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Vascular and Interventional Radiology in Blunt Abdominopelvic Trauma - Institutional Practice and Review of the Literature

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Abstract

Trauma is the leading cause of mortality among young Americans. One third of these patients die from exsanguination. Primary management of blunt trauma is non-operative for most hemodynamically stable patients. Advances in endovascular equipment and techniques have led to an established role for adjunctive endovascular therapy in selected patients. Here we provide a literature review and discuss the role of endovascular therapy in the setting of blunt abdominopelvic trauma with an emphasis on a multidisciplinary approach.

Keywords: Traumatic haemorrhage; Hyper-acute treatment; CT imaging; Vascular and interventional radiology; Traumatic brain injury

Introduction

Trauma is the leading cause of mortality among Americans 1-44 years old and is responsible for 193,000 deaths annually. One third of these patients die from exsanguination. Current practice guidelines emphasizing non-operative management (NOM) of most hemodynamically stable blunt trauma patients and advances in endovascular equipment and techniques have led to an established role for adjunctive endovascular therapy in the arrest of traumatic hemorrhage.

Prospective randomized trials are difficult to perform in the trauma setting for a number of reasons. The trauma patient population varies widely with respect to the type and extent of injuries, clinical status on presentation, patient demographics, and the presence of pre-existing comorbidities. In addition, the often hyper-acute treatment scenario creates an obstacle to randomization. This has lead to a lack of level 1 evidence and a reliance on retrospective studies and expert consensus guidelines [1,2].

The last two decades have witnessed major advances in the management of trauma patients from the standpoints of diagnostic and interventional radiology. Innovations in digital subtraction angiography, embolic agents, microcatheters, and stent graft technology have broadened the scope and improved the efficiency and efficacy of endovascular treatment for traumatic hemorrhage. With the advent of rapid acquisition multidetector CT imaging, angiography is no longer required for diagnosis and characterization of solid organ and major vascular injuries, instead being reserved for therapeutic or problem-solving scenarios. Contrast enhanced CT (CECT) is highly sensitive and specific and is routinely performed in most patients with blunt abdominopelvic trauma. CECT is invaluable for localizing sites of injury prior to angiography. The American Association for the Surgery of Trauma (AAST) has devised the organ injury scales (OIS) to grade traumatic organ injury, thereby standardizing reporting and communication [3].

Effective integration of vascular and interventional radiology (VIR) into the trauma management paradigm requires an on-call VIR team composed of an interventional radiologist with an assistant, a nurse skilled in critical care, and an interventional radiology technologist. The team response time should be within 60 minutes. Availability of contemporary angiographic equipment with digital subtraction capabilities and a complete array of VIR supplies (i.e. angiographic catheters, microcatheters, guidewires, stents, stent-grafts, and embolic agents) are required.

The importance of rapid patient assessment and resuscitation prior to and during the VIR procedure cannot be overstated. Multiple injuries are the rule rather than the exception in trauma patients. Because VIR procedures can be time consuming, it is crucial that life and limb threatening injuries are recognized and prioritized. For example, a patient with traumatic brain injury and pelvic trauma may require decompressive craniectomy prior to pelvic angiography and embolization (AE). Likewise, an unstable pelvic fracture may require external fixation or pre-peritoneal packing prior to AE. In general, patient triage is managed by the trauma surgery team; however, multidisciplinary patient assessment and communication between all collaborative services are crucial for effective care. Institutional trauma management using an algorithm-driven protocol is an effective means to apply best-practice therapies to these often critically ill patients.

AE is the most commonly utilized VIR technique in the acute trauma setting, with stent and stent graft placement playing a role in specific scenarios. Embolization is the intentional introduction of material into the vasculature to cause mechanical occlusion and thereby arrest blood flow. The primary goal of AE in the trauma setting is to arrest hemorrhage. A secondary goal is to minimize non-target embolization, thereby preserving organ function and limiting ischemic sequelae. We typically use metallic coils and/or gelatin sponge (Gel foam, Pfizer, New York, NY). Gel foam is a temporary embolic agent, with recanalization of the embolized vessel occurring within 2-4 weeks in most cases [4]. Most embolic agents require a functional coagulation cascade to work effectively. It is therefore crucial that AE is performed before the onset of the coagulopathy which develops in one third of patients with hypothermia and major hemorrhage requiring multiple blood transfusions [5]. N-butyl cyanoacrylate (nBCA) (Trufill, Codman, Raynham, MA) and ethylene vinyl alcohol copolymer (Onyx, Covidien, Plymouth, MN) are notable exceptions, effective even in the setting of coagulopathy. Cost, availability, time consuming preparation, and a technical learning curve preclude the widespread use of nBCA and Onyx in the trauma setting. Stent placement may be indicated in the setting of traumatic dissection of large or medium sized visceral arteries. The endovascular management of hemorrhage arising from large arteries (common hepatic artery, proper hepatic artery, main renal artery, etc.) entails deployment of a stent-graft to cover the site of arterial injury.

Splenic Embolization

The spleen is the most commonly injured organ in blunt abdominal trauma [6]. Missed splenic injury remains the most common cause of preventable death in trauma patients [7]. Patients with splenic injury who are hemodynamic unstable or only transiently respond to resuscitation are treated with emergent laparotomy. NOM with observation is currently the standