Penetrating Injuries to the Abdomen - I & II

(Editors’ note: the review on penetrating abdominal trauma will be posted in two sections, in February and March 2009 and the associated online discussion and CME questions will continue throughout this period. A pdf of the entire review will be available March 2009)

1. Introduction

2. Initial Assessment
   2.1. Initial Management
   2.2. Stab Wounds
   2.3. Gun Shot Wounds

3. Diagnosis and Investigations
   3.1. Ultrasound
   3.2. CT scan
   3.3. DPL
   3.4. Rigid sigmoidoscopy
   3.5. Angiography

4. Solid Organ Injury
   4.1. Hepato-biliary-pancreatic injuries
      4.1.1. Liver
      4.1.2. Gall Bladder and Common Bile Duct
      4.1.3. Portal Vein
      4.1.4. Pancreas
   4.2. Spleen

5. Hollow Viscus Injury
   5.1. Stomach
   5.2. Duodenum
   5.3. Small Intestine
   5.4. Colon
   5.5. Rectum

6. Recommendations

7. References
1. Introduction
In the US, penetrating injuries comprise approximately 6% and 10% of hospitalizations and emergency room visits, respectively. However, they account for the second most common mechanism of fatal injury after motor vehicle related injuries, at 20% of all injury-related deaths.[1] The absolute numbers vary across global locations but the epidemiological fact remains unchanged - that penetrating injuries in particular, firearm related injury, are highly lethal. In the next two months’ reviews we will discuss penetrating injuries of the abdomen: the recognition, diagnosis, and the treatment decision-making for intra-abdominal injury.

2. Initial Assessment
Trauma surgeons classify the torso into 5 main areas: chest, thoraco-abdominal, anterior abdomen, flank and back. The organs found within the peritoneal cavity can be injured by a penetrating wound in any 4 of these 5 regions. The approach to diagnosis and treatment differs and is determined by the type of weapon, either a firearm or a stab wound and the trajectory of its entry. For the purposes of this discussion we will consider the use of the word abdomen to refer to all 4 of the above noted regions of the torso (thoraco-abdominal, anterior abdomen, flank and back) unless otherwise specifically delineated. Historically, all patients who sustained a penetrating injury to the abdomen were treated with an exploratory laparotomy as the accepted standard of care. However, as the field of trauma surgery expanded to handle more civilian injury and less war injury, trauma surgeons recognized that laparotomies were being performed in a substantial number of patients without significant internal organ injury.[10] In conjunction with this, the consequences of a negative laparotomy were shown to be associated with long term sequelae. [16]

Therefore, the first question to be asked when approaching a patient with penetrating injury to the abdomen is as follows: “Is there an internal organ injury?” The clinical examination remains the hallmark diagnostic test to determine intra-abdominal injury. Any patient who presents with hemodynamic instability or physical signs of acute peritonitis or diffuse abdominal tenderness requires an immediate laparotomy, irrespective of the location of the penetrating wound. This laparotomy should be performed in the midline with an incision that extends from the xiphisternum to the symphysis pubis without exception. Remember, this is an operation to save the patient’s life and therefore, any compromise on adequate exposure can affect the potential positive outcome. If the weapon or object which penetrated the abdomen is still in place at the time the patient arrives at the health facility, no attempt at removal should be made in the emergency room. This can vary from an unintentional impalement on an object to retained knives or arrows after an intentional attack. The patient should be taken to the operating room with the object remaining in place. If possible, the external portion of the object can be removed close to the patient’s body to allow them to lay flat once under general anesthetic. The laparotomy should be performed and the object removed under direct vision of the organs and vessels that it transects. It is only in this fashion that quick control of vascular and major organ injuries can be accomplished safely. In the case of a potential vascular injury, proximal and distal control of the involved vascular structure should be obtained prior to removal of the impaled object.
Evaluation of hemodynamic instability requires the combined assessment of vital signs such as pulse rate and pulse pressure, blood pressure, urine output, sensorium, capillary
and skin refill, and base deficit as measured by the laboratory. All these factors must be taken together in a complete picture to determine if the patient is hemodynamically stable or not. Factors such as extremes of age, medication, pregnancy, spinal cord injury, illicit substance intoxication, athletes, or pre-existing medical conditions such as chronic hypertension can alter physical signs and symptoms such that acute blood loss is masked.

The trauma patient, who initially does not display an immediate need for operative intervention, does require repeat examinations. Any deteriorating trend in vital signs and/or base deficit, especially in a patient who continues to receive fluid or blood resuscitation, is a strong indication that the patient is hemodynamically unstable and, potentially, has a clinically relevant intra-abdominal injury. A rigid abdomen with involuntary abdominal wall muscle contraction is the hallmark of peritonitis, but even diffuse abdominal tenderness, especially when found away from the site of injury can be an indicator of an intra-abdominal injury warranting exploratory laparotomy. Only patients who have an associated spinal cord injury, severe head injury or with severe intoxication require further investigation beyond clinical examination alone to minimize missed abdominal injuries.

Patients with internal injury, who present after sustaining a penetrating trauma without any of the signs or symptoms of an intra-abdominal injury, pose a diagnostic dilemma to differentiate them from those patients who have no intra-abdominal injuries. There are a number of diagnostic approaches used in these situations that we will discuss in more detail in the next section, but the first step in the approach to penetrating trauma depends on the mechanism of injury. In the asymptomatic patient the mechanism of injury: stab wound versus firearm as well as the location of that wound: anterior abdomen, flank, back and thoraco-abdominal areas are the main determinants for deciding on the treatment approach to undertake. A decision algorithm for the approach to the patient with penetrating trauma to the abdomen is summarized in Figure 1.
2.1. Initial Management
The initial management of any trauma patient should include the ABCs of resuscitation, especially keeping the patient warm and cross-matching for blood with the availability of uncross-matched blood for immediate use. Any patient, who is hemodynamically unstable especially if hypotensive, should preferentially be given blood rather than crystalloid as a resuscitation fluid. Laboratory tests that can be useful in the initial care of the patient are the coagulation profile, base deficit and hematocrit, if they are available. All three are helpful for monitoring of the response to resuscitation and for outcome prediction or patient prognosis. [25] No other laboratory tests are useful at this point. In penetrating trauma, permissive hypotension until the patient has reached the operating room has been suggested. [23] Bickell et al. suggested using minimal fluid and blood products so that the blood pressure was “allowed” to remain low-normal so as to
minimize bleeding from the internal injury until operative repair could occur at which time full resuscitation would begin. He was able to show a reduction in mortality but other authors have not been able to replicate this result. [24] This approach is only for very select situations, if at all, where select patients arrive at the trauma center within minutes of injury and can be moved to the operating room expeditiously. Hypotension should not be the routine goal for patients with penetrating injuries in other settings.

An exploratory laparotomy in a trauma patient should always be performed with a midline incision irrespective of the injury suspected, as it is the only incision that allows wide exposure of the peritoneal, retroperitoneal and pelvic areas. A right subcostal extension to the midline incision can be added if necessary to improve exposure for biliary tract injuries. If there is a significant amount of hemoperitoneum, then the first step after releasing the tamponade is to pack all four quadrants of the peritoneal cavity with laparotomy pads. If the patient is hypotensive or becomes hypotensive after releasing the peritoneal tamponade, the surgeon should keep the packs in and allow the anesthesiology team to give blood products to regain a mean arterial pressure above 60.

2.2. Stab Wounds

Stab wounds to the anterior abdomen have been shown to be associated with a 30-50% incidence of intra-abdominal injury that requires operative repair. [11][12] Therefore, over half of the patients can be discharged without an operation. Local wound exploration can be performed using good lighting in the emergency department. If the anterior fascia is intact and the patient has no abdominal tenderness then the patient can be safely discharged from the hospital without need for a period of observation. However, if an abdominal stab wound penetrates the anterior abdominal fascia then that patient requires serial clinical examinations for at least 24 hours before discharge as initially undetected injuries will become symptomatic within this time frame. Evisceration of bowel or omentum or free air on an abdominal radiograph has been reported to be associated with intra-abdominal injury even in the absence of symptoms and therefore, should mandate operative intervention. [14] DPL and ultrasound play a limited role, if any, in deciding on operative management in stab wounds and are rarely used as clinical adjuncts to the physical examination.

Stab wounds to the back and flank result in an even fewer number of intra-abdominal injuries, reported as low as 15% in one study. [13] However, a patient who is otherwise asymptomatic, but displays hematuria, blood per rectum or a right upper quadrant stab which may involve the liver, should be considered for a CT scan or rigid sigmoidoscopy if available. Asymptomatic patients with flank or back wounds in centers, without a CT scan available to verify or eliminate peritoneal penetration, should be observed for 18-24 hours to rule out an intra-abdominal injury. There has been concern that the physical examination is unreliable in the intoxicated patient, but it has been shown that it can be reliable in the presence of mild to moderate intoxication. [11]

In summary, for a patient who has sustained a stab wound to the abdomen a careful clinical examination of the patient with a repeat examination at frequent (4-8 hours), regular intervals, preferably by the same clinician, is the most accurate approach to determine onset of signs and symptoms indicative of the need for operative intervention.
2.3. Gun Shot Wounds
Gun shot wounds unlike stab wounds are associated with a higher likelihood of intra-abdominal injury that requires repair, up to 90% of patients as reported by some trauma centers.[17, 18] Therefore, gun shot wounds are more likely to be taken directly to the operating room, especially in centers where the frequency of gun shot wounds is less common.

