prolonged proximal aortic control is anticipated, an atraumatic aortic vascular clamp should be placed. Injuries to the proximal abdominal aorta often necessitate that the vessel be controlled in the chest to permit repair.

In patients who have sustained parenchymal injuries to solid viscera, control of the vascular inflow is crucial as both a diagnostic and a therapeutic maneuver. Gaining control of the splenic hilum effectively arrests further splenic hemorrhage. Similarly, use of the Pringle maneuver [see 7:7 Injuries to the Liver, Biliary Tract, Spleen, and Diaphragm] to control the vessels in the porta hepatis (the hepatic artery and the portal vein) helps determine the source of perihepatic hemorrhage. This maneuver is initially performed by digitally compressing the portal structures; if digital compression causes the hemorrhage to diminish, the surgeon’s hand is replaced with an atraumatic vascular clamp or a Rumel tourniquet. Although the Pringle maneuver can be maintained for at least 30 to 45 minutes without causing permanent liver damage, the clamp or tourniquet should be removed as soon as is feasible. In the vast majority of cases of liver trauma—aside from those involving an injury to the retrohepatic vena cava—the use of the Pringle maneuver, combined with perihepatic packing, should arrest hemorrhage.

In patients who have sustained injuries to the retrohepatic vena cava, it may be necessary to gain vascular control by performing hepatic exclusion before definitive repair can be attempted [see 7:7 Injuries to the Liver, Biliary Tract, Spleen, and Diaphragm]. Hepatic exclusion may be achieved by means of either atriocaval shunting (which is rarely if ever used) or occlusion of the inferior vena cava both above and below the liver. The latter may lead to significant hemodynamic instability, particularly in volume-depleted
patients; however, it may reasonably be considered in patients whose volume status is adequate. Complete hepatic exclusion involves both (1) atriocaval shunting or clamping of both the infrahepatic and the suprarehepatic inferior vena cava and (2) control of hepatic arterial and portal venous inflow. In general, injuries to the retrohepatic vena cava are best dealt with by means of damage-control procedures.

Hepatic parenchymal hemorrhage can be challenging, and any of a number of techniques may be used to control it, depending on the location, type, and degree of bleeding. These techniques range from simple electrocauterization and parenchymal suturing to argon beam cauterization, direct vessel ligation, hepatotomy, and even resection [see 7:7 Injuries to the Liver, Biliary Tract, Spleen, and Diaphragm]. In difficult cases, it may be advisable to perform an abbreviated laparotomy, pack the liver extensively, and transport the patient to the angiography suite, where selective embolization can be performed; the patient can then be transported to the ICU, undergo warming, and have any coagulopathy corrected before returning to the OR to have the packs removed.

Mesenteric bleeding can usually be controlled with manual compression of the vessel followed by suture ligation. Retroperitoneal hematomas are often harbingers of vascular injury, and proximal and distal vascular control should be obtained before exploration is initiated [see 7:10 Injuries to the Great Vessels of the Abdomen]. Typically, bleeding from injured hollow viscera is minor and can be controlled by repairing the injury; on occasion, however, temporary hemostatic suturing or stapling may be required.

CONTROL OF CONTAMINATION

Once hemorrhage has been controlled, the next priority is to control contamination. All gross spillage should be removed from the abdomen with suction and laparotomy pads, and further contamination should be prevented by temporarily closing small enterotomies with Babcock clamps (or, alternatively, with a continuous suture or skin staples). When multiple enterotomies are present, suture closure is preferred (to ensure that multiple clamps are not present in the operative field). If the injuries are in close proximity, the preferred method of controlling intestinal spillage is to apply atrumatic bowel clamps at both the proximal and the distal end of the injury site. Alternatively, if the injured segment will have to be resected, rapid control of further spillage can be obtained by firing a GI stapler at each end of the injured segment.

REPAIR OF VASCULAR INJURIES

Once intestinal contamination has been dealt with, the next priority is definitive vascular repair [see 7:10 Injuries to the Great Vessels of the Abdomen]. If proximal and distal control of the injured vessel has not already been obtained, it is obtained at this point. The extent of the vascular injury is determined, dead or devitalized tissue is carefully debried, and vessel continuity is reestablished if possible. If the injury is not amenable to primary repair and the vessel cannot be ligated, autogenous tissue should be obtained (usually from the proximal greater saphenous vein) and used for either patch angioplasty or interposition grafting. If no suitable autogenous venous tissue is available, synthetic material may be considered as an alternative vascular conduit. For aortic or iliac arterial injuries, primary ligation with subsequent extra-anatomic bypass is an acceptable alternative. In cases in which an abbreviated laparotomy is necessary, vascular shunting may serve as a substitute for definitive repair until hypothermia, coagulopathy, and acidosis are corrected.

