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Trends in nonoperative management of traumatic injuries: A synopsis

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ABSTRACT

Nonoperative management of both blunt and penetrating injuries can be challenging. Over the past two decades, there has been a major shift from operative to selective nonoperative management of traumatic injuries. The increased utilization of nonoperative, or 'conservative', surgical management of abdominal solid organ injuries is facilitated by the various sophisticated and highly accurate non-invasive imaging tools at the trauma surgeon's disposal. This review discusses selected topics in nonoperative management of both blunt and penetrating trauma. Potential complications and pitfalls of nonoperative management are discussed. Adjunctive interventional therapies used in treatment of nonoperative management-related complications are also discussed.

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INTRODUCTION

Over the past two decades, there has been a major shift from operative to selective nonoperative management of traumatic injuries. Traumatologists caring for adult patients began to follow the trend initiated by their pediatric counterparts after an increasing amount of evidence supported nonoperative management of great majority of pediatric splenic and hepatic injuries. It was subsequently shown that even the presence of hemoperitoneum and altered mental status do not seem to negate initial nonoperative management in blunt abdominal trauma, even in patients with higher grade injuries or those of older age.[1]

The increased utilization of nonoperative, or 'conservative', surgical management of abdominal solid organ injuries is facilitated by the various sophisticated and highly accurate non-invasive imaging tools at the trauma surgeon's disposal. The nonoperative approach relies heavily on the availability of trauma-trained surgeons, modern radiographic imaging (particularly computed tomography), accurate interpretation of such high quality radiographic images, as well as the presence of appropriate supporting infrastructure and ancillary services.[1]

Although initially met with some resistance, selective nonoperative management of abdominal stab wounds has become routine in most trauma centers.[2] More recently, some trauma centers began to employ selective nonoperative management of gunshot wounds.[2-3] The increasing utilization of selective nonoperative approach for gunshot wounds follows the trends in nonoperative management of other types of traumatic injuries.

However, the feasibility and safety of the nonoperative approach to blunt or penetrating traumatic injury, especially in a limited-resource environment (such as limited availability of intensive care unit (ICU) and advanced imaging/interventional techniques like computed tomography and angiography) remains a contentious issue.

HISTORICAL BACKGROUND

Nonoperative management of penetrating abdominal trauma remained the standard of care through most of the 19th century. This paradigm began to change after 1887, when the American Surgical Association recommended exploration of civilian penetrating abdominal wounds.[2] Due to high mortality associated with nonoperative management of penetrating abdominal injuries, a policy of routine operative exploration evolved during World War I.[2] This dictum was further augmented by the fact that many surgeons coming back from World War II advocated continued use of mandatory surgical exploration for all civilian gunshot wounds.[3] This approach appeared to be associated with significant reductions in mortality and remained the standard of care until 1960's and 1970's when a trend toward selective nonoperative management of abdominal stab wounds began.[2] Mandatory exploration of all gunshot wounds to the abdomen remained the standard practice until 1990's, when trauma centers in the United States and South Africa published their experiences on selective nonoperative management of those injuries.[2]

Patients admitted with blunt abdominal trauma (BAT) are actually shown to have definite intra-abdominal injuries only in approximately one-third of the cases. On the other hand, the abdomen epitomizes the problem of missed injuries, with significant findings being absent in up to one third of patients with BAT.[4] Of note, a missed splenic injury is the most common cause of preventable death in BAT patients. The masking effect of concurrent extra-abdominal injuries and altered sensorium from shock, head injury or alcohol/drug intoxication, further compound the problem.[5-6] The propensity for low pressure bleeding from solid viscera makes it difficult to predict which injuries are likely to be self-limiting based solely on initial findings.[4]

The most common presenting features of intra-abdominal injury are abdominal pain, tenderness, guarding and distention.[7] Other symptoms such as shortness of breath or chest pain may also be associated with significant abdominal injuries. One must remember, however, that 40% of patients with significant hemoperitoneum have no peritoneal signs.[8-9]

The trend in favor of nonoperative management of solid organ injuries has been clearly shown by studies of blunt hepatic, splenic, and renal injuries, and further aided by the increasing availability and accuracy of various advanced imaging techniques and patient monitoring technologies.[8,10-11] This resulted in a sharp decline in both therapeutic and non-therapeutic laparotomy rates.

Whereas nonoperative management carries the inherent risks of a missed hollow visceral injury, delayed bleeding, and transfusion-related risks, laparotomy carries a different set of risks that are related to the surgeon, the anesthesia, the nature of operation and

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potential complications, and patient-related risk factors. Evidence seems to support the contention that the choice between the two modalities of management should be guided by hemodynamic considerations rather than the severity of organ injury.[9]

UNNECESSARY LAPAROTOMY

Trauma literature describes a category of laparotomies that reveal no pathologic findings and are termed 'nontherapeutic'. Nontherapeutic laparotomy (NTL) is also defined by some as a laparotomy for a minor injury that, in retrospect, required no surgical treatment.[2] It is partly because of this experience that the trauma surgeon's scope of practice has shifted toward selective nonoperative management of an entire spectrum of injuries.

The reported incidence of NTL for trauma varies from 1.7% to 38%, depending on the experience and practice patterns of the individual trauma center.[2] In one prospective study of 938 laparotomies for blunt or penetrating injuries, 27% were deemed 'unnecessary'.[12] In another study by Leppaniemi, a policy of mandatory operative exploration for stab wounds resulted in 37% negative laparotomy rate.[13] In contrast, centers practicing a policy of selective nonoperative management demonstrated a significantly lower rate of NTL (3.2% to 10%).[14-17]

A collected review of over 8100 patients with penetrating abdominal trauma found the overall incidence of 'unnecessary' operative explorations to be approximately 20%.[2] Of interest, the reported incidence of NTL for blunt trauma is similar to that in penetrating trauma (approximately 20%).[18-19]

Nontherapeutic laparotomies are associated with significant morbidity and costs. The reported incidence of laparotomy or anesthesia-related early complications varies between 8.6% and 25.6%.[12,20] For late complications, such as bowel obstruction or incisional hernia, the reported overall incidence is between 2.4% and 5%.[13,21]

Both overall cost and hospital stay for patients undergoing NTL are also significantly greater than for patients successfully managed nonoperatively.[15,17] In one study, the mean hospital charges for patients with abdominal gunshot wounds successfully managed nonoperatively were nearly $10,000 less than those for patients with unnecessary operations.[15] In fact, a policy of selective nonoperative management for abdominal gunshot wounds has been shown to save both a significant amount of hospital days and hospital-related charges.[17]

Table 1. Unnecessary laparotomy – Statistics.

Percentage of unnecessary laparotomies	1.7% to 38% (average 20%)
Associated early complications	8.6% to 25.6%
Associated late complications	2.4% and 5%
Hospital cost difference	$10,000 more for operative

Benefits of selective nonoperative management should be weighed against the consequences of missed injuries and delayed diagnosis. In one review of patients with penetrating trauma, the overall incidence of delayed diagnosis was 3.4%, with no deaths attributed to the delayed treatment and morbidity comparable to that in patients receiving an early operation.[2] Similar results were reported in blunt traumatic injuries.[22] The time delay beyond which the morbidity increases is not precisely known, but some have suggested a time frame of 6 to 12 hours.[2] The injured organ, the length of delay, and the degree of peritoneal contamination are all likely to play a role in the incidence and severity of complications related to delay in diagnosis and/or treatment.

GENERAL PRINCIPLES OF NONOPERATIVE MANAGEMENT OF TRAUMATIC INJURIES

Physical examination remains the cornerstone of trauma triage. Peritonitis and/or hemodynamic instability constitute strong indications for emergency laparotomy. The findings of significant traumatic injury can be subtle and the diagnosis of intra-abdominal injury uncertain. Moreover, between 20% and 40% of patients with significant hemoperitoneum have a benign abdominal examination upon initial assessment.[9]

The physical examination has significant limitations in certain situations. For example, the older trauma patient taking medications such as angiotensin converting enzyme inhibitors or beta blocking agents may not manifest the signs of early shock.[2] Similarly, young patients, especially with short prehospital transport times, may not exhibit signs or symptoms of shock despite the presence of significant internal bleeding.[2] Patients with associated severe head or spinal injury may be difficult to assess. Altered sensorium due to alcohol or other substances may affect the accuracy of clinical assessment. Combative and intoxicated patients pose further diagnostic dilemma, not only due to the lack of reliable physical examination, but also due to the potential danger to health care personnel and lack of cooperation during imaging studies, which require the patient to remain still.

Especially challenging is the evaluation of a hemodynamically unstable patient with multiple injuries and 'competing priorities' (i.e., concurrent head injury, aortic injury, pelvic fractures, and extremity trauma). Probability of injury can be estimated from knowledge of the mechanism and confirmation by CT scan may allow observation if the patient is hemodynamically stable. In patients for whom clinical examination is not reliable, special investigations can be crucial in early and accurate triage. Lack of reliable physical examination may constitute a relative contraindication to nonoperative management of traumatic injuries in patients who fall into this 'indeterminate' zone.

