Current management of penetrating torso trauma: nontherapeutic is not good enough anymore

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A highly organized approach to the evaluation and treatment of penetrating torso injuries based on regional anatomy provides rapid diagnostic and therapeutic consistency. It also minimizes delays in diagnosis, missed injuries and nontherapeutic laparotomies. This review discusses an optimal sequence of structured rapid assessments that allow the clinician to rapidly proceed to gold standard therapies with a minimal risk of associated morbidity.

En présence de traumatismes thoraciques pénétrants, une approche diagnostique et thérapeutique hautement organisée permet de standardiser et daccélérer l'évaluation et le traitement. Ce type d'approche s'accompagne aussi d'une réduction des retards de diagnostic, des lésions susceptibles de passer inaperçues et des laparotomies non thérapeutiques. La présente synthèse propose une séquence optimale d'évaluations structurées rapides qui peuvent aider le clinicien à traiter le patient selon les règles de l'art, avec un risque minimum de morbidités associées.

Over the past century, the management of penetrating torso trauma has engaged in repeated cycles involving both operative and nonoperative algorithms. In part, this sequence has been based on alterations in hospital resources, advances in diagnostic imaging and period-specific beliefs of well-known thought leaders.

Since the introduction of firearms at the 1346 Battle of Crecy, the management of penetrating abdominal wounds has been debated. In 1834, a French military surgeon (Dr. Baudens) completed the first reported exploratory laparotomy for a penetrating abdominal injury.[1] She commented that one must "introduce a finger or small sponge into the wound to determine the presence of blood, feces or bubbles of gas, and therefore proceed to laparotomy." On a practical note, however, this viewpoint was stunted by the rudimentary delivery of "anesthesia" until 1846.[2] Despite a subsequent 1887 American Surgical Association statement mandating operative exploration (laparotomy) for all civilian abdominal gunshot wounds, widespread adoption of this approach was not immediately successful either. In the Anglo-Boer War (1899–1902), for example, Sir William McCormick dictated a policy of no exploration. This contrasted Princess Von Gedroit's experience in the Russian–Japanese War (1904–1905) with mandatory operative exploration of all abdominal gunshot wounds. It was not until midway through World War I (1915) that a substantial improvement in mortality was noted with a policy of frequent laparotomy.[3] Routine exploration then remained the standard of care for decades and is partially responsible for the observed decrease in mortality from World War I (53%) to World War II (24%), the Korean conflict (12%) and the Vietnam War (9%).[3] Routine exploration was also popularized throughout the United States as these surgeon-soldiers returned home to work in civilian centres.

In the 1960s, Shaftan[4,5] (United States), Nance and Cohn[6] (United States) and Stein and Lissoos[7] (South Africa) reintroduced the concept of nonoperative management of selected penetrating abdominal wounds. This was

primarily a response to the overwhelming increase in patient volumes associated with the proliferation of handguns in urban America. There was also an epiphany that civilian weapons were much less powerful than the military-grade guns to which surgeons had become accustomed. Over the past decade, this approach ("selective conservatism") has become increasingly popular for both stab and gunshot wounds of the abdomen.[8–10]

It must also be stated at the outset that despite the transformational impact of cross-sectional imaging on the care of modern trauma patients, penetrating scenarios often render this ubiquitous test unhelpful. Although a policy of liberal computed tomography (CT) for severely injured blunt trauma patients has clearly become the standard of care, anatomic and algorithmic approaches to stab and gunshot wounds differentiate the experienced and efficient clinician from the uncomfortable one. As a result, the aim of this review is to discuss a logical and systematic approach to the diagnosis and management of patients with penetrating torso trauma.

