CHAPTER 77 ■ THE DIFFICULT POST-OPERATIVE ABDOMEN

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The practice of surgery inevitably carries the risk of postoperative complications and difficult therapeutic choices. Some of the most vexing operative dilemmas result from managing a difficult postoperative abdomen. Routine intra-abdominal therapies will result in adhesion formation, which may plague the patient with recurring episodes of abdominal pain and partial or complete bowel obstruction. Enterocutaneous, intra-abdominal, or pancreatic fistulas may result from the natural progression of intra-abdominal pathology or may be the sequelae of invasive procedures. Abdominal catastrophes may result in a compartment syndrome mandating aggressive management decisions including temporary abdominal closures and planned ventral hernias. Less common issues, including radiation enteritis and short bowel syndrome, may significantly impact lifestyle and health, requiring surgical attention.

In this chapter, we will address many of these difficult postoperative issues. Our discussion will include etiology, diagnosis, and therapeutic approaches. The core principles of careful surgical technique and meticulous patient management, including wound care, nutritional management, and timing of recurrent interventions, are key in treating these obstacles.

ADHESIONS

Intra-abdominal adhesions are an unavoidable consequence of operative therapy. Intra-abdominal adhesions are the primary cause for postoperative bowel obstruction, accounting for approximately 75% of cases (1). Adhesions intrinsically play a crucial role in postoperative healing. Formation of adhesive tissue protects an anastomosis and prevents leaks, in addition to assisting in the body’s attempt to isolate intra-abdominal catastrophes like abscesses. When adhesive bands become too dense, kink, or encompass loops of bowel, they may result in negative consequences such as bowel obstruction and persistent abdominal pain. In this chapter, we will discuss the development of adhesions, their natural history, and methods of prevention.

Adhesion formation occurs in the course of repairing an injury site, anastomosis, or incision. Within the first 48 to 72 hours of injury, macrophages converge to form a protective layer over the injured tissue. These macrophages further differentiate into mesothelial cells, while additional fibroblasts and mesothelial cells are recruited from nearby locales. These cell populations complete the initial stages of healing over a period of 7 to 10 days (2,3). Ultimately, these healing cell populations will not only continue the process of restoring tissue integrity but may form unnatural connections. Adhesive connections may occur between loops of bowel, intra-abdominal structures and the abdominal wall, and between the pelvis and nearby structures (bowel, gynecologic organs, etc.) resulting in intra-abdominal pathology and patient morbidity.

Most (94%–98%) of abdominal adhesions are acquired, either from operative therapy or via inflammatory processes (i.e., Crohn’s disease, cancer, etc.). The remaining 2% to 6% of adhesions are congenital and largely consist of Ladd bands. In the operative abdomen, adhesions are present in 30% to 40% of patients. The most frequent morbidity in those with postoperative adhesions is small bowel obstruction, which accounts for 12% to 17% of hospital admissions following previous abdominal surgery. One quarter of these admissions occur within the first year following surgery, and 2% to 5% of small bowel obstructions due to adhesions will require operative adhesiolysis (2). The degree of morbidity related to adhesion formation is profoundly affected by the type of surgery performed. Laparoscopic surgeries have been shown to have a 15% adhesion rate as opposed to open laparotomies, in which 50% result in adhesion formation. Adhesion formation tends to follow predictable patterns. Adhesions form more commonly following surgery to the small and large bowel than with other intra-abdominal organs, especially in surgeries involving bowel distal to the transverse colon or involving gynecologic organs (1). The areas most frequently affected are the under surface
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FISTULAS

A fistula is an abnormal communication between two spaces. In the abdomen, varieties of fistulas differ tremendously and include such types as pancreatic fistulas, biliary fistulas, fistulas between two intra-abdominal organs (i.e., colocolonic fistulas), and enteroatmospheric fistulas. The natural history of a fistula begins as a leak from bowel or other intra-abdominal organ. The ultimate type of fistula depends on whether the leak is uncontrolled, partially controlled, or well controlled. An uncontrolled leak will result in peritonitis, which immediately results in surgical exploration and correction. A partially controlled leak may result in an intra-abdominal abscess, which will require definitive therapy. Controlled leaks result in fistulas, and the most dreaded of these is the enterocutaneous fistula. Management of fistulas can be a long-term challenge for surgeon and patient.

An enteroatmospheric fistula is an abnormal communication between lumen of bowel and the skin. Fistulas are postoperative complications in 71% to 90% of cases, though they may occur spontaneously (2,6). Spontaneous causes of fistulas are uncommon but may include malignancy, inflammatory processes such as Crohn’s disease, or vascular insufficiency, as seen in radiation enteritis. The iatrogenic fistula is the most common and presents a difficult management problem. Iatrogenic fistulas may result from inadvertent enterotomies, intra-abdominal infections, direct injury or bowel desiccation in the open abdomen, misplaced stitches, or anastomotic breakdown. Impaired tissue perfusion from hypotension or vascular disease may predispose to this complication, as well infections, steroids, and malnutrition.

An enterocutaneous fistula typically presents as discolored, watery drainage from the midline incision. A seeming wound infection opened at bedside will result in copious drainage of discolored, watery material or frank succus. Passage of gas from the midline wound is diagnostic of an enterocutaneous fistula. Patients will usually demonstrate signs of advancing infection including increasing temperature, white blood cell count,

Adhesions result from trauma to tissues, relative ischemia, infection within the abdominal cavity, inflammatory processes, or by the presence of foreign bodies such as suture, talc from gloves, and lint from sponges. To minimize adhesions, principles of good surgical technique are the best defense. Gentle tissue handling with strict hemostasis and minimization of intraperitoneal trauma are core principles. In addition, frequent irrigation to dilute or to remove contaminants and the use of small, nonreactive suture material will diminish the contribution to adhesiogenesis. Raw surfaces or anastomoses should be protected by autologous tissue, either with a tongue of omentum or via mobilized local tissue flaps. Perhaps the most effective method of preventing serious adhesions is via the use of the omentum. As is well known, the omentum is key to protecting areas of inflammation and infection within the abdomen. In a similar manner, the omentum may be used to wrap anastomoses or to protect abdominal contents from a healing midline incision. Unfortunately, the omentum is often too limited by prior inflammatory processes or surgery to be of use.

Barriers to Adhesiogenesis

Despite meticulous technique and conscientious efforts to prevent adhesion, they will continue to form with attendant postoperative morbidity and mortality. Research efforts have focused on developing materials to minimize the occurrence and severity of adhesions. The most common method of decreasing the number and strength of adhesions is with one of a variety of barrier materials. Seprafilm (Seprafilm Adhesion Barrier, Genzyme Corporation, Cambridge, MA) is an FDA-approved material composed of hyaluronic acid and carboxymethylcellulose. Applied to regions at risk for adhesions, it forms a deposit that acts as a mechanical barrier to adhesion formation. It is eventually reabsorbed by the body after 7 to 10 days. One large study demonstrated no difference in rates of small bowel obstruction with Seprafilm; however, the need for operative therapy to treat adhesions was significantly reduced (1). Of note, Seprafilm should not be used to wrap anastomoses to decrease adhesions at these sites, as this has resulted in higher rates of fistula formation (1). Interceed (Gyneicae Interceed, Johnson & Johnson, New Jersey) is an older option that is a mechanical barrier designed to be placed over injured surfaces and operative sites. It is composed of oxidized regenerated meshlike cellulose; data have been mixed on its effectiveness. Although some studies have demonstrated that Interceed is safe and effective in reducing adhesions, other studies have shown no clinical benefit from its use (4). Additionally, it requires a completely hemostatic field, and the region in question must be completely covered for effective results, not always practical especially in laparoscopic surgery. Other methods to decrease adhesion formation have been shown to be less effective in adhesion prevention and are not used commonly in clinical practice. Gore-Tex Surgical Membrane (W.L. Gore and Associates, Flagstaff, AZ), a thin PTFE (polytetrafluoroethylene) membrane that prevents cellular penetration, must be secured in place and removed at a later date. This method is cumbersome, has not shown significant clinical benefit in preventing adhesions, and is not commonly used. Streptokinase infusion has shown no benefit in reducing adhesions. The use of tissue plasminogen activator to break down adhesions has shown some promise in animal studies but has not been proven in humans to date (4,5). These latter methods are of interest, either historically or in a research perspective, but are not commonly used in clinical practice.

Regardless of which product is ultimately chosen, the ideal barrier would be nonreactive in vivo, would be active during the key healing stages, and then reabsorbed by the body when no longer needed. Locales that remain prime candidates for adhesion barriers include around temporary stomas, around the Hartmann pouch after colectomy, beneath the midline incision, and in the pelvis following surgery in that region, especially in patients prone to inflammation. Research interest in this area remains high as adhesion-related morbidity continues to plague surgical patients.
and persistent ileus. In less common cases, patients may develop profound shock due to electrolyte imbalances and sepsis. In these cases, emergent re-exploration is necessary. However, if the patient presents with drainage or an obvious fistula but is hemodynamically stable, conservative management is warranted, at least in the short term.

### Conservative Management of the Enterocutaneous Fistula

Management is predicated on controlling output, managing electrolyte fluxes and nutritional deficiencies, and maximizing the potential for spontaneous closure (Fig. 77.1). In the immediate care of the patient, aggressive fluid resuscitation and close monitoring of electrolyte balance are mandatory to maintain stability. If the patient remains stable without the need for emergent operative intervention, nutritional replacement should begin immediately. This patient population is exceptionally prone to malnutrition from protein losses, increased metabolic demands, and limited or no oral intake. Parenteral nutrition is nearly mandatory to provide early and aggressive nutritional repletion, to allow close management of electrolyte and protein balances, and to decrease volume transit past the fistula in the gastrointestinal tract. Perhaps a greater challenge in this patient population is control of fistula output. Enteric contents are extremely caustic to the skin and surrounding tissues. An immediate goal in caring for patients with fistulas is to create some method to isolate enteric contents from the skin. For a simple enterocutaneous fistula, a stoma appliance may be all that is needed. However, many fistulas present in open wounds, including on granulating abdomens. These tissue fields are not amenable to the placement of a simple stoma appliance. In these situations, a close association between the wound beds, including on granulating abdomens. These tissue fields are not amenable to the placement of a simple stoma appliance. In these situations, a close association between the fistula and an abscess, association with a malignancy, distal bowel obstruction leading to increased pressure and transit through the fistulous tract, epithelialization of the tract, and a short neck with wide fistula mouth. As noted, long-standing fistulas with high outputs are unlikely to close spontaneously.

The patient and surgeon are not completely at the mercy of physiology and chance while awaiting spontaneous closure. At least in the short term, parenteral nutrition is pursued to decrease volume transiting the gastrointestinal tract and through the fistula. A positive nitrogen balance and a transferrin level greater than 200 mg/dL are also associated with successful closure (7). The use of octreotide or other somatostatin analogue (100 μg intravenously every 8 hours) may decrease secretion in the gastrointestinal tract as well. Somatostatin inhibits the secretion of most gastrointestinal hormones and enhances fluid and electrolyte absorption, thereby decreasing intraluminal volume and potentially decreasing fistula output. Despite the theoretical benefits of somatostatin use, clinical studies have revealed mixed results on effectiveness. Although some studies have demonstrated a decreased fistula output and higher rate of spontaneous closure, an equivalent literature reveals no statistical difference in output or closure rates (8). As side effects are relatively mild, including gastrointestinal discomfort and increased biliary sludge, we recommend trying a somatostatin analogue in conjunction with other conservative therapies while waiting for a fistula to close spontaneously. However, somatostatin analogues should not be relied on as a primary therapy to close fistulas.

### Spontaneous Closure

The goal of conservative therapy is to achieve spontaneous closure of the fistula. Spontaneous closure is dependent largely on inherent characteristics of the fistula. Most fistulas that close without intervention will do so in the first 3 to 6 weeks after appearance. Fistulas with long tracts and narrow mouths are most likely to resolve independently. Additionally, low-output fistulas, defined as having an output less than 500 mL per day, have a higher likelihood of closure than high-output fistulas. A fistula that is not closed by 3 months is unlikely to close without surgical therapy. Additionally, many patient factors have been associated with failure of the fistula to close spontaneously. Factors that will virtually ensure patency of the fistula include the presence of a foreign body in the fistula tract, close association between the fistula and an abscess, association with a malignancy, distal bowel obstruction leading to increased pressure and transit through the fistulous tract, epithelialization of the tract, and a short neck with wide fistula mouth. As noted, long-standing fistulas with high outputs are unlikely to close spontaneously.

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### Surgical Therapy for Enterocutaneous Fistulas

If after approximately 3 months a fistula has failed to resolve, the likelihood of closure without operative intervention is poor. The first step in surgical closure is defining the fistula. The best method of defining a fistula tract is via fistulogram. In the standard method, Gastrografin is injected into the tract and fluoroscopy is used to follow the progress of the contrast. A fistulogram is useful to define the length of the tract, tortuosity, tract diameter, and which segment of the gastrointestinal tract is involved. An alternative method described in the
The pancreatic fistula is of an entirely different nature. In surgical patients, these fistulas most often result from trauma or iatrogenic injury, though a small percentage will be the result of pancreatitis. The cardinal principles of management are diagnosing of the fistula and wide drainage. A pancreatic fistula may drain from 100 to 1,000 mL of fluid per day. The resulting pancreatic ascites may cause abdominal pain, fever, and a plethora of vague symptoms including abdominal bloating, hiccups, intolerance to oral intake, and abscess. Pancreatic fluid contains a large amount of bicarbonate compared to plasma (70–90 mEq/L), and inadequate replacement of bicarbonate may lead to nonanion gap metabolic acidosis. All patients respond differently to a pancreatic leak, and whereas some may present in profound shock, other patients may tolerate large-output pancreatic fistulas with few signs or symptoms. The source of this variability in clinical presentation is poorly understood but is likely due to the degree of enzymatic activation of the leaking fluid. The most common method of diagnosis is by CT scan. If the patient is of reasonable body habitus and transport is hazardous, an ultrasonic ultrasound may provide equivalent information.

For most patients, the initial treatment for a pancreatic fistula is simply drainage. In the modern era, interventional radiology is invaluable in placing these drains. However, if at initial operation there is concern for postoperative leak, widespread drainage with a closed-system drain should be established before closing the patient's abdomen. Wide drainage of pancreatic secretions should allow time for the patient to stabilize and prevent damage to other abdominal organs. Frequently, patience to allow long-term drainage to resolve will permit spontaneous closure of the pancreatic fistula. In addition to drains, adjuncts such as total parental nutrition and octreotide may be helpful in decreasing secretory stimulation to the pancreas. A multiseries review demonstrated that the octreotide group (administered 100 μg subcutaneously every 8 hours immediately after procedures deemed at high risk for pancreatic fistulas) had reduced fistula outputs, lower serum amylase and lipase levels, and an earlier return of positive nitrogen balance than in control groups (8). As in many areas of research, there is an opposing literature demonstrating no statistically significant improvement in patient outcomes with octreotide therapy. However, it is reasonable to pursue this therapy for a time-limited course (approximately 1 week) to improve chances of spontaneous resolution.

Conservative management with drains is generally pursued for up to 6 months and has a success rate of up to 97% in some studies (11). Depending on the cause of the fistula, intervention may be indicated on an earlier basis. If drainage fails to resolve the fistula, an imaging study should be pursued to define the duct and to determine if an obstructive process is mandating fistula patency. Although both magnetic resonance choledangiopancreatography (MRCP) and endoscopic retrograde cholangiopancreatography (ERCP) may provide equivalent information, ERCP is preferred. ERCP allows the opportunity to identify pathology of the pancreatic duct and also allows the opportunity to intervene. Stenting of
a proximal obstruction may be adequate to allow prograde drainage of pancreatic secretions and closure of the fistula, thereby avoiding surgical therapy (12). When all less invasive therapies fail, however, exploratory laparotomy remains the gold standard for definitive therapy. Options at laparotomy depend on the level of the injury. Primary duct repair is unlikely in most circumstances. Rather, a fistula resulting from the distal duct (perhaps secondary to a splenectomy) is well treated by distal pancreatectomy. If the leaking duct is sufficiently large, as is seen in relation to a ductal obstruction, a pancreaticojunostomy may be performed to allow for a low-resistance drainage pathway. Pancreatic fistulas involving the proximal duct are most often iatrogenic or related to trauma and are troublesome to deal with, in light of other major structures in the region. For these patients, a pancreatocaudal enterostomy (Whipple procedure) will resect the leaking portion of pancreas and allow reconstruction. The Whipple procedure should be entertained only in patients with good physiologic reserve. As noted, an attempt at conservative therapy and complete preoperative imaging and optimization are mandatory as these procedures are a major commitment for surgeon and patient. Despite the wealth of surgical options, most pancreatic fistulas will resolve with appropriate drainage, and thus, surgical correction is an end-stage option for correction of the fistula (11).