NONOPERATIVE MANAGEMENT OF BLUNT ABDOMINAL TRAUMA

Nonoperative management of blunt traumatic injuries is well established, and strategies based on CT scan diagnosis and the hemodynamic stability of the patient are now being widely used in the treatment of solid organ injury, including the liver, the spleen, the kidneys, as well as pelvic injuries. In blunt abdominal trauma (BAT), including severe solid organ injuries, selective nonoperative management has become the standard of care.[1]

If the decision has been made to observe the patient and to pursue nonoperative management, close monitoring of vital signs and frequently repeated physical examinations are instituted. An increased temperature or respiratory rate can indicate a hollow viscus perforation or abscess formation. Pulse and blood pressure can also change with sepsis or intra-abdominal bleeding. Adjunctive laboratory testing, such as serial determination of white blood cell count, hemoglobin and hematocrit levels, and serum lactic acid level and base deficit can also help determine if

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the nonoperative approach is failing. The development of peritonitis on physical examination and lack of response to nonoperative treatment, constitute an indication for surgery.

Table 2. Success of non-operative management strategy for different organ/anatomic location injuries (in alphabetical order) and mechanism of injury (blunt vs penetrating).

BLUNT	
Adrenal	80%
Aortic (selective initial medical management)	>80%
Bowel (hematoma)	10-15%
Duodenum (hematoma)	50-60%
Esophagus	Very rarely
Kidney	85%
Liver	80%
Pancreas	Low grade injuries only
Spleen	80-90%
Urinary bladder (extraperitoneal)	>75%
PENETRATING	
Overall	20%
Back and flank	60%
Extremity	Variable, case by case
Kidney	15%
Liver	20-30%
Neck (selective nonoperative management)	Variable, case by case
Pelvic/gluteal area	65-70%
Spleen	<5%

TRAUMA IMAGING: DETERMINATION OF THE INITIAL TREATMENT COURSE

The condition of the patient and the specific pattern of suspected injury will determine the imaging modality most appropriate in the given situation. Entire assortment of radiographic studies is available to the modern trauma surgeon, including plain radiograms, computed tomography, magnetic resonance imaging, and ultrasonographic imaging techniques. Imaging has become essential in the early decision-making process as to whether to proceed to the operating theater, interventional radiology suite, the trauma-surgical floor or the intensive care unit.

The location of the imaging equipment and the clinical capabilities of the supporting healthcare team and facilities should always be considered. Regardless of the type of radiographic investigation, the trauma patient who is undergoing the study should always be monitored appropriately. In addition, the trauma team should carefully plan the resuscitative sequence in order to minimize the loss of time and avoid radiographs that are technically impaired or have low diagnostic yield.

Although the overall value of traditional roentgenograms in the evaluation of patients with BAT is limited, they can demonstrate clinically useful findings. Whenever hemodynamic stability allows, blunt trauma patients should have plain radiographs of the cervical spine, chest, and pelvis as part of their evaluation. The need for further imaging is based on the mechanism of injury and findings during the initial and secondary trauma assessments. Plain films should be read carefully, in a systematic and standard fashion.

The chest roentgenogram is useful in confirming or demonstrating suspected pneumothorax, hemothorax, and widened mediastinum. It provides direct evidence for initiation of immediate therapy (i.e., tube thoracostomy). The chest radiograph may also aid in the diagnosis of abdominal injuries such as ruptured hemidiaphragm (i.e., a nasogastric tube seen in the chest) or pneumoperitoneum.

The pelvic and/or chest radiograph can demonstrate fractures of the thoracic and/or lumbar spine. The presence of transverse fractures of the vertebral bodies (i.e., Chance fractures) suggests a higher likelihood of blunt bowel or pancreatic injuries. In addition, free intraperitoneal air, or trapped retroperitoneal air from duodenal or colonic injury, may be seen. Penetrating wounds should have a radiographic marker (i.e. paper clip) placed over each penetration site and radiographs obtained to determine trajectory and retained bullets or fragments.

Although by no means definitive, a negative initial plain radiographic workup allows the trauma physician to continue on the path of non-operative management, keeping in mind that any deterioration in patient status or additional findings on subsequent imaging, physical examination, or laboratory investigations, may constitute an indication for change in therapeutic approach.

As an added benefit, the Focused Assessment with Sonography in Trauma (FAST) examination can be performed repeatedly, providing an excellent adjunct to serial physical examinations in the nonoperative management of traumatic injury.[23] In many centers, the FAST examination has virtually replaced diagnostic peritoneal lavage (DPL) as the procedure of choice in the evaluation of hemodynamically unstable trauma patients. The American College of Surgeons included the use of ultrasound in the Advanced Trauma Life Support secondary survey since 1999.

The FAST examination is based on the assumption that all clinically significant abdominal injuries are associated with hemoperitoneum. The current FAST protocol consists of four acoustic windows (pericardial, perihepatic, perisplenic, and pelvic – the four P's) with the patient supine. The detection of free intraperitoneal fluid is based on factors such as the body habitus, injury location, presence of clotted blood, patient positioning, and the amount of free fluid present. The FAST examination is interpreted as positive if fluid is found in any of the four acoustic windows and is interpreted as negative if no fluid is seen. An examination is deemed indeterminate if any of the windows cannot be adequately assessed. The minimum threshold for detecting hemoperitoneum remains a subject of interest. Studies show that as little as 30 to 70 mL of blood could be detected ultrasonographically.[24-25] Of interest, a small anechoic stripe in the Morison's pouch represents approximately 250 mL of fluid, while 0.5-cm and 1-cm stripes represent approximately 500 mL and 1 L of free fluid, respectively.[25]

The pericardial view is obtained using a subcostal or transthoracic window. It provides a 4-chamber view of the heart and can detect the presence of hemopericardium, which is demonstrated by the separation of the visceral and parietal pericardial layers. The perihepatic view visualizes the liver, diaphragm, and right kidney. It reveals fluid in the Morison's pouch, the subphrenic space, and the right pleural space. The perisplenic view visualizes the spleen and the left kidney and reveals fluid in the splenorenal recess, the left pleural space, and the subphrenic space. The pelvic view uses

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the bladder as a sonographic window. This view is best obtained while the patient has a full bladder. In males, free fluid is seen as an anechoic area (sonographically black) in the rectovesicular pouch or cephalad to the bladder. In females, fluid accumulates in the pouch of Douglas, posterior to the uterus.

Reported sensitivities and negative predictive values for ultrasound in detecting the hemoperitoneum are 78-99% and 93-99%, respectively. FAST examination relies on hemoperitoneum to identify patients with injury. In one study of 772 blunt trauma patients undergoing FAST scans, 15/52 (29%) patients with confirmed abdominal injury had no hemoperitoneum on FAST or CT scan.[26] Hence, the reliance of hemoperitoneum as the sole indicator of abdominal visceral injury limits the utility of FAST as a diagnostic screening tool in hemodynamically stable patients with BAT, and CT scanning may be necessary to further delineate the injuries. In order to define the subsets of patients who would benefit the most from trauma bay FAST examinations, Rozycki et al found that ultrasound was most sensitive and specific in patients with penetrating chest wounds or in hypotensive BAT patients (sensitivity and specificity nearly 100%).[27]

Hemodynamically stable patients with negative FAST results require close observation, serial abdominal examinations, and a follow-up FAST examination (if resources permit). However, one should strongly consider performing a CT scan, especially if the patient is intoxicated or has other associated injuries. Hemodynamically unstable patients with negative FAST constitute a diagnostic challenge. Other diagnostic options available in this situation include repeated FAST, DPL, laparoscopy, exploratory laparotomy, and, possibly, a CT scan after aggressive resuscitation.

Certain limitations of FAST ultrasonography, if ignored, can result in significant harm. For example, FAST does not identify retroperitoneal hemorrhage or hollow viscus perforations and may give false negative results in cases of significant intraperitoneal bleeding.[2] While some studies report excellent sensitivity, ranging from 90% to 100%, other studies report significantly lower sensitivity and negative predictive value.[27-31] Given the wealth of literature available on FAST examinations, the consensus remains that although a positive FAST is a strong predictor of injury, a negative FAST does not rule out significant intra-abdominal injury or bleeding. Thus, additional diagnostic studies should be performed if FAST is negative.[2] Moreover, the role of FAST should be validated by each individual trauma center.

Table 3. Synopsis of general principles of nonoperative management.

- Maintain high index of clinical suspicion
- Always keep the mechanism of injury in mind
- Patient should be examinable, with clear mental status
- Patient should be hemodynamically stable, with no obvious operative indications
- Be cautious when committing to nonoperative management in multiply injured patients
- Adequate healthcare team resources must be available (ability to perform frequent physical exams, re-imaging, repeat laboratory)
- Appropriate setting for nonoperative observation is available (observation ward, intensive care unit, monitored emergency department bed)
- Operative management should be available and instituted promptly if indicated by signs/symptoms

Computed tomography in trauma has evolved to the point of nearly becoming a universal part of the initial trauma patient evaluation, and is arguably the most valuable and most widely used tool in the initial evaluation of the hemodynamically stable patient with BAT. Modern helical CT technology has improved the speed and accuracy of the image acquisition process, which can now be performed in potentially unstable (metastable) patients who might not have been able to tolerate the long scanning times of the older imaging machines. The presence of the CT scanner in the emergency department, within seconds of the trauma bay, may enable the speedy evaluation of critically injured patients.

Computed tomography can provide highly reliable information about the presence and size of hemoperitoneum, the extent of many solid-organ injuries, and can visualize the retroperitoneum (the pancreas, the duodenum, and the genitourinary system) and many cases of hollow viscus perforation. The evolution of high-quality, multi-detector, fast CT scanning allows accurate assessment of organ injury grading and ongoing bleeding (i.e., the presence of radiographic 'blush').