REPAIR OF DAMAGED OR DEVIATALIZED BOWEL

Once vascular injuries have been addressed, the next priority is to repair any enteric injuries [see 7:8 Injuries to the Stomach, Small Bowel, Colon, and Rectum]. Because the stomach is a large and well-vascularized organ, gastric injuries are usually amenable to primary repair. Injuries to the small intestine that involve less than 50% of bowel circumference after debridement of devitalized edges can be repaired with either a single-layer or a two-layer closure; single-layer closure, being less likely to compromise the lumen of the bowel, is generally preferred. In cases involving multiple enterotomies in close proximity or a large area of devitalized tissue, a segmental enterectomy with primary anastomosis is preferable. The anastomosis may be either hand-sewn or stapled; the latter tends to be more expeditious but less cost-effective.

Solitary injuries to the colon that do not necessitate resection after debridement and are not associated with multiple transfusions or significant gross contamination are managed by means of primary closure. Large or multiple injuries to the right colon are best managed with a right hemicolectomy followed by an immediate ileocolic anastomosis. Similar injuries to the left colon are generally treated with resection and proximal diversion. The distal limb may be exteriorized as a mucous fistula, or, if inadequate bowel length renders diversion impossible, a Hartmann procedure may be performed.

REPAIR OF RETROPERITONEAL INJURIES

Once all injuries within the peritoneal cavity have been addressed, the next priority is to inspect the retroperitoneum once more, paying particular attention to the possibility of hematoma expansion. The decision whether to explore a retroperitoneal hematoma is based on the mechanism of injury and on the zone in which the injury is located. All zone 1 hematomas should be explored regardless of the injury mechanism: they signal possible aortic, vena caval, duodenal, or pancreatic injury. Zone 2 and 3 hematomas should be explored in cases of penetrating trauma but not, as a rule, in cases of blunt trauma (with the exception of expanding zone 2 hematomas).

Before a retroperitoneal hematoma is opened, proximal vascular control should be obtained so that hemorrhage will be minimized once the effect of the tamponade has been lost. Injuries to retroperitoneal organs (e.g., the kidneys, the pancreas, and the adrenal glands) are treated by means of debridement or resection, with drainage as indicated. Vascular injuries are repaired as discussed previously [see Repair of Vascular Injuries, above, and 7:10 Injuries to the Great Vessels of the Abdomen].

Closure

GENERAL TECHNIQUE

Once the abdominal exploration has been completed, the abdomen is copiously irrigated with an isotonic crystalloid solution. The closure method employed is typically determined on the basis of five main considerations: (1) the degree of blood loss, (2) the volume of resuscitation fluid received, (3) the degree of contamination, (4) the patient’s perceived nutritional status, and (5) the patient’s hemodynamic stability. In cases that necessitate an abbreviated or damage-control procedure, the speed with which the closure can be performed may be the most important factor. Provided that the risk of subsequent abdominal compartment syndrome (ACS) is considered to be low, every effort should be made to close the fascia. Fascial closure is usually accomplished with a continu-
ous absorbable or nonabsorbable monofilament suture, though it may also be accomplished with interrupted sutures. The rate of fascial dehiscence is essentially the same for the two techniques; however, the extent of dehiscence is more limited when closure is done with interrupted sutures. With either technique, it is important not to place excessive tension on the fascial tissues.

In cases where there is a specific reason to be concerned about possible dehiscence (e.g., in patients who are malnourished or obese or are receiving steroid therapy), large monofilament sutures may be placed at intervals within the standard closure to serve as retention sutures. They may be tied over bolsters created from a red rubber catheter or over plastic skin bridges [see Figure 6]. If rapid closure is required, the abdomen may be closed with four or five retention sutures of this type that are placed through the abdominal wall and just above the peritoneum. These sutures must be checked daily and should be loosened if there is evidence that they are cutting through the abdominal skin as a consequence of edema creating increased tension on the wound.