Challenges with penetrating torso trauma

Penetrating trauma presents considerable difficulties for the clinician. Potential challenges include the use of external wounds as markers of internal injuries; injury patterns that are not always predictable; multiple wounds; single wounds that traverse multiple anatomic areas (i.e., chest and abdomen); hemodynamic instability; major vascular injuries, which are much more common than in blunt trauma; and a substantially worse reliability of the physical examination for detecting peritonitis in the context of a rapid increase in morbid obesity. Common traps include, but are not limited to, missing additional wounds and therefore missiles, assuming a straight line of trajectory, assuming "entry" versus "exit" wounds, relying on "probing" a wound, missing cavitary penetration, relying on initial hemodynamic stability and not recognizing missile and/or air embolization.

Initial assessment and resuscitation

Rapid prehospital transport of patients with penetrating injuries to a trauma centre is paramount.[8,11–13] The time interval from injury to control of hemorrhage is the dominant variable defining patient survival.[8,12–15] As a result, urban centres with advanced prehospital systems and experienced trauma surgeons (i.e., rapid decision-making) often show impressive survival characteristics despite major vascular injuries.[16–19] Given that patients with penetrating torso injuries behave much differently than those with blunt trauma, they should also be assessed using unique approaches.[8] More specifically, all patients must be thoroughly and immediately inspected for penetrating wounds (i.e., axilla, groin, perianal, perineum). Palpation of the actual penetrating wound is extremely tender to the patient and therefore unhelpful. Missing wounds is a common source of preventable morbidity.

The clinician should initiate the diagnostic search for injuries of relevance with the tests that will prompt transfer to the operating theatre if found to be positive. All wounds should also be rapidly marked (radio-opaque marker) to improve the interpretation of subsequent radiographs. Both anterior–posterior and cross-table lateral radiographs are essential early in the resuscitation to provide data on possible injuries and trajectories. In general, the number of holes added to the number of missiles should provide an even number. This rule is rarely broken. Plain radiographs also prompt intervention in scenarios of hemothorax, pneumothorax and/or free intraperitoneal air. Although the clinician's goal should be to avoid missing any injuries, a complete diagnosis of all injuries is not mandatory before operative intervention in hypotensive patients nearing physiologic exhaustion. In addition, a nontherapeutic laparotomy remains a preventable form of significant morbidity that can be avoided using an organized approach to penetrating injuries.[8–10] More specifically, complications occur in up to 41% of all patients,[20–23] leading to a substantially increased length of stay in hospital[24,25] and significant costs.[24–26]

Early focused assessment with sonography for trauma (FAST) examination is mandatory for detection of a possible pericardial hemorrhage (i.e., cardiac injury).[27–30] Although it is also helpful in detecting the presence of fluid within the peritoneal cavity, this should not directly alter a clinician's management in the absence of hypotension, diffuse peritonitis or evisceration.[8–10,27–30] As a result, the dominant utility of FAST in penetrating scenarios is to rule out pericardial tamponade and evaluate patients with multisystem injuries.

The remaining approach to the initial assessment of patients with penetrating torso trauma relies on a combination of many basic advanced trauma life support (ATLS) principles[31] (e.g., adequate intravenous access, prevention of hypothermia) with the addition of very early transition to blood products as per damage control resuscitation principles in hemodynamically unstable patients.[32–34] This includes an immediate transfer to the operating theatre for hemorrhage control as the dominant guiding principle for improving the patient's probability of survival. The apparent success of "hypotensive resuscitation" in both the civilian and military contexts is also crucial.[35,36] More specifically, elevation of a patient's systolic blood pressure greater than 80 mm Hg before obtaining definitive hemorrhage control has clear and repeatable consequences with regard to increased bleeding.[37–39] This is a direct result of intraluminal clot ejection and reversal of vascular spasm in completely transected vessels.