Figure 1. Angiographic (A) and computed tomographic (B-D) appearance of intravenous contrast extravasation or 'blush'. Anatomic locations include pelvis (A and C), kidney (B) and liver (D).

The CT scan allows the detection and grading of solid organ injuries. In addition, CT can reveal other associated injuries, notably vertebral and pelvic fractures, as well as thoracic and extremity injuries. Computed tomography, unlike DPL or FAST, has the capability to fairly accurately determine the source of hemorrhage. Moreover, retroperitoneal injuries that are missed on DPL and FAST examinations, can be detected on CT scans. Tomographic images can help quantitate the amount of blood in the abdomen and visualize individual organs with precision. Limitations of CT scans include marginal sensitivity for diagnosing diaphragmatic, pancreatic, and hollow visceral injuries. Also, CT is relatively expensive and requires intravenous and/or oral contrast, which may cause adverse reactions.

In addition to the imaging accuracy of the CT, it can play a critical role in selecting the therapeutic modality in patients with solid organ injuries. This includes, for example, the determination of whether the trauma physician should resort to operative treatment versus angiographic embolization for selected injuries.

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Computed tomography is very helpful in the evaluation of blunt thoracoabdominal injuries. Here, the chest can be evaluated for injury to the thoracic aorta, pulmonary contusion can be differentiated from hemothorax, and occult pneumothoraces can be visualized.[32-33] Coronal image reconstructions can help determine the presence or absence of diaphragmatic injury as well as injuries of the bony skeleton.

BLUNT INJURIES: ORGAN- AND REGION-SPECIFIC APPROACHES TO NONOPERATIVE THERAPY

Management of blunt traumatic injuries can be complex, difficult, and depends on multiple clinical factors. Modern trauma surgeons depend on the conglomerate of clinical examination, laboratory tests, and radiographic studies in their decision-making process. With growing understanding of anatomic patterns of injury, we continue to refine our ability to appropriately apply nonoperative management strategies. The organ- and region-specific approach to injuries seems to be the most logical to follow in this review, making our discussion organized and systematic. We will begin with organ- and region-specific synopsis of blunt traumatic injury.

To exemplify the gradual transition from operative to nonoperative management strategy, hepatic trauma, which used to be a common reason to venture to the operative theatre, now is the staple in nonoperative management of BAT. Significant recent evidence for nonoperative management of splenic injuries has been inspired by the successes of the nonoperative hepatic injury management. Other organ injuries, including renal and pancreatic, are also increasingly being managed nonoperatively. Our discussion will begin with splenic injuries.

NONOPERATIVE MANAGEMENT OF SPLENIC INJURIES

Splenic injury is the most common indication for laparotomy following BAT. Blunt splenic injuries result from compression or deceleration due to a variety of mechanisms, from falls to motor vehicular accidents. The spleen receives approximately 5% of cardiac output, primarily through the splenic artery, making any splenic bleeding potentially life threatening. The splenic artery usually bifurcates into superior and inferior polar arteries, and the spleen has an open microcirculation without endothelium.

Clinical presentation of splenic injury may vary widely. Of importance is the presence of referred left shoulder pain (Kehr's sign) as well as the association of splenic injury with left lower rib fractures (ribs 9 through 12). In fact, up to 25% of patients with left lower rib fractures can have some degree of splenic injury.

In modern trauma practice, more and more splenic injuries are treated nonoperatively.[1] If hemodynamically stable, adult patients with lower grade splenic injuries (grades I and II) can most often be treated nonoperatively. Grade III splenic injuries can be treated nonoperatively, based on patient stability and reliability of the physical examination. Even very severe splenic injuries, associated with significant hemoperitoneum, have been successfully managed nonoperatively.[34] There is evidence that nonoperative management of splenic injury that rapidly stabilizes with little fluid or blood replacement is successful in 80% to 90% of cases.[34-35]

Computed tomographic findings that may predict failure of nonoperative therapy include the presence of large hemoperitoneum, as well as the presence of radiographic 'blush'. Nonoperative treatment of splenic injuries fails in approximately 15-20% of adults. Because of that, patients with significant splenic injuries treated nonoperatively should be observed in the intensive care unit for 48 hours and have immediate access to CT imaging, angiography, and/or the operating room.

Figure 2. Computed tomographic appearance of a significant splenic injury in a hemodynamically stable patient. This injury was managed nonoperatively.

NONOPERATIVE MANAGEMENT OF HEPATIC INJURIES

Though hepatic and splenic injuries still represent the most common injuries in BAT, the liberal use of high resolution CT scanning has showed that the liver and not the spleen is the commonest solid organ injured in blunt abdominal trauma.[8,35]

The frequency of blunt hepatic and splenic injuries appears to be fairly constant, while the percentage of patients managed nonoperatively has increased dramatically since the 1990's.[1] Modern imaging techniques, more than ever, are able to demonstrate small, otherwise undetectable hepatic injuries. Because physical examination is often unreliable in the blunt trauma patient, up to 40% of liver injuries may be missed on physical examination. Therefore, in hemodynamically stable blunt trauma patients, computed tomography is preferred. Most hemodynamically stable patients with hepatic trauma can be treated nonoperatively, provided that no other injuries that require laparotomy are present.[34] In fact, even AAST grade IV or V hepatic injuries, with associated large-volume hemoperitoneum or some degree of transfusion requirement, can be managed nonoperatively.[34,36] In addition, there is emerging evidence that nonoperative management of hepatic injury that rapidly stabilizes with little fluid or blood replacement is successful in over 80% of cases.[34-35,37] Moreover, it seems that neither advanced patient age nor higher grade of injury appear to correlate with the incidence of failure of nonoperative therapy.[1] Predictors of decreased success of nonoperative management include large hemoperitoneum, arterial 'blush' or pooling of contrast, as well as high grade (IV and V) injuries.

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Figure 3. Severe liver injury that was successfully managed nonoperatively.

The criteria for nonoperative treatment of blunt hepatic trauma include hemodynamic stability, absence of peritonitis, reliable exam in a neurologically intact patient, delineation of the injury by CT and radiographic absence of other operative injuries, less than two units of packed red blood cells transfused for the injury, as well as CT documentation of resolution of the injury. In addition, posterior right hepatic lobe and 'split liver' injuries (where seemingly extensive injury occurs along a relatively avascular plane) can usually be managed nonoperatively.

Observation of patients with blunt hepatic injury depends mainly on injury grade. Grade I and II injuries can generally be observed on the ward. Injuries of grades III and above should be observed in the intensive care unit for the first 48 hours. Observation includes serial hematocrit determinations, 3 to 5 days of bed rest, and a follow-up CT scan at approximately 48 hours post-injury for injury grades III or higher. Most liver injuries treated nonoperatively heal by 8 to 12 weeks.

NONOPERATIVE TREATMENT OF BLUNT DUODENAL AND BOWEL INJURIES

Nonoperative management of duodenal injuries is largely limited to isolated contusions due to blunt trauma. Although more common in children than in adults, intramural duodenal hematomas are potentially amenable to nonoperative management. In these patients, a follow-up upper gastrointestinal series with gastrografin should be performed every 7 days if the obstruction persists clinically. Other components of therapy in nonoperatively treated duodenal injuries include nasogastric suction and intravenous alimentation. The usually accepted time limit to nonoperative management is 2 to 3 weeks. In one study, 57% of duodenal injuries were managed nonoperatively.[38]

Similar to duodenal injuries, small or large bowel injury that appears to be limited to a bowel wall hematoma on high-resolution imaging, can potentially be observed. Frequent clinical re-examinations should be performed, up to and including repeated CT studies and ultrasound assessments. If any evidence of clinical worsening or peritonitis develops, the patient should be taken to the operating room promptly.

Table 4. Impact of radiography on nonoperative trauma management.

- Plain roentgenography remains valuable to modern trauma physician
- High resolution computed tomography allows very accurate organ injury assessment
- Ultrasonographic techniques can actively assist with nonoperative management
- Every trauma practitioner should be intimately familiar with FAST ultrasonography
- Interventional radiologists play an important role in nonoperative trauma management
- Clinical judgment still most important when determining operative vs nonoperative management
- Advanced image reconstructions may be helpful when dealing with suspected aortic, spinal, and diaphragmatic injuries

NONOPERATIVE TREATMENT OF BLUNT PANCREATIC INJURIES

Isolated pancreatic injuries resulting from non-penetrating trauma are rare. Less than 10% of all major trauma events result in injury of the pancreas, and most of them are associated with other solid organ injuries. Several series report a range of 1.6 to 4.5 associated injuries per patient. Rarely, the pancreas is the sole organ injured.[39-41]

If the patient is stable enough to undergo imaging, the initial test of choice is a high-definition CT scan performed with intravenous contrast. The findings on CT which may indicate pancreatic injury include: (a) peripancreatic intra- and extra-peritoneal fluid; (b) fluid in the lesser sac; (c) pancreatic hematoma or laceration; (d) diffuse gland enlargement with pancreatitis or focal edema at the site of injury; (e) thickening of the left anterior renal fascia. These findings are unusual and often subtle, and patients with pancreatic injury rarely exhibit more than one finding.[42] Computed tomographic imaging can also suggest disruption of the pancreatic duct. The presence of a complete fracture is usually, but not always, associated with a concomitant duct transection.[43-45] A finding which is easy to recognize, and can direct attention to additional subtle findings of pancreatic injury, is the presence of fluid interdigitating between the pancreas and the splenic vein.[46]

One recently suggested CT grading scheme parallels the surgical classification of Moore, without including direct evaluation of pancreatic duct integrity: (a) ***grade A***, pancreatitis or superficial laceration (less than 50% pancreatic thickness); (b) ***grade B1***, deep laceration (greater than 50% pancreatic thickness) of the pancreatic tail; (c) ***grade B2***, transection (entire thickness) of the pancreatic tail; (d) ***grade C1***, deep laceration of the pancreatic head; (e) and ***grade C2***, transection of the pancreatic head.[45] The difficulties involved in initial CT scan grading of pancreatic injury highlight the need to proceed with great caution if nonoperative path is taken. False negative results or underestimation of initial CT scan grading may be associated with unopacified bowel loops adjacent to the pancreas, motion and streak artifacts, as well as suboptimal bolus enhancement. In grade B or C injuries, the pancreatic fracture line is not easily detected when the separation of the fractured pancreatic fragments is minimal or nonexistent.[44] Furthermore, overestimation on CT could occur in grade C injuries because deep lacerations though the proximal pancreas are sometimes not associated with disruption of the proximal main duct, and transections through the proximal pancreas may merely disrupt the minor duct.[45] CT can also be useful in demonstrating

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complications such as abscesses, fistulae, pancreatitis and pseudocysts.