**ABDOMINAL COMPARTMENT SYNDROME**

Abdominal compartment syndrome has historically been a source of significant patient morbidity and mortality. First described in 1984, abdominal compartment syndrome was the result of an intra-abdominal catastrophe (ruptured abdominal aortic aneurysm) resulting in elevated pressure and multiple highly morbid sequelae (13). More recently, secondary abdominal compartment syndrome has resulted from massive resuscitations required by major trauma, burns, and pancreatitis. Regardless of the source of the compartment syndrome, those requiring decompressive laparotomy have a mortality rate of 13% to 33% (14). Occurrence of abdominal compartment syndrome has been lessened somewhat within the last decade due to increased recognition of the phenomenon and prophylactic use of the open abdomen technique. In operative cases requiring decompressive laparotomy, the abdomen is left open with a distended and tense abdomen. These patients will frequently demonstrate hemodynamic instability with difficulty ventilating and poor urine output. Examination of the patient’s ventilatory status will reveal elevated peak inspiratory pressures, often well above 30 mm Hg. If the patient is ventilated with a pressure-control ventilatory method, he or she will alternately demonstrate low tidal volumes. As clinical suspicion increases, a bladder pressure may be transduced for definitive diagnosis. An arterial pressure line is attached to the patient’s Foley catheter, and approximately 60 mL of sterile saline is introduced. Abdominal pressures greater than 15 mm Hg are indicative of abdominal compartment syndrome. When the transduced pressure reaches 25 to 30 mm Hg, a decompressive laparotomy is indicated as therapy for abdominal compartment syndrome (16,17). Of importance, decompressive laparotomy may be indicated at lower intra-abdominal pressures depending on the patient’s clinical condition (18). After decompressing the abdominal contents, the abdomen is left open with a temporary abdominal closure until swelling diminishes enough to allow closure. Although decompressive laparotomy for abdominal compartment syndrome is life-saving, it continues to be associated with a 42% to 68% mortality rate (15) although a lower mortality rate has been reported and is dependent on the severity score (19).

The Open Abdomen

Over the last two decades, management strategies for abdominal domain have changed drastically. Even as few as 15 to 20 years ago, the surgical bias was that the abdomen must be closed at all costs. Two increasingly recognized trends in surgery have led to a change in perspective, where the open abdomen is no longer a catastrophe but rather a tool in the surgeon’s armamentarium. First, the increasing recognition of primary and secondary abdominal compartment syndrome has led many surgeons to choose the open abdomen as a management strategy for the short term. Second, “damage control laparotomies” have become increasingly common in treating major abdominal trauma. Although the idea of abbreviated laparotomy was first described by Stone et al. in 1983 (20), the formal nomenclature and increasing popularity are credited to Rotondo et al. in 1993 (21). Damage control laparotomy is aimed at limiting intraoperative times for deteriorating patients, allowing transfer to the intensive care unit for vigorous resuscitation. Intraoperatively, major vascular hemorrhage
is controlled, either by ligation or packing, and gross bowel contamination is controlled through ligation, often leaving the gastrointestinal tract in discontinuity. The patient's abdomen is then closed in a rapid and temporary manner, with a plan to return when the patient is more stable to effect definitive repair. Damage control laparotomy remains an aggressive strategy for treatment of patients who develop the deadly triad of coagulopathy, hypothermia, and metabolic acidosis (Fig. 77.2). By definition, it requires use of the open abdomen technique, at least until definitive surgical repair is possible.

The open abdomen, while an appropriate management technique, may ultimately become a Gordian knot. The questions of how to manage an open abdomen, and how and when to close it, may be difficult. Continuing management of the open abdomen involves three primary decision-making stages—initial operative management, decision to close primarily versus a planned ventral hernia, and definitive closure of the planned ventral hernia. At the time of the initial damage control laparotomy, the surgeon must choose to temporarily close the abdomen. The original temporary abdominal dressing is known as the Bogota bag. Initially described from its use in Colombia during the 1980s, it consists of covering the abdominal contents with a sterile saline bag to protect the bowel until reexploration. A derivation of the Bogota bag is a widely used method of temporary abdominal closure in current practice. A plastic drape, such as a sterile cassette cover, is placed over the bowels to prevent them from injury and to allow drainage of fluid. A sponge or blue towel, with two large Jackson-Pratt drains (Cardinal Health, McGaw Park, IL), is then placed over the plastic drape. The entire system is folded under the fascia to contain the abdominal contents. An adhesive drape is placed over the abdomen to maintain sterility, contain contents, and prevent free drainage of fluid (Fig. 77.3). The drains are placed to suction to allow egress of blood and edema fluid. This dressing is then left intact until return to the operating room (22). This method is preferred to a traditional Bogota bag, as it allows control of abdominal edema with no significant additional investment in time or supplies in the operating room. Regardless of method, the primary goal at this stage is rapid closure with protection of intra-abdominal contents. The exact technique is the surgeon’s choice (19,23).

After an appropriate resuscitation period, typically 24 to 48 hours, the patient is returned to the operating room. If definitive therapy is complete, the decision to close primarily depends on the quantity of intra-abdominal edema and the quality of the fascia. Whenever possible, primary closure of fascia is ideal. The goal of every closure is to minimize tension on the fascia. High-tension closures not only result in elevated intra-abdominal pressures, but also lead to ischemia of the involved fascia with subsequent breakdown and the risk of dehiscence. If it is not possible to close the fascia, or if further trips to the operating room are indicated, the surgeon should choose a temporary closure that prevents lateral retraction of the fascia and facilitates later primary closure. Vicryl mesh sewn directly to the fascia is a form of temporary abdominal closure that may be pleated later in the intensive care unit. Mesh pleating and wound care may continue until intra-abdominal swelling diminishes and the fascia is near enough to close (13). Alternatively, vacuum-assisted fascial closure may be pursued. The most commonly used system is made by KCI (KCI Wound VAC System, Kinetic Concepts, Inc., San Antonio, TX) and involves a pre-created plastic drape with incorporated sponge, a separate wound sponge, and adhesive dressing with suction tubing. In this method, the bowels are protected with the plastic drape containing the incorporated sponge. A specially designed drainage sponge with constant suction is then placed, and the abdomen is covered with an adhesive dressing. The sponge suction provides constant medial tension, without disrupting the fascia, to prevent lateral retraction (22,23). Regardless of which method is chosen, most studies have indicated a high rate of primary closure if the patient has a net...

FIGURE 77.2. The “bloody vicious cycle” of coagulopathy, hypothermia, and metabolic acidosis.
negative fluid balance at the time of operation. Therefore, management of the patient’s volume status may be as important as the method of temporary closure in allowing later reaproximation of the fascia. However, net negative volume balance is extremely difficult to achieve in critically ill trauma patients requiring large-volume resuscitations. Therefore, a large percentage of these patients will go on to planned giant ventral hernias. In a study by Jernigan et al. (24) in 2003, 42% of patients with temporary closures for hemorrhagic shock ultimately were managed with planned, giant ventral hernias.

**Closure of the Giant Ventral Hernia**

For those who are not closed primarily, the ultimate management may be with the creation of a giant ventral hernia. These patients are managed for the first 1 to 2 weeks postinjury with Vicryl mesh and dressing changes or vacuum-assisted abdominal closures. Once the abdominal contents display a healthy bed of granulation tissue, the abdomen is given a split-thickness or full-thickness skin graft. The patient is then observed for 6 to 12 months as she or he undergoes rehabilitation and nutritional repletion.

As the ventral hernias are somewhat debilitating and cosmetically displeasing, most patients will be eager for definitive closure of the hernia (Fig. 77.4). The surgeon must consider the patient’s nutritional status, as well as the laxity of the skin graft, prior to offering closure. Over time, the skin graft and intraabdominal adhesions will soften, allowing easier graft removal and adhesiolysis. Rushing to repair a giant ventral hernia will result in operating in a hostile abdomen, with the risk of enteringomies and injury to the patient. As noted above, the ideal window for most patients appears to be at 6 to 12 months (Table 77.1) (23). The repair of the giant ventral hernia is also a good time for repair of any fistulas and reversal of stomas.

Most giant ventral hernias will not be amenable to primary closure. Therefore, the surgeon must decide the best method of restoring abdominal domain. The use of mesh is one option but may not be possible if enterotomies are made during the lysis of abdominal adhesions will soften, allowing easier graft removal and adhesiolysis. Rushing to repair a giant ventral hernia will result in operating in a hostile abdomen, with the risk of enterotomies and injury to the patient. As noted above, the ideal window for most patients appears to be at 6 to 12 months (Table 77.1) (23). The repair of the giant ventral hernia is also a good time for repair of any fistulas and reversal of stomas. Most giant ventral hernias will not be amenable to primary closure. Therefore, the surgeon must decide the best method of restoring abdominal domain. The use of mesh is one option but may not be possible if enterotomies are made during the lysis of abdominal pressures controlled, resuscitated, no elevation of abdominal pressures

**Unable to close primarily**

- Vicryl mesh: for 2–3 weeks until adequate granulation bed
- Wound vac: until adequate granulation bed

**2–3 weeks, granulation**

- Split-thickness skin graft
- Planned ventral hernia

**6–12 months**

- Closures of planned ventral hernia: with mesh
- Separation of components

**TABLE 77.1**

<table>
<thead>
<tr>
<th>Initial Surgery</th>
<th>Cassette cover for damage control</th>
<th>Laporotomy</th>
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<tbody>
<tr>
<td>24–48 degrees</td>
<td>Primary closure—of hemorrhage</td>
<td></td>
</tr>
<tr>
<td>Unable to close</td>
<td>Primarily</td>
<td></td>
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<tr>
<td>2–3 weeks,</td>
<td>Granulation</td>
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<tr>
<td>6–12 months</td>
<td>Planned ventral hernia</td>
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If the fascia will still not come together in a tension-free manner, a full separation of components is indicated. An incision is made in the anterolateral rectus sheath and the posteromedial rectus sheath bilaterally. The medial posterior sheath is then sewn to the lateral edge of the anterior sheath to provide added length of abdominal wall (Fig. 77.5). When the fascia is...
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**SHORT BOWEL SYNDROME**

Short bowel is defined as a gastrointestinal length of 2 m, or less, and the cause may vary greatly between children and adults. Short bowel is an outcome of intra-abdominal catastrophe resulting in extensive surgical resection. Children most commonly end with short gut syndrome following a congenital or neonatal process such as necrotizing enterocolitis, intestinal atresia, volvulus, or gastroschisis. Adults acquire short gut syndrome following extensive surgical resection necessitated by malignancy, trauma, obstruction, or vascular insufficiency. Regardless of the cause, a patient’s ultimate outcome is largely determined by the length of remaining small bowel and the presence or absence of the colon. Presence of the colon can extend the functional capacity of the remaining bowel. To have the potential for enteral autonomy, a patient requires at least 150 cm of small bowel, or 60 to 90 cm if the colon is present (26). Presence of the ileocecal valve is also important in maintaining hydration and modulating gastrointestinal transit time.

Short gut syndrome is most obviously defined by difficulty meeting nutritional requirements and dependence on parenteral nutrition. Patients will complain of weight loss, diarrhea, and stratorrhhea. On a physiologic level, patients develop gastric emptying abnormalities and rapid transit times due to short intestinal length. Dehydration is a constant threat if the colon is absent due to an inability to reabsorb the approximately 4 L of gastrointestinal secretions per day. Malabsorption results in deficiencies in B12, fat-soluble vitamins, and bile salts. Short gut patients are also prone to cholelithiasis and nephrolithiasis due to altered absorption of bile salts and oxalate, peptic ulcers due to increased gastric secretions, line sepsis from deep catheters for delivery of parenteral nutrition, and liver dysfunction from that same parenteral nutrition (27).

A surgeon’s role in managing short gut starts in the operating room with the very first incision. At the initial operation, the surgeon should make every effort to preserve bowel length, as well as the ileocecal valve. In some cases, it may be safest to limit resection and return at a later date to inspect marginally viable bowel. Initial postoperative therapy is often supportive, as this patient population is critically ill after emerging from the operating room. Early central venous access with immediate institution of parenteral nutrition aids in healing and prevents malnutrition. The long-term management of short gut patients then requires a multidisciplinary team involving physicians and nurses, nutritionists, patients, and their families.

Patients with short gut generally fall into two groups—those with insufficient length (usually less than 45–60 cm) who require lifelong parenteral nutrition and those with adequate length to potentially adapt and become partially or totally enterally independent. Adaptation is a process whereby the absorptive surface of the gut alters to increase digestive capacity and improve nutritional potential. In most cases, the ability is dependent on time and the nature of the remaining bowel. The ileum is capable of adapting to many jejunal functions, but the reverse is less successful (27). Some studies advocate the use of recombinant growth hormone to improve adaptation. In patients who are nutritionally maximized, growth hormone promotes mucosal hyperplasia and increases villous surface area. The process is further enhanced by high-carbohydrate, low-fat diets. Although minimal evidence exists in humans, animal studies have shown enhanced adaptation and nutritional repletion with selective use of growth hormone. Glutamine has also been proven beneficial and works synergistically with growth hormone. Glutamine, and trophic feeds, stimulate enterocytes and enhance cell proliferation. Even in patients who are completely parenterally dependent, low-rate trophic feeds maintain mucosal health (28). Additionally, preservation of colonic length improves fluid reabsorption. This improves patient hydration, leading to a more normal bowel regimen and improving the success of adaptation and weaning from parenteral nutrition. With these facts in mind, surgeons have a number of adjuncts to improve intestinal performance once bowel length is defined.

Occasionally, surgical therapy is required to deal with the sequelae of short gut or to promote adaptation. In patients with enteral continuity who are increasing oral intake, rapid transit due to inadequate length for absorption may result in persistent and disabling diarrhea and worsening of malnutrition. In these cases, conservative therapies such as medication and diet modification are the first line of therapy. If these are inadequate, segmental interposition may be attempted. Ideally, approximately 10 cm of small bowel is reversed and interposed in the gastrointestinal tract. When intraluminal contents reach the reversed segment, the antiperistaltic flow slows transit time.

In cases where small bowel length is inadequate, a colonic limb may be interposed. This option is much less favored and rarely
performed. Creation of an artificial valve is also a possibility for those lacking a native ileocecal valve. The key to creation of a successful valve is an appropriate length, as one that is too short will have minimal impact on transit time and one that is too long may cause obstruction. An ideal length is felt to be 2 cm although evidence regarding effectiveness is limited, as this is not a commonly performed procedure (29). Of note, surgical therapy for short bowel syndrome is pursued infrequently and is generally referred to tertiary centers with extensive experience managing these challenging patients.

In some cases, patients may have adequate remaining length for enteral independence but suffer from poor function secondary to obstruction, pseudo-obstruction, or dilation. Initial focus should be on relief of the obstruction. Obviously, adhesive bands obstructing the bowel lumen should be dealt with by simple lysis. In some cases, however, the small bowel may demonstrate one or multiple strictures. As bowel length in short gut patients is obviously at a premium, resection with anastomosis is not a good option. To preserve length and relieve obstruction, a stricturoplasty remains a reasonable alternative. In standard Heineke-Mikulicz stricturoplasty, a longitudinal incision is made along the length of the stricture. The enterotomy is then closed in one or two layers in a transverse direction. More involved stricturoplasties may be indicated depending on the specific details of the situation. However, a standard stricturoplasty should be adequate for most circumstances. Alternatively, a dilated, poorly functioning segment of bowel may exist as short gut patients due to distal obstructions, like strictures. When the distal obstruction has been dealt with, the dilated segment(s) may be treated by tapering enteroplasty. In this situation, interrupted Lambert stitches are placed on intact bowel to imbricate the wall and to decrease the caliber of the lumen. All of these procedures have specific indications and are pursued to maximize function of minimal bowel length.