However, in other patient series, especially with gun shot wounds to the back, the incidence of significant intra-abdominal injury is much lower - prompting many trauma centers to consider selective management.[19, 20, 21] Selective management is the term given patients who present asymptomatic after an injury and who are followed clinically rather than undergo immediate exploratory laparotomy. However, the essential component to the adoption of selective management is the ability to closely follow patients clinically and the ability to intervene in a timely manner, if the patient’s condition changes, with an immediately available operating room and staff. One main concern of selective management is the risk of complications such as sepsis and even death due to delayed diagnosis of injuries. However, in trauma centers that are able to meet the key components mentioned above, only 0.3% of the patients developed a complication that could be considered a result of the delayed operative intervention and none of these patients died nor suffered long term morbidity. [20] Therefore, a center that does not have 24 hour availability of nursing staff, surgical staff and operating room staff as well as monitoring capabilities should not undertake selective management of gun shot wounds of the abdomen.

3. Diagnosis and Investigations
In the last section we discussed the absolute indications for operative exploration of a patient with a penetrating injury to the abdomen and the cornerstone of initial evaluation - clinical abdominal examination. However, many patients may present with an intra-abdominal injury but lack the hard signs of peritonitis, abdominal tenderness, hemodynamic instability and the clinical examination of their abdomen is unreliable. In these patients, further diagnostic tests and procedures are warranted. We will now discuss the diagnostic and investigative options available to determine intra-abdominal injury and the appropriate treatment approach in asymptomatic patients with positive diagnostic findings.

3.1. Ultrasound
FAST, focused abdominal sonography for trauma, has become the standard of care to detect intra-abdominal fluid during the initial assessment of the injured patient with blunt and penetrating trauma. The FAST is now routinely performed by surgeons and emergency medicine physicians in the initial assessment of injured patients in the emergency department. A positive FAST examination is highly sensitive for hemoperitoneum and clinically significant abdominal organ injury in blunt trauma patients. [2] The FAST exam is an operator dependent technique and therefore, results must be interpreted in the context of the experience of the personnel performing it. The utility of the FAST in abdominal penetrating trauma is less accurate, with a sensitivity to detect hemoperitoneum being reported as low as 67%.[4] The specificity of the FAST in penetrating trauma is higher (>90%) than the sensitivity (45-65%), i.e. the ability to accurately choose patients without injury as having no injury; but this is a clinically less useful function. [15] However, the FAST is very sensitive and highly accurate for
detecting pericardial fluid (i.e. blood) in a patient who has sustained a penetrating injury to the heart. The patient who has a wound in the cardiac box – a square formed by four lines that bisect through the bilateral nipples and the costal margins and which includes the epigastrum area of the abdomen, should have a pericardial FAST if ultrasound is available. Therefore, in most trauma centers FAST may be performed on a patient with penetrating trauma because it is often available, but it plays a minor if any role in the decision making in the patient’s management.

3.2. CT Scan
Computed Tomography (CT scan) of the abdomen is the standard diagnostic test for blunt trauma patients who clinically do not require immediate operative intervention in resource-rich settings. The CT scan is accurate in showing intraperitoneal fluid/blood and defining injuries in the solid organs after blunt trauma. The CT scan of the abdomen is now also utilized to assess the possibility of intra-abdominal injury in patients who have sustained a firearm injury who present without symptoms and thereby are considered for nonoperative management. The CT scan can show the trajectory of the bullet tract and assist in deciding on peritoneal penetration as well as any organ injury or the presence of hemoperitoneum. If a patient has no peritoneal penetration confirmed by CT scan then he may be discharged without a period of observation. Any ongoing bleeding or any hollow viscus perforation requires operative repair. If the bullet track passes near the colon, but without actual free air or contrast extravasation, then the patient must be watched closely because of the potential for the development of colon injury second to blast effect from the bullet. A CT scan is usually obtained with double contrast – oral and IV. However, there has been some evidence to suggest that oral may not increase the rate of detection of bowel injury and may delay the timing of the CT scan as well as a risk of aspiration. For penetrating wounds to the flank and back, many trauma surgeons suggest a triple contrast CT scan – oral, IV and rectal contrast. The addition of rectal contrast has been shown to increase the rate of detection of retroperitoneal colon injuries that can occur in back or flank penetrating wounds.

3.3. DPL
The diagnostic peritoneal lavage (DPL) is performed predominantly by the open technique where a small sagittal incision (2-3 cm) is made in the midline just below or above the umbilicus. If there is an associated pelvic fracture or a pregnant uterus then the incision should be made above the umbilicus. The incision is carried through the subcutaneous tissue to the fascia in which another 1 cm sagittal incision is made. A hemostat is used to bluntly enter the peritoneal cavity through the peritoneum while the fascia is elevated using Kelley instruments to avoid potential injury to underlying bowel. At this point, a 10 cc syringe is attached to a long thin catheter or hollow tubing (at least 10 cm in length) which is directed into the abdomen inferiorly without pressure. If 10+ ml of gross blood is aspirated then the DPL is positive and one should proceed with an exploratory laparotomy. If not, then the catheter is attached to a one liter bag of normal saline which is allowed to run into the peritoneal cavity. Once all the fluid is entered, then the empty bag is placed on the ground and using gravity, the fluid is allowed to run back into the bag. The fluid can be analyzed for cell count and biochemistry (see Figure 2).

<table>
<thead>
<tr>
<th>WBC</th>
<th>Presence of one of</th>
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</thead>
</table>

Figure 2: Cell count Criterion for DPL performed in Penetrating Injury
### RBC Count

<table>
<thead>
<tr>
<th>Positive DPL Result</th>
<th>RBC Count</th>
<th>Count</th>
<th>the following:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;10,000 cells/mm³</td>
<td>&gt;500 cells/mm³</td>
<td>Amylase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Alkaline Phosphatase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bilirubin</td>
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The fluid can also be inspected macroscopically by placing newspaper or any printed paper behind the transparent fluid bag. If the printing is easily readable through the red-stained fluid then the DPL is considered negative or in other words, the cell count is reliably lower than the threshold cut-off for positive determined by laboratory examination as described in Figure 2. If the print is unreadable, the DPL is positive and the surgeon should proceed with an exploratory laparotomy.

The laboratory-determined red cell count threshold for a positive DPL is lower in penetrating trauma than it is in blunt trauma. As a result, it misses fewer injuries but does increase the number of non-therapeutic laparotomies based on DPL findings alone. DPL is not often used in penetrating trauma because of the high number of false positives. The indications include asymptomatic patients who cannot be followed clinically because of other associated injuries such as severe brain injury; if clinical observation by skilled personnel is unavailable; or if operative treatment is not available locally and a decision in regards to internal injury cannot be made clinically due to associated other injuries such as brain injury and the need for transfer to another facility needs to be confirmed.

### 3.4. Rigid Sigmoidoscopy

Rigid sigmoidoscopy is useful for examination of the extraperitoneal rectum. For penetrating wounds to the lower back, buttocks or lateral upper thigh, especially gun shot wounds and wounds that traverse the midline, there is a potential for injury to the rectum. As the last 10-12 cm of rectum is extraperitoneal, symptoms of perforation and injury such as pain, peritonitis or sepsis may be nonexistent or present late in the course. A rectal exam should always be performed first, but alone is an inadequate examination for the entire extraperitoneal rectum. The rigid sigmoidoscopy will often demonstrate the injury and allow primary repair in many instances.[8] If blood is detected in the rectal lumen, even if no rectal wall perforation or laceration is seen, an injury must be assumed and a diverting colostomy performed (see 5.5. Rectal injury).[9] In a patient with a pelvic gun shot wound who requires an exploratory laparotomy, the patient can be placed in lithotomy and a rigid sigmoidoscopy can be performed before or during the operation. This allows examination of the extraperitoneal rectum without opening the peritoneal reflection from within the abdominal cavity and potentially exposing another body area to contamination and ultimately infection and abscess. [10]

### 3.5. Angiography

Angiography is rarely used in penetrating injury. However, in a stable, asymptomatic patient chosen for selective management a CT scan may show an isolated injury to the spleen, liver or kidney and angiography can play a role in their management.

Angiography may be used to rule out successful nonoperative management of patients if
their CT scan shows a vascular contrast blush within the organ in question. This signifies ongoing hemorrhage despite the patient’s present stability and predicts failure of nonoperative management. This clinical scenario more commonly happens in the kidney as it is a retroperitoneal organ where the bleeding can be more easily contained minimizing clinical signs. Also, in opening the hematoma around the kidney, which is contained within the retroperitoneum, uncontrolled bleeding may ensue that could result in the need for a nephrectomy. Therefore, in an attempt to avoid surgical loss of the kidney, where the bleeding vessel is localized, therapeutic angiographic embolization may be utilized instead of operation. Angiography for diagnosis and embolization of a bleeding vessel requires the appropriate equipment and personnel.