The indications for emergency department (ED) thoracotomy (EDT) remain controversial.[8,40,41] Patients with penetrating cardiac trauma and loss of signs of life within the trauma bay continue to benefit most from EDT. As the time without vital signs increases, so does the unlikeliness of functional neurologic salvage in a moribund patient. There remains no role for ED laparotomy. Despite initial enthusiasm in the 1970s,[42] it is clear that EDT for the purpose of reducing hemorrhage within the peritoneal cavity (i.e., major abdominal vascular injury) is widely unhelpful. Back bleeding from the large blood volume below the aortic clamp remains a standard source of exsanguination. As a result, penetrating torso wounds also mandate central venous access (if needed) through subclavian or internal jugular lines (i.e., above the diaphragm). Resuscitation through a femoral central line is unhelpful in the context of an injury to the right iliac vein, inferior vena cava, liver or hepatic veins.[8] It should also be noted that despite highly debated discussions of absolute indications for EDT dating back nearly 40 years, patients with narrow complex pulseless electrical activity (PEA) are generally good candidates for EDT.[40,41] Patients who arrive in asystole represent the opposite end of the spectrum and are almost uniformly nonsalvagable. Patients who arrive in wide complex PEA represent a transition toward cardiac death and, as a result, are very rarely salvaged with functional neurologic outcomes despite the usual 1–3 hours of attempted resuscitation and operative intervention. Caution must be used before initiating EDT in these patients.

The presence of blood, feces, urine and/or succus in nasogastric tubes or blood in a Foley catheter should alert the clinician to potential organs of injury. Finally, a detailed discussion of damage control indications and procedures is beyond the scope of this review, but it must be remembered that candidates for damage control surgery (including open abdomens) are only those patients with continued and progressive decompensation with regard to intraoperative physiology despite ongoing massive resuscitation.

Evaluation by regional anatomy (zones and boxes)

The human torso can be divided into various zones and boxes of regional anatomy. Because the treatment of penetrating injuries is based on anatomy and physiology, this template provides the clinician with a structured approach to diagnosing and treating all wounds.[8–10] More specifically, a systematic evaluation of each zone using known regional anatomy and external markers of trauma is crucial (Box 1). In general, this approach minimizes missed injuries as well as any delays in diagnosis. It also provides a consistent and predictable approach to all injuries and therefore avoids unnecessary laparotomies and associated resource implications.

It must be noted that both the thoracoabdominal and abdominopelvic regions are unique because penetrating wounds to these zones may cause injuries in either body cavity/area. Particularly in the case of gunshot injuries, trajectories can also extend across 3 or more anatomic regions (pelvis–abdomen–thorax–neck). The thoracoabdominal region is marked by the fourth intercostal space superiorly (nipple level) and the costal margin inferiorly around the entire torso.[43] This region changes with each cycle of breathing given the continuous movement of the diaphragm. The cardiac box is restricted by the nipple lines laterally, sternal notch superiorly and xiphoid process inferiorly. This box is clearly a crucial region for evaluation given the risk of cardiac tamponade and rapid death. The pelvis is limited superiorly by the iliac crest (posterior) and pubic crest (anterior), as well as inferiorly by the gluteal fold (posterior) and base of the testes (anterior). The anterior abdomen is marked posteriorly by the mid-axillary line, inferiorly by the pubic crest, superiorly by the xiphoid process and costal margins and bilaterally by the iliac crests. The flank and back region is limited anteriorly by the mid-axillary line, superiorly by the level of the scapula tips and inferiorly by the iliac crests.[44]

Abdominal stab wounds

Stab wounds represent an injury with significantly less kinetic energy than gunshot wounds. This reality results in a substantially lower chance of injury requiring repair and therefore should parlay into a lower intervention rate. Among all patients with stab wounds, approximately 55% arrive at a trauma centre with hypotension (i.e.,

Box 1. Organs of potential concern within anatomical zones and boxes

Right thorax
- Lung
- Superior vena cava

Left thorax
- Lung
- Aorta

Transmediastinal

Anterior mediastinum
- Heart
- Trachea
- Great vessels

Posterior mediastinum
- Aorta
- Esophagus
- Spine

Anterior abdomen
- Stomach
- Small bowel
- Transverse colon
- Mesentary
- Liver/porta hepatis
- Spleen

Back and flank
- Retroperitoneal colon
- Kidneys
- Ureters
- Pancreas
- Aorta
- Inferior vena cava
- Spine

True pelvis
- Iliac arteries and veins
- Bladder
- Urethra
- Ureters
- Rectum
- Vagina
- Uterus

Cardiac box
- Heart

hemodynamic alterations), diffuse peritonitis and/or evisceration.[8] Regardless of anatomic zone, these represent absolute indications for emergent operative intervention in most centres.