When bowel length is too short, additional centimeters may be gained via a lengthening procedure. This may mean the difference between total parental nutrition dependence and partial enteral autonomy. In lengthening procedures, the antimesenteric border is incised, as well as the mesenteric border. Care must be taken to preserve the blood supply to both sides. Each side is then closed to form parallel tubes. These tubes are anastomosed end to end to create a segment that is twice as long but with a narrower lumen (2). A final option in pursuit of enteral independence is small bowel transplantation. Depending on the patient's hepatic function, a complete small bowel and liver transplant may be required. Small bowel transplantation remains an area of growth and continued challenge in the transplant community. Indications for small bowel transplantation include permanent intestinal failure as demonstrated by occlusion of two or more major veins, frequent episodes of line sepsis, unacceptable quality of life, or liver failure. With current induction and maintenance therapies, the 1-year survival for small bowel transplantation is approximately 65% and is only slightly lower at 59% when liver transplantation is included (30). With early evaluation and referral, specialized centers are achieving much better 2-year survival after small bowel transplantation with less morbidity related to immunosuppressive dosing. Transplant centers have been able to maintain good graft function while weaning patients off steroids and minimizing dosing of the most toxic immunosuppressive agents. Transplant remains an imperfect choice for short gut patients but has increasing promise for patients who have exhausted alternatives.

RADIATION ENTERITIS

Radiation damage to the gastrointestinal organs can be a particularly vexing problem for the surgeon and the patient. Ionizing radiation is delivered neoadjuvantly or adjuvantly for neoplastic processes occurring in organs of the pelvis. Radiation damages mitotically active cells of the mucosal surface epithelium, especially crypt cells. The incidence of injury is dependent on such factors as volume of irradiated small bowel, total dose delivered as well as dose per fraction, and type of radiation being delivered (31). In addition, radiation causes production of oxygen free radicals which further damages tissue at the cellular level. These cellular disruptions manifest as obliteratorative arteritis with subsequent bowel ischemia. Affected bowels may develop strictures, perforate, or develop fistulas (Fig. 77-7). Additionally, inflammation resulting from injury causes formation of dense local adhesions. Of patients undergoing abdominal and pelvic radiation, 50% to 75% will have some symptoms related to the therapy in the months to years following treatment. The most common symptoms are vague abdominal pain, diarrhea, rectal bleeding, and tenesmus. In 1% to 15%, bothersome symptoms will progress into actual radiation enteritis. Although symptoms most commonly occur during therapy, and may be abrogated by decreasing the radiation dose by 10%, patients may develop chronic radiation enteritis years after treatment. In the case of late radiation enteritis, workup should include dismissing recurrence of the initial neoplasm (2,32).

Initial management of radiation enteritis should embrace conservative measures. Sitz baths and stool softeners are effective initial treatments for rectal and anal symptoms. Opiates, antispasmodics, and anticholinergics will decrease transit time if diarrhea is the primary problem. Steroid enemas and sucralfate (by mouth or by rectum) can diminish irritation of the mucosa, which results in rectal pain and bleeding. If the patient is malfed from chronic enteritis, total parenteral nutrition FIGURE 77-7. The effects of ionizing radiation on gastrointestinal cells and overall small bowel.
Surgical Therapy for Radiation Enteritis

Surgical therapy for radiation enteritis encompasses two phases—prevention and therapy. If radiation is planned as an adjuvant therapy following surgery, some techniques may be used to diminish radiation injury. Simple nonsurgical methods to diminish radiation injury include patient positioning, multiple field techniques, and bladder distention (31). Following pelvic surgery, reperturbation of the operative field will diminish local adhesions, which may serve to draw small bowel into the radiation field. Intra-operative efforts are designed to decrease the volume of small bowel included in the radiation field postoperatively. Use of mesh to construct a stent for exclusion of small bowel from the pelvis has had some success. However, this increases the risk of mesh-related hernias with the attendant risk of obstruction or strangulation, the rate of deep venous thrombosis, and the incidence of pelvic fluid collections. Using omentum to exclude the pelvis is rarely an option. This alternative is not available for most patients but has a lower incidence of the aforementioned mesh-related complications. Small bowel displacement systems, though not commonly used, have had some success in physically excluding up to 50% of small bowel volume from the radiation field (31).

The second role of surgery is in the treatment of complications of radiation enteritis. The most common indication for surgery remains obstruction, but other indications include excessive bleeding, intractable diarrhea, pain, fistulas, and persistent abscess. Any surgical intervention should use the least invasive procedure required to address the issue. Excessive handling of radiated tissues commonly results in unplanned enterotomies and may interrupt an already tenuous blood supply. Any suspicious-appearing areas should be biopsied to evaluate for radiation enteritis. The involved segment, if involved in obstruction or fistula, should be excised, and the anastomosis should attempt to include nonradiated bowel. Minimal lysis of adhesions should be pursued to prevent disruption of tenacious blood supplies. If dense adhesions prevent access to the involved segment, a gastrointestinal bypass may be necessary. This option will predispose a patient to blind loop syndrome and bleeding but may be a better option than attempting to mobilize frozen bowel (32).

Approximately 2% to 5% of patients with a history of pelvic radiation therapy will develop chronic proctopathy, which may include rectal pain and bleeding (33). First-line therapies of sucralfate and steroid enemas are of limited benefit. Endoscopic coagulation of bleeding with electrocautery or laser has been successful for limited bleeding sites. Laser photocoagulation has a low morbidity rate of 5% to 15% but requires multiple treatment sessions. The most effective nonoperative therapy remains the topical application of 4% formalin, with 85% of treatment sessions. The most effective nonoperative therapy remains the topical application of 4% formalin, with 85% of patients responding after two instillations or less (33). When these measures fail, invasive therapy is pursued. If there is a component of stricture, initial therapy should include serial dilatation. However, if this is unsuccessful or the indication is intractable pain, severe incontinence, or profound bleeding, a diverting colostomy may be necessary. In worst-case situations, abdominoperineal resection may be pursued. In the event of fistulas, the fistula tract and involved tissue at either end must be resected and the sites closed. An interposition flap of omentum or muscle should then be placed to protect the repair sites. Again, prevention is truly the best option for the problem of radiation enteritis. New radiation regimens with lower doses and more specific direction potentially provide the most benefit for this patient population.

SUMMARY

Even the most routine abdominal surgery has the potential for a difficult postoperative course. When postoperative patients do not progress as anticipated, or when complications develop, a high index of suspicion is important for rapid diagnosis and treatment. The cornerstone of every difficult postoperative problem is meticulous and careful technique at the time of the original surgery. Once the problem is manifest, attention to the patient’s condition and conservative management are widely favored initial approaches. Ultimate therapeutic choices may have a profound effect on the patient’s eventual recovery and quality of life. Whether the final cure is by careful manipulation of patient physiology or by surgical intervention, the critical care surgeon must be well versed in a multitude of complex postoperative issues to provide exceptional and appropriate therapy.

PEARLS

- Routes to provide enteral feedings should be considered at the time of surgery for patients in whom oral intake is not anticipated for some time. Either surgical jejunostomy or manual placement of small nasoenteric feeding tubes past the pylorus will help the patients with early nutrition and possible avoidance of parental nutrition.
- All tubes and drains must be secured to minimize inadvertent dislodgement. Loss of carefully placed tubes and drains can lead to significant morbidity.
- Avoid re-entering the abdomen in the first 2 to 3 weeks after previous surgery (if possible). This is the peak time for dense adhesions and iatrogenic injury may occur.
- Carefully assess the patient’s general condition before entering a hostile abdomen. Cardiovascular and pulmonary status, nutritional support, blood sugar control, and coagulation profile should be optimized if possible.

REFERENCES

CHAPTER 78  CRITICAL CARE OF HEPATOPANCREATOBILIARY SURGERY PATIENTS

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Patients are admitted to the intensive care unit (ICU) for a variety of reasons following hepatopancreatobiliary (HPB) surgery, including maintenance or restoration of normal physiology immediately after extensive surgery and the subsequent management of complications that develop. Many of the issues that require ICU management are common to all ICU patients and will not be discussed in this chapter; however, there are recurring issues that are relatively specific to HPB surgery patients that will be discussed. The role of normal liver physiology and its alteration during HPB surgery and disease states will be discussed, as well as the management of common problems that arise after HPB surgery.

HPB surgery is composed of surgery of the liver, bile duct, and pancreas, and may include portal decompressive procedures for complications of portal hypertension. Surgical procedures on the pancreas and bile duct alone generally do not require care in a critical care setting immediately after leaving the operating room unless complications occur. Liver resections, particularly when extensive, can require admission to a critical care unit immediately following surgery due to the alterations in normal physiology that occur during the procedure itself. An understanding of normal liver physiology and the alterations it undergoes during surgery is important when managing these patients.

LIVER ANATOMY AND PHYSIOLOGY

The liver is approximately 4% to 5% of total body weight and has multiple complex functions. The anatomy of the liver...
has been described using various and different methods (1–5); however, surgical anatomy is based on the segmental nature of vascular and bile duct distribution. The liver receives a dual blood supply from both the portal vein and hepatic artery that run, along with the bile duct, within the glissonian sheath or main portal pedicle. The portal pedicle divides into right and left branches and then supplies the liver in a segmental fashion. Venous drainage is via the hepatic veins, which drain directly into the inferior vena cava. Hepatic segmentation is based on the distribution of the portal pedicles and their relation to the hepatic veins (Fig. 78.1). The three hepatic veins run in the portal scissura and divide the liver into four sectors, which are, in turn, divided by the portal pedicles running in the hepatic scissura. The liver is divided into right and left hemilivers by the middle hepatic vein. The right hemiliver is divided by the right hepatic vein into anterior and posterior sectors. The anterior sector is divided by the plane of the portal pedicle into an inferior segment V and a superior segment VIII. The posterior sector is divided by the plane of the portal pedicle into an inferior segment VI and a superior segment VII. The left hemiliver lies to the left of the middle hepatic vein and is divided into anterior and posterior sectors by the left hepatic vein. The anterior sector is divided by the umbilical fissure into segment IV medially and segment III laterally. The segment posterior to the left hepatic vein is segment II. Segment IV can be divided by the plane of the portal pedicle into a superior segment IVa and an inferior segment IVb. Segment I is the caudate lobe, which lies between the inferior vena cava and the hepatic veins. The caudate lobe has variable portal venous, hepatic arterial and biliary anatomy, and is essentially independent of the portal pedicle divisions and hepatic venous drainage.

Segmental anatomy becomes important in considering surgical resection when essentially any segment or combination of segments can be resected if attention is paid to maintaining vascular and biliary continuity to the remaining segments.

Common liver resections performed that may require ICU admission after surgery are left or right hepatectomies, in which approximately 50% of liver volume is removed, or more extensive procedures such as right or left trisectomectomy, in which up to 80% of the liver is removed (Fig. 78.1). If less than 40% of the liver is resected in patients with normal underlying liver function, then relatively little derangement of liver physiology is noted.

The liver performs many functions, including uptake, storage, and eventual distribution of nutrients from the blood or gastrointestinal tract, as well as synthesis, metabolism, and elimination of a variety of endogenous and exogenous substances and toxins (including narcotics and other drugs). Although the liver is only 4% to 5% of total body weight, it is responsible for 20% to 23% of body oxygen consumption and 20% of total energy expenditure (6). The liver receives a dual blood supply, with 75% of flow from the portal vein and 25% from the hepatic artery. Total blood flow (7) to the liver is approximately 1.5 L/min/1.73 m². While decreasing portal venous flow causes a subsequent increase in hepatic arterial flow, with complete portal occlusion or diversion, hepatic arterial flow does not completely compensate, and total liver blood flow is diminished (8). The opposite is not true, however (i.e., decreasing flow in the hepatic artery does not increase flow in the portal vein). There is autoregulation of hepatic arterial flow but not of the portal venous system. Portal flow is increased by food intake, bile salts, secretin, pentagastrin, vasoactive intestinal peptide (VIP), glucagon, isoproterenol, prostaglandin E₁ and E₂, and papaverine. Portal flow is decreased by serotonin, angiotensin, vasopressin, nitrates, and somatostatin.

Bile, composed of inorganic ions and organic solutes, is formed at the canalicular membrane of the hepatocyte, as well as in the bile ductules, and is secreted by an active process that is relatively independent of blood flow (9). The major organic components of bile are the conjugated bile acids, cholesterol, phospholipid, bile pigments, and protein. Under normal conditions, 600 to 1,000 mL of bile is produced per day (10). Bile secretory pressure is approximately 10 to 20 cm saline, with maximal secretory pressures of 30 to 35 cm in the presence of complete biliary obstruction.

Bilirubin, a degradation product of heme, is eliminated almost entirely in the bile. Bilirubin circulates bound to albumin and is removed from plasma by the liver via a carrier-mediated transport system. In the hepatocyte, bilirubin is bound to gluconic acid before being secreted in bile. The liver maintains the ability to clear bilirubin with partial duct obstruction. Complete obstruction of one of the right or left hepatic ducts alone will cause marked liver enzyme abnormalities, but rarely causes jaundice.

The liver synthesizes many of the major human plasma proteins including albumin, y-globulin, and many of the coagulation proteins. Liver dysfunction can have a profound effect on coagulation through the decreased production of coagulation proteins or, in the case of obstructive jaundice, there is decreased activity of factors II, V, VII, IX, and X, secondary to a lack of vitamin K–dependent posttranslational modification. Reversal of coagulation abnormalities by exogenous administration of vitamin K allows differentiation between synthetic
dysfunction and lack of vitamin K absorption secondary to obstructive jaundice.

After liver resection, liver function is altered through both a reduction in functional liver mass and potential ischemia/reperfusion injury to the liver remnant. With extensive liver resection in patients with normal presurgical underlying liver function, reduction of functional liver volume below 25% has been associated with an increased risk of both liver failure and mortality (11). To reduce the risk of liver failure in this setting, preoperative portal vein embolization (PVE) has been developed. During PVE, the portal vein of the side of the liver to be resected is embolized percutaneously. Diversion of portal flow and its hepatotrophic factors to the future liver remnant (FLR) causes growth and hypertrophy of the FLR of about 30% (Fig. 78.2) over a 6-week period and has been shown to reduce the complications associated with subsequent extended liver resections (12).

![FIGURE 78.2. Right portal vein embolization preoperatively allows an increase of functional liver remnant of approximately 30% from prior to embolization (A) to postembolization (B). MHV, middle hepatic vein. (Reused with permission from Hemming AW, Reed AI, Howard RJ, et al. Preoperative portal vein embolization for extended hepatectomy. Ann Surg. 2003;237[5]:686–691.)](image)

**Surgical Procedures**

**Liver Resection**

The liver is a tremendously vascular organ. Since intra- or postoperative complications are often related to excessive blood loss (13), a number of techniques have been developed to achieve preresection vascular control and decreased bleeding. While liver resection may be performed, in many cases without the need for interruption of blood flow to the liver, it is sometimes necessary to reduce blood flow to prevent excessive blood loss. Selective inflow control can be established by division or occlusion of the vascular structures supplying the segment(s) of liver to be removed. The right or left portal pedicle containing the respective portal vein, hepatic artery, and bile duct are controlled with a vascular clamp. This technique has the advantage of preserving blood flow to the segment of the liver being preserved, but is generally only useful in smaller resections.

Total inflow occlusion (Pringle maneuver) clamps the entire inflow of the liver at the hepatoduodenal ligament, and has been shown to reduce blood loss during the parenchymal transection phase of the resection (14). While there is some concern regarding warm ischemic injury, abundant data show that the normal liver can tolerate inflow occlusion for up to 1 hour, and there are reports suggesting that some cirrhotic livers can safely tolerate 60 minutes of inflow occlusion as well (13). We use total inflow occlusion when selective occlusion provides insufficient control. Clamp times are expected to be less than 30 minutes for formal hepatectomies, but may be higher for more complex parenchymal transections. In such cases, total occlusion is carried out in 15-minute increments with 5-minute reperfusion intervals. An alternative to the intermittent clamping technique is to use ischemic preconditioning, during which the liver inflow is occluded for 10 minutes, after which it is allowed to reperfuse for 15 minutes prior to clamping again for a sustained time period up to 1 hour. Intermittent clamping is associated with more blood loss than ischemic preconditioning; however, the protective results of ischemic preconditioning in ischemia reperfusion injury have not been uniform across age groups, and may not be as effective in livers that have been exposed to preoperative chemotherapy (16).

Total vascular isolation of the liver with both inflow occlusion and occlusion of the supra- and infrahepatic vena cava can be useful for technically demanding cases where the vena cava or proximal hepatic veins are involved with tumor (Fig. 78.3). Total isolation has been shown to be safe for up to 60 minutes in normal liver, but can be accompanied by varying degrees of hemodynamic instability (17). In cases where this is required, we carry out as much of the operation as possible prior to isolation of the liver to reduce the ischemic time and the period of hemodynamic instability.