4. Solid Organ Injury

4.1. Hepato-biliary-pancreatic injuries

4.1.1. Liver

In any patient whose penetrating wound is in the right upper quadrant, injury to the biliary tract should be suspected. Nonoperative management has been utilized by some Level I trauma centers in the USA for right upper quadrant gun shot wounds, but it can be associated with missed stomach and intestinal injuries and late complications such as biliopleural fistulas. Only a center with the capability to do a CT scan, 24 hour regular patient monitoring and 24 hour operating room availability should even consider this approach for gun shot wounds of the right upper quadrant. The correct approach for suspected right upper quadrant gun shot injury, in virtually all situations in low-income countries, will be a midline laparotomy.

After removing the packs and inspecting the entire peritoneal cavity for injury, the initial approach to control bleeding liver parenchymal injuries include: 1) electrocautery 2) omental plug 3) direct suture ligation and 4) hemostatic agents. Any liver wound or bullet trajectory that is not bleeding should not be probed or manipulated. As the blood supply to the liver is predominantly the low pressure venous systems of the portal and hepatic veins, a large number of injuries stop bleeding without any need for operative repair.

Liver wounds can be compressed with direct pressure using laparotomy pads while full exposure is gained by transecting the falciform, left and right triangular and coronary ligaments (all or some of these ligaments are mobilized depending on which segment/s of the liver are injured). Any ligament that has a large hematoma contained within it should not be opened as this likely represents a vena caval or hepatic vein injury and entering the hematoma may result in brisk exsanguination. Ongoing bleeding after a period of initial compression can be controlled by using electrocautery placed on coagulation settings of at least 50 and up to 80-100. Direct ligation of visible bleeding vessels using prolene or other nonabsorbable suture can be used. If bleeding is not in one discrete area then a tongue of viable omentum can be used as a type of “patch” placed into the defect. Recently a variety of absorbable hemostatic agents, blood-clot inducing material, have become commercially available. The commonest examples are fibrin glue a liquid made from a mixture of cryoprecipitate (fibrinogen), thrombin and calcium; surgicel, an oxidized cellulose material for laying on bleeding surfaces and gelfoam, a syrofoam-textured material made from porous, purified pork Skin Gelatin USP granules. They are used extensively in the USA, but provide the same function as do perihepatic packing,
electrocautery, suture ligation and omental patching in obtaining hemostasis but at greater economic cost.

For the liver wound that is bleeding profusely, a Pringle maneuver can assist in reducing flow so that the injury can be better visualized and repaired. A noncrushing clamp is placed through the Foramen of Winslow across the contents of the lesser omentum or porta hepatitis. If bleeding remains profuse, this is a serious warning sign that there is a significant retrohepatic injury: inferior vena cava, major hepatic injury or caudate lobe injury which will be discussed below. In the case of severe exsanguinating hemorrhage not controlled by the Pringle maneuver, then total vascular occlusion can be utilized. This entails a Pringle maneuver, clamping of the aorta at the diaphragmatic hiatus and clamping of the inferior vena cava at the superior aspect of the liver at the diaphragm. A Pringle maneuver can be maintained for upwards of 60-75 minutes but after 30 minutes, some surgeons would consider opening the clamp for 5 minutes to allow for reperfusion. Obviously total vascular occlusion will cause significant ischemia to the liver as well as the body below the abdominal aorta and therefore, should only be used in patients who are in extremis second to exsanguination from a severe liver parenchymal or vascular injury.

In severe liver parenchymal injury the same approaches can be used for hemostasis: electrocautery, direct suture ligation and omental patches, but the extent of bleeding often requires more visualization. Fracturing liver parenchyma by pinching the parenchyma between your fingers (“finger fracture”) or by using a hemostat will widen and increase the wound edge or bullet tract to allow better access to bleeding vessels in the wound so that they can be selectively ligated, directly sutured, cauterized or clipped. This technique of hepatotomy requires ligation of any bile canaliculi or vessels encountered while approaching the area of bleeding and can often involve increased bleeding from this normal liver parenchyma. If the bullet or stab wound tract is deep within a liver segment, which may require a large amount of normal liver to be opened to access it, then an alternative approach is to suture ligate the open superior and inferior aspects of the wound with 0-chromic cat gut suture on a large blunt tipped needle using figure of eight or mattress suture technique. This maneuver often tamponades further bleeding within a deep bullet or stab wound tract. One must observe the wound for 10 minutes to ascertain that no expanding hematoma is occurring signaling the failure of this technique to achieve hemostasis. This 0-chromic cat gut can also be used on lacerations that are not deep but are not controlled by topical hemostasis like electrocautery or hemostatic agents. If placement of the sutures is done blindly then they should not be placed deeper than 3-4 cm because an injury to a large vessel or bile duct branch could occur which may cause hemobilia or an expanding intrahepatic hematoma.

Perihepatic packing is technically the easiest hemostatic method to perform, is often successful and therefore is often the most widely employed for significant liver hemorrhage. Folded laparotomy packs are placed ventral and dorsal on the liver so that the liver is compressed between the anterior thoraco-abdominal wall, diaphragm and the posterior retroperitoneum after the liver has been mobilized as described above. Packing early has been associated with an improved survival. If this method is used as the definitive or an adjunct approach to hemostasis the packs are left in for 24-72 hours, the abdominal fascia is not closed (“open abdomen”) and the patient is taken to the intensive care unit to optimize resuscitation with blood products including fresh frozen plasma, cryoprecipitate and platelet infusion, if available. The techniques involved in
damage control laparotomy where the abdomen is left “open” are beyond the scope of this review but the commonest initial dressing for an open abdomen is a plastic covering to protect the intestines followed by drains for fluid collection and the last layer is an adhesive clear dressing, for example IobanTM, to keep the dressing in place. The abdomen is left open to prevent the development of abdominal compartment syndrome. The abdominal compartment syndrome defined as an intra-abdominal pressure of greater than 25 mmHg causes significant morbidity. The large volume of resuscitation, any ongoing intra-abdominal hemorrhage and the presence of laparotomy pads combined place these patients at a very high risk of developing this syndrome. The difficulty comes with pack removal for a raw newly hemostatic liver surface which can rebleed. Feliciano and Pachter have suggested placing a nonadherent plastic drape between the laparotomy pads and any raw liver surfaces to minimize the chance of rebleeding at reoperation. [37] The timing of pack removal remains controversial. The decision to remove the packs is balanced between adequate time for physiological restoration to allow for hemostasis and increased risk of sepsis secondary to foreign bodies within the peritoneal cavity. One author showed that three days appeared to be the threshold which, if passed, resulted in a substantial increase in sepsis.[38] Furthermore at reoperation, it is paramount to remove peritoneal clot and debride any devitalized liver parenchyma in order to minimize the development of perihepatic infection after packing.

If the injury has transected one anatomic lobe or segment or when the injury itself has devascularized the majority of that lobe or segment, then an anatomic resection may be needed to achieve hemostasis. [32] Anatomic resections for less severe injuries have not been associated with improved survival. [31] The raw surface of the resection can be covered with a viable omental patch. The omentum is first mobilized from the transverse colon mesentery and then the greater curvature of the stomach protecting the right gastric epiploic vessel.[30] Then advancing a tongue of omentum on its vascular pedicle it can be placed on the resection surface or within a wound to lessen the dead space. The macrophage activity of the omentum is the key to its effective hemostatic activity. Rather than attempt an anatomic resection in a hemodynamically unstable patient, if there is extensive lobar damage not responding to suture ligation or electrocautery, some trauma centers recommend application of wide aortic clamps, across the entire bleeding area of the liver can sometimes achieve hemostasis.[33] These clamps, if they slow the hemorrhage, can then be left in place for even up to 36 hours and any resulting necrotic liver tissue can be resected or debrided at a second operation. Sattler and Gentilello have described a tamponade technique they named the “liver bag”. [40] A radiographic cassette bag was placed around the already-mobilized liver to completely encase the liver and the opening of the bag was closed around the porta hepatitis using umbilical tape to tamponade the hemorrhage. The patient had the bag removed after 3 days without recurrence of hemorrhage.