There is a significant increase in pancreas-specific complications in patients who required delayed surgical intervention.[47] The reasons for the delay in diagnosis and treatment of isolated pancreatic trauma include the fact that pancreatic injury can be asymptomatic in up to 20% of patients, laboratory findings are often nonspecific (in particular, initial serum amylase levels may be normal in about 25% of patients), and underestimation of the severity of pancreatic injury on the initial computed tomogram is possible.[47-48] Lastly, it is possible for low severity blunt abdominal trauma to be associated with isolated pancreatic injury.

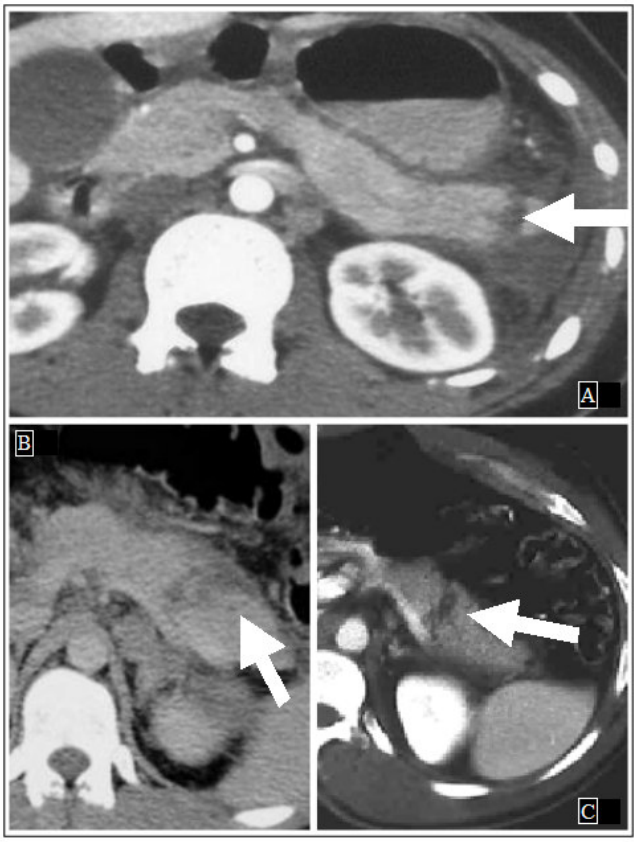

Figure 4. Examples of CT appearance of traumatic pancreatic lacerations. Patients A and C required surgery. Patient B was treated nonoperatively.

It is important to first separate patients into two groups: (a) those who need immediate surgery and (b) those who qualify for nonoperative observation. While nonoperative management of other solid organ injuries (spleen, liver) is an accepted practice, nonoperative management of pancreatic injuries is controversial. The integrity or disruption of the pancreatic duct is the principal determinant in the management of pancreatic injuries. Because prompt surgical intervention is usually undertaken in patients with penetrating injuries or multiple organ involvement, delay in diagnosis of a pancreatic ductal injury most commonly occurs in patients with BAT isolated to the pancreas. Some authors claim that CT grading of the degree of severity of blunt pancreatic trauma can be useful in predicting ductal integrity or disruption, although this is not universal.[43,47,49]

In cases of isolated pancreatic injury, serial physical examinations and repeated CT scans may be important in diagnosis and grading of pancreatic injury if non-operative management is to be undertaken.[49] One always has to keep in mind that the initial CT scan may provide a false sense of security and will sometimes miss or underestimate pancreatic injuries that ultimately require operative treatment.

NONOPERATIVE TREATMENT OF BLUNT RENAL INJURIES

Approximately 80% of renal injuries in the United States are due to blunt mechanism, and are associated with a 5% incidence of renal loss. Blunt renal injury is suggested by the mechanism of injury, the presence of hematuria, as well as physical findings and radiography. Computed tomography of renal injuries has evolved to a point where renal injury staging can be done almost exclusively by CT criteria.

In the setting of blunt renal trauma and selected instances of penetrating renal trauma, nonoperative approach may be chosen, starting with careful patient selection as the preliminary step. One series of predominantly blunt renal injuries showed that 85% of patients could be treated successfully without surgery. Exclusion of concurrent injuries is key in choosing nonoperative treatment.

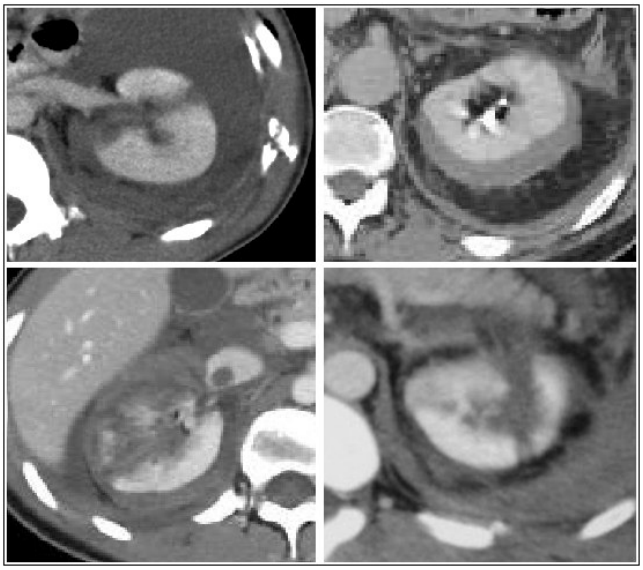

Figure 5. Computed tomographic examples of blunt renal injuries.

The anatomic structure of the kidney lends itself well to nonoperative management in the setting of blunt trauma. The kidney has an end arterial blood supply with a segmental pattern of division that supplies the renal parenchyma. When subjected to blunt force, renal lacerations tend to occur through the parenchyma. The resulting hematoma may displace renal tissue, but the segmental vessels themselves often are not lacerated. The closed retroperitoneal space around the kidney also promotes tamponade of bleeding renal injuries. Finally, the kidney is rich in tissue factor, further promoting hemostasis after injury via activation of the extrinsic coagulation pathway.

Nonoperative treatment of renal trauma (grades I to III) has become standard. If the injury is properly staged, nonoperative management is successful for contusions, contained lacerations,

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and even lesions with moderate amount of extravasation of urine or blood in the hemodynamically stable patient.

Traumatic renal artery thrombosis usually results in renal loss. Although renal salvage has been reported with arterial repair when the warm ischemia time is less than four hours, this is unusual without early operative intervention and repair. Nonoperative management is recommended in stable patients, with the understanding that late nephrectomy may be required for control of hypertension or sequelae of renal infarction.

Interventional radiology has extended the applicability of the nonoperative approach to renal injury. Percutaneous drainage of perinephric fluid collections or urinomas has been used to address one clinical complication of nonoperative management. In addition, angiography with selective embolization and/or stenting has been used in the setting of isolated renal vascular trauma. Another method to maximize the success of the nonoperative approach includes endourologic stenting. With these strategies, successful nonoperative management of renal lacerations may be achieved in a great majority of patients.

NONOPERATIVE TREATMENT OF BLUNT URINARY BLADDER INJURIES

Bladder injuries following blunt trauma are rare, constituting less than 2% of surgical abdominal injuries. The relative rarity of these injuries has been attributed to the protected position of the bladder deep in the bony pelvis, which also makes bladder injury a marker for other severe injuries, and significant associated mortality.[50] Bladder injuries following blunt trauma are significantly associated with pelvic fractures, with over 80% of patients with bladder injuries having a pelvic fracture, and approximately 10% of patients with pelvic fractures having a bladder injury.[51-52]

Majority of patients with bladder injury present with gross hematuria, although a small minority will only have microscopic hematuria.[50-51] Gross hematuria is felt to be associated with more significant injury (i.e., bladder rupture) while microhematuria has been seen commonly with bladder contusions or hematomas.[51]

The algorithm for management of suspected urinary tract injury starts with proper history and physical examination. Lower abdominal pain, tenderness, and bruising over the lower abdomen and perineum may be present. However, these signs and symptoms may be difficult to discern from the findings associated with pelvic fractures. Some intraperitoneal bladder injuries are discovered when a urethral catheter fails to return urine. In patients with a delayed diagnosis of bladder injury, fever, absence of voiding, peritoneal irritation, and elevated blood urea nitrogen may be observed. Any patient with these signs and symptoms should have formal cystography to rule out bladder injury.