The most troublesome bleeding sources during liver resection are usually from hepatic vein branches, which may be minimized by maintaining the central venous pressure (CVP) below 5 mm Hg during the period of hepatic transection. Cooperation of the anesthetist in minimizing volume loading, and occasionally using pharmacologic agents to reduce CVP, is essential. However, if total vascular isolation is to be used, volume loading prior to caval clamping is required to avoid an acute decrease in cardiac output at the time the clamps are applied.
Knowledge of the details of intraoperative conduct of the operation is therefore important to the physicians who are to manage the postoperative care of the liver resection patient in the ICU setting. Was inflow occlusion or vascular isolation required, and for how long? Prolonged clamp times are associated with greater liver dysfunction. Was the patient maintained with a low CVP throughout the course of the surgery? If so, then the patient may need volume expansion on arrival to the ICU. How much liver remains, and is it normal? If the percentage of remaining liver is less than 25% in normal livers or less than 40% in cirrhotic livers or livers with bile duct obstruction, then the chance of liver failure and the need for its management are higher. Was there significant blood or fluid requirements? Patients may need a period of ventilation while fluid shifts and equilibrates.

Pancreatic and Bile Duct Surgery

The majority of patients who undergo pancreatic or bile duct surgeries do not require admission to an ICU setting in the immediate postoperative period because of issues specific to the pancreaticobiliary surgery itself. In general, procedures on the pancreas or biliary tree should not be associated with major intraoperative hemodynamic changes or alterations in physiology. Tumors of the head of the pancreas or bile duct may involve the portal vein or cause extensive fibrotic reaction in the area. Technical difficulties can arise in which damage occurs to, or resection is required for, the portal vein (Fig. 78.4). If portal vein resection or repair is required, it is more likely that the patient will require ICU care. Portal vein resection, when planned, requires variable durations of portal venous outflow obstruction from the gut, which are usually short and well tolerated, but can increase the amount of fluid third-spaced into the bowel wall. Portal vein injury, however, can lead to massive transfusion requirements and hypotension that can require postoperative ICU care. The more common indications for admission to the ICU after pancreatic or biliary surgery are either an underlying medical condition or the development of a postoperative complication. Pancreatic or bile leaks, which can lead to sepsis, will be discussed later in the chapter.
Portal Decompressive Procedures

Surgical portal decompressive procedures, although a rarity since the introduction of the transjugular intrahepatic portosystemic shunt (TIPS), remain indicated in select patients with variceal bleeding and preserved liver function who have failed medical management and are not transplant candidates. The myriad technical variations of surgical portal systemic shunts are beyond the scope of this chapter, but certain commonalities exist. Whether total or partial shunts, selective or nonselective, patients will have had the high-pressure portal system surgically connected to the low-pressure caval circulation to lower the pressure in the portal venous system and stop variceal bleeding. Reduction of portal flow in patients who have borderline liver function can precipitate liver dysfunction or failure. Additionally, the fraction of portal flow that is diverted into the systemic circulation through the shunt is not cleared by the liver until it returns to the liver via the arterial circulation. This may induce encephalopathy; shunts that divert most or all of the portal flow into the systemic circulation are more likely to induce encephalopathy than those shunts that are selective or partial. One special case scenario is Budd-Chiari syndrome, in which the hepatic venous outflow is obstructed, usually due to thrombosis secondary to a hypercoagulable state. In this disorder, blood flow perfuses the hepatic sinusoids from both the hepatic artery and portal vein but cannot exit through the blocked hepatic veins. A functional side-to-side shunt is performed (portacaval, mesocaval) that allows hepatic arterial blood to flow into the sinusoids and then exit via the portal vein, and through the shunt into the systemic circulation. It is not uncommon for liver function to deteriorate initially after the shunt is performed, with subsequent gradual improvement and liver regeneration. Support of liver function may be required immediately after the shunt while liver function stabilizes. In some cases, the shunt may precipitate acute liver failure, making urgent liver transplantation the only option.

Immediate Postoperative Management

Postoperative fluid management is important in the care of patients after major hepatobiliary surgery. In particular, postoperative fluid shifts in patients who have had major liver resection can be difficult to manage. Intraoperatively, most liver resections are performed with low central venous pressure and low intravascular volume. While this practice minimizes bleeding during the hepatic parenchymal transection phase of the procedure, it may pose some difficulty postoperatively, as these patients may have signs of hypovolemia with low urine output and low blood pressure. Volume reexpansion should be gentle, as partial liver resection leads to hypoalbuminemia, and pulmonary edema and ascites can develop with aggressive reexpansion. Although the use of albumin infusions is generally frowned upon in critical care medicine, albumin and fresh frozen plasma may be useful in the resuscitation of patients after liver resection, as the physiology is similar to patients with cirrhosis. We use albumin-containing fluids for volume expansion; however, it is generally reserved for abnormalities in coagulation. Serial lactate levels are helpful in the postoperative management of patients after liver resection. Elevated lactate levels may be a marker of hypovolemia, but the lack of response to volume can indicate liver dysfunction.

After liver resection, glucose metabolism is altered due to both a reduction in functional liver mass and the relative dysfunction of the remaining liver secondary to ischemia reperfusion injury if vascular control has been used during the procedure. As glycogen stores are depleted, the liver uses gluconeogenesis to provide glucose. Resulting from this alteration in hepatic physiology, hypoglycemia may occur, although lethal hypoglycemia is rare. It has become standard practice in most critical care units to tightly control blood glucose levels. While the advantages of this approach, particularly the reduced risk of sepsis, remain for patients after major liver resection, aggressive blood glucose control with insulin infusions requires closer monitoring and may necessitate reduced insulin dosing to prevent hypoglycemia. Patients who have undergone shunt surgery require a different approach than patients undergoing other types of hepatobiliary surgery. These individuals need more aggressive fluid management immediately postoperatively to maintain circulating intravascular volume and reduce the risk of shunt thrombosis. Maintenance fluid should be 0.45% saline solution with 5% dextrose to provide the liver with carbohydrate. After the immediate postoperative period, patients are also at risk for ascites formation, so excessive sodium should be minimized and additional volume expansion—if needed—should be albumin or fresh frozen plasma. Diuretics can be reinstituted after the immediate postoperative period. A general rule is to use a combination of Lasix and spironolactone, with 100 mg of spironolactone for every 40 mg of Lasix. Antibiotics are administered for 48 hours postoperatively to minimize infection from bacterial translocation.

Encephalopathy is rare in patients after liver resection, unless they are in liver failure or have pre-existing liver disease. The presence of asterixis can be an early sign of encephalopathy. Encephalopathy is treated with lactulose and dietary protein restriction, as in other patients with end-stage liver disease. Infection, dehydration, and bleeding, as well as narcotic use, must be evaluated, as they can trigger decomposition that leads to encephalopathy.

Hypophosphatemia

While the exact mechanism of the hypophosphatemia seen after hepatic resection remains unclear, care must be taken to aggressively replace the low serum phosphate, since increased utilization during liver regeneration and a renal wasting mechanism have been proposed (18). Regardless of the etiology, the clinical consequences of hypophosphatemia are well established and include respiratory depression, diaphragmatic insufficiency, seizures, and cardiac irritability. In addition, hepatocellular regeneration is dependent on adenosine triphosphate (ATP), and after liver resection, regeneration may be impaired if phosphate is not replaced (19). In a series of 35 liver resections, 21% had significant postoperative hypophosphatemia (less than 2.5 mg/dL) after surgery. This group had a significant increase in complications (80%) compared to the normophosphatemic group (28%) (20).
Liver Function: Assessment and Support

Liver function should be carefully monitored after major liver resections and shunt surgery, as liver failure is a risk in any major hepatobiliary surgery. The risk of liver failure increases with the extent of hepatotomy and in patients with preoperative liver disease or cirrhosis (22,23). Although standard liver function tests are helpful after major liver resection or shunt surgery, they may not show elevation until the patient has significant liver failure. Transaminases are frequently elevated into the 200 to 300 units/dL range post resection due to the direct effect of mechanical injury to the liver during transaction, as well as to partial devascularization of areas of the liver. Measurements of liver function, including the prothrombin time and lactate, are more helpful in evaluating early postoperative liver dysfunction.

Elevated total and indirect bilirubin are also useful indicators of postoperative liver dysfunction. However, isolated elevation of total bilirubin in the presence of normal liver function can have other etiologies. Perioperative blood transfusions can lead to hemolysis and hyperbilirubinemia, with a predominance of direct bilirubinemia, and can be diagnosed with a standard hemolytic workup. Bile leaks or obstruction can also lead to an elevated serum bilirubin. The diagnosis and treatment of bile leaks is covered later in this chapter. Many popular anesthetics, antibiotics, and other drugs can cause hepatotoxicity and elevation of the serum bilirubin and need to be reduced or stopped if liver failure occurs.

When postoperative liver dysfunction does develop, it is important to exclude sepsis and anatomic causes of liver failure. A postoperative ultrasound can evaluate for portal vein, hepatic arterial, or hepatic vein thrombosis or obstruction, which may be amenable to surgical intervention. If the patient does not have sepsis, drug toxicity, biliary obstruction or leak, or vascular occlusion, liver failure is likely related to a pre-existing liver disease and/or the extent of resection. Treatment is then supportive, with correction of coagulopathy, encephalopathy, and ascites as described above. Systemic antibiotics or gut decontamination may be beneficial, since the liver Kupffer cells play a role in decreasing bacterial translocation from the portal blood flow, and patients with liver failure or biliary leak or obstruction may have an increased risk of bacteremia and sepsis.

N-Acetylcysteine has been shown to decrease liver injury after acetaminophen overdose (24) and lessen ischemia reperfusion injury of the liver (25). Intravenous infusions of prostaglandin have also been linked to improvement of ischemia reperfusion injury and liver damage (26). Although definitive clinical data are lacking, both N-acetylcysteine and prostaglandin (PG) E2 have been used to ameliorate postoperative liver damage in both liver resection and transplant patients. N-acetylcysteine is given as a continuous infusion of 40 mL of 10% solution mixed in 250 mL of D5W and given over 16 hours. Prostaglandin is also given as a continuous intravenous infusion, starting at 0.13 μg/kg/hour. It is titrated up to 1 μg/kg/hour based on systemic hypotension.

Coagulopathy

Coagulopathy is common after liver resection, and several studies have demonstrated an increase in prothrombin time directly proportional to the extent of liver resection (27,28). This coagulopathy has been attributed to impaired synthesis and clearance of clotting factors, inhibitors, and regulatory proteins (29,30). Patients with underlying liver disease and cirrhosis also often have thrombocytopenia and qualitative platelet defects. In addition, intraoperative hypothermia and perioperative transfusions, while not routine, are not uncommon during major hepatobiliary surgery, and can contribute to postoperative coagulopathy.

Serial hemoglobin and prothrombin levels should be measured. Because of the vascular nature of hepatobiliary surgery combined with postoperative coagulopathy from decreased liver function, as well as the frequent need for intravascular volume expansion, serial hemoglobin levels should be followed for postoperative bleeding. In general, we would obtain a hematocrit and international normalized ratio (INR) on ICU arrival and then repeat them, every 6 hours, for the next 24 hours. The surgeon should be notified of excessive bloody output from the drains, increasing abdominal distention, or hemodynamic instability. If coagulopathy does develop, it should be corrected if the INR goes above 2.0 (31), both with vitamin K and fresh frozen plasma. Any patient who is bleeding should have his or her coagulopathy completely corrected. For severe bleeding, both aprotinin and activated factor VII are safe in patients who requires transfusion. Once the postoperative coagulopathy has resolved or stabilized, all patients should be given subcutaneous heparin or low-molecular-weight heparin with sequential compression devices to prevent the formation of deep venous thrombosis.

Pain Management and Sedation

The large subcostal incision needed for major hepatobiliary surgery can result in significant pain after surgery. However, altered pharmacokinetics and coagulopathy, in particular after partial liver resection or shunt surgery, can make postoperative pain management a challenging proposition. Patients with liver failure or compromised liver function secondary to hepatomegaly have altered metabolism of many common medications, in particular narcotics and sedatives that require hepatic clearance.

One of the more common problems that arises in the ICU after liver resection is oversedation of patients. A standard dose of narcotics given to a patient who has had 80% of the liver resected may well cause prolonged respiratory depression and signs and symptoms of respiratory depression. Narcotics and benzodiazepines should be used at the minimum dose required to achieve pain control. After liver resection, it is recommended that basal rates on patient-controlled anesthesia pumps be
avoids, as metabolism of narcotics is difficult to forecast. Benzodiazepines also have altered clearance after liver resection, and should be administered at a lower dose or, if possible, avoided altogether. In patients requiring ongoing endotracheal intubation and mechanical ventilation, we have found it useful to use sedative agents such as propofol rather than narcotics since the level of sedation can be more easily titrated and reversed. Our institution has, at present, no experience with dexmedetomidine.

Epidural pain management may be the optimal analgesic technique after liver resection. Unfortunately, it is contraindicated in many patients because of postoperative coagulopathy. Recent literature has examined the use of epidural catheters in patients undergoing living donor partial hepatic resection. In a review of eight patients with epidural catheters, good pain control was achieved, with only one case of oversedation requiring naloxone. Although postoperative coagulopathy did occur, it was not to the extent that factor transfusion was needed prior to catheter removal, and there were no cases of hemorrhage (33). Epidural analgesia may be useful in select patients who do not have underlying liver disease and who are not undergoing extensive resections.

Nutrition

Although nutrition plays an important role in the care of any critically ill patient, the role of the liver in protein and carbohydrate metabolism makes proper postoperative nutrition imperative in the management of patients after major hepato-biliary surgery. Even with restored liver function when liver function is temporarily reduced. Patients with preoperative biliary obstruction, malignancy, and cirrhosis are at a higher risk for nutrition-related complications after major liver or bile duct surgery. Preoperative nutritional risk factors associated with postoperative complications in hepatobiliary surgery include weight loss greater than 14% lean body mass over 6 months, serum albumin less than 3 g/dL, hematocrit of less than 30%, total body potassium less than 85% of normal, less than the 25th percentile for midarm circumference, and skin test anergy (34). Preoperative bilirubin, albumin, prealbumin, prothrombin time, transferrin, as well as replacement of vitamin A, and should be administered at a lower dose or, if possible, avoided altogether. In patients requiring ongoing endotracheal intubation and mechanical ventilation, we have found it useful to use sedative agents such as propofol rather than narcotics since the level of sedation can be more easily titrated and reversed. Our institution has, at present, no experience with dexmedetomidine.

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also been investigated in their role to improve regeneration, although, again, conclusive evidence is lacking. Adequate liver regeneration is also dependent on protein and calories. Postoperative parenteral nutrition should be supplemented with protein and fat, but low on glucose to improve hepatic regeneration. General goals are 10 kcal/kg/day, with 1.0 to 1.5 g/kg protein; glucose approximating 5 mg/kg/minute, and fat should not exceed 30% of the calories. Patients with cancer may need an increase of up to 35 kcal/kg/day and 2 g/kg protein.

Renal Failure

Acute renal failure occurs after major hepatobiliary surgery in 10% of patients (41) and, similar to other critically ill patients, significantly increases postoperative mortality (42). Risk factors for perioperative renal failure include postoperative sepsis, preoperative uremia, preoperative anemia, malignant disease, and preoperative jaundice (41,43,44). In particular, preoperative obstructive jaundice appears to be a significant risk factor, with an estimated 10% of patients developing postoperative renal failure (45). Both dehydration and endotoxin production from bile duct obstruction have been postulated to cause renal failure in these patients (46). Many studies have been done to try to decrease this risk, including using mannitol, bile salts, hydration, and lactulose (45–48).

In all patients with acute renal failure, adequate hydration, treatment of sepsis, and avoidance of nephrotoxic drugs are mandatory. However, in patients with obstructive jaundice, lactulose and bile salts may decrease endotoxin absorption, and have been shown in some studies to be beneficial in the prevention of renal failure (44,45). Preoperative biliary drainage to help lessen the perioperative inflammatory response is also an important adjunct to prevent postoperative renal failure. Once acute renal failure does occur, supportive care and dialysis are needed until renal function returns.

Patients with advanced cirrhosis or postoperative liver failure can develop hepatorenal syndrome (HRS). This is more significant in the acute care of patients with liver failure or after liver transplantation. Hepatorenal syndrome is a diagnosis of exclusion, with decreased renal function associated with a urine sodium less than 10 mg/dL combined with a urine osmolality greater than plasma osmolality that does not respond to volume administration. The cause of hepatorenal syndrome is likely multifactorial, but is primarily related to circulatory disturbances in patients with advanced liver disease, reduced liver function, and portal hypertension. Systemic vasodilatation and low mean arterial pressure results in renal vasoconstriction and a reduction in the glomerular filtration rate (49). Although liver transplantation remains the only cure for HRS, vasoconstrictors, albumin infusions, and transhepatic portosystemic shunts are able to reduce HRS and may prevent its development in patients with spontaneous bacterial peritonitis (50).