Bullet tracts that traverse the liver are often long and deep and visualization of bleeding areas deep within the tract is impossible. Packing the tract with omentum as described above will often be successful, but if not, Pegotti and colleagues have advocated the use of balloon tamponade. [34] The basic concept is to utilize a perforated tube or foley catheter covered with a penrose drain which is tied at the distal and proximal end of the tube and allow contrast (if available) or any sterile fluid to fill the penrose drain from the central tubing once the tubing has been passed into the full length of the tract. This allows the penrose drain filled with fluid to tamponade the entire length of the bullet tract and if successful, it can be left in place 24-48 hours to assure ongoing hemostasis. In institutions
where angiography is available, if a transhepatic tract continues to bleed despite these maneuvers then the patient may have perihepatic packs placed and undergo angioembolization. In patients with a single deep bleeding wound that responds to the Pringle maneuver but not to the various methods already mentioned, complete hepatic artery ligation can be considered. When the portal vein remains patent, severe hepatic necrosis is uncommon but it is more common in the traumatic patient who already has a hypoperfused liver from the hemorrhagic shock. [41], [42]

When retrohepatic bleeding occurs either from the inferior vena cava or the hepatic veins three approaches have been described to arrest bleeding: 1) direct suture repair with or without total vascular occlusion; 2) lobar resection; and 3) tamponade and containment of the bleeding. [43] The mortality rate for any of these injuries no matter the approach is high and survival rates are below 50% in the best series. [44] In the first approach, the surgeon mobilizes the liver, rotates it medially and using finger fracture to reach the main vein that is bleeding, directly repairs it with a running prolene or nonreactive nonabsorbable suture. In order to visualize this area, shunting maneuvers have been proposed as alternatives to total vascular occlusion. The most widely recognized shunt is the one proposed by Schrock in 1968. The goal was to place a chest tube through the right atrium of the heart into the infrarenal IVC and to continue to allow flow through the IVC while bypassing the area of injury and giving a bloodless operative field. However, this is a complicated technique which requires a second incision (right thoracotomy) in an already severely hypoperfused patient. In the literature, it is associated with a very high mortality rate (70-90%) and as a result of this it is rarely employed. [45] The second approach, lobar resection, is only recommended when the bullet has already performed the majority of the resection, otherwise mortality rates are very high. The third approach is presently thought to be the optimal one and has the lowest mortality rates reported in the literature. [46], [47]

Tamponade with laparotomy pads and omental patch when possible has been shown to be effective even for major hepatic venous injury. If available, angioembolization can be used as an adjunct for associated hepatic arterial bleeding after packing. Penrose drains left in and around the liver after injury have been shown to be associated with increased infection and only closed suction drains are recommended for use. The incidence of perihepatic abscess is unchanged by the placement of a closed suction drain versus no drain unless there is a bile leak present intra-operatively. The placement of a penrose drain is associated with a substantially higher rate of infection and therefore, they are no longer recommended.[48] The main complications after penetrating liver trauma are recurrent hemorrhage, hemobilia, biliary fistulae, and other rare fistulae. The bullet trajectory may connect surrounding structures and can cause unusual fistulae.

4.1.2. Gall Bladder and Bile Duct
Gall bladder injury is diagnosed mainly at laparotomy and any perforation, avulsion or devascularization (second to a portal triad or hepatic artery injury) should be treated with cholecystectomy. Injury to the gall bladder is usually evident by direct inspection of the organ. There should never be an attempt to primarily repair a gall bladder injury, even if it is a relatively small injury.

Bile duct injury is one of the few organs more commonly injured after a penetrating rather than a blunt trauma and it is more likely to be a partial transection rather, than a complete transection. [49] Common bile duct injuries are suspected during laparotomies
where there is extensive bile staining and leakage in the upper abdomen. Duct injuries that are not obvious by direct inspection can be confirmed by squeezing the gall bladder initially and looking for increased or new bile leakage. If no leakage is seen, then infusion of a contrast solution into the gall bladder with a gentle clamping of the bile duct above the cystic duct-common bile duct junction will diagnosis the presence of any duct injury. Alternatively, if x-ray facilities are unavailable, then an infusion of normal saline in the same fashion as the contrast dye followed by careful inspection for pooling or collecting of the saline extraluminally can assist in demonstrating a ductal injury. Fortunately most penetrating injuries to the common duct, like the gall bladder, are easily seen with diligent direct inspection.

Bile duct injuries should be repaired only after hemorrhage has been controlled. If a person needs is to undergo damage control, a closed suction drain such as a penrose drain can be left near the injury or a T-tube can be placed across the injury and it can be repaired later after the patient has been resuscitated. Small lacerations and avulsions can be repaired primarily with 6-0 polyglycolic (absorbable) suture without T-tube placement being careful not to narrow the lumen. Complete transections can be repaired with primary end-end anastomosis over a T-tube as long as there is no tension and care was taken, not to devascularize the duct by excessive periductal dissection. If there is extensive ductal injury with loss of tissue, then the surgeon must use an enteric anastomosis most commonly a Roux-en-Y hepaticojejunostomy with cholecystectomy and T-tube drainage. This operation involves an anastomosis between the common bile duct to a 40 cm Roux limb in an end-to-side anastomosis. The T-tube will be placed in the common bile duct through a separate incision in the duct with one arm of the tube crossing the enteric-duct anastomosis. This anastomosis is best performed using the proximal common bile duct rather than the distal hepatic duct because of improved vascularity. If the common bile duct injury is close to the bifurcation of the right and left branches, then these can be sutured together medially before performing the hepaticojejunostomy anastomosis.

4.1.3. Portal Vein
Portal vein injury is associated with a high mortality rate, and if associated with a hepatic artery injury the mortality rate approaches 100%. If the injury is mid-vein then proximal and distal control is obtainable and a primary repair is feasible. If the laceration is posterior to the pancreas, then transection of the pancreas may be necessary to get adequate exposure followed by a completion distal pancreatectomy which is performed at the end of the procedure. The only repair that has a reasonable survival is lateral venoraphy or primary repair. This is more likely a reflection of the severity of the injury than the success of the repair. End-to-end anastomosis or interposition grafts with PTFE or saphenous vein or port-caval shunts all have very poor survival rates. Portal vein ligation has been associated with survival but is only a salvage maneuver for a patient who is in extremis from severe exsanguination. Patients who have their portal vein ligated will have extensive bowel edema with possible bowel necrosis and develop abdominal compartment syndrome. However, flow studies show that the few patients who survive resolve their portal hypertension over time.

4.1.4. Pancreas
In the literature, penetrating injury to the pancreas is associated with a mortality
rate of 3-32%. Because of its location the pancreas is rarely injured in isolation. Therefore, the majority of its associated mortality is due to hemorrhage or other associated injuries, while another half of the deaths occur late in the hospitalization due to sepsis or multiple organ failure. It has been estimated that, of the late deaths, approximately one third can be directly related to the original pancreatic injury. The morbidity and mortality related to injuries of the pancreas is almost solely due to pancreatic duct injury. Ductal injuries must be recognized and treated appropriately. The pancreas is intimately associated with the 1st through 3rd portions of the duodenum and injuries often occur to both structures simultaneously (see 5.2. Duodenum).

Pancreatic injuries must always be considered in any penetrating trauma of the upper abdomen or thoraco-abdominal area. Patients can be unstable due to hemorrhage from the gland itself or surrounding vascular structures. Ductal disruption is associated with abdominal pain, tenderness and peritonitis and is present approximately 15% of the time. The serum amylase is unreliable as a marker of pancreatic injury and its initial value should not be used diagnostically to determine the presence or absence of pancreatic injury. In stable patients and in centers with the resources, ductal disruption can be demonstrated by endoscopic retrograde cholangiopancreatography (ERCP). More recently, in trauma centers, the magnetic resonance cholangiopancreatography (MRCP) has also been utilized to visualize pancreatic injuries in stable patients with persistent amylase elevation or CT scan findings that are unclear. However, in penetrating trauma, the verification of a pancreatic duct or parenchymal injury is most commonly and appropriately made at the time of exploratory laparotomy.

The pancreas is exposed mainly through the Kocher maneuver (see 5.2. Duodenum) and entry into the lesser sac. The mobilization of the 1st and 2nd part of the duodenum with a Kocher maneuver will allow palpation and visualization of the body, head and uncinate process of the pancreas. The incision of the gastrocolic ligament (best entered on the left side where it is less vascular) will allow entry into the lesser sac and utilizing a large retractor to hold the stomach cephalad the entire anterior surface of the pancreas can be visualized. The superior surface and the splenic artery in this location can also be inspected. Careful division of the retroperitoneal attachments of the pancreas along the inferior border will expose the posterior surface of the pancreas to define any injury.

Further visualization of the pancreas can be achieved by mobilizing the spleen and the tail of the pancreas toward the midline. Penetrating injuries to the head or anywhere along the body of the pancreas must be considered to involve the pancreatic duct. Direct visualization of the duct in the transected or lacerated pancreas can be noted but more commonly, due to the small size of a normal pancreatic duct, an efflux of pancreatic fluid is the main sign of a ductal injury. Depending on the time from injury to laparotomy, there may be noticeable surrounding fat necrosis secondary to the activation and enzymatic digestion of fat by pancreatic lipase as is seen in pancreatitis. If a duct injury is suspected based on the location of the wound, but there are no obvious signs of pancreatic fluid leak, then to confirm a ductal injury an x-ray contrast study as described above to detect common duct injuries can also be performed to detect pancreatic duct injuries, especially in the head of the pancreas (See 4.1.2. above).

Alternatively, a duodenotomy may be performed and direct cannulation of the ampulla of Vater and thereby the pancreatic duct can be achieved using a blunt-tipped fine probe. If the probe is visualized within the pancreatic injury then the diagnosis of ductal
involvement is confirmed. If x-rays are available, contrast may be introduced into the ampulla of Vater and contrast extravasation would demonstrate a pancreatic duct injury and its location. As with the common bile duct, the infusion of normal saline slowly with inspection within the penetrating pancreatic wound for pooling or collection of fluid could confirm ductal transection. Accurate determination of associated ductal injury in penetrating trauma to the pancreas has been shown to reduce complications from 55% to 15%. [73] Therefore, a diligent search for any ductal disruption is warranted.