Inspection for blood at the urethral meatus should be performed during routine trauma evaluation, and this sign is present is approximately half of significant urethral injuries.[53] Passage of a urinary catheter should not be attempted in these patients, and an immediate retrograde urethrogram should be obtained to rule out urethral injury. Anywhere between 10% and 17% of patients with bladder injuries will have associated urethral rupture.[51,53] If findings on urethrography are normal, a urinary catheter can be placed. However, if these findings are abnormal, suprapubic urinary catheter, bladder exploration and repair should be considered.

If no urethral injury is present, the determination of whether bladder rupture is present, and classifying it as intraperitoneal or extraperitoneal follows. Nonoperative management applies only to extraperitoneal ruptures, which can be drained with a urinary catheter. Retrograde cystography with plain abdominal roentgenographic imaging has been proven to be very accurate.[50] The technique has two important technical considerations: (a) the bladder needs to be filled completely; (b) a post-drainage film is essential. Approximately 300 mL of diluted contrast medium is infused into the bladder by gravity.

Given the widespread utilization of computed tomography in modern trauma practice, CT cystography has gained popularity as a study of choice for evaluation of potential bladder trauma. Diluted contrast medium is infused into the bladder by gravity, and pelvic tomography is subsequently performed. Again, post-drainage film is crucial.

The management of intraperitoneal bladder ruptures is operative and will not be discussed in this review. Extraperitoneal ruptures, which are isolated in approximately two thirds of cases, may be amenable to nonoperative management.[50] These can commonly be managed with urinary catheter drainage alone, although some argue that a bone fragment projecting into the rupture (a rare occurrence), open pelvic fracture, and rectal perforation may constitute a contraindication to nonoperative management.[54] Open pelvic fractures and rectal perforations are associated with high risk of serious infection if managed conservatively.[55] Others suggest that if clots obstruct the urinary catheter within 48 hours of injury, then open repair should be undertaken and a suprapubic tube placed.[56] A relative indication for operative repair of extraperitoneal ruptures is found in patients undergoing exploratory laparotomy for other reasons.[56]

In extraperitoneal bladder ruptures, antimicrobial agents are instituted on the day of injury and continued until 3 days after the urinary catheter is removed.[56] Follow-up cystography should be performed in cases of extraperitoneal bladder rupture at 10-14 days post-injury.[57] Most ruptures will heal by 10 days, and nearly all heal by 3 weeks.[56-57] If the cystogram shows no extravasation, the catheter can be removed. Otherwise, cystography is repeated at 21 days.[57] Most authors report few complications with nonoperative management of extraperitoneal bladder rupture.

NONOPERATIVE MANAGEMENT OF PENETRATING TRAUMA

Let us start the discussion of this topic on a contrarian note. When should penetrating trauma victim be operated on? These circumstances include hemodynamic instability, trajectory of the projectile suspicious for internal injuries, peritonitis, evisceration, pneumoperitoneum on imaging, massive hemothorax, hemopericardium, blood in the nasogastric tube, blood in the urinary catheter, and rectal bleeding.

The key to successful nonoperative management of penetrating injuries is to remember that such approach should be employed only in certain selected scenarios. Traditionally, penetrating trauma has been associated with significant incidence of non-therapeutic operative interventions. More evidence is emerging that observation and selective non-operative approach may have been underutilized in the past. Surgeons have been reluctant to

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move toward nonoperative management because many consider a non-therapeutic laparotomy to be relatively harmless. However, several studies clearly demonstrate that this point of view is far from optimal (see earlier section on non-therapeutic laparotomy).

Selective nonoperative management of penetrating abdominal wounds invokes several important principles. First, adequate resources have to be present in order to provide continued and timely monitoring of the injured, with immediate feedback when failure of nonoperative therapy is suspected. Second, high-quality imaging modalities have to be readily available for the purpose of initial definition of the path of the projectile as well as for re-imaging (if appropriate) when failure of nonoperative management is suspected. Three, adequate resources (operating surgeon, operative suite, nursing staff, house staff) need to be in place in order to quickly institute operative therapy if needed.

When a patient is being evaluated for possible nonoperative management of penetrating injury, the treating physician must ask two questions. First, did the projectile enter the peritoneal, retroperitoneal, or pelvic cavity? And second, if it did, is there an injury that will require an operation? Accurate determination of the projectile trajectory can help answer both of these questions. Thus, the decision about whether a patient can undergo nonoperative management depends on the clinical evaluation and trajectory determination.[3] To simplify the decision -making process, hemodynamically unstable patients with penetrating injury automatically fail nonoperative management.

Selective nonoperative management is practiced widely in stab wounds and BAT, but routine laparotomy is still the standard of care in abdominal gunshot wounds. Mandatory exploration is the standard approach to management of patients with gunshot wounds to the abdomen and back. This policy can be associated with a high incidence of unnecessary laparotomies and significant morbidity. In order to simplify and systematize the decision-making algorithm for nonoperative management of penetrating injury, the following sections will be divided into mechanism-based, and regional anatomy-based considerations (as opposed to organ-specific considerations for blunt injury).

Table 5. Important considerations when treating penetrating trauma nonoperatively.

- Nonoperative approach should be employed ***selectively*** in the setting of penetrating traumatic injury
- Patients who sustained penetrating trauma and are being treated nonoperatively must be hemodynamically stable, and must be able to give reliable serial physical examinations
- Establishing accurate trajectory of the penetrating injury is of utmost importance
- Trajectory determination = Injury identification
- Advanced imaging techniques (high-resolution computed tomography) allow for accurate trajectory determination and facilitate nonoperative management
- Adequate resources have to be present in order to provide continued and timely monitoring of injured patients, providing immediate feedback when failure of nonoperative therapy is suspected
- Adequate resources (operating surgeon, operative suite, nursing staff, house staff) need to be in place in order to expeditiously institute operative therapy, if needed

PENETRATING INJURIES: MECHANISM-BASED CONSIDERATIONS

There are several factors that differentiate penetrating military and civilian wounds. Civilian injuries tend to be caused by handguns with low-caliber missiles and muzzle velocities between 800 and 1,400 feet/second.[58] Typically, these weapons cause a relatively small wound associated with minimal damage caused by blast or cavitation effect. Tissue damage is limited to a small area around the missile path, and usually only organs directly in the path of the projectile are injured.[58]

Figure 6. Examples of high-velocity military projectiles (left), low-velocity handgun projectiles (right upper) and high-velocity handgun projectiles (right lower).

Blast injury and cavitation are much greater with high-velocity missiles, such as those from rifles and military weapons, or from shotgun wounds.[59] These projectiles cause much more widespread tissue destruction along a missile path that is significantly wider than the actual projectile. The tissue destruction often involves large areas of necrosis, and most surgical interventions for these wounds involve exploration and debridement, even without signs of peritonitis or evidence of peritoneal penetration.

Figure 7. Examples of weapons used in stabbing injuries. From left to right: bayonet, military knife, ice pick, screwdriver.

Stab wounds can be broadly divided into those with wider blades (knives, bayonets, etc), and those with long punctate objects (ice picks, screwdrivers, etc). Stab wounds tend to cause direct

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damage around the wound, with less damage to surrounding tissues. Special attention should be paid to the exact mechanism of stabbing and the suspected path and depth of the stabbing blade, as imaging techniques will not be as useful here as they are in injuries caused by bullets.

PENETRATING INJURIES: REGIONAL AND ANATOMIC CONSIDERATIONS

The approach to nonoperative management of penetrating traumatic injury should be based on regional and anatomic considerations of the projectile path as well as the patient's clinical stability. Subsequent sections will focus on regional anatomy in relation to injury in an attempt to systematize and simplify the overall approach to the penetrating trauma patient.

THE ABDOMEN

Evidence dating back to the 1990's suggests that selected patients with abdominal gunshot wounds can be successfully treated utilizing the nonoperative approach. In one study, approximately 80% of patients exhibited peritonitis and were taken directly to the operating room, while 20% of patients were treated nonoperatively and did not require a laparotomy.[60] Among patients who were observed, eight had negative physical examinations, even with indirect evidence of peritoneal penetration (i.e., by estimation of trajectory by surface wounds). The negative and nontherapeutic laparotomy rates for the two groups were 5% and 1%, respectively. Selection was based entirely on physical examination and plain radiographs. Advanced imaging technology, such as CT scans, was not utilized.

Demetriades and co-workers confirmed the utility of physical examination in evaluation of intra-abdominal injury in a prospective evaluation of 146 patients with abdominal gunshot wounds.[61] Similar to previous reports, most patients (72%) had a positive clinical examination on admission, prompting an immediate laparotomy. Of the 41 (28%) patients who were observed, seven eventually underwent delayed laparotomy, with no apparent added morbidity or mortality.

In the largest series of nonoperative management of abdominal gunshot wounds, 1856 patients from the University of Southern California medical center were evaluated.[17] A total of 792 (42%) patients were initially triaged to nonoperative observation, of whom 712 were eventually discharged without an operation. Of the 80 patients who failed nonoperative management and underwent a delayed laparotomy, 57 had injuries requiring operative repair. Although the primary tool of triage determination was the physical examination, most patients chosen for nonoperative management also underwent a CT scan. The combined negative and nontherapeutic laparotomy rate was 13% in patients undergoing immediate exploration and 29% in those receiving a delayed operation. There were five complications, including three intraabdominal abscesses, one ileus, and one case of acute respiratory distress syndrome, that were attributed to a delay in treatment among the 80 patients who underwent delayed exploration, but no deaths. Combined, this and the other studies support the physical examination as a sensitive indicator of intraabdominal injury after penetrating trauma.