Flank and back

The remaining 45% of patients present with hemodynamic stability, no evisceration and an absence of significant torso tenderness remote to the actual wound site.[8] Management of these stable patients is based on the site of the wound. In those with flank and/or back wounds, cross-sectional imaging is a common option after completion of the initial assessment.[9,44–47] If selected, this should generally involve triple-phase (oral, intravenous and rectal) contrast CT of the entire torso. When the clinican's aim is to detect retroperitoneal contrast leakage from potential colonic injuries, adequate distention with rectal contrast is critical. If the colonic site of interest is not well opacified (i.e., right flank stab but insufficient rectal contrast), then the study is generally considered inadequate. To ensure optimal results, detailed communication with both the radiology technician and patient is essential. If patients with stab wounds to the flank and back undergo a policy of routine laparotomy/exploration, the associated nontherapeutic rate will approximate 85%.[8]

Anterior abdomen

Management of the patient with an anterior abdominal stab wound offers substantially more diagnostic options and discussion. These options include, but are not limited to, routine laparotomy, local wound exploration, screening laparoscopy, CT, diagnostic peritoneal lavage (DPL) and observation. It should be noted that CT in these patients is much less useful than in the context of gunshot wounds because it is the high kinetic energy of a bullet and entrainment of air that provides the clinician with an excellent visual trajectory/tract.[8–10] The deepest extent of a knife trajectory, however, is typically very difficult to delineate and is often misleading. As a result of these observations, in addition to the clear inadequacies of CT for confirming injuries to the diaphragm or bowel, most high-volume centres do not routinely image anterior abdominal stab wounds with CT.

Although the literature is filled with individual case series describing extreme examples, a policy of routine laparotomy for anterior abdominal stab wounds will result in a nontherapeutic laparotomy rate of nearly 60%.[25,48–51] With the addition of a local wound exploration (LWE), this rate can be decreased to less than 50%.[52–54] It must be noted, however, that the definition of an LWE is a surgical procedure performed with appropriate sterile technique and instruments that define either the base of the wound or the most superficial fascial level (whichever is encountered first). If the wound proceeds beyond the fascia, the LWE is considered positive. Progression to deeper layers of the abdominal wall is frowned upon given the increase in local morbidity as well as the associated high rate of known penetration of the peritoneum when the anterior fascial layer is violated. As a result, the LWE fundamentally differs from "probing" the wound with a finger or instrument. Probing is notoriously unreliable and therefore cannot be recommended in any scenario with the exception of confirming a completely tangential torso wound in a stable patient. The dominant utility of the LWE is that patients who are found to be "negative" can undergo tissue closure and be discharged from the hospital. It should be noted, however, that if a patient is admitted for serial observation following a positive LWE, the subsequent physical examinations can be complicated by pain associated with the LWE itself.

Proceeding in an anatomic fashion, another diagnostic option is laparoscopy.[55–57] This procedure can be divided into 3 distinct entities: laparoscopy defined as "positive" when penetration of the peritoneum has occurred (screening laparoscopy); laparoscopy that includes a full inspection of all intraperitoneal and retroperitoneal structures (diagnostic laparoscopy), including the lesser sac, gastroesophageal junction and pelvis; and laparoscopy with active repair of injured structures (therapeutic laparoscopy).[55] Secondary to its ease of completion and therefore extrapolation to most trauma surgeons, screening laparoscopy has become the most common of these entities. If a positive screening laparoscopy is used as a trigger for a subsequent laparotomy, the nontherapeutic laparotomy rate decreases slightly to 40% of all patients.[48,49,55] It should also be noted that presumably owing to variable skill levels, the published missed injury rate associated with diagnostic laparoscopy ranges from 0% to 82%.[55] Despite this wide range, larger studies cluster at 9%–18%.[55] One recent and novel idea to address this recurrent issue is to combine laparoscopy with DPL.[58] Once the laparoscopy is complete, a standard DPL is performed through any port.[58] This combined approach may also limit the dominant problem with stand-alone DPL. More specifically, using DPL alone as an indication (> 10 000 RBC/mm^3) for subsequent laparotomy in patients with anterior abdominal stab wounds is overly sensitive and results in an unacceptably high rate of nontherapeutic explorations.