Pancreatic parenchymal injuries, without pancreatic duct injury, can be treated by surgical hemostasis and adequate drainage with a good outcome. [82] At least two drains, placed within the peritoneal cavity cephalad and caudal or anterior and posterior to the area of injury depending on its location, and should be placed, with closed drainage systems employed whenever available. Attempts at closing lacerations or capsular tears can actually increase bleeding and further damage parenchyma. Injuries left "unsutured" heal mainly without ongoing leakage. However, the ones that do form a pancreatic fistula can be treated nonoperatively with adequate nutrition and drainage (by the originally placed drains as described above). An option is to place a feeding jejunostomy tube for enteral feeding if the pancreatic injury is large enough to be concerning for ongoing leakage and gastric ileus. The drainage from the drains can be sent for amylase measurement if available and when levels fall below or to serum amylase levels and the patient is tolerating an oral diet or full enteral tube feeds, the drains can be removed.

Untreated ductal injuries on the other hand cause major pancreatic fistula that close less often spontaneously and can result in pancreatic ascites. The treatment of a ductal injury is based on its location. Injuries to the left of the mesenteric vessels can be included in a distal pancreatectomy and the remaining pancreas will be at least 50%, minimizing the chance of the development of diabetes or fat malabsorption. [83] The pancreas is divided, at the level of the ductal injury, and the proximal pancreas is closed with nonabsorbable mattress sutures. The duct itself in otherwise healthy trauma patients is usually too small to be visualized and closed. However, if it is visible then it should be closed separately from the parenchyma using a nonabsorbable suture. All patients should also receive a feeding jejunostomy tube to allow for early enteral feeding reducing septic complications postoperatively.

When ductal injury occurs in the head of the pancreas or to the right of the mesenteric vessels then a Whipple's procedure is often required, especially if there is involvement of the ampulla of Vater, the common bile duct or the duodenum. Whipple's operation after pancreatic trauma is required about 3% of the time. [85] If the Whipple's operation or pancreaticoduodenectomy is delayed to the second or third day post-injury after an initial operation (damage control operation) during which excessive hemorrhage and bile leakage are controlled, the outcome is similar to elective Whipple resection for cancer. [84]

4.2. Spleen
Unlike, blunt trauma, penetrating injury to the spleen is usually dealt with operatively. In the patient who is hemodynamically stable, the commonest reason to operate on a penetrating splenic injury is related to a concern over other organ injury and involvement of the left diaphragm. A splenic injury is often associated with a hole in the left hemi-diaphragm that is not otherwise visible except through laparotomy (or diagnostic laparoscopy if the equipment and expertise is available). Asymptomatic diaphragmatic
injuries upon presentation can develop late complications of herniation of the spleen, stomach or colon if left untreated. Late diaphragmatic hernias post-trauma have been reported even decades after the initial traumatic event.

A splenic injury should always be suspected in any penetrating injury in the left upper quadrant or left flank. If a patient does not have any signs or symptoms of bleeding then assessment of the patient should follow the algorithm set out in Figure 1. Additional investigations can also include chest x-rays, diagnostic peritoneal lavage and abdominal CT scan, if available. Chest x-rays may be helpful in suggesting a splenic injury if there is a left hemothorax or an elevated left diaphragm but a normal chest x-ray does not rule it out. Diagnostic peritoneal lavage can also be used and a positive result (>10 ml of aspirated blood; fluid has RBC count > 10,000/mm3 or you cannot read newsprint through the fluid) warrants exploratory laparotomy and splenorrhaphy or splenectomy.

In penetrating injury, the splenic injury is more often an arterial vessel that is not amenable to splenic salvage maneuvers. If the spleen is not actively hemorrhaging and the laceration is repairable then splenic salvage is warranted even in penetrating trauma. Any injury to the spleen can be associated with injuries to surrounding structures: stomach, pancreas, transverse and left colon, left kidney and the left lobe of the liver. All surrounding structures should be closely inspected intra-operatively. When splenic repair is being considered then the spleen should be mobilized medially with the tail of the pancreas, to minimize iatrogenic pancreatic injury. This provides the best exposure to the splenic hilum. As in all trauma laparotomies, the midline incision should be used and be extended to the left of the xiphisternum, if necessary. Upon entry into the abdomen, if hemoperitoneum is discovered, then even when splenic injury is suspected; all four quadrants of the abdomen should be packed with lap pads. Then, careful removal of the packs one quadrant at a time, inspecting all structures in each quadrant assures no missed injuries. The spleen should be mobilized gently as an injury can be easily worsened, changing a potential splenorrhaphy into a splenectomy. The spleen should be elevated from lateral to medial, taking down the lateral wall attachments first, followed by the splenophrenic and splenorenal ligaments. The spleen should then be lifted medially by placing the surgeon's hand posteriorly between the spleen and the left kidney. The tail of the pancreas should be raised with the spleen as one unit. The short gastric vessels are the last to be ligated and depending on the location and severity of the injury, they may be left in-situ. Injury to the greater curvature of the stomach should be avoided during short gastric vessel ligation. The short gastric vessels can be very short and any suspect injury to the stomach wall no matter how small should be over sewn with a Lambert suture. Delayed gastric rupture has occurred from even a small area of stomach wall that has been necrosed in a clamp or the tie of a gastric vessel. As the spleen is elevated, lap sponges can be placed posteriorly to improve visibility. Lastly, the splenocolic ligaments between the spleen and the left colon should be divided. While mobilization is being undertaken, hemorrhage from the spleen can be controlled by direct finger compression or if severe bleeding by clamping the splenic hilum gently with a noncrushing clamp. The splenic fossa should be packed with lap sponges.

After mobilization of the spleen as described above, the injured area can be inspected. If the splenic injury is no longer actively bleeding, does not involve the hilum of the spleen, and there are no other associated serious intra-abdominal or thoracic injuries requiring immediate attention, then splenorrhaphy can be considered rather than proceeding with splenectomy. The surgical options and approaches to splenorrhaphy are similar to the
previously described techniques for hepatic repair: 1) suture repair with a large blunt
needle and chromic catgut placing interrupted simple or mattress sutures across
lacerations; 2) omental patch placed into lacerations or defects and sutured in place with a
few interrupted absorbable sutures such as vicryl; 3) placement of hemostatic agents such
as surgical or fibrin glue if available; 4) completion partial splenectomy where a transected
portion of the spleen is removed and the open parenchymal surface is sutured
closed with chromic catgut and reinforced with an omental patch and lastly, 5) if omentum is unavailable, the spleen can be "wrapped" in a vicryl mesh (absorbable mesh)
which can act to oppose lacerated and open parenchymal surfaces. There is no evidence
to suggest that one method is more successful than the others and choice is usually based
on the surgeon's previous experience and the injury s/he is faced with. If splenorrhaphy is
performed the patient should be watched closely post-operatively for any signs or
symptoms of recurrent hemorrhage which would mandate reoperation and splenectomy.

Splenectomy is completed by ligating and transecting the hilum. It is preferable to ligate
the vein and artery separately if possible to prevent the possible development of
arteriovenous fistula. Once the spleen is removed, the greater curve of the stomach, the
tail of the pancreas, the left kidney and ureter and the splenic fossa should all be carefully
inspected for iatrogenic injury, urine, pancreatic leak or ongoing bleeding. Unless there is
concern over a potential pancreatic or urine leak, no drain should be left after an
uncomplicated splenectomy or splenorrhaphy.

Antibiotics should be given at incision but there is no need to continue prophylactic
antibiotics post-operatively because of a splenic injury alone. In a stable patient, pieces of
spleen may be transplanted into pockets within the greater omentum in an attempt to
preserve splenic function and reduce the risk of postsplenectomy sepsis. This severe and
often fatal sepsis is more common in the pediatric population, but has occurred at all
ages. All post-operative splenectomy patients with a fever should receive antibiotics early
and empirically to cover all encapsulated bacterial organisms. All splenectomy patients
should receive vaccines to cover hemophilus, pneumococcus and meningococcus 2
weeks post-operatively preferably or prior to discharge, if available.

5. Hollow Viscus Injury
5.1. Stomach
Patients with penetrating injuries to the stomach almost always present with peritoneal
signs. The leakage of the low pH content of the stomach causes a rapid, severe peritoneal
irritation that almost universally results in significant clinical signs of peritonitis. Bloody
aspirate from a nasogastric tube can be a sign of a gastric injury, but it is not specific or
sensitive enough as a single test to define a gastric injury.
GI contamination from the stomach can be controlled with a running absorbable suture
temporarily until definitive repair is undertaken later in the operation. Once ongoing
hemorrhage and GI contamination is controlled, the full anterior and posterior aspect of
the stomach must be evaluated. The stomach should be decompressed with a nasogastric
tube as soon as possible. The posterior stomach is accessed by entering the lesser sac
through an avascular window in the left lateral aspect of the greater omentum between
the stomach and the left transverse colon. This is the best location as it minimizes injury
to the transverse mesocolon and potential injury to the middle colic vessels. The
gastrocolic portion of the greater omentum can be ligated toward the left and right aspect
of the stomach, being careful to preserve the gastroepiploic vessels on the greater curve
of the stomach in order to improve visualization of the posterior aspect of the stomach, if necessary. The gastroesophageal junction and proximal lesser curvature are also difficult areas of the stomach to completely visualize. The left triangular ligament of the left lobe of the liver often must be divided to allow exposure of the full stomach. Remember the proximal greater curvature has the short gastric vessels, as well as the splenic capsule that can be injured with minimal traction resulting in unnecessary bleeding. If there is an injury in this portion of the stomach, the short gastric vessels can be ligated to improve exposure.