POSTOPERATIVE COMPLICATIONS FOLLOWING LIVER RESECTION

The morbidity associated with liver resection is reported to range between 30.7% and 47.7% (51–54). In addition to the standard complications associated with all major operations, liver resection is associated with specific problems including bleeding, bile leaks, liver insufficiency, ascites, pleural effusions, and infections.

Risk factors of complications following liver resection include increased blood loss, increased number of segments resected, increased preoperative bilirubin, increased prothrombin time, prolonged operative time, resection of segment VIII, diabetes, and concomitant surgical procedures (53,55–59).

Mortality

The in-hospital mortality due to liver resection has decreased over the last two decades, and high-volume centers have reported rates of 0% to 5% (51–53,60–62). The decrease in mortality is attributed to improved surgical technique, intraoperative anesthesia management, and perioperative care. These changes have helped decrease in-hospital mortality in liver resection patients despite their increased mean age and comorbidities (51).

Risk factors associated with increased mortality include hyperalimentation, thrombocytopenia, preoperative total bilirubin greater than 6 mg/dL, serum creatinine greater than 1.5 mg/dL, cholangitis, major hepatic resection, increased number of segments resected, synchronous abdominal procedure, major comorbid illness, diabetes mellitus, and blood transfusion requirements (51,52,58–62).

Specific surgical strategies to decrease mortality include minimizing blood loss and transfusions, and avoiding ischemic injury to the remnant liver. Specific posthepatectomy strategies include minimizing ongoing liver injury by maintaining tissue oxygenation, early nutritional support to facilitate liver regeneration, and replenishing phosphate levels (60).

Bleeding

Bleeding was once the “Achilles heel” of liver resection surgery, but has decreased dramatically over the last two decades due to a better appreciation of liver anatomy, surgical technique, and improved anesthesia management (60). As a result, centers routinely performing liver resections have noted decreased estimated blood loss of 300 mL to 750 mL and perioperative transfusion rates of 17.3% to 28.3% (51,52,62). Risk factors for increased bleeding from liver resection include cirrhosis, portal hypertension, increased segments resected, coagulopathy, thrombocytopenia, and elevated central venous pressure during resection (59,66).

Strategies to minimize blood loss during liver resection include appropriate patient selection—especially avoiding resection in patients with portal hypertension—and maintenance of central venous pressure under 6 mm Hg, Pringle maneuver, preoperative correction of coagulopathy and thrombocytopenia, use of fibrin sealant on raw liver surfaces, use of intraoperative ultrasound to locate the hepatic venous branches, and utilization of selective hepatic vascular exclusion (66–70).

Bile Leak

Biliary leaks occur in 3.6% to 17% of liver resection cases (71–74), and are associated with increased mortality and concomitant complications (71,72,73). Risk factors associated
with biliary leaks following liver resection include older age, preoperative leukocytosis, left-sided hepatocarcinoma, prolonged operative time, (71) and resection of segment IV (71,74). When liver resections were performed for hepatocellular carcinoma (HCC), risk factors for bile leaks included central tumor location and preoperative transarterial chemoembolization (TACE) (72).

Various strategies have been described to prevent bile leaks following resection. A few groups have shown that the use of fibrin glue on the cut surface of the liver results in such a reduction (74); others have combined fibrin glue with bioabsorbable polyglycolic acid to significantly reduce bile leaks (76). While these small studies may indicate some effect of fibrin glue in reducing biliary leaks, there are at least as many studies that show no difference in bile leak rate when fibrin glue is employed. Most bile leaks following liver resections without biliary reconstructions are small and can be managed nonoperatively. If a drain was not placed during the surgical procedure, a percutaneous drain is placed to prevent abdominal sepsis from an undrained bilaoma and to control the leak (71), and broad-spectrum antibiotics are started for fever, leukocytosis, or positive bile cultures. Persistent drainage for 2 to 3 days of more than 100 mL of bilious fluid confirms an active leak, and is managed with endoscopic retrograde cholangiopancreatography (ERCP), sphincterotomy, and stent placement. This procedure may define the location of the leak and facilitate enteric biliary drainage and leak closure. When leaks are at the resected hepatic duct stump, a stent traversing the leak may further facilitate leak closure, although the main principle of treatment is to reduce the pressure in the biliary tree and allow spontaneous closure (73). Early endoscopic management of biliary leaks can minimize hospital length of stay and are not associated with late biliary complications (73). Others have used endoscopically placed nasobiliary tubes to decompress the biliary system, as it allows easy repeat cholangiograms and later removal (73,77). Although most leaks will close with time with these measures, they may persist for months (78).

From 0% to 32% of patients ultimately require reoperation because the leak cannot be controlled, and these procedures are associated with a high mortality rate (71,73,77). Biliary enteric drainage is performed on patients in whom ERCP cannot be performed for technical reasons, or with persistent on leaking despite ERCP. Important factors contributing to a good outcome are early reoperation, control of the biliary fistula before surgery, and utilization of healthy bile duct edges for enteric anastomosis. Hemobilia may complicate bile leaks or liver resections or may occur secondary to trauma. Open communication from a branch of the hepatic artery to the biliary tree occurs and leads to intermittent, and sometimes exsanguinating, gastrointestinal (GI) bleeding. Identification is made when blood is seen exiting the ampulla when endoscopy is performed for upper GI bleeding. Computed tomography (CT) scanning with arterial phase contrast can localize the bleeding within the liver; however, management is by angiographic embolization.

Liver Failure and Dysfunction

Liver failure complicates liver resection in up to 12% of cases (57), and occurs when inadequate functional liver volume is left after resection. This complication occurs primarily in patients undergoing resection for hepatocellular carcinoma with underlying liver disease, and is often a consequence of patient selection and choice of operation.

Risk factors for hepatic insufficiency in cirrhosis include major resections, especially right lobectomy, portal hypertension, long-standing jaundice, Childs-Pugh Turcotte (CPT) score greater than A, and hepatic steatosis (79). More recently, preoperative chemotherapy has become routine in patients with colorectal cancer metastatic to the liver. While there is no doubt that the addition of newer agents such as irinotecan, oxaliplatin, and Avastin have improved long-term results, they also cause an increase in both hepatic steatosis as well as steatohepatitis, which can contribute to postoperative liver dysfunction. By assessing the patient’s functional liver status, the surgeon can estimate the maximum amount of liver mass that can be resected while preserving adequate functional liver volume. In patients with a normal liver, up to 75% of total liver volume can be resected safely. It is patients with abnormal livers, such as those with cirrhosis, who need careful assessment. In general, Child-Pugh class C is a contraindication to any sort of resection. Early Child’s class B patients without portal hypertension may undergo minor resections—from wedge resection to a single segmentectomy. However, these patients may be better served by nonsurgical local ablative techniques. Child-Pugh class A patients who are considered for major hepatectomy—resection of four or more segments—should undergo assessment of both liver and physiologic status (80,81). Others have found that a Model for End-Stage Liver Disease (MELD) score equal to or greater than 11 predicts liver failure following HCC resection (82). Portal hypertension, defined as a hepatic vein pressure gradient (HVPG) greater than 10 mm Hg, and as suggested by signs such as esophageal varices, anatomic portosystemic shunts, and ascites (83), has been associated with increased morbidity and mortality following major resection (84). Thrombocytopenia with platelet counts less than 100,000 cells/μL is one laboratory indicator of portal hypertension and has been associated with in-hospital mortality following liver resection (80).

Although various tests exist to assess liver function in Child-Pugh class A and B patients before a possible major liver resection—defined as greater than or equal to four segments—one test which has not been uniformly adopted is the indocyanine green (ICG) clearance test, commonly used in Asia, is one method of quantifying liver function (85–87). Early studies have shown that an ICG retention at 15 minutes (ICGR15) of less than 20% allows safe, limited liver resection, and a value of less than 14% is associated with near-zero operative mortality (88–90). In Child-Pugh class A patients with right-sided lesions curable by major resection but whose liver reserve may be inadequate, preoperative ipsilateral portal vein embolization increases the remnant contralateral liver volume (91). Portal vein embolization is generally performed in patients with a predicted function liver remnant of less than 25% in noncirrhotics or less than 40% in patients with significant fibrosis and/or cirrhosis. Liver failure following liver resection presents clinically with encephalopathy and ascites. In severe cases, these patients appear similar to those with fulminant liver failure, presenting with marked acidosis, jaundice, and hemodynamic instability. The patient ultimately succumbs to multiorgan failure and sepsis. In mild cases, treatment is supportive, with judicious fluid management, optimization of tissue oxygenation, infection prophylaxis, and nutritional support if recovery is prolonged. The goal in the mild and salvageable cases is to

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promote immediate liver functional recovery from the insults inherent to liver resection; to promote liver regeneration with nutritional and electrolyte replantation, particularly phosphate; and to minimize the chance of infectious complications. Although early studies demonstrated a significantly improved hepatic oxygen delivery and extraction in patients receiving N-acetylcysteine for nonacetaminophen-induced liver failure (92,93), subsequent conflicting studies have failed to support a definitive role in patients following liver resection (94). Nonetheless, many centers, including our own, selectively administer N-acetylcysteine in patients with marginal liver function following resection, based mainly on a favorable small series and anecdotal benefits (95). This practice may be reasonable because of the sheer number of favorable outcome reports and the good drug safety profile, but controlled trials are needed.

**Aspects and Pleural Effusion**

Aspects occurs in up to 9% of liver resections (57) and is associated with deceased survival, as it is a surrogate marker of liver insufficiency and because of its potential contribution to peritoneal insufficiency (75). Pleural effusion, usually occurring on the right side and frequently accompanying aspects, is found following liver resection in 3.8% to 21% of cases (57, 96) and is usually asymptomatic, requiring no treatment. Effusion may develop from underlying aspects that crosses the diaphragm. In addition, the same pathophysiologic processes of fluid overload and hypoproteinaemia that cause aspects may also contribute to the development of pleural effusions. Risk factors for both aspects and pleural effusion include right lobectomy, diabetes mellitus, poor nutritional status and hypoproteinemia, left-sided cardiac insufficiency, and liver and renal insufficiency (79–97). In addition, risk factors specifically associated with pleural effusion have been found to include resection for hepatocellular carcinoma with underlying liver disease, subhepatic collections, postoperative liver insufficiency with aspects, and duration of inflow occlusion (96).

**Strategies to Prevent Postresection Aspects and Pleural Effusion**

Strategies to prevent postresection aspects and pleural effusion include avoiding overhydration, including gentle diuresis; preventing renal insufficiency by avoiding nephrotoxic drugs and hypotension; early detection and treatment of infection; maintaining adequate nutrition; and the use of perioperative drains (97). The appropriate selection of patients and resection to maintain adequate liver function, especially in patients with hepatomas and underlying liver disease, will minimize the risk of liver failure and subsequent aspects.

**Complications Following Pancreatic Surgery**

The mortality rate following pancreaticoduodenectomy (PD) ranges from 2.7% to 6.8% (108–112). Risk factors for perioperative mortality include elevated serum bilirubin, the diameter of the pancreatic duct, increased intraoperative blood loss, pancreatic fistulae, and older age (109). Complications are seen to occur in 22.1% to 30.2% of PDs, and include pancreatic fistulae, delayed gastric emptying, bleeding, abdominal abscesses, and wound infections (108,109).

Pancreatic fistulae are a dreaded complication of PD, occurring in 12% to 18% of patients (108,110,111,113–116). Pancreatic fistulae are associated with a mortality rate ranging to 19% (104,105,108,111). These patients often die secondarily to massive erasive bleeding from sepsis and pancreatic enzyme accumulation. These bleeding episodes occur in 1% to 8.8% of PD patients and carry a mortality rate of 47% to 50% (112,117,118).

Risk factors for pancreatic fistulae include small duct size, soft pancreas texture, duration of surgery greater than 8 hours, diabetes mellitus, lower creatinine clearance, preoperative jaundice, and increased intraoperative blood loss (108,114,116,119). Despite numerous studies evaluating potential strategies to prevent pancreatic fistulae following...
PD, including the use of octreotide, fibrin sealants, pancreatic stents, and different methods and sites of pancreatic anastomosis, has shown promising results (113,120–124).

Pancreatic fistulae are initially detected on postoperative day 6 as abdominal pain, fever, nausea/vomiting, and leukocytosis. Fistulae are then confirmed by CT scan demonstrating fluid collection behind the pancreatic anastomosis, elevated serum amylase, drain output greater than 50 mL/day, and drain amylase 10-fold greater than serum amylase (111,122). Management is initially conservative, with bowel rest, total parenteral nutrition, antibiotics, and monitoring of clinical signs and symptoms and drain output. If repeat imaging demonstrates increased accumulation of fluid and the patient does not respond to conservative measures, another drain may be placed transcatheterly to prevent progression to abdominal sepsis. Eighty to ninety percent of patients seal pancreatic fistulae with these measures (110,115). However, those patients who develop uncontrolled leaks and abdominal sepsis may require surgery, usually for completion pancreatectomy. In addition, a smaller group of patients with fistulae will suffer life-threatening sepsis intra-abdominal bleeding, usually from the stump of the gastrointestinal shower, small arterial branches to the pancreas, or, rarely, the portal vein. These patients will present with signs and symptoms of sepsis and hypovolemia, such as fever, abdominal pain, hypotension, anemia, and bloody drain output. These patients are treated by rapid resuscitation and angiography for potential embolization of the bleeding arterial branch. If arterial bleeding cannot be controlled in this manner, or if the bleeding is venous, the patient is explored for hemostasis and completion pancreatectomy. However, surgery in this setting is associated with a high mortality, with up to 36% of such patients dying if they require surgery for bleeding after PD (112,118).

References


Section VIII: The Surgical Patient


CHAPTER 79 ■ CRITICAL CARE OF THE THORACIC SURGICAL PATIENT

THOMAS L. HIGGINS • PATRICK MAILLOUX

IMMEDIATE CONCERNS

Thoracic surgical patients are among the most complicated admissions to intensive care due to their challenging preoperative status, the variety of possible operative procedures, airway and pleural appliances, and requirements for postoperative interventions, including airway management, mechanical ventilation, and pain control. Information transfer is key: the ICU physicians and nurses must have a clear understanding of the operative procedure accomplished, the patient’s expected medical course, and the predictable potential complications. More time than usual must be allotted for briefing of the ICU team by the operating team.

Immediate concerns include assessment of oxygenation, cardiovascular support to ensure adequate oxygen delivery, provision of ventilation support if needed, and transferral of monitors and drains that accompany the patient from the operating room. Special concerns apply to fluid management (discussed in detail below) and pain control, which is especially important, as pain will limit respiratory effort and can precipitate delirium and agitation. Table 79.1 provides a checklist for immediate internosurgical care.

In operations where the pleural space has been opened, the patient will arrive with at least one—but usually two or more—chest tubes. Complete lung expansion helps to force out any remaining extrapleural air, which exits through an apical chest tube. Removal of air from the thorax is demonstrated when bubbling is seen in the water seal bottle. The posterior/inferior tube(s) should be draining blood, and some clots are expected; however, a large quantity of clots suggests continued bleeding. An immediate chest radiograph will confirm both the absence of significant pneumothorax or effusions as well as properly placed invasive lines and chest tube.