SKIN CLOSURE

If the patient has minor injuries without evidence of enteric contamination, the skin may be closed primarily. Stapled closure is most expeditious, but suture closure is also acceptable. A degree of clinical judgment is required in assessing a wound’s suitability for closure. If the skin is closed primarily, it should be inspected daily, and the wound should be opened without delay if there is concern about subsequent infection. Alternatively, primary delayed closure may be performed by leaving the wound open, packed with moist gauze. If the wound shows no evidence of infection when examined after 3 to 5 days, it may be closed with Steri-Strips or with interrupted sutures that are placed (without being tied) during the original operation. If intraperitoneal contamination has occurred, either primary delayed closure should be performed or the wound should be packed and left to heal by secondary intention.

ABBREVIATED OR DAMAGE-CONTROL LAPAROTOMY

If a patient remains unstable after surgical bleeding and contamination have been controlled or is cold and coagulopathic, an abbreviated or damage-control procedure is indicated. It may be necessary to perform a rapid abdominal closure—with the proviso that further exploration, as well as definitive repair of injuries that have been temporarily controlled, will be required. The decision to perform a damage-control procedure should be made at an early stage, before the so-called lethal triad (hypothermia, acidosis and coagulopathy) has had time to develop. Damage control has undoubtedly led to improved survival for trauma patients, but it has also led to an increase in the number of patients whose abdomens are left open.

TEMPORARY ABDOMINAL CLOSURE

When a damage-control procedure is required, it is often most expedient to perform a rapid temporary abdominal closure, then to transport the patient to the intensive care unit. This measure may also be necessary in patients whose abdomens cannot be closed because of intestinal or organ edema caused by intraoperative fluid resuscitation. The simplest form of temporary abdominal closure is the use of towel clips to close only the skin [see Figure 7], in conjunction with the application of a bioocclusive dressing to control fluid loss and contamination. This closure, however, leaves the patient still at risk for subsequent ACS.

The first temporary abdominal dressing described was the so-called Bogotá bag—that is, an empty intravenous fluid bag that was cut in half and sewn to the wound edges. This dressing can still be used in circumstances where no other equipment is available. The so-called vacuum pack technique involves the placement of a sterile plastic drape over the bowel contents and under the fascia, followed by insertion of two or more suction drains, over which sterile towels or open laparotomy pads may be placed. To minimize heat loss and insensible fluid loss, an adherent bioocclusive dressing is placed over the entire dressing and the abdominal wall, with the drains attached to suction. Several commercial devices are now available that can be used to facilitate temporary closure of the open abdomen; these include the VAC Abdominal Dressing System (Kinetic Concepts Inc., San Antonio, Texas) and the Wittmann Patch (Star Surgical, Burlington, Wisconsin).
MANAGEMENT OF THE OPEN ABDOMEN

Once the patient’s physiologic status has stabilized, he or she should be returned to the OR for reexploration and definitive repair of any remaining injuries [see Figure 8], preferably within 48 hours after the first operation. At this juncture, the abdomen should be assessed for the feasibility of closure. In some patients, the fascial edges cannot be approximated, because of edema; in others, reapproximation may cause a significant rise in intra-abdominal pressure, as evidenced by a rise in pulmonary inspiratory pressures. These patients are at risk for ACS, and their abdomens should be left open.

At this point, if temporary abdominal coverage continues to be required, a temporary abdominal dressing should be placed that attempts to prevent fascial retraction and the associated increased risk of nonclosure of the abdomen. Options include dynamic retention sutures, the Suture Tension Adjustment Reel (STAR) (WoundTEK, Inc., Newport, Rhode Island), the Wittmann Patch, nonabsorbable mesh, fascial zippers, and the VAC Abdominal Dressing System.20-25 Once the dressing is placed, it should be examined every 24 to 48 hours, depending on the degree of contamination; this is often best done in the OR, but it may also be done in the ICU if the patient remains unstable. At every subsequent procedure, the fascia should be assessed for the possibility of closure. Partial closure of the incision (i.e., closure of the cephalad and caudal portions) should be considered, even if full closure cannot be accomplished. In approximately 50% of patients, closure of the fascia is not possible; however, there is some evidence to suggest that this figure may be lowered by employing some of the devices now commercially available.20,26,27