Anytime one hole is found, usually an anterior one, a search must be made for a second hole, often a posterior hole. Perforations and lacerations on the lesser and greater curvature of the stomach are often difficult to find and any hematoma or area of contusion needs to be carefully inspected, including dissection of the associated area of stomach mesentery to expose the stomach wall and confirm its integrity. If a second perforation is not found, then the stomach can be insufflated with air (place a clamp on the proximal duodenum) and saline can be placed in the peritoneal cavity filling over the stomach. Any bubbling of air through the stomach can be used to localize the area of an unseen injury. Alternatively, after clamping the stomach it can be filled with methylene blue mixed in saline - lap sponges placed around the stomach will be stained blue by any leak of the methylene-saline mixture from the stomach. Lastly, the one discovered hole can be extended to allow inspection of the stomach from the interior to discover the second wound.

Identified stomach perforations and lacerations should have the traumatized edges resected. As the stomach is very vascular it should be closed in two layers, to ensure hemostasis: a full thickness inner layer of an absorbable running suture followed by an interrupted Lembert or seromuscular absorbable suture. If there is excessive hemorrhage then the inner running suture layer may also be locked. In the pyloric area, a pyloroplasty should be performed to avoid pyloric stenosis. If there is extensive destruction then a partial gastrectomy may be performed with a Billroth I anastomosis if there is enough duodenum or a Billroth II, gastrojejunostomy if the proximal duodenum is also damaged. Hematomas of the wall should be evacuated; hemostasis achieved and closure with absorbable Lembert sutures only if no full thickness injury is encountered. If a gastric injury is associated with a diaphragmatic injury especially if there is extensive contamination, then the chest cavity should be extensively irrigated to prevent potential empyema. Drainage of primary repairs or anastomotic lines on the stomach is not usually necessary.

5.2. Duodenum
Injuries to the duodenum often take on increased importance because of its proximity to many life-sustaining structures such as the pancreas, portal vein, common bile duct, pancreatic duct and superior mesenteric vein and artery. Also, the duodenum is partially a retroperitoneal structure such that isolated injuries can have an occult initial presentation. Its posterior boundaries include the kidney, inferior vena cava and aorta. Therefore, location of the duodenal injury and inspecting all its neighboring structures is paramount to minimizing missed injuries in this area from a penetrating injury.

The majority of duodenal injuries are due to penetrating injuries and these should always be considered in any penetrating wound to the upper abdomen or thoraco-abdominal area or when there is a midline upper abdominal hematoma discovered during exploratory
laparotomy. Any signs of blood, bile or air in the retroperitoneum, mandate a complete exploration of the duodenum in its entire length. The initial approach to the patient with a duodenal injury does not differ from the principles set out in 2. Initial Assessment and Figure 1. An unstable patient should always be taken directly to the operating room. If the patient is stable, initial chest and abdomen x-rays utilizing paper clips taped to cover the penetrating wounds can assist in location of the wounds on x-rays. This may allow an increased index of suspicion for the potential of injuries to the duodenum and surrounding structures. The duodenum is a retroperitoneal structure and, therefore, may not present with peritonitis. Air in the retroperitoneal space around the kidney (mainly right) or along the psoas muscle shadow, though rare, is a classic sign of retroperitoneal duodenal injury. Both CT scans and even contrast duodenography have in the order of up to a 20% false negative rate - specific findings but not very sensitive for injury. Therefore, they are not relied upon to definitively exclude duodenal injury.

At exploratory laparotomy, the duodenum requires careful inspection both anteriorly and posteriorly, mandating the performance of a Kocher maneuver. This is performed by sharply dividing the peritoneal attachments to the "C" or second portion of the duodenum starting from cephalad to caudal on the anti-mesenteric side of the duodenum. This allows the duodenum and the head of the pancreas to be elevated together, palpated anterior to posterior, and visualize all surfaces for injury as well as excluding surrounding named vascular injury. The hepatic flexure of the colon (right colon) also requires mobilization in order to complete the opening of the retroperitoneal attachments of the duodenum around the 3rd portion and up to the mesenteric vessels. If the injury involves the fourth portion of the duodenum, then careful division of the Ligament of Trietz may be necessary, but care must be taken to avoid the inferior mesenteric vein which runs laterally to the 4th part of the duodenum in this ligament. The duodenum can now be mobilized from left to right and the body of the pancreas can also be better visualized. The small bowel can also be reflected superiorly and with careful incision of the right side of the root of the mesentery at the base of the transverse colon, the third portion of the duodenum is exposed.

Once the location of the injury is verified through appropriate exposure, the treatment decision-making is dependent on the extent of injury and associated pancreatic injury involvement. The extent of duodenal injuries include: partial to full thickness lacerations or perforations, complete transection with loss of continuity and length, lacerations involving the ampulla of Vater, devascularization and finally, intramural hematomas without laceration or perforation. Lacerations to the duodenum from partial to complete transection can be repaired primarily if there is no significant devascularization or repair does not involve excessive tension (after excising all nonviable and damaged edges). A single layer interrupted repair with, preferably absorbable suture such as PDS, or alternatively any monofilament absorbable suture can be performed. Repairs performed in two layers must be certain to maintain an adequate lumen size. Repair is usually performed in the direction of the injury, with single layer interrupted repair, even with longitudinal lacerations; the concern of luminal compromise is no longer warranted.

When there is a laceration on the mesenteric or pancreatic side of the duodenum full mobilization of the area for adequate closure may be impossible without devascularization or injury to the pancreas. In these cases, repair can be performed from the luminal side of the laceration through an anti-mesenteric duodenotomy.
Many trauma centers, advocate placement of a feeding jejunostomy tube after repair of a duodenal injury for enteral feeding, along with nasogastric suction. With the more extensive injuries, especially if there was significant tissue destruction or pancreatic injury, healing may require longer than the usual 5-7 days before return to adequate GI integrity, and therefore, the jejunostomy tube allows concurrent enteral feeding minimizing septic complications. However, in small (<2 cm) lacerations involving only one duodenal surface, especially with minimal tissue destruction such as in stab wounds, nasogastric suction without a jejunostomy feeding tube may be acceptable.

Complete transection of the duodenum can be repaired primarily in an end-to-end fashion as long as the edges are viable and reach without tension after minimal mobilization. This is often more difficult to achieve in the 2nd and 3rd portions of the duodenum because of its attachment to the pancreas. Injuries due to gunshot wounds, involvement of the 2nd portion of the duodenum, injuries greater than 75% of the circumference of the wall, and repairs attempted greater than 24 hours from the time of injury were found to be major determinants of a poor outcome, if primary repair was attempted. [77]

When primary repairs are undertaken in the presence of any of the factors mentioned above or in association with an injury, then protection of the repair is performed using a pyloric exclusion technique. One of the most commonly used techniques was described by Vaughn et al., where the stomach is opened anteriorly on the greater curve of the stomach near the pylorus and the pylorus is over sewn with a running nonabsorbable suture, such as prolene.[78] The gastrotomy is then incorporated into a side-to-side loop gastro-jejunostomy, performed to allow alternative gastric drainage until the duodenum heals and the pylorus spontaneously opens. A feeding jejunostomy tube is usually also placed away from the limbs of the gastrojejunostomy. The pylorus opens in 6-12 weeks so a vagotony to prevent jejunal ulceration in the gastro-jejunostomy is unnecessary. Severe duodenal injuries, even repaired with minimal tension and adequate vascularization have a higher rate of breakdown and fistula formation than the other parts of the small bowel. Therefore, the pyloric exclusion technique allows conservative nonoperative treatment of the majority of duodenal fistulae that may occur. These will eventually close if there are no associated abscesses and the patient's nutrition is maintained by oral feeding or via the jejunostomy enteral feeding tube.

In cases, where the patient is unstable and there is extensive tissue destruction, then over-sewing the proximal open end of the duodenum, placing a lateral (or anti-mesenteric) duodenostomy tube and a retrograde jejunostomy tube has been reported. [79] Alternatively, over-sewing the duodenal injury to minimize ongoing bile leakage and then placing extraluminal drainage with two or more Jackson Pratt or similar closed drainage systems. The duodenal injury can then be repaired at a later date when the patient has stabilized. The procedure of choice in these instances is excision of the damaged duodenum and reconstruction with a loop of jejunum passed through the transverse mesocolon. If the injury involves the area of the ampulla of Vater (but it is still intact) then a side-to-end duodenojejunostomy with Roux-en-Y repair should be performed. If the injury is below and away from the ampulla of Vater then a direct end-to-end anastomosis can be performed. In injuries where there is complete disruption of the ampulla of Vater with or without common bile duct injury, initial control of the bile leakage by the methods mentioned above and then a reassessment for the need to perform a Whipple's operation should be made after the patient has stabilized in 24-48 hours. The
undertaking of a Whipple's procedure at the initial operation has been discouraged in more recent years as the associated mortality rate is extremely high.