THORACOABDOMINAL WOUNDS

The thoracoabdominal area extends from the nipple line to the costal margins bilaterally. This region represents a space that can be filled by thoracic and abdominal contents. The difficulty in determining trajectory in this region is partly caused by the diaphragmatic mobility and the changing relationship of the internal structures to surface landmarks. The right side of this region is mostly occupied by the liver, whereas the left side contains the spleen, stomach, colon, and small bowel. Because of these anatomic relationships, injuries to this region are treated differently, depending on which side the injury is found on.[3]

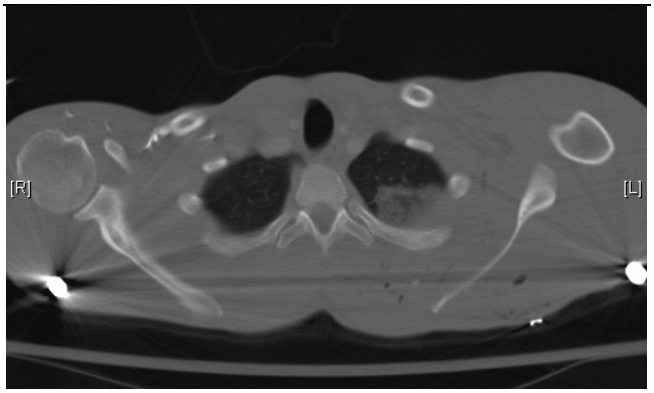

Figure 8. An example of nonoperatively treated gunshot wound to the upper back. Note the injury tract seen on this computed tomographic scan.

Isolated penetrating injuries to the right thoracoabdomen will generally involve the liver and the diaphragm. Although it has been postulated that diaphragmatic injuries on the right side are less severe because the liver acts to obturate the defect and prevent late herniation of bowel contents, this theory may not be true.[62] Overall, right thoracoabdominal gunshot injuries account for less than 7% of all abdominal gunshot wounds.[63] A nonoperative approach to this specific injury has evolved from the frustration of operating on non-bleeding injuries confined to the liver. In one series of right thoracoabdominal gunshot injuries, the majority of patients had both a chest injury (hemothorax, pulmonary contusion) and a solid organ injury (liver, kidney). The chest injuries were treated with tube thoracostomy only, and the solid organ injuries were observed without the need for intervention.[63] In another series of 33 patients with right thoracoabdominal gunshot wounds treated nonoperatively, only one underwent a laparotomy for worsening clinical symptoms, which proved to be nontherapeutic.[64] Another study of 16 hemodynamically stable patients with right thoracoabdominal gunshot injuries were treated nonoperatively after evaluation with abdominal CT.[65] In this group of patients, five underwent a delayed laparotomy for peritonitis or abdominal compartment syndrome. In the remaining 11 patients treated nonoperatively, one patient developed a biloma that was treated with percutaneous drainage. At some institutions, penetrating injuries to right thoracoabdominal region, with CT-proven trajectory through the liver and no clinical or radiographic evidence of other injuries, frequently undergo selective nonoperative management.

In contrast to the right side, injury to the left thoracoabdomen has a higher chance of diaphragmatic and hollow visceral injury. Because abdominal CT is not sensitive or specific for determining diaphragmatic injury, other methods must be utilized.[66] Murray et

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al reported the incidence of diaphragmatic injury with left thoracoabdominal gunshot wounds at 42%.[67] In that study, all patients underwent diagnostic laparoscopy to rule out diaphragmatic injury. In patients who were determined to have a diaphragmatic defect, 31% had no signs of peritonitis and 40% had a normal chest radiograph. Because of these findings, the authors recommend diagnostic laparoscopy for all patients with left thoracoabdominal gunshot injuries.

THE BACK AND FLANK

The surface landmarks for the flank region include the tips of the scapulae superiorly, the iliac crests inferiorly, the anterior axillary lines and the posterior axillary lines. The back region is bounded by the posterior axillary line bilaterally, the scapular tip superiorly, and the iliac crest inferiorly. Evaluating patients with penetrating injuries to these areas is especially difficult. First, there is paucity of literature supporting nonoperative management in this anatomic area, and existing studies have small numbers of patients. Also, there is the clinical challenge of penetrating injuries involving only the retroperitoneum, which can cause the classic signs of peritoneal irritation to be delayed or missing altogether. Finally, some adjuncts, such as laparoscopy, FAST ultrasound and diagnostic peritoneal lavage, are of limited value in evaluating the retroperitoneum.

Abdominal CT has been shown to be sensitive and specific for diagnosing injuries in this area and is considered the test of choice for wounds thought to be limited to the retroperitoneum. A variation of the standard CT scan is performed with "triple contrast." In addition to the standard oral and intravenous contrast, soluble contrast is placed into the colon as an enema. Proponents of this type of preparation believe that it can help identify subtle injuries to the retroperitoneal colon. The disadvantages are the inconvenience, delay that the preparation necessitates, and added cost. Injuries to the colon by posterior wounds are rare, comprising only 1% of patients at risk for such injury.[68] After studying 145 patients with posterior stab wounds, one study failed to find a single patient in whom colonic contrast helped to identify an injury.[69]

Velmahos et al, reviewed an extensive clinical experience with back and flank gunshot wounds.[16] According to clinical examination alone, without utilizing abdominal CT or diagnostic peritoneal lavage, patients were selected for nonoperative treatment. Overall, 130 (69%) of 206 patients studied were treated by observation. There were 4 (3%) delayed laparotomies, all of which were nontherapeutic. The authors concluded that selective nonoperative management of back and flank gunshot wounds is appropriate and safe. Ginzburg et al, used abdominal CT to characterize 45 gunshot injuries to the flank.[70] Of these, 40 patients had negative abdominal CT results, were observed for 24 hours, and had no delayed laparotomies or complications.

THE PELVIS

The pelvis is an anatomically restricted space with densely crowded internal structures. A study from the University of Pennsylvania demonstrated that transpelvic penetrating injuries have an 85% chance of causing an internal organ injury.[71] However, this group was able to use a selective nonoperative approach similar to the one used in abdominal and back wounds. Unique adjuncts in pelvic injury included urinalysis to diagnose injury to the urethra and bladder and rigid proctoscopy to identify rectal injury. Hematuria or hematochezia are both clinical findings that have a high predictive value for pelvic organ injury.[71]

Velmahos et al, applied a selective operative approach to evaluate 59 patients with pelvic or gluteal gunshot wounds.[72-73] According to physical examination, adjunct examinations, and in some cases CT scan, 40 (67.8%) patients underwent nonoperative management. There were no delayed explorations in this group of patients, and the authors concluded that the clinical examination alone was 100% sensitive and 95.3% specific for identifying internal organ injuries after pelvic gunshot wounds.

PENETRATING NECK INJURIES

Penetrating injuries to the neck pose a diagnostic and therapeutic challenge. Treatment of these injuries has varied historically. Before the World War II, few penetrating neck wounds underwent operative treatment unless major bleeding or deep injuries were obvious; reported mortality rates ranged between 11% and 18%.[74] Fogelman and Stewart in 1956, reported a mortality rate of 6% with prompt exploration versus 35% in cases with delayed or omitted operation.[75] This led to the widespread theory of treating penetrating neck injuries much like penetrating abdominal wounds, and the dictum of surgical exploration if platysma is violated. Using this methodology, Jones et al. reported a mortality of 3.6% in 1967.[76]

The very high density of important vascular, neurologic, and aerodigestive structures within the neck make the management of penetrating injuries difficult and contributes to the morbidity and mortality in this group of patients. Current management of penetrating neck injuries depends on several factors, which include patient stability, injury location, injury mechanism (gunshot wounds carry higher risk of major injury), and presence of findings suggesting aerodigestive injury.

Patients with signs of significant neck injury or those who are unstable should undergo prompt surgical exploration following rapid initial clinical assessment and airway control. Those who do not fall into this group will proceed further on the nonoperative management path, which will largely depend on injury location.

Zone I injuries pose potential danger to the great vessels, the trachea, the esophagus, thoracic duct, the upper mediastinum and lung apices. Structures in Zone II include the carotid and vertebral arteries, jugular veins, pharynx, larynx, esophagus, and trachea. Of note, injuries to zone II can be readily evaluated and exposed operatively. Important structures in Zone III include the distal extracranial carotid and vertebral arteries as well as segments of the jugular veins.

Today, the majority of penetrating neck injuries can be managed without surgical intervention, but meticulous attention to physical signs and clinical symptoms is crucial.[77-79] Previous dictum revolved around strong recommendation for early mandatory routine exploration of penetrating cervical trauma, especially in the 'zone II' region.[75] These recommendations were based on a 1956 review of 274 patients by Fogelman and Stewart, where patients who underwent early exploration had an operative mortality of 6%; those explored late or not at all had a mortality of 35%.[75] More recently, Demetriades and colleagues have demonstrated that conservative non-operative management of penetrating neck injuries can be performed safely if there are no clinical findings suggestive of vascular or aerodigestive injury.[80] This approach is consistent with the findings of Golueke et al,

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who prospectively randomized 160 patients with penetrating neck injuries and found no statistical difference in length of stay, morbidity or mortality between those patients who underwent routine or selective exploration of their injuries.[81] They concluded that surgeons should base their treatment on their own experience and the particular circumstances surrounding the patient.