PREOPERATIVE CONSIDERATIONS: IDENTIFYING THE HIGH-RISK PATIENT

The patient undergoing thoracic surgery is frequently older, with concurrent medical problems and often debilitated due to cancer and associated malnutrition. Pulmonary abnorma

ities commonly arise from prior occupational exposure, tobacco use, or a primary disease process. Prior history of asthma, wheezing, or allergic airway responses are risk factors and serve to identify patients in whom bronchodilator management may be needed in the postoperative period. Many thoracic surgical patients have preoperative pulmonary function tests (PFTs), particularly if lung resection is contemplated. However, these tests by themselves are not reliable predictors of postoperative pulmonary function. The FEV1 (forced expiratory volume in 1 second) provides a reasonable indicator of a patient's postoperative ability to cough effectively and clear secretions. A postoperative FEV1, is affected by inspiratory muscle strength, elastic recoil, and degree of obstructive air trapping, as well as any surgical removal of lung tissue. However, the decrease in FEV1 after lung resection for cancer is not necessarily a simple proportional relationship if an obstructed lobar or mainstem bronchus was present. A cutoff value for a postpneumonectomy FEV1 of 800 mL is commonly used as a criterion of resectability, since this amount is required to generate a sufficient cough to clear secretions.
TABLE 79.1 IMMEDIATE ICU CONSIDERATIONS IN THE THORACIC SURGICAL PATIENT

Preparation:
- Supplemental oxygen or mechanical ventilator ready
- Bedside monitoring: ECG, pulse oximetry; possible arterial, central, or PA line
- Infusion pumps if inotropes, vasopressors, or vasodilators in use
- Wall suction to connect to pleural drainage system

On Arrival in ICU:
- Connect patient to bedside monitors and ventilator (if needed)
- Auscultate breath sounds and observe chest excursion; suction if necessary
- Assess adequacy of circulation (BP, HR, pulse oximetry)
- Assess adequacy of oxygenation and ventilation (via ABG or noninvasive devices)
- Consider need for lung-protective ventilation if trauma/sepsis/operative issues
- Fluid management: confirm need for continued maintenance fluid; generally keep “dry”
- Monitor inputs and outputs; label all chest tubes and chart outputs
- Control pain with intravenous analgesics and/or regional anesthetics/analgesics
- Order any necessary laboratory studies and chest radiograph

Information to Be Obtained from Operating Room Team:
- Patient name, age, gender, and brief history
- Operation performed and any major problems encountered
- Circulatory and ventilatory requirements as determined in OR
- Current drug infusions and titration plans; timing and dose antibiotics
- Anesthetic agents given and plans for awakening/exubation (if relevant)
- Fluids and blood products given; urine output during case
- Estimated blood loss, assessment of hemostasis at closing, and blood products available including surgical salvage if any
- Laboratory results (e.g., ABGs, Hct) obtained during operating room

ABG, arterial blood gas; BP, blood pressure; ECG, electrocardiogram; Hct, hematocrit; HR, heart rate; OR, operating room; PA, pulmonary artery.

Surgical entry to the chest cavity, even if tissue is not resected, produces substantial changes in lung function, with lateral thoracotomy producing greater postoperative impairment than median sternotomy. Following thoracotomy, forced vital capacity (FVC) and functional residual capacity (FRC) can fall to less than 60% of their preoperative values on the first postoperative day. Subsequent return to baseline can take up to 14 days. Any decline in FRC is especially important, because the resulting atelectasis contributes to physiologic shunting and hypoxemia. In patients with severe chronic obstruction, the best predictors of postoperative ventilation requirements are arterial pO2 less than 70% of that predicted for age and the presence of dyspnea at rest (1). Factors associated with postoperative pneumonia after elective surgery include low preoperative serum albumin values, high American Society of Anesthesiologists (ASA) physical status classification, smoking history, prolonged preoperative stay, longer operative procedure, and thoracic or upper abdominal site for surgery (2).

Advanced age is frequently cited as a surgical risk factor. Elderly patients have a number of age-related changes in pulmonary function, including decreased elastic recoil and progressive stiffening of the chest wall, increase in the ratio of FRC to total lung capacity, and diminished vital capacity and FEV1 (3). The activity of upper airway reflexes is blunted, which may result in impaired clearance of secretions and the ability to protect the airway.

Obesity results in decreases in FRC and expiratory reserve volume (ERV), causing the ERV to drop below closing volume, resulting in perfused, unventilated segments of lung and a widened alveolar-arterial (A-a) pO2 gradient. Obese patients are more likely to cough poorly, retain secretions, and develop baseline atelectasis.

Cigarette smoking is well recognized for its contribution to perioperative morbidity via its effects on the cardiovascular system, mucus secretion and clearance, and small airway narrowing. Although patients are invariably counseled to stop smoking prior to elective surgery, data from coronary artery bypass patients suggests this should occur at least 8 weeks prior to surgery, because smoking cessation just prior to surgery may actually increase the risk of postoperative pulmonary complications (4), probably due to transient increases in sputum volume. Expectations as to the duration of postoperative respiratory failure allow the caregiver to heighten his or her awareness if the patient develops unanticipated cardiovascular or respiratory deterioration. A very large patient population from the Veterans Affairs Medical Centers provided a database for researchers to learn what factors play a role in predicting respiratory failure risk.

TABLE 79.2 RESPIRATORY FAILURE RISK INDEX

<table>
<thead>
<tr>
<th>Preoperative predictor</th>
<th>Point value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of surgery</td>
<td></td>
</tr>
<tr>
<td>Abdominal aortic aneurysm</td>
<td>27</td>
</tr>
<tr>
<td>Thoracic procedure</td>
<td>21</td>
</tr>
<tr>
<td>Neurosurgery, upper abdominal, or peripheral vascular</td>
<td>14</td>
</tr>
<tr>
<td>Neck procedure</td>
<td>11</td>
</tr>
<tr>
<td>Emergency surgery</td>
<td>11</td>
</tr>
<tr>
<td>Albumin (&lt;3.0 g/dL)</td>
<td>9</td>
</tr>
<tr>
<td>Blood urea nitrogen (&gt;30 mg/dL)</td>
<td>8</td>
</tr>
<tr>
<td>Partially or fully dependent functional status</td>
<td>7</td>
</tr>
<tr>
<td>History of chronic obstructive pulmonary disease</td>
<td>6</td>
</tr>
<tr>
<td>Age (years) ≥70</td>
<td>6</td>
</tr>
<tr>
<td>60–69</td>
<td>4</td>
</tr>
</tbody>
</table>

Postoperative respiratory failure (5). Factors negatively influencing outcome included the type of surgery, emergency surgery, low preoperative albumin, high preoperative blood urea nitrogen, partial or full dependent status, chronic obstructive pulmonary disease (COPD), and age older than 60 years (5). These factors are all assigned a point status (Table 79.2); more points increase the probability of postoperative respiratory failure (Table 79.3). It is important to realize that women noted do not have gender specificity.

**OPERATING ROOM EVENTS THAT IMPACT ICU CARE**

The pace of postoperative recovery depends on the amount and types of anesthetic agents given as premedication and during the operative procedure. Anesthetic delivery is constrained by patient factors. The need for high inspired oxygen concentrations, particularly during one-lung anesthesia, limits the ability to use nitrous oxide. A goal of early extubation limits the use of opioids. Regional techniques (spinal, epidural) can supplement general anesthesia but are generally not applicable to operative interventions, particularly during one-lung anesthesia, limits the ability to provide a high enough spinal level. Controlled ventilation is necessary to sustain respiration during open thoracic procedures because of the difficulty in providing a high enough spinal level. Controlled ventilation is necessary to sustain respiration during open thoracic procedures because of the difficulty in providing a high enough spinal level. Controlled ventilation is necessary to sustain respiration during open thoracic procedures because of the difficulty in providing a high enough spinal level. Controlled ventilation is necessary to sustain respiration during open thoracic procedures because of the difficulty in providing a high enough spinal level.

**RESPIRATORY FAILURE RISK INDEX SCORES AND OUTCOMES**

<table>
<thead>
<tr>
<th>Class</th>
<th>Point total</th>
<th>Predicted probability of PRF (%)</th>
<th>Observed phase I (% RF)</th>
<th>Observed phase II (% RF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>39,567 (48%)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>11–19</td>
<td>18,809 (23%)</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>3</td>
<td>20–27</td>
<td>13,865 (17%)</td>
<td>5.0</td>
<td>5.3</td>
</tr>
<tr>
<td>4</td>
<td>28–40</td>
<td>7,976 (10%)</td>
<td>11.6</td>
<td>11.9</td>
</tr>
<tr>
<td>5</td>
<td>&gt;40</td>
<td>1,502 (2%)</td>
<td>30.5</td>
<td>30.9</td>
</tr>
</tbody>
</table>


**IMMEDIATE POSTOPERATIVE ISSUES**

Usual postoperative monitoring includes intermittent blood pressure determinations, continuous electrocardiography, and pulse oximetry. In selected patients, assessing intravascular volume status and cardiopulmonary function may be facilitated with central venous pressure or pulmonary artery catheters.
Chest tubes are usually inserted to drain the surgical site at the end of the procedure, except in pneumonectomy patients, where the standard practice is to avoid a chest tube unless there is the need to monitor the pneumonectomy space postoperatively. Chest tubes should never be clamped during patient transport because of the dangers of unrecognized bleeding and tension pneumothorax. Chest tubes, except for those in pneumonectomy spaces, are usually connected to a vacuum regulator to provide >20 cm H₂O of suction. A chest radiograph will confirm endotracheal, nasogastric, and chest tube placement, as well as identify any pneumothorax, mediastinal shift, or significant atelectasis. Routine chest radiographs are not necessary after an uncomplicated removal of chest tubes, and the decision to reinser a chest tube is usually based on clinical appearance rather than radiologic findings (6).

Commercially available chest tube systems vary in their appearance, but all provide calibrated drainage chambers, a method to release excess positive pressure, and regulated amounts of negative pressure. Air bubbles are normally expected in the chamber that limits the amount of applied suction; air bubbles in the water seal chamber represent an active leak. Hourly output from chest tubes should be recorded and the operative team notified if drainage is greater than 100 mL/hour for more than 4 hours, or if greater than 200 mL of drainage is recorded in any 1-hour observation period. Expected chest tube drainage from major procedures in the first 24 hours is roughly 300 to 600 mL, tapering to less than 200 mL by the second day. Daily chest radiographs are usually obtained while chest tubes are in place. The level of fluid in the water seal chamber should fluctuate with each respiration (assuming no air leak) and serve as confirmation of patency. Most pulmonary resection patients will return with mild to moderate air leaks, which become problematic only if the underlying lung parenchyma does not completely expand to fill the pleural space, or if a significant percentage of tidal volume is lost through the chest tubes with mechanical ventilation. Additional pleural drainage may then be required or changes in ventilation made to minimize the air leak and optimize ventilation. Leaks may occur only above a given inflation pressure, and ventilation techniques such as smaller volumes at higher rates, pressure-controlled inverse ratio ventilation, or high-frequency oscillation (HFO) may sometimes minimize leaks and allow a seal to develop. Once all air leaks resolve and drainage is minimal (<100 mL/24 hours), chest tubes may be removed during the inspiratory phase of ventilation while the patient performs a Valsalva maneuver.

Prophylactic positive end-expiratory pressure (PEEP) is sometimes used in an effort to decrease postoperative drain output, especially from mediastinal drains in cardiac surgery patients. The evidence, however, suggests that higher PEEP levels do not affect chest tube output or transfusion requirements (7).

Intensive insulin therapy, defined as maintaining blood glucose between 80 and 110 mg/dL, leads to improved survival in patients admitted to a surgical ICU when compared to the conventional therapy of initiating insulin once the glucose level exceeds 215 mg/dL (8).

**EXTUBATION AND AIRWAY CONCERNS**

Extubation can often be accomplished in the operating room, but continued ventilation may be necessary in the presence of concurrent cardiac illness, inability to protect the airway, malnutrition, or coexisting lung disease. Silent aspiration of gastric contents is an important complication following pulmonary resections, and maintenance of endotracheal intubation for 24 hours postoperatively has been shown to decrease the occurrence of pneumonia and the operative mortality rate (9) in high-risk patients.

Measurement of maximal inspiratory pressure (MIP, often called negative inspiratory pressure) is helpful in determining respiratory muscle strength, particularly in patients recovering from thymectomy for myasthenia gravis, and in those who received long-acting neuromuscular blocking agents in the operating room. Residual neuromuscular blockade can be assessed using a train-of-four monitor and reversed, if necessary, with small doses of neostigmine plus vagolytic agents such as atropine or glycopyrrolate. Ideally, the patient should be awake and following instructions, and have an adequate gag reflex (signifying airway protection) and cough (for secretion clearance). Measured parameters suggesting readiness for extubation include a respiratory rate to tidal volume (f/Vt) ratio of <100, a MIP of greater than 25 cm H₂O and adequate oxygen saturation (>92%) on FiO₂ <50% at PEEP <5 cm H₂O. Although many patients will not strictly meet these criteria for extubation, it is usually best to attempt weaning and extubation rather than risk the complications of continued ventilation. Specific indications to delay extubation are in Table 79.4.

Laryngeal and glottic edema frequently occurs after airway manipulation or intubation with a large double-lumen endotracheal tube. The presence of serious laryngeal edema can be detected (after first suctioning the posterior pharynx) by deflating the endotracheal tube cuff and observing the endotracheal tube, and watching for evidence of airway obstruction. Endotracheal intubation may need to be maintained while edema resolves. Racemic epinephrine and corticosteroids are traditionally used, although the literature support for this is sparse. If there is any doubt about airway patency, the endotracheal tube should be removed, and either direct laryngoscopic or fiberoptic observation, with a percutaneous tracheostomy set immediately at hand to provide airway access should reintubation be impossible because of airway swelling. Only a few thoracic surgery patients require postoperative ventilation. In thoracic surgery patients, reduction of baro-trauma becomes an additional consideration. Low tidal volumes (6 mL/kg) are recommended in the population at risk for acute respiratory distress syndrome (ARDS) (10), but this approach has not been well studied in routine thoracotomy.

### Table 79.4

**INDICATIONS FOR CONTINUED POSTOPERATIVE VENTILATION**

- Airway compromise due to edema or bleeding
- Inadequate pulmonary reserve post surgery
- Compromised myocardial function, especially with perioperative infarction
- Expected large fluid shifts with thoracoabdominal procedures
- Severe neurologic impairment
- Continued bleeding with likelihood of return to operating room
- Esophageal surgery patients (risk for reflux and aspiration—delay extubation until airway reflexes have fully recovered as for full stomach intubation)
patients. The normal inspiratory-to-expiratory ratio is about 1:2, and inspiratory times longer than 1 second are poorly tol-
erated in awake patients. Longer inspiratory times reduce peak
airway pressure but require addition of sedative agents and,
in patients with significant airway obstruction, may not allow
sufficient time for exhalation, resulting in auto-PEEP with con-
sequent hemodynamic compromise.

Intermittent mandatory ventilation or continuous positive
airway pressure (CPAP) with pressure support can be used. The
FiO₂ in the early postoperative period is generally set at 50%
to 60% and reduced as clinically appropriate. The combina-
tion of pulse oximetry and end-tidal carbon dioxide monitoring
will reduce the need for frequent arterial blood gas sampling.
Controversy still exists as to the optimal level of PEEP in the
thoracic surgery patient. Low levels of PEEP (3–5 cm) may be
helpful in restoring functional residual capacity and substitut-
ing for the "physiologic PEEP" of the glottis.

High-frequency jet ventilation (HFJV) has a role in the op-
erating room during "shared airway" procedures (i.e., laryn-
goscopy, bronchoscopy, microlaryngeal procedures, and air-
way surgery). The role of high-frequency jet ventilation in the
intensive care unit, particularly for management of hyoxemic
respiratory failure, is poorly defined, the one exception being
ventilation of a patient with a bronchopleural fistula. In theory,
HFJV allows ventilation at lower airway pressures than con-
tventional ventilation. The reduction in ventilation pressure will
minimize the amount of air passing through the fistula and may
promote healing by allowing adjacent tissues to approximate
and possibly seal the fistula. In the face of decreased pulmonary
compliance, the beneficial effect of HFJV in lowering airway
pressure may be lost (11).

Section VIII: The Surgical Patient

POSTOPERATIVE FLUID MANAGEMENT

Thoracic surgery patients present unique issues in terms of fluid
management in the postoperative period due to the height-
ened potential for pulmonary edema. Postpneumonectomy pul-
monary edema occurs in approximately 4% to 27% of patients
(12,13) and pulmonary edema from all causes in 27% of pneu-
monectomy patients (13). Understanding the contribution of
inseparable (600–1,200 mL/day in a 70-kg adult) and measured
fluid loss during the surgical procedure provides valuable in-
formation when anticipating the patient’s needs in the post-
operative period. Thoracic surgery patients may also lose an
additional 6 to 8 mL/kg per hour of third-space fluid from the
intestinal space and intracavitary areas (14). The choice of
fluid for resuscitation is left to the discretion of the caregiver,
as there is no known difference in outcome with use of either
isotonic crystalloid or colloid.

During their procedures, patients are exposed to intraopera-
tive handling of the lung, fresh frozen plasma (FFP), prolonged
one-lung ventilation, collapse and re-expansion of the lung, as
well as increases in postresection pulmonary artery pressures
(15). These factors all contribute to the lung parenchyma being
primed for a more profound inflammatory response and poten-
tial fluid accumulation. Patients undergoing procedures involv-
ing the mediastinum, such as esophagectomies or tumor exci-
sion, experience even more profound fluid shifts and likely pose
a greater management challenge in the postoperative period.