Duodenal hematomas are less common in penetrating injury but can occur. They typically present after 48 hours after the injury with signs and symptoms of gastric outlet obstruction.[80] Initial management should entail nasogastric suction and IV hydration and observation for 5-7 days as the majority resolve with time.[81] However, if symptoms persist then operative evacuation may be necessary. If a duodenal intramural hematoma is found during an exploratory laparotomy and there is no associated perforation, most trauma surgeons would advocate not evacuating the lesion and treating the patient with nasogastric suction and hydration as most resolve spontaneously. However, if the hematoma distorts anatomy significantly, either evacuation with careful primary repair may be undertaken or placement of a feeding jejunostomy tube to allow enteral nutrition until the hematoma resolves are alternatives for these larger lumen-compromising hematomas.

5.3. Small Bowel
In penetrating injuries, small bowel injury is relatively common especially in comparison to the incidence found in patients who have sustained a blunt force trauma. With gun shot wounds to the abdomen that penetrate the fascia, the incidence approaches 80% while after a stab wound it is closer to 30%.[60] The operative management of small bowel injuries is relatively uncomplicated and therefore, the main factor determining a successful patient outcome is the timely diagnosis of the injury. With the increasing application of nonoperative management for penetrating injury as well as blunt in the hemodynamically stable patient, the possibility of a small bowel injury must always be paramount in the surgeon's mind. Missed injuries can lead to abdominal sepsis and death.

As discussed in 2. Initial Assessment, penetrating injuries can be treated nonoperatively if the patient is completely symptom-free and has no distracting injuries or intoxication. However, this is the safest and most successful only for stab wounds, while the nonoperative management of gun shot wounds requires more experience, close clinical observation and in most instances is not recommended.[61] Any patient with diffuse abdominal tenderness, peritonitis, active hemorrhage or hemodynamic instability, should be taken immediately to the operating room. Also, evisceration after a stab wound warrants a laparotomy as it is associated with a 75% chance of an intra-abdominal injury, even without any clinical signs or symptoms.[62] Small bowel injuries, unlike gastric or colonic injuries, can lack obvious peritoneal signs early after an injury. This is due to the fact that small bowel succus entericus has a neutral pH and is sterile in the normal individual. Therefore, ascertaining the time of injury is important in considering the presence or absence of small bowel injuries. Also, depending on the mechanism, stab versus gun shot wound, and the number and size of bowel "holes" there may be a limited amount of succus spillage initially masking early symptoms. Except for patients on high dose steroids or who are severely immunocompromised, the majority of small bowel injuries become clinical symptomatic with positive physical examination findings within 24 hours of injury.

Abdominal examination to detect injury to the small bowel is accurate more than 90% of the time and especially when performed serially by the same clinician. Laboratory tests such as hematocrit, white blood cell count and serum amylase are not useful in the initial evaluation of a patient with small bowel injury. However, the development of fever
(temperature greater than 38.5 Celsius), a rising white blood cell count with a shift to the appearance of immature cells or "bands" in the count, a rising amylase, development of metabolic acidosis, unexplained tachycardia or hypotension are suggestive of a small bowel injury.

A midline incision should be utilized to enter the abdomen. If a gunshot wound has made a large abdominal defect, it may be used and extended to explore the abdomen in some cases. If there is significant bleeding upon entry, after packing, GI contamination should be controlled with Babcock clamps until life-threatening bleeding injuries are controlled. Alternatively, a running suture with catgut or vicryl can be placed over intestinal perforations to temporarily control GI contamination. This can also be useful if there is ongoing bleeding from the perforated intestinal wall.

The small bowel should be eviscerated and carefully inspected from the ligament of Trietz to the ileo-cecal valve on at least two occasions during the same operation. Penetrating injuries are often multiple and can be surprisingly small and inconspicuous and require careful circumferential inspection of the bowel wall including the mesenteric side. Any hematomas must be opened, evacuated and the adjoining bowel wall examined for its integrity. After all areas of injury on the bowel are found then the appropriate type of repair can be planned. Primary repair after resection of traumatized edges is the preferred method of repair. Single layer closure with interrupted absorbable suture or two layer closure, have equal effectiveness. If available, a longer lasting absorbable suture such as PDS is preferred especially if a single layer closure is completed. If the areas of injury are multiple or there is extensive damage, then resection of all involved area in continuity is necessary. However, if resection may compromise adequate length for future absorption, then every attempt should be made to primarily repair the bowel. The direction of repair is most often transversely to minimize the potential for stenosis but long anti-mesenteric injuries may have to be closed following the long axis. This type of repair may be closed with one layer to minimize narrowing of the lumen. The direction of the repair will also be determined by assuring a tension-free repair as well as an adequate lumen size. If >50% of the circumference of the bowel is damaged, then usually resection is required to prevent clinically significant luminal narrowing.[63] The proximal intestine has the largest diameter which narrows as it goes distal into the ileum, and as such, primary repair are more often possible in proximal injuries. Areas of small bowel, where the mesentery has been damaged and the bowel has been devascularized, must be resected and re-anastomosed. The main two choices of method of repair are either hand-sewn or stapled anastomosis. There has been controversial over this choice with retrospective trials trending toward a lower morbidity rate after hand-sewn anastomoses.[64] [65] At present, the decision to hand sew or to use a stapler is based on availability of stapling equipment, surgeon choice and with similar complication rates. The technique of closure is not as important as following the basic principles of all intestinal anastomoses: tension-free, good blood supply, adequate lumen size, and watertight closure.

Mesenteric hematomas should be re-inspected throughout the operation to detect any expansion. If the hematoma is seen to be expanding, it should be opened, evacuated and hemostasis achieved. The ligament of Trietz may be divided to access proximal jejunal injuries but care must be taken to avoid injuring the inferior mesenteric vein. If necessary, the vein may be ligated to improve visualization and repair of the proximal bowel. Bleeding at the base of the mesentery must be done under direct visualization of the
bleeding vessel, if possible, as damage to the main artery; especially since injury to the superior mesentery artery at its root can compromise the blood supply of the entire midgut.

Small bowel anastomoses have low leak rates in the nontrauma setting. But in trauma, intestinal anastomoses have an increased risk of leak and breakdown if any of the following factors are present: shock with massive fluid and blood resuscitation, associated pancreatic injury, or the development of an abdominal compartment syndrome. [66], [67] If a patient is severely injured and has developed acidosis, hypothermia and is coagulopathic, then damage control measures mandate limiting definitive surgical repairs. Damaged bowel may be resected and the ends stapled or sewn shut and left in the abdomen without immediate re-anastomosis. After 24-48 hours of intensive resuscitation and restoration of more near normal physiology, the patient can be brought back to the operating room to have any intestinal anastomosis performed at that time. Any patient who has blind-end loop of bowel requires a nasogastric tube to intermittent suction to minimize bowel distension.

5.4. Colon
The commonest penetrating injury to the colon is direct perforation. However, serosal injuries or partial thickness injuries can occur, especially after gunshot wounds, due to a "blast effect" of the passing bullet. This blast effect can cause contusion, ischemia and eventual perforation of the colon wall without entering the colon. Blast effect can also occur to the retroperitoneal colon from bullets that pass through the soft tissues of the back, not entering the colon but passing close enough to affect this damage.[86] The diagnosis of the patient with a colon injury should follow the initial steps discussed in Section 2. Initial Assessment and the algorithm in Figure 1. However, the main stay of diagnosis of a colonic injury is by physical examination: peritonitis with or without signs of abdominal tenderness. Patients who are initially completely asymptomatic and hemodynamically stable, should be followed closely for increasing symptoms of abdominal pain or increasing signs of fever, white blood cell count or worsening base deficit. Patients with retroperitoneal injuries often present initially asymptomatically. In a review of penetrating flank wounds in our institution, we found that all initially asymptomatic retroperitoneal injuries developed signs and symptoms within 18 hours from the time of admission.[87] This time lapse between injury and definitive repair in retroperitoneal injuries is not associated with an increase in complications.[88]

During an exploratory laparotomy for trauma, any hematoma, contusion, discoloration of the colonic wall should be inspected and dissected to assure an intact, viable colonic wall underneath this injury. Any hematoma in the mesentery should also be explored to ascertain that no significant vessel is only temporarily being tamponaded. Also, ligation of any mesenteric vessels requires close observation of the associated colon for the duration of the laparotomy to ensure that portion of the colon has enough collateral circulation to remain viable. Any devascularized or compromised colon should be resected as a postoperative leak in a multi-system trauma patient is associated with a high rate of morbidity and mortality.