An alternate and increasingly popular option to manage patients with an anterior abdominal stab wound in the absence of hypotension, diffuse peritonitis and evisceration is admission and observation with serial clinical examinations.[8–10,59–61] Selective nonoperative management (SNOM; formally termed "selective conservatism") can now arguably be considered the standard of care for stab wounds in numerous centres of varying resources and cultures. While opponents of this philosophy often erroneously cite the presence of

highly specialized observation wards in high-volume centres, it is undeniable that if serial clinical examinations by a physician (including trainees) are not available, SNOM is not safely possible. Exclusion of patients with concurrent traumatic brain or spinal cord injuries or intoxication as well as those undergoing nonabdominal operative procedures who are unable to cooperate in serial clinical examinations is also crucial. The physical examination must be reliable when applied to any patient. It must also be stated that patients undergoing SNOM should receive little narcotic analgesics, which can mask clinical findings, and must be monitored for changes in vital signs and laboratory tests (white blood cell count and hemoglobin). Isolated omental evisceration is not an absolute contraindication to SNOM.[48,62,63] There is no evidence of increased morbidity or length of stay in hospital in patients who undergo SNOM.[8–10,59–65] Most visceral injuries requiring repair after anterior abdominal stab wounds will transition to a positive clinical examination within 12 hours.[64] This duration is extended to 18 hours for flank and back wounds.[65]

Thoracoabdominal stab wounds

Historically, patients who require a laparotomy for the abdominal component of their injury complex require a concurrent tube thoracostomy and thoracotomy in two-thirds and one-third of cases, respectively.[8] It is essential, however, that all patients with left upper quadrant anterior abdominal stab wounds undergo a diagnostic laparoscopy for an associated diaphragm injury before discharge.[9,10,66,67] This modality is excellent at both detection and repair in up to one-third of patients who have an associated diaphragm injury.[55,66,67] The time frame of performing laparoscopy is debated. While some clinicians prefer to perform this intervention earlier, waiting 12–24 hours after admission may benefit the patient by lowering the risk of missing associated injuries.[10] More specifically, patients with concurrent injuries requiring repair will evolve with regard to peritonitis before the scheduled laparoscopy and will therefore be candidates for a combined repair (either laparoscopy or laparotomy).

Debate also exists over the utility of laparoscopy in patients with right upper quadrant stab wounds given the substantial coverage of the diaphragm in this hemitorso by the liver.[9,67] Despite this anatomic advantage, hepatic herniation and lacerations of the diaphragm anterior to the liver are not entirely uncommon. It should also be noted that a standard upright/supine chest radiograph is notoriously insensitive to small diaphragm injuries and must not be relied on to rule out diaphragm trauma.[66]

Cardiac box

Concern over potential cardiac injuries should be uncommon upon completion of the pericardial window during the FAST examination. This test is incredibly sensitive for detecting cardiac trauma.[27–29] The isolated exception (i.e., false negative) occurs in a patient with a right-sided (low pressure) cardiac injury and a concurrent hole in the pericardium leading to a recurrent low-volume hemothorax despite tube thoracostomy.[68] As a result, any patient with a residual hemothorax in the context of adequate thoracic drainage and a potential cardiac trajectory must undergo an urgent pericardial window.[68] This procedure can be completed with local or general anesthetic. The patient must be prepared and draped for a sternotomy before induction with any general anesthetic, however, given the risk of concurrent cardiac arrest due to alterations in cardiac physiology. A pericardial window may also be indicated in select patients with associated subcutaneous emphysema and/or morbid obesity that prevent adequate ultrasound visualization.[27–29] If positive, a patient with a stab wound should undergo a median sternotomy, as opposed to a patient who sustains a gunshot wound (lateral or bilateral thoracotomy may be preferred over a median sternotomy).