There is no one formula applicable across the broad spec-
trum of patient types seen in this population to adequately
predict fluid needs. Traditional markers of perfusion may de-
termine if a patient is adequately volume-resuscitated. These
include urine output (usually >0.5 mL/kg per hour), mental
status, blood pressure, heart rate, blood lactate level, capillary
refill time, venous oxygen saturation, filling pressures, and car-
diaca performance.

Resection patients, especially those with a right-sided pneu-
monectomy who experienced high ventilatory pressures during
surgery (13), require greater scrutiny when determining fluid
needs due to the increased risk for postpneumonectomy pul-
monary edema. Ideally, the clinician will limit crystalloid in-
fusion to 20 mL/kg for the first 24 hours in this cohort (12).
If a state of poor perfusion persists, invasive devices allowing
for precise hemodynamic monitoring and oxygen consumption
need consideration in an effort to accurately establish goals of
therapy.

PAIN MANAGEMENT

The pain associated with thoracotomy is considered one of the
most intense of any surgical procedure (16). Adequate pain
control is important not only to ensure patient comfort, but
also to avoid potential cardiac and pulmonary complications.
Early pain management is also important in an effort to re-
duce the chances of developing long-term postthoracotomy
pain (17). The reasons for pain in this setting are many and
include the skin incision, dissection of the intercostal muscles
and pleura, pleural irritation, chest tube insertion, and pro-
longed rib retraction leading to ligamentous and muscle injury
(14). Without satisfactory pain relief, the patient is exposed to
adverse effects, including the inability to breathe deeply, which
decreases vital capacity and functional residual capacity. Splint-
ing also occurs, making it more difficult to clear secretions.
These factors increase the likelihood of developing respiratory
failure in the postoperative period. The cardiovascular system
is at risk, as pain is associated with elevated circulating levels
of catecholamines, which act on the myocardium to increase
oxygen consumption.

Various options exist for pain management. They include
systemic analgesics, neuraxial opioids, and local anesthetics
via the epidural or intrathecal route; regional anesthesia such
as intercostal and paravertebral nerve blocks; and adjuvant
therapies such as transcutaneous electrical nerve stimulation
(TENS) or applied heat.

The mainstay of postoperative pain control is systemic
analgesics in the form of opioids. Agents such as morphine,
fentanyl, and hydromorphone are frequently used and can be
administered intravenously, subcutaneously, or intramuscu-
larly, with the intravenous route providing the most pre-
dictable responses. Opioid side effects remain the greatest issue,
with respiratory depression, nausea, vomiting, and ileus being
a few examples. Nonopiate medications such as nonsteroidal
anti-inflammatory drugs (NSAIDs)—including the parental
prostaglandin inhibitor, ketorolac (18)—are reasonable ad-
juncts to the opioids. Because NSAIDs may exacerbate renal
dysfunction, it is necessary to exercise caution when using them
in the presence of underlying renal insufficiency. Also, NSAIDs
may pose a risk with postoperative healing; one animal model
demonstrated less effective pleural adhesions following pleurodesis (19).

Thoracic opioids and local anesthetics via the epidural or intrathecal route provide excellent regional pain control. Epidural catheters are the preferred route, and when local anesthetics, either with or without opioids, are infused in this manner, the incidence of pulmonary complications decreases relative to that with systemic opioids (20). The initiation of epidural catheters prior to the operation appears to be the ideal approach, as it allows for better management of pain in the postoperative setting (21). Hypotension due to sympathetic blockade is a potential side effect when local anesthetics such as bupivacaine are administered. Therefore, it may be necessary to either decrease the dose or eliminate the local anesthetic completely from the infusion and use opioids exclusively.

Intercostal and paravertebral nerve blocks provide regional pain control. These blocks may be performed either intraoperatively or postoperatively and can provide relief lasting up to 12 hours; repetitive dosing may be needed and can even be accomplished by cryolesion of the intercostal nerves during the surgery (22). Chest tube insertion sites are potential sites of discomfort and may be blocked either directly or proximally. Intercostal nerve blocks are relatively contraindicated in postpneumonectomy patients due to the risks of entering and contaminating the empty chest cavity; the presence of splinting on the pneumonectomy side may actually be beneficial in reducing atelectasis in the remaining lung.

Intrapleural catheters can be used to deliver local anesthetic. These catheters are inserted in the posterior pleural cavity and threaded toward the lung apex; local anesthetics, such as bupivacaine or lidocaine, can be administered via intermittent bolus or continuous infusion. They are not a viable option in the setting of pleural effusion (the anesthetic is diluted) or pleural fibrosis; complications include technical difficulties during placement, pneumothorax, toxicity to the anesthetic, and tachyphylaxis to the local anesthetic with time.

The described methods are some of the traditional modalities used when controlling pain in the thoracic surgery patient. TENS, heat and cold application, music therapy, and relaxation techniques are additional means of providing a comfortable setting (22). In addition, patients requiring prolonged postoperative mechanical ventilation may benefit from the centrally acting \( \alpha \)-adrenergic agonist, dexmedetomidine. In the coronary artery bypass grafting population, this agent decreased the amount of narcotics needed to achieve adequate pain control and may thereby decrease the untoward side effects of excessive narcotic use (23).

**SPECIFIC PATIENT POPULATIONS**

**Thoracic Trauma**

Trauma patients are typically evaluated and treated for acute, life-threatening injuries prior to their arrival in the ICU. The role of the critical care physician is to understand the nature of the injuries—whether blunt or penetrating—and the anticipated clinical course. In addition, maintaining a high degree of vigilance is paramount for diagnosing potential missed injuries.

Typical blunt injuries to the chest include rib fractures, flail chest, hemothorax, pneumothorax, tension pneumothorax, pulmonary contusion, cardiac contusion, and aortic disruption. Penetrating trauma such as gunshot and stabbings are less predictable in terms of the injuries generated and therefore require a case-by-case assessment in terms of management issues. Uncontrolled hemoptysis or cavitary lesions following penetrating injury require emergent surgical intervention.

Mortality increases in thoracic trauma with increasing age, lower Glasgow coma scale scores, liver injury, splenic injury, more than five rib fractures, and long bone fractures. Mortality rates typically are between 9% and 20% in the United States (24). If the patient suffers an out-of-hospital cardiac arrest in relation to his or her trauma, the chances of survival diminish even further, with less than 10% of patients in this group surviving to hospital discharge (25). A proposed therapeutic algorithm is illustrated in Figure 79.1 and will be discussed below in detail.

**Rib Fractures**

Rib fractures are the most common type of chest trauma, with ribs five through nine being the most susceptible. Rib fractures by themselves are rarely life-threatening but may serve as indicators for more severe intrathoracic or infra-abdominal injuries. Pain may be significant and impairs usual respiratory mechanics, leading to splinting, hypoventilation, atelectasis, and potentially pneumonia as pulmonary toilet is compromised. First and/or second rib fractures indicate a large transfer of energy to the thoracic cage and should raise further suspicion for other intrathoracic or intra-abdominal injuries such as aortic rupture or tear (26). The elderly, defined in this instance as 65 years of age and older, pose a particular problem when faced with these types of injuries; mortality increases by 19% with each rib fracture and the risk of pneumonia by 27% (27). The implications of age begin at 45 years, given that those with four or more rib fractures in this group show more in-hospital complications, such as increased ventilator and ICU days (28).

One intervention, however, may prove valuable in improving the outcome of patients with multiple rib fractures. Provided patients are suitable candidates for epidural analgesia, this method of pain control is associated with a decreased incidence of nosocomial pneumonia and shorter duration of mechanical ventilation in those with three or more rib fractures (29).

**Flail Chest**

Flail chest occurs when two or more adjacent ribs are fractured at two or more sites. This leads to a paradoxical movement of that segment during inspiration, manifested as an inward collapse. As with rib fractures, pain control is important to avoid splinting and to facilitate pulmonary toilet. Positive pressure ventilation, whether invasive or noninvasive, may be required to stent open the affected lung region and thereby avoid atelectasis.

**Hemothorax**

Hemothorax is a collection of blood in the pleural cavity. Patients potentially experience chest pain, dyspnea, and tachycardia along with dullness to percussion and decreased or absent breath sounds to auscultation on the affected side. Chest radiographs help to confirm the diagnosis if the collection of blood is large enough (i.e., >200 mL) to be seen radiographically. The mainstays of therapy are ensuring adequate circulating blood volume and tube thoracostomy to drain blood from the pleural space. Thoracostomy is required if bleeding continues at a
Section VIII: The Surgical Patient

BLUNT CHEST TRAUMA ALGORITHM

Patient transported to emergency/trauma center

Mechanism of injury: Blunt chest trauma or cardiac trauma

Patient hemodynamically unstable

Yes

Echo

Admit to monitored bed

TEE TTE Serial ECGs Chest X-ray Physical exam Cardiac troponin

Physical exam

Abnormal study

Normal study

Discharge patient

Consider Holter monitor as outpatient

Observation monitored bed

TEE can be performed pre-op or intra-op with follow-up imaging post-operatively

FIGURE 78.1. Therapeutic algorithm. ECGs, electrocardiograms; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography.

significant rate, defined as 1,500 mL of blood output with initial tube placement or continuous bleeding of at least 250 mL/hour for 4 hours or if the patient’s vital signs suddenly decompensate (26). Failure to adequately drain the hemothorax potentially leads to a condition of retained clot. This is problematic, as it may progress to empyema or fibrothorax. Options for therapy include further large-diameter tube thoracostomy, open thoracotomy, video-assisted thoracoscopic (VATS), or intrapleural fibrinolytic therapy. Further tube thoracostomy likely has a limited role, as it does not consistently liberate clotted blood products, and early surgical drainage with VATS decreases the duration of tube drainage, length of hospital stay, and hospital cost (30). VATS is the surgical intervention of choice because it is less invasive than open thoracotomy and just as effective, unless there are extensive adhesions (31). Fibrinolytic therapy offers a possible alternative to thoracoscopy or decortication, especially if the time from injury to therapy is delayed, with a response rate of up to 92% in terms of resolution (32).

PNEUMOTHORAX

Pneumothorax is the accumulation of air, originating from the lung, between the visceral and parietal pleura, and is the most common intrathoracic finding following blunt or penetrating trauma. The size of the pneumothorax is expressed as a percentage, determined by its size relative to the entire lung on an anterior-posterior chest radiographic film. Treatment with tube thoracostomy is indicated when the size is >20%, the patient is on positive pressure ventilation, and there are signs and symptoms of hypoxia and dyspnea. If following tube placement the lung does not completely re-expand and there is a persistent air leak, it is important to search for a more severe tracheal or bronchial injury, as this situation would require surgical intervention.

TENSION PNEUMOTHORAX

Tension pneumothorax is a life-threatening condition requiring immediate therapy. It occurs when air accumulates in a hemithorax under pressure, causing impaired venous return and cardiac output. The absence of breath sounds on the affected side, along with deviation of the trachea and mediastinum away from that side, are the hallmarks of this condition, especially in the presence of severe hypotension. Initial therapy includes relief of the pressure by placing a large-bore (14-gauge) intravenous catheter into the second intercostal space in the midclavicular line on the affected side, followed by tube thoracostomy to treat the pneumothorax.

PULMONARY CONTUSION

Pulmonary contusion is a result of blunt force transmitted across the thorax. The mechanism for its development is not completely understood but is felt to be related to compression and re-expansion of the lung tissue, leading to capillary disruption with interstitial and intra-alveolar edema, decreased compliance, and hypoxemia due to a shunt physiology (26). Care is largely supportive in this population, with close
attention to pain management and pulmonary toilet. Typical chest radiographic findings are shown in Figure 79.2.

**Cardiac Contusion**

Cardiac contusion is a potential complication of blunt chest trauma (Fig. 79.3). Its exact incidence is unclear, as different studies used varying criteria to make the diagnosis (33). It is typically well tolerated in mildly injured patients but may lead to fatal arrhythmias or cardiogenic shock if severe. Rapid deceleration, as occurs in motor vehicle accidents, is the most common cause since, in this situation, the heart moves freely and can strike the internal sternum with a substantial amount of force (33). Electrocardiography findings in cardiac contusion are summarized in Table 79.5. Biomarkers, such as creatine kinase (CK) or troponin I and T, are potentially helpful in the diagnosis, as the histologic changes associated with contusion are similar to those seen with infarction. Troponin I and T are specific to the myocardium and may avoid false positives by relying solely on CK, as trauma patients often have diffuse muscular damage leading to massive CK release from many tissues. Electrocardiography may show nonspecific findings, such as sinus tachycardia and premature atrial or ventricular systoles, and not provide further clarification of the diagnosis (33). Echocardiography, whether transthoracic (TTE) or transesophageal (TEE), offers the best insight into cardiac damage from contusion due to its ability to directly visualize wall motion abnormalities (Table 79.6). Treatment involves cardiac monitoring and stabilization of the traumatically induced injuries, supporting blood pressure and cardiac output as indicated. (See algorithm, Fig. 79.1.)

**Aortic Disruption**

Aortic disruption leads to a high mortality, as only 13% to 15% of these patients reach the hospital alive. Those surviving that

---

**FIGURE 79.2.** There are multiple fractured ribs on the right with several fractured in more than one place. This leads to a flail segment with inspiration.

**FIGURE 79.3.** Diffuse infiltrative pattern on the left side is consistent with findings seen following pulmonary contusion.

---

**TABLE 79.5**

<table>
<thead>
<tr>
<th>ELECTROCARDIOGRAPHIC FINDINGS IN CARDIAC CONTUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonspecific abnormalities</td>
</tr>
<tr>
<td>Pericarditis-like ST-segment elevation or PTA depression</td>
</tr>
<tr>
<td>Prolonged QT interval</td>
</tr>
<tr>
<td>Myocardial injury</td>
</tr>
<tr>
<td>New Q wave</td>
</tr>
<tr>
<td>ST-T segment elevation or depression</td>
</tr>
<tr>
<td>Conduction disorders</td>
</tr>
<tr>
<td>Right bundle branch block</td>
</tr>
<tr>
<td>Fascicular block</td>
</tr>
<tr>
<td>Atrioventricular (AV) nodal conduction disorders (1st-, 2nd-, and 3rd-degree AV block)</td>
</tr>
<tr>
<td>Arrhythmias</td>
</tr>
<tr>
<td>Sinus tachycardia</td>
</tr>
<tr>
<td>Atrial and ventricular extrasystoles</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
</tr>
<tr>
<td>Sinus bradycardia</td>
</tr>
<tr>
<td>Atrial tachycardia</td>
</tr>
</tbody>
</table>


**TABLE 79.6**

<table>
<thead>
<tr>
<th>ECHOCARDIOGRAPHIC FINDINGS IN ACUTE CARDIAC CONTUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transesophageal Echocardiography</td>
</tr>
<tr>
<td>Regional wall motion abnormalities</td>
</tr>
<tr>
<td>Pericardial effusion</td>
</tr>
<tr>
<td>Valvular lesions</td>
</tr>
<tr>
<td>Right and left ventricular enlargement</td>
</tr>
<tr>
<td>Ventricular septal rupture</td>
</tr>
<tr>
<td>Intracardiac thrombus</td>
</tr>
<tr>
<td>Transesophageal Echocardiography</td>
</tr>
<tr>
<td>Aortic endocardial laceration or aortic dissection</td>
</tr>
<tr>
<td>Aortic rupture</td>
</tr>
</tbody>
</table>
long have a 30% chance of subsequent rupture and death (34). Diagnostic modalities include findings on chest radiograph of a widened mediastinum, aortography (the gold standard), CT scanning, and TEE. Treatment is immediate surgery by a cardiothoracic surgeon to repair the injury.

Posttraumatic empyema occurs in up to 2% of the thoracic trauma population and is most often caused by Staphylococcus aureus (35). Factors increasing the likelihood of developing empyema include retained hemothorax, pulmonary contusion, and multiple chest tube placement (36). Of note, since most empyemas are of a parapneumonic etiology (37), pneumonia has little impact on the development of pleural space infection in this population. Treatment includes removal of the infected fluid or collection and may be accomplished by guided drainage, VATS, or open thoracotomy.