ABDOMINAL COMPARTMENT SYNDROME

Patients who undergo fascial closure are at risk for ACS as a consequence of ongoing resuscitation efforts and associated bowel and organ edema. ACS is defined as intra-abdominal hypertension greater than 25 mm Hg in conjunction with dysfunction of one or more organ systems (e.g., pulmonary, renal, or cardiac).28,29 Intra-abdominal pressure is determined indirectly by measuring bladder pressure. Bladder pressure can be measured by using an arterial transducer at the level of the symphysis pubis that is connected to the urinary catheter after 30 to 50 ml of sterile water has been introduced. Alternatively, an idea of the intra-abdominal pressure can be gained by raising the Foley tubing above the bed after instillation of the water, then measuring the column.30 A rising trend in pressure can be as significant as a single elevated measurement. Patients who have undergone a long operation, have been the object of vigorous resuscitation efforts, or who have sustained mul-

**Figure 7** Shown is a "quick out" closure with surgical towel clips.

**Figure 8** Algorithm outlines the approach to the open abdomen in a patient with abdominal injuries.
tiple injuries should be monitored closely for the development of ACS. If the diagnostic criteria for ACS are met, prompt abdominal decompression is indicated. On occasion, this measure may have to be carried out at the bedside in the ICU.

Occasionally, ACS develops in patients who have a temporary abdominal dressing in place (so-called tertiary ACS). Accordingly, it is mandatory to continue to monitor intra-abdominal pressure in these patients.

**CLOSURE OF THE OPEN ABDOMEN**

It is important to close the abdomen as early as possible: an open abdomen carries an increased risk of desiccation of the intestines and subsequent fistula formation. In certain patients, however, despite aggressive efforts to close the fascia, it proves impossible to accomplish primary closure, even after many days and repeated procedures. There are several techniques that may be employed to obtain final closure in this situation.

The simplest method is to allow granulation tissue to form over the omentum and the exposed intestines and later, when there is a good clean granulation bed with no evidence of infection, to place a split-thickness skin graft. Alternatively, a piece of absorbable mesh may be placed; this helps facilitate dressing changes, provides a modicum of protection to the intestines, and serves to control evisceration [see Figure 9]. A skin graft can then be placed in the same fashion, once a granulation bed has developed.

Another option is to employ relaxing incisions, either to allow a skin-only closure or to allow the skin to be closed over absorbable mesh. Open skin wounds should be left open to heal by secondary intention. Unfortunately, the use of relaxing incisions will not prevent the formation of large ventral hernias, which will have to be repaired at a later date.

Abdominal fascial defects may also be closed with sheets of nonincorporable synthetic material (e.g., Gore-Tex; W.L. Gore and Associates, Inc., Newark, Delaware). The advantages of these nonabsorbable materials are that they do not react with tissue and that they are associated with a low incidence of complications (e.g., fistula formation). The disadvantages are that they are expensive and that they must ultimately be removed unless the skin can be closed over them to prevent contamination.

Another option for achieving primary closure of the abdomen is component separation of the rectus sheath. The external oblique aponeurosis is incised and mobilized, along with the rectus sheath, to bring the fascia to the midline. Defects as wide as 14 to 20 cm can be bridged in this fashion, but recurrent hernia rates remain high.

Several biosynthetic materials are now available to be used for bridging abdominal fascial defects. One such material is Surgisis (Cook Biotech Inc., West Lafayette, Indiana), a porcine submucosal matrix that can provide scaffolding for the ingrowth of fibrous tissue while supporting abdominal contents and permitting skin closure. Another is AlloDerm (LifeCell Corp., Branchburg, New Jersey), a denatured human cadaveric product that can be used in a similar fashion to replace denuded fascia or to bridge the fascial gap in cases where primary closure cannot be accomplished. At present, long-term follow-up data are lacking for both products, and their use is further limited by their very high cost.

Morbidity is very high in these patients; subsequent complications range from prolonged ventilator dependence to enteric fistulas to massive ventral hernias. Major ventral hernias represent a significant technical challenge and should not be repaired until the patient’s recovery from injury is complete and his or her nutritional and general status has returned to normal. This may take as long as 12 months from the time of the initial trauma.

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**Figure 9** Mesh may be used for temporary or permanent abdominal closure in patients at risk for increased abdominal pressure. (a) Mesh is sutured into the fascial plane, then covered with a split-thickness skin graft. (b) The abdominal defect is closed with mesh.
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Recommended Reading

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Acknowledgments

Figures 2 and 5 Susan Brust, C.M.I.
Figures 3 and 4 Carol Donner.