Abdominal gunshot wounds

Given the higher kinetic energy associated with gunshot wounds, the incidence of injury and therefore laparotomy, is significantly higher than with stab wounds.[8–10] As a result, a policy of routine laparotomy in patients with gunshot wounds to the torso will result in a nontherapeutic laparotomy rate of up to 20%.[9,10,44,69–75] If the missile can be proven to have entered the peritoneal cavity remote from isolated solid organ injuries, the rate of nontherapeutic laparotomy is likely as low as 2%–4%.[9,10,44,69–75] This discrepancy is clearly impacted by the increasing prevalence of obesity in our society. As a result, tangential extraperitoneal wounds are becoming more common. The even higher complication risk associated with morbidly obese patients makes excluding those patients who do not need operative interventions that much more crucial.

Based on these high risks of injury requiring operative therapy, SNOM of gunshot wounds must be limited to patients with high-fidelity, cross-sectional imaging and careful selection. Computed tomography scans are absolutely critical in plotting missile trajectory and risk stratifying potential consequences of direct and kinetic trauma. In the past decade, SNOM of patients with gunshot injuries to solid organs, such as the liver and kidneys, is increasingly common and successful.[9,10,44,69,72–74] This concept relies on receipt of a normotensive patient without peritonitis. The published series of patients with high-grade hepatic and renal gunshot injuries who are safely managed without a laparotomy are increasingly impressive.[9,10,44,69,72–74] These include patients who may require

angioembolization for moderate arterial hemorrhage and/or pseudoanuerysms. It must be clear though that when missile trajectory and hollow viscous structures intersect or when free fluid/air is adjacent to a hollow viscous structure laparotomy is indicated. It must also be noted that high-grade hepatic injuries with significant spillage of intraperitoneal blood and/or bile may require a delayed laparoscopic washout and drainage.[76,77] If bilious drainage persists, an edoscopically placed intrabiliary stent is indicated to decrease biliary pressures and enhance closure of the fistula. Furthermore, hematuria following insertion of a Foley catheter does not mandate operative exploration in a hemodynamically stable patient without diffuse peritonitis given SNOM principles. It clearly requires subsequent investigation.

Pelvic gunshot wounds

Transpelvic gunshot wounds are particularly challenging given the high number of anatomic structures at risk, as well as the potential involvement of multiple zones (anterior abdomen, back/flank, true pelvis). As a result, 85% of all transpevic trajectories will cause injury to an internal organ.[8,78–81] As noted above, a clinician's diagnostic workup should begin with whichever test has the highest likelihood of mandating operative intervention. These tests include bedside rigid sigmoidoscopy (presence of blood and/or bone), cystography, lower extremity distal pulse quality and presence (femoral, popliteal) and ankle-brachial indices (ABI). Loss of distal pulses and/or an ABI less than 0.9 mandates immediate investigation. This may include angiography and/or operative exploration for iliac arterial injuries (particularly for a sustained ABI < 0.8). In experienced hands, concurrent diagnosis and repair may be most efficient within the operating theatre (although preoperative CT-angiography represents a reasonable alternative). Finally, it should also be noted that although balloon catheters[82] and temporary intravascular shunts,[83,84] represent excellent methods of achieving vascular control, technical details are beyond the scope of this review.

Conclusion

An organized approach to the evaluation and treatment of penetrating torso injuries based on regional anatomy provides diagnostic and therapeutic consistency for the clinician. It also minimizes both delays in diagnosis and missed injuries. In addition, this approach prevents the significant morbidity associated with nontherapeutic laparotomies while concurrently conserving hospital and societal resources. This framework allows the clinician to answer the questions, "Did the projectile/injury enter the peritoneal, retroperitoneal or pelvic cavity?" and "Is it an injury that will require a laparotomy to repair?".

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