### Lung Volume Reduction Surgery

Lung volume reduction surgery (LVRS) is used in an effort to improve the pulmonary dynamics of patients with severe emphysema by palliating dyspnea and improving functional status. This population is prone to more postoperative complications than most other thoracic surgery patients due to their underlying fragile nature. Anticipated complications include arrhythmias, prolonged respiratory failure, air leaks, pneumonia, and ICU readmission. Air leaks occur in 90% of patients and rarely require surgical intervention (38). The prevalence of air leaks correlates with a more prolonged, complicated hospital course, and severity is predicted by patient characteristics such as worsened pulmonary function, use of inhaled steroids, distribution of disease (lower lobe disease is less frequent and has shorter duration), and presence of adhesions (38). Management involves chest tube drainage with efforts to minimize or eliminate suction so the tissue has the greatest chance to heal.

### Esophageal Surgery

Esophageal surgery patients undergo procedures that traumatis the lung, the interposed stomach, and the diaphragm. Patients who undergo esophageal resection for carcinoma tend to be malnourished. Pulmonary complications, including atelectasis, pneumonia, aspiration, and retained secretions, are all possible. Up to 29% of patients experience respiratory complications (39) with increasing patient age and decreasing performance on spirometry, which is predictive of increased risk (40). Aspiration risk is minimized by having patients undergo a thorough swallowing evaluation, including radiographic testing, prior to initiating oral intake.

The most dangerous complication of esophageal surgery is leakage from the surgical site. Anastomotic leak occurs in as many as 11% of patients, and factors impacting the incidence include high estimated intraoperative blood loss, cervical location of the anastomosis, and the development of postoperative ARDS (41). Interestingly, the use of thoracic epidural analgesia is associated with a decreased occurrence of anastomotic leak (41). Mortality associated with anastomotic leaks is historically high, but with improved surgical techniques, the patients now face a more promising outcome. One center showed a reduction in mortality with intrathoracic leaks from 43% to 3.3% over a 34-year period (42). Early identification is important, and endoscopy provides a safe method for determining the integrity of the graft and whether surgery is necessary to avoid loss of the graft (43).

### RESPIRATORY THERAPY

Thoracic surgical patients often have significant underlying COPD, impaired mucociliary clearance, excessive secretions, and/or increased closing volumes, all of which predispose to atelectasis. The respiratory therapist plays an important role in providing secretion management and chest physiotherapy (percussion and vibration). Other modalities supporting recovery include adequate hydration, aerosolized bronchodilators, humidified oxygen, and early identification and treatment of infection of the tracheobronchial tree. Chest physiotherapy should begin as soon as the patient has recovered sufficiently from anesthesia to cooperate. Mucolytic agents (such as N-acetylcysteine) are helpful in solubilizing thick secretions, but may cause bronchospasms. Oral or nasotracheal suctioning is used in selected extubated patients, but discomfort and the possibility of complications (hypoxemia, vagal-mediated bradycardia, or cardiac arrest) limit routine use. A mini-tracheostomy (bedside percutaneous cricoidotomy for suctioning) can provide access to the lower airway in patients with thick secretions. Inadequate clearance of secretions often requires flexible bronchoscopy, which is of greatest benefit in the extubated patient who cannot adequately be suctioned. If pulmonary parenchymal involvement is confined to one lung, altering body position can improve gas exchange by changing the relationships between ventilation and perfusion. The lateral decubitus position, with the uninvolved lung down, allows maximal blood flow to ventilated areas during spontaneous ventilation. This relationship may be altered with mechanical breaths and application of PEEP. Specialized beds can be set to supine, lateral, or rotating modes to optimize oxygenation (44).

### COMPLICATIONS

Complications common to all thoracic surgical patients are listed in Table 79.7. Those more likely to occur following specific procedures are listed in Table 79.8.

Airway complications can be precipitated by prolonged intubation with large or double-lumen endotracheal tubes, passage of bronchial blockers, use of rigid bronchoscopes, or frequent reintubation. Edema of the larynx or trachea can substantially narrow the cross-sectional area of the airway. Assessing the patient for an air leak around an occluded endotracheal tube just prior to extubation may identify significant laryngeal and supraglottic edema. Upright or sitting position, intravenous corticosteroids (45), and racemic epinephrine respiratory treatments are the mainstay of edema reduction. A critical airway may be converted to an adequate airway by the administration of Heliox, a helium and oxygen mixture (46). Helium, being less dense and less viscous than nitrogen, allows maintenance of laminar flow through a critically narrowed or completely occluded airway. Prolonged endotracheal intubation or temporary tracheostomy may be required to allow resolution of airway edema.
The recurrent laryngeal nerves branch from the vagus nerves as they enter the chest. The right recurrent laryngeal nerve arises high in the apex of the right chest and loops around the aortic arch in the left chest before it enters the tracheoesophageal groove. The left recurrent laryngeal nerve, which is more susceptible to injury, wraps around the subclavian artery to travel back to the larynx in the tracheoesophageal groove. Dysfunction of these nerves is frequently due to recurrent lung carcinoma. The patient should be positioned with the operated or pneumonectomy side down to trap remaining fluid in the pneumonectomy cavity, and full expansion of the lung with vigorous chest physiotherapy helps to close these small distal fistulae. A substantial persistent air leak from the chest tube, or incomplete expansion of the lung, suggests a significant bronchopleural fistula. Major proximal airway problems such as failure of the anastomosis, disruption of a bronchial closure, or retained secretions or foreign bodies can be identified by bronchoscopy. Within the first 7 postoperative days, any fistula is likely to be due to a technical problem. More than 1 week after the operation, but usually within the first 6 weeks, fistulae are more often due to an empyema or local peribronchial abscess. Late occurrence of a bronchopleural fistula (more than 6 months after the operation) is frequently due to recurrent lung carcinoma.

Early postoperative bronchopleural fistula in a pneumonectomy patient is a surgical emergency. The typical presentation is sudden expectoration of copious amounts of pink, frothy sputum, which may be misdiagnosed as pulmonary edema. The patient should be positioned with the operated or pneumonectomy side down to trap remaining fluid in the pneumonectomy cavity. Further management will likely include both bronchoscopy to assess the stump closure and immediate reoperation.

Empyema is initially treated with closed tube drainage and antibiotic therapy. After the patient has been stabilized and any bronchopleural fistula identified and treated, drainage of the empyema cavity is converted from closed tube drainage to open tube drainage. A chest radiograph helps to determine if the mediastinum is fixed or whether it has shifted and compressed the contralateral remaining lung. If the mediastinum is stable, drainage of the cavity may be permanently converted to open drainage. This may take the form of rib resection and marsupialization of the pneumonectomy cavity (Clagett window or Eloesser flap). With time, the pneumonectomy cavity shrinks in size, and the window or flap may be closed.

Postoperative hypoxemia is common and may be due to sepsis, ARDS, pneumonia, or pulmonary embolization. If pulmonary emboli are suspected, ventilation/perfusion scanning, spiral computed tomography, and pulmonary angiography should be done, and treatment initiated with anticoagulation or lytic therapy, depending on timing and indications. If these measures are contraindicated, an inferior vena caval filter should be placed. Systemic tumor emboli, though uncommon, may be seen after pulmonary resections for primary bronchogenic carcinomas or metastatic sarcomas.

### TABLE 79.7

POSTOPERATIVE COMPLICATIONS FOLLOWING ANY THORACIC PROCEDURE

<table>
<thead>
<tr>
<th>Complication</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airway edema/stridor</td>
<td>Retained secretions and blood in the airway are especially common if the airway was opened, such as during a bronchopleural procedure or closure of a bronchial stump. Mechanical airway obstruction secondary to secretions may be aggravated by bronchospasm, and preoperative bronchodilators should be continued in patients with reactive airways, as secretions can precipitate coughing and bronchospasm.</td>
</tr>
</tbody>
</table>
TABLE 79.8

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior mediastinotomy (Chamberlain)</td>
<td>Damage to recurrent laryngeal nerve (particularly left)</td>
</tr>
<tr>
<td>Bronchoscopy/mediastinoscopy</td>
<td>Bleeding from major vessels if torn, air leak with biopsy of bronchus</td>
</tr>
<tr>
<td>Bronchopleural fistula repair</td>
<td>Persistent leak, dehiscence</td>
</tr>
<tr>
<td>Bronchopulmonary lavage</td>
<td>Respiratory distress/contralateral spillage</td>
</tr>
<tr>
<td>Bullectomy</td>
<td></td>
</tr>
<tr>
<td>Chest wall reconstruction</td>
<td>Tension pneumothorax, air leak</td>
</tr>
<tr>
<td>Clagett window</td>
<td></td>
</tr>
<tr>
<td>Collis-Belsey</td>
<td>Air leak</td>
</tr>
<tr>
<td>Decortication</td>
<td></td>
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<tr>
<td>Esophageal dilatation</td>
<td></td>
</tr>
<tr>
<td>Esophagoscopy</td>
<td></td>
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<tr>
<td>Esophagegastroectomy</td>
<td></td>
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<tr>
<td>Heller myotomy</td>
<td></td>
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<tr>
<td>Lobectomy</td>
<td></td>
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<tr>
<td>Mediastinal tumor excision</td>
<td></td>
</tr>
<tr>
<td>Nissen fundoplication</td>
<td></td>
</tr>
<tr>
<td>Pectus repair</td>
<td></td>
</tr>
<tr>
<td>Pleuroscopy</td>
<td></td>
</tr>
<tr>
<td>Pneumonectomy</td>
<td></td>
</tr>
<tr>
<td>Thoracic aortic aneurysm</td>
<td></td>
</tr>
<tr>
<td>Thymectomy</td>
<td></td>
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<tr>
<td>Lung transplant</td>
<td></td>
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<tr>
<td>Tracheal resection</td>
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</table>


Massive postoperative hemorrhage can present as significant shock and occasionally occurs during transfer of the patient to the recovery room or ICU. This potentially lethal condition can be the result of a slipped tie from the pulmonary vein—or, less commonly, the pulmonary artery—and requires emergent reoperation. Slower postoperative hemorrhage usually results from small bleeding arteries or veins in the mediastinum or chest wall. Reoperation is required for control of bleeding and to evaluate the hemothorax to prevent future fibrothorax or restrictive lung disease.

PULMONARY PARENCHYMAL COMPLICATIONS

**Tracheoesophageal Fistula**

A communication may occur between the anterior esophageal wall and membranous (posterior) wall of the trachea following prolonged intubation due to pressure exerted from the cuff of the endotracheal or tracheostomy tube, which can lead to potential tissue necrosis. Tracheoesophageal fistula should be suspected when feedings are aspirated from the airway. Surgical revision of the damaged area is the definitive therapy but may not be practical in patients still requiring positive pressure ventilation, and may need to be delayed until the patient has been weaned off mechanical ventilation (48). Stenting of the esophagus, performed at the bedside in the ICU, allows for temporary sealing of the fistula until the patient is a suitable candidate for final surgical repair (49).

**Tracheoinnominate Fistula**

Bleeding seen 48 hours or greater following tracheostomy raises concern about the presence of a tracheoinnominate fistula. Even though this occurs rarely, it is a life-threatening complication and requires urgent action. Most cases arise when pressure necrosis on the posterior aspect of the blood vessel occurs due to overinflation of the endotracheal cuff. Initial steps include hyperinflation of the tracheostomy cuff or direct arterial compression with a finger to tamponade the bleeding. Bronchoscopy is the diagnostic procedure of choice, followed by surgery to divide the innominate artery, with subsequent separation of the trachea from the divided artery by viable tissue (50).

**Atelectasis**

The most common complication following thoracic surgery is atelectasis. Potential contributors include hypoventilation, splinting, bronchospasm, poor cough, retained secretions, pneumothorax, and trauma to the lung during the surgical procedure. Most patients in the ICU will tolerate some degree of...
Lobar Collapse and Torsion

Lobar collapse most commonly occurs in either the right upper lobe following surgery that uses a double-lumen endotracheal tube or in the right middle lobe after right upper lobectomy, which alters the anatomy, allowing the horizontal fissure to rise. This results in compression on the right middle lobe bronchus and subsequent occlusion.

Lobar torsion occurs as the result of a lung segment twisting about its hilar structures. This twisting occludes the bronchial, arterial, and venous supply to the affected segment, with infarction occurring if the process is not recognized and treated. The right middle lobe and lingula are at greatest risk following surgery (with an increased risk for each additional minute), due to the use of prophylactic perioperative antibiotics. Factors increasing the risk of torsion include testing the pleural fluid which is high in triglycerides and chyliomicones. The leakage site is localized with lymphangiography or CT scanning, and the clinical situation will dictate the type of management. It occurs in approximately 4% of patients undergoing esophageal surgery with the transhiatal approach as compared to transabdominal; an increased number of positive nodes are predictive of its incidence (52). Management initially includes chest tube drainage and parenteral nutrition to decrease the thoracic duct output. If the drainage resolves with conservative management, surgical intervention can likely be reserved for those not decreasing their chylous output (53).

PLEURAL COMPLICATIONS

Pneumothorax is the second most frequent postoperative complication after atelectasis (14). Signs and symptoms of a pneumothorax range from subtle to severe and include increased work of breathing, decreased breath sounds and chest movement, wheezing, hypoxia, increased airway pressures if still on the ventilator, and hemodynamic instability if tension pneumothorax occurs. A chest radiograph is the first modality used in the diagnosis of pneumothorax, save for the instance when tension is present and chest tube placement must occur immediately to prevent further clinical deterioration of the patient. If a pneumothorax develops on the surgical side and chest tubes are already present, it is necessary to ensure that the tubes are functioning properly. This involves inspecting the entire system for any evidence of leaks, inadequate suction, or loss of tubing patency due to blood clots. It is possible to declot chest tubes with vigorous stripping or by placing a balloon occlusion catheter to physically remove the obstruction.

Pleural effusions persisting in the postoperative period should be evaluated via thoracentesis to determine if there is an intrathoracic or extrathoracic cause. If the fluid is transudative, the underlying cause needs to be addressed. If the fluid is exudative, a high suspicion for empyema must be maintained. If pleural effusions and pneumothoraces do not resolve over time, the decision for more definitive therapy, such as pleurodesis, needs to be entertained.

Thoracic duct injury is a known complication following any surgery involving dissection in the posterior mediastinum and may result in chylothorax. Confirmation of the diagnosis includes testing the pleural fluid which is high in triglycerides and chyliomicones. The leakage site is localized with lymphangiography or CT scanning, and the clinical situation will dictate the type of management. It occurs in approximately 4% of patients undergoing esophageal surgery with the transhiatal approach as compared to transabdominal; an increased number of positive nodes are predictive of its incidence (52). Management initially includes chest tube drainage and parenteral nutrition to decrease the thoracic duct output. If the drainage resolves with conservative management, surgical intervention can likely be reserved for those not decreasing their chylous output (53).

OTHER COMPLICATIONS

Postoperative Infections

The incidence of developing nosocomial infection following lung surgery increases with a history of COPD, duration of surgery (with an increased risk for each additional minute), and ICU admission (54). Surgical site infection occurs rarely due to the use of prophylactic perioperative antibiotics. Factors increasing the risk of infection at the incision site include emergent thoracotomy in the trauma patient and procedures for treatment of empyema, lung abscess, mediastinitis, or perforated esophagus. Any unexplained fever requires careful inspection of the surgical site.

When air tracks into the subcutaneous space via the path of least resistance, it generates subcutaneous emphysema. The air is forced along these pathways with positive pressure ventilation and instances of increased intrathoracic pressure during spontaneous breathing. Coughing and forced exhalation are two examples. Subcutaneous air may be striking in appearance but rarely affects patient outcome in a detrimental way. If the collection of air is massive enough to compromise the airway, endotracheal intubation may be indicated, realizing the pitfalls of instituting positive pressure ventilation in such a situation. Following sterile preparation, puncturing the skin with small-gauge (no. 25) needles provides a conduit for the subcutaneous air to escape and decrease the cosmetic deformation.

SUMMARY

The thoracic patient presents unique management issues due to the complexities of fluid management, preoperative morbidity, the need for specialized pain control to preserve respiratory function, and the need for expertise in the management of pneumothorax, pleural effusions, and pleuropneumothorax.
function, and nature of drainage devices left in place postoperatively. As a critical care physician, it is important to understand the interplay of these circumstances when anticipating the patient’s postoperative needs in the ICU. The pulmonary system is more susceptible to adverse events if fluid management is not judiciously managed. Patients undergoing thoracotomies for lung or esophageal surgery tend to have an impaired functional status and nutrition at baseline, negatively impacting their postoperative course. If pain control is inadequate, the patient will have impaired pulmonary function, which potentially delays recovery. Chest tubes require extra vigilance due to the potential of complications should they malfunction. With a well thought out care plan, the outcome for thoracotomy patients will be positive and the road to recovery smooth.

References