The traditional treatment for any colonic injury is complete resection of the area of damaged colon and the creation of an end colostomy. However, this approach requires the patient to undergo a second operation in the future with an associated complication rate. Therefore, there has been increasing interest in treating colonic injury with one definitive operation at the time of injury. Presently, any patient who presents without
shock, extensive fecal contamination, multiple associated injuries, significant blood loss with blood transfusion greater than 6 units, prolonged delay to operation or a left sided colon injury, may be considered for primary repair as opposed to resection and creation of a colostomy.[89] A primary repair of a colonic perforation is usually performed when less than 50% of the circumference of the colon is involved in the injury or in right sided colon injuries, that require resection, an ileo-colonic anastomosis can be performed. As confidence in primary repair has increased some surgeons have broadened the scope to include the primary repair of a left colon lesion where the injury is small (<4 cm), associated with minimal tissue destruction and the other criteria mentioned above are met. Prospective randomized studies from 1979 to present, have shown there is no increased morbidity or mortality to perform a primary repair or resection and anastomosis of a right colon lesion in comparison to diverting colostomy.[90], [91], and [92]

The American Association of Surgery for Trauma embarked upon a multicenter prospective noncontrolled study of more severe colon injuries treated by either primary repair or diverting colostomy. Once again there was no difference between the groups in terms of complications and in a multivariate analysis of the data; type of surgical repair (primary versus colostomy) was not an independent predictor of outcome. [93] Therefore, more and more surgeons are widening their indications for primary repair and resection and anastomosis rather than colostomy for operative management of colonic injuries. When performing a primary repair, controversy persists in regards to stapled (when available) versus hand-sewn and one layer hand-sewn repairs versus two layer hand-sewn, but there is no strong evidence to conclude the preeminence of one of these techniques over the others.[94][95] The main tenets of a well-vascularized, tension-free, water-tight anastomotic or repair line are vital to minimizing post-operative complications and mortality. Issues of suture type, amount, and number of layers still remain surgeon choice.

In situations where a colostomy is utilized, there is good reason to consider a preference for a completely diverting loop colostomy rather than an end colostomy. Complete diversion can be achieved by suturing over the distal end of the loop after exteriorization. Almost all trauma colostomies are nonpermanent therefore ease of re-anastomosis at a future operation is a major advantage of loop colostomy over end colostomy. The literature has shown that primary repair does not require drainage and it is not routinely utilized in most trauma centers. [96] Although there is a wide discrepancy in wound infection rates when primarily closing the skin after colon trauma in the literature, the standard of care in most trauma centers is to leave the skin open and allow healing by secondary intention. Wound infection is a major risk factor for wound dehiscence and necrotizing soft tissue infections and therefore, not closing the skin after colon trauma, remains the prominent approach to postoperative wound care. The commonest major complication after colon injury is infection, often occurring in greater than 50% of the patients. [93] [97] Abscess formation is a common sequel and its occurrence is associated with significant mortality.[98] Therefore, there remained debate over the use of prophylactic antibiotics: doses, timing, amount and type. However, recent evidence shows that infection rates after colonic injury are not reduced by the prolonged administration of antibiotics post-operatively.[99] Therefore, patients with colonic injuries should receive a single broad spectrum antibiotic agent for a total of 24 hours post-operatively only.
5.5. Rectum
Any penetrating injury in the region of the pelvis, including the gluteal region should be considered as possibly involving the intra-peritoneal or extra-peritoneal rectum. As has been described above a chest x-ray and abdominal x-ray should be taken (in the stable patient) with paper clips over the penetrating wounds. If the trajectory between two bullet wounds or a single bullet wound is above a line which can be drawn between the greater trochanters on the x-ray then the likelihood of a rectal injury is greatly increased. In our institution, a penetrating wound above this line on the x-ray mandates a rigid sigmoidoscopy examination. The clinical abdominal examination is only useful with intraperitoneal rectal injuries which will present with peritonitis and abdominal tenderness. The posterior 2/3 and the lower 1/3 of the rectum are extra-peritoneal and initial symptoms are usually absent. Therefore, a high index of suspicion is required and should include a digital rectal examination with palpation of the entire mucosal surface for defects and a rigid sigmoidoscopy if available. Either of these examinations is considered positive for rectal injury if blood is seen on the examining glove or through the scope. It is not necessary to delineate the exact injury for it to be recognized as present and be definitively treated. If available, a CT scan of the pelvis is also employed for pelvic penetrating injuries. An alternative could be rectal contrast x-ray to display a rectal injury.

Intraperitoneal injuries are treated as colon injuries discussed in the previous section and increasingly are treated with primary repair without colostomy. For extra-peritoneal injuries the traditional standard of care has been a diverting colostomy with presacral drainage and rectal washout. Rectal washout is no longer performed and it is now believed to increase the rate of infection by "pushing" stool/bacteria into surrounding tissues. [100] Presacral drainage is also being utilized less and less. A recent randomized control trial found no difference in the number of patients who developed infection between the group with a presacral drain and the group without. [101] Therefore, presacral drains are used less commonly but diverting colostomy, usually loop colostomy, remains the standard of care for an extraperitoneal rectal injury. If the rectal injury is visible through the anus then a primary repair can be performed. However, primary repair is not essential to a good outcome. Rectal fistula and pelvic sepsis are rare and their occurrence is not correlated to initial primary repair of the defect. If primary repair is performed, a colostomy is still believed to be necessary because of the lack of a serosa in the extraperitoneal rectum and the anatomical difficulty in assuring a water-tight seal. Therefore, overall, diverting colostomy with or without primary repair remains the main treatment for extra-peritoneal rectal injuries.

6. Recommendations
Penetrating injuries to the torso are highly lethal and are associated with internal injuries in a large number of patients, especially after a gun shot wound. Any patient hemodynamically unstable or with acute peritonitis mandates an operation. However, with the refinement of the field of trauma surgery, alternative options have developed for patients who sustain a penetrating injury but do not require immediate operation. In this review, we have covered the recent treatment approaches utilized based on the patient's presenting condition as well as the operative and nonoperative approach to specific organ injuries. A summary of recommendations from this review include:
The clinical examination remains the hallmark diagnostic test to determine intra-abdominal injury. And when a patient requires an operation, the laparotomy should be performed in the midline with an incision that extends from the xiphisternum to the symphysis pubis without exception.

The vital signs such as pulse rate and pulse pressure, blood pressure, urine output, sensorium, capillary and skin refill, and base deficit as measured by the laboratory are all factors that must be taken together in a complete picture to determine if the patient is hemodynamically stable or not. Hypotension is only one of many signs of hemodynamic instability.

In the asymptomatic patient the mechanism of injury: stab wound versus firearm as well as the location of that wound: anterior abdomen, flank, back and thoraco-abdominal areas are the main determinants for deciding on the treatment approach to undertake.

CT scans can show the trajectory of the bullet tract and assist in deciding on peritoneal penetration as well as any organ injury or the presence of hemoperitoneum in patients who are asymptomatic. The 2 main areas of injury most commonly missed in CT scans are bowel and diaphragmatic injuries.

The initial approach to control bleeding liver injuries includes one or all of the following: electrocautery; or omental plug; or direct suture ligation; or hemostatic agents. Perihepatic packing is technically the easiest method to perform, is often successful and therefore is often the most widely employed. If in doubt, always pack the liver, it will stop the majority of liver injuries.

Most penetrating injuries to the biliary tract system, including the common duct and gall bladder are diagnosed at operation and are easily seen with diligent direct inspection.

The pancreas is rarely injured in isolation and the majority of injuries, unless they also involve the duct, are successfully treated with drainage alone. Duct injuries must be recognized and treated appropriately.

If the spleen is not actively hemorrhaging and the laceration is repairable then splenic salvage is warranted even in penetrating trauma. Any injury to the spleen can be associated with injuries to surrounding structures: stomach, pancreas, transverse and left colon, left kidney and the left lobe of the liver.

Enterotomies found anywhere in the GI tract from stomach to rectum must evoke a careful inspection for a second hole. Penetrating injuries come in "twos". All anterior holes must mandate a search for a second hole, often a posterior one.

The duodenum is partially a retroperitoneal structure such that isolated injuries can have an occult initial presentation. Air in the retroperitoneum on x-ray is a duodenal injury until proven otherwise. Bile staining or hematoma, in the retroperitoneum mandates complete mobilization and inspection of the duodenum looking for injury.

In the presence of acidosis, hypothermia and coagulopathy, then damage control measures mandate limiting definitive surgical repairs. In this setting, damaged bowel may be resected and re-anastomosis may be performed without major sequelae after 24-48 hours.

During an exploratory laparotomy for trauma, any hematoma, contusion, discoloration of any bowel wall should be inspected carefully, including needed dissection, to assure no wall injury is present. Loss of mesentery and devascularization of bowel segments mandates resection of associated bowel to avoid delayed perforation.
Primary repair of the colon or resection and anastamosis without colostomy may be considered when all of the following criteria are met: any patient who presents without shock; no extensive fecal contamination; not having multiple associated injuries; no significant blood loss which requires a blood transfusion of greater than 6 units, no prolonged delay to operation or if it is not a left sided colon injury.

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