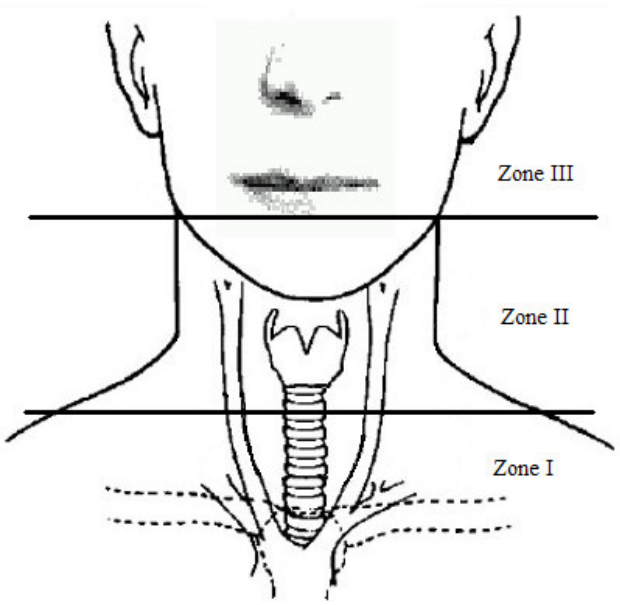

Figure 9. Schematic representation of the three zones of the neck.

While the evidence for non-operative management of penetrating cervical injury is compelling, the extent of the diagnostic evaluation remains as crucial as ever. McConnell and Trunkey, in a meta-analysis of penetrating neck trauma, found that the incidence of isolated esophageal injury was 6.6%, isolated spinal cord damage was 3%, and the overall incidence of injury in the neck was proportional to the volume occupied by the organ.[82] In the presence of symptoms or signs of aerodigestive or vascular injury, advances imaging is clearly indicated. In addition to the signs and symptoms routinely assessed, the mechanism of injury must be considered. Gunshot wounds may not follow a predictable trajectory, and may travel in unexpected patterns if they impact upon bony structures.[83-86] In addition to the path of the bullet, two additional factors must be considered: the blast effect and the possibility of either bullet or bone fragments causing additional injury. Because of this, upper aerodigestive endoscopy and high-definition 'thin cut' CT scans should be considered, and further supplemented by other endoscopic and radiographic techniques.

The significance of the aerodigestive injury may be magnified by the presence of other concurrent injuries, especially to the vascular or neurologic structures. In most cases, small perforations of the cervical esophagus do not lead to catastrophic consequences.[87] However, the combination of esophageal and dural injury can lead to neurologic complications including meningitis and quadriparesis.[88-90]

In summary, accumulated evidence points away from the zone-based approach to neck injuries and the practice of mandatory neck exploration. The new paradigm focuses on a combination of physiologic considerations and prompt determination of the presence of vascular and/or aerodigestive injury. High-definition radiographic testing and endoscopic techniques are crucial in this approach to neck injuries.

NONOPERATIVE MANAGEMENT OF PERIPHERAL VASCULAR INJURIES

Assessment for vascular injury must be performed in all traumatized extremities. The significance of missed vascular injury in the extremity translates into limb loss and/or functional loss and disability. Delay in recognition and treatment is the leading cause of preventable limb loss in the setting of peripheral vascular injury. Vascular injuries most commonly result from penetrating trauma, with injuries to the brachial vessels of the upper extremity and superficial femoral vessels of the lower extremity being most common in the civilian trauma practice. Management of peripheral arterial injuries is continuously evolving, and the traditional dictum of mandatory exploration for all potential vascular injuries has changed to one of selective evaluation and nonoperative management of "minimal" injuries.

Nonocclusive "minimal" arterial injuries are well documented to have a benign natural history. These injuries should be followed, rather than immediately operated upon, if they are asymptomatic (i.e., absence of hard signs), the vessel is patent, and there is no gross extravasation. Most of these minor injuries never require surgery.

There is a well-defined subset of physical exam characteristics that help the trauma physician single out injuries that may fail selective nonoperative management. Detailed physical examination for suspected vascular injury includes assessment of pulses, Doppler signals, capillary refill, skin temperature, and motor and sensory function. Associated soft tissue and skeletal injuries should be noted, as these may alter clinical management. In addition, the use of "hard" signs of vascular injury as indicators of need for surgery yields an accuracy of over 95%. On the other hand, most clinically occult vascular injuries resolve on their own and never require surgery.

Table 6. 'Hard' and 'soft' signs associated with peripheral vascular injury.

Hard signs of vascular injury
Absent pulses
Bruit or palpable thrill
Active hemorrhage
Expanding hematoma
Distal ischemia
Soft signs of vascular injury
Hematoma
History of hemorrhage at the scene of the injury
Unexplained hypotension
Peripheral nerve deficit

Increasing body of evidence advocates nonoperative management of vascular injuries with "minimal" findings on arteriography. These injuries are characterized by: (a) minimal vessel

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irregularities, (b) small intimal flaps, (c) small pseudoaneurysm (<1 cm), (d) small arteriovenous fistulae. Also important, "proximity" alone is not an indication for arteriography. Interventional radiologic techniques such as stenting across injured arterial segments, are being employed more frequently, with acceptable results.[91-93]

Important diagnostic adjuncts in the setting of peripheral vascular injury include measurements of the ankle-brachial and the ankle-ankle index. In the absence of pre-existing severe peripheral arterial disease, an ankle-brachial index (ABI) measurement of less than 0.40 constitutes an indication for operative intervention. ABI values between 0.40 and 0.90 warrant emergent arterial imaging.

SPECIAL CONSIDERATIONS IN NONOPERATIVE MANAGEMENT OF TRAUMA

Certain types of injuries to pharynx and esophagus can be amenable to nonoperative management. Nonoperative approach to these injuries generally applies to small injuries, with no free flow of contrast material into surrounding tissues. It is also important to determine that no other lesions requiring surgical intervention exist, and there continue to be minimal or no symptoms over time. Furthermore, there should be no evidence of active infection and antibiotic treatment should be initiated promptly after the injury. Adjuncts in successful nonoperative management of pharyngeal and esophageal injuries include nasogastric suction, adequate nutrition (either parenteral or via jejunostomy tube), antibiotic therapy, and nothing by mouth. Antibiotic coverage used in the setting of these injuries should adequately address oropharyngeal flora, with appropriate gram-negative anaerobic and antifungal coverage. Adequate enteral nutrition given via post-pyloric route, may be associated with lower infection and mortality rates.

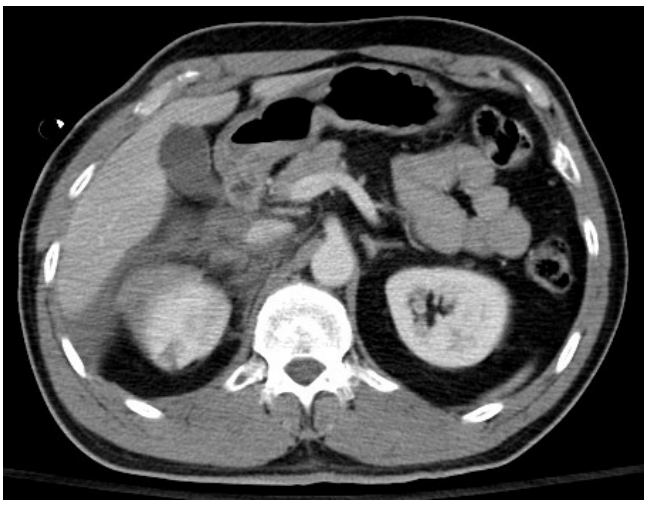

Figure 10. An example of right adrenal injury with concurrent right renal laceration and hemoperitoneum. This patient was managed nonoperatively

Adrenal gland trauma, a rare and largely coincidental finding during initial radiographic evaluation of patients who sustained severe trauma, has been associated with high injury severity and associated mortality of nearly 33% (5 times the mortality of patients without concomitant adrenal gland trauma).[94] Although nearly 80% of patients with documented adrenal gland trauma in one study were treated nonoperatively, these patients sustained significant other associated severe injuries, including liver injury (58%), rib fractures (51%), renal injury (41%), and splenic injury (33%). Pulmonary complications were most common, followed by infection/sepsis, and cardiovascular complications in this group.[94]

Nonoperative management of blunt aortic injury (AI) is centered around adequate blood pressure and heart rate control.[95-96] Appropriate beta-adrenergic blockade with short-acting beta-blockers is essential when nonoperative path of management for traumatic AI is chosen. Addition of nitroprusside and/or calcium channel blocker should be considered for blood pressure control, if needed. Different authors vary on the preferred target systolic blood pressure in the setting of blunt AI, with desired systolic blood pressure ranges between 100 mmHg and 140 mmHg, with evidence that most trauma patients can tolerate the lower limit of blood pressure quite well.[97-99] Heart rate goal in nonoperative blunt AI should be kept around 60-80 beats per minute.[96] Patients should subsequently be followed by CT angiography, MR angiography, and/or TEE done up to one week after the initial injury.[95] Delayed rupture of aortic injuries has been quoted at approximately 1.5% to 4% among patients who are stable enough to undergo the initial workup, including CT scan and aortography.[95] Studies also demonstrate that the incidence of remote rupture of AI is uncommon with proper treatment, and that some patients have regression of AI with anti-hypertensive management.[100-102] For example, only 7% of patients with a history of acute AI developed chronic thoracic aneurysms in one study with median followup period of 22 years.[103] Aortic stenting can be successful, although operative repair is still the most reliable and proven treatment.[95] It may also be that a hybrid approach consisting of initial nonoperative management followed by delayed surgical repair may be most beneficial, as the mortality of delayed operation has been quoted at 10% as opposed over 30% mortality for patients undergoing emergent operation.[98]

Severe pelvic fractures resulting from blunt injury should undergo external fixation, and associated zone III retroperitoneal hematomas should not be explored, as this will most commonly be disastrous. External fixation controls a significant amount of bleeding. Angiography and embolization may be required. These patients are best treated with supportive therapy in the intensive care unit environment, and surgery is reserved only for significant arterial or visceral injuries associated with fractures.

Table 7. Key points regarding nonoperative management of blunt aortic injuries.

- Adequate beta-adrenergic blockade with short-acting agents
- Addition of nitroprusside or calcium channel blocker can be considered when further blood pressure control is needed
- Maintenance of systolic blood pressure between 100 mmHg and 140 mmHg
- Maintenance of heart rate between 60 and 80 beats per minute
- Repeat traditional aortography, CT aortography, MR aortography, or transesophageal echocardiography up to one week after the initial injury
- Delayed aortic rupture has been quoted at approximately 1.5% to 4% among patients who are stable enough to undergo the initial workup
- Incidence of remote rupture is very low with appropriate treatment, and some studies show arteriographic resolution of small injuries
- Aortic stenting techniques continue to evolve and improve
- Mortality of delayed repair may be lower than mortality of emergent operation

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THE ROLE OF INTERVENTIONAL RADIOLOGY

Interventional radiology has been one of the most important adjuncts in nonoperative management of trauma, especially in recent years. Angiography is a valuable modality in the nonoperative management of multitude of injuries. It has been successfully used as an adjunct to surgery and as the definitive treatment modality in selected blunt and penetrating trauma scenarios. Although traditionally viewed as an adjunct to surgical treatment of complex liver and pelvic injuries, over the past decade it has been used more aggressively for nonoperative control of bleeding due to other solid organ injuries. Angiographic techniques contribute significantly to the reduced number of operative interventions in modern trauma practice.

The selection of patients for angiographic intervention is based on clinical examination and computed tomographic (CT) scan findings. The patient must be hemodynamically stable or at least transiently responsive to resuscitation, with no peritoneal signs, and the CT scan must demonstrate solid-organ or pelvic injury with evidence of active bleeding. The presence of angiographic 'blush' or pooling of contrast material in the parenchyma of a ruptured solid organ or in the pelvic region constitute a strong indication for angiographic embolization.[104-106] Angiographic intervention has been successful in selected cases of blunt splenic or renal injury, and even in patients with high-grade blunt liver injury.[104-105,107-108] In fact, the success rate in renal injuries is significantly higher than in liver or splenic injuries, mainly because of the presence of the Gerota's fascia, which serves as a containment barrier. With appropriate institution-specific protocols and a dedicated team of interventional radiologists, many patients can be spared an operation and the potential complications associated with it.

Table 8. Types of minimally invasive procedural interventions in trauma patient management.

- Arteriographic interventions, including embolization, stenting, and diagnostic applications
- Percutaneous drainage of bile collections, urinomas, abscesses, hematomas
- Endoscopic stenting of bile duct injuries and selected urinary tract injuries
- Minimally-invasive endoscopic-guided placement of various adjunctive devices, including percutaneous gastrostomy (PEG) or jejunostomy (PEJ) enteric access tubes, and percutaneous endoscopically-guided tracheostomy placement

Perhaps the most successful example of application of the angiographic approach to traumatic injury is in cases of severe pelvic hemorrhage. Life-threatening pelvic hemorrhage is primarily caused by arterial injury and most bleeding sites originate from branches of the hypogastric artery. An aggressive surgical approach may not be successful because bleeding sites are difficult to localize surgically, arterial ligation often does not achieve hemostasis, and opening of the retroperitoneum may negate the tamponading effect of the hematoma as well as increase the danger of infection. Angiography with selective embolization can successfully control the hemorrhage. Early embolization is very important in reducing transfusion requirements and associated complications.[109] More recently, angiographic intervention has been successful in the nonoperative management of penetrating injuries to the liver and kidneys, including gunshot wounds.[110]

Most of the local complications following nonoperative management of traumatic injuries, including bilomas, urinomas, or abscesses, can be managed with percutaneous drainage. In addition, interventional radiology has helped trauma surgeons significantly with placement of both permanent and retrievable vena caval filters in situations when anticoagulation (prophylactic or therapeutic) for deep venous thrombosis is not feasible.[111]

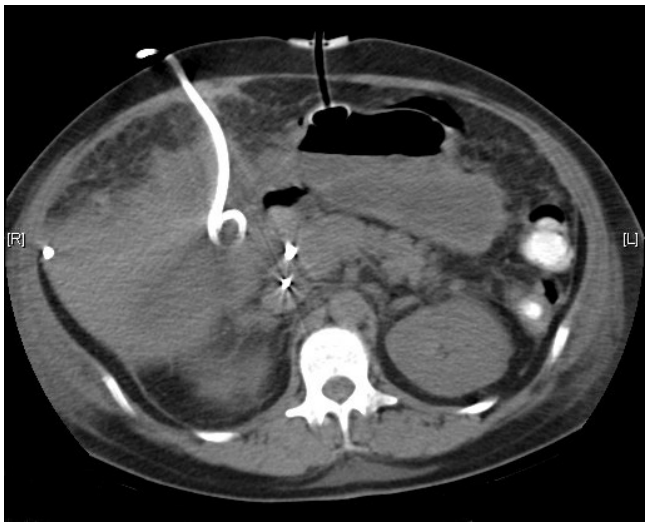

Figure 11. Computed tomographic image showing an example of simultaneous use of a percutaneous pigtail catheter to drain a bile collection (left) and a PEG tube (center) in the same patient.

COMPLICATIONS OF NONOPERATIVE MANAGEMENT OF TRAUMATIC INJURIES

Complications associated with nonoperative management of blunt traumatic injuries include, but are not limited to, the following: missed injuries, delays in diagnosis and/or treatment, potential iatrogenic injuries resulting from minimally-invasive techniques, intra-abdominal sepsis and abscess, inadequate resuscitation, delayed rupture of traumatic pseudoaneurysms (especially splenic).

Infections prevail as one of the most common causes of morbidity in trauma patients. Infection has been one of the late consequences of nonoperative management of traumatic injuries, especially in the setting of critically ill patients who require prolonged intensive care unit stays. Clinicians caring for severely injured patients who are being managed nonoperatively should have a high index of suspicion and should approach suspected infectious complications aggressively.

Table 9. Synopsis of complications associated with nonoperative management of traumatic injuries.

- Missed injuries
- Delay in diagnosis and/or treatment
- Inadequate/delayed resuscitation
- Retained hematomas (at risk for infection/abscess)
- Iatrogenic injuries secondary to minimally invasive treatment
- Abdominal sepsis and/or abscess
- Biliary/pancreatic leaks secondary to biliary/pancreatic injury
- Urinary collection secondary to renal/ureteral/bladder injury
- Delayed rupture of pseudoaneurysms
- Delayed aortic rupture
- Complications of delayed treatment of vascular injury (thrombosis, compartment syndrome, potential limb loss)

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Many of the complications of nonoperative management of traumatic injuries are amenable to percutaneous of endoscopic interventions and do not require formal surgical exploration. For example, biliary leaks and bile collections following nonoperative management of hepatobiliary injuries can be successfully managed utilizing percutaneous cholangiographic techniques and endoscopic retrograde cholangiopancreatographic techniques.[112-113]

Although many post-traumatic hematomas resolve spontaneously, percutaneous techniques may be of therapeutic and diagnostic value, and may obviate surgical intervention if successful. The benefits of percutaneous drainage of hematomas (ability to obtain fluid gram stain and cultures, relief of compressive symptoms, potential cure) has to be weighed in the context of associated risks (bleeding, introducing infection, damage to surrounding structures).

Certain complications of nonoperative management of pancreatic injuries may also require further invasive treatment. These include pancreatic fistulae, pancreatic ascites, and post-traumatic pancreatitis with potential for pseudocyst formation. While many of these injuries can be treated with a combination of ERCP and percutaneous techniques, some may require an operation.[113]

Complications of nonoperative management of urinary tract injuries include urinoma formation, which may be amenable to a combination of urologic endoscopic procedures (retrograde stenting) and interventional radiologic procedures (percutaneous drainage). Lastly, various types of traumatic pseudoaneurysms may qualify for percutaneous interventions, with operative treatment reserved for failures of nonoperative or minimally invasive therapy.[114]

CONCLUSIONS

Nonoperative management of both blunt and penetrating traumatic injuries can be challenging. However, it can be quite satisfying to be able to successfully manage patients with severe and multiple traumatic injuries in nonoperative fashion. The advent of sophisticated imaging technologies and adjunctive minimally invasive techniques has somewhat lightened the trauma surgeon's operative burden. Despite that, more than ever, nothing surpasses the value of repeated clinical assessment by an experienced trauma surgeon, in guiding the ultimate therapeutic decisions. After all, the ultimate default pathway for severely injured trauma patients who failed nonoperative management is the operating theatre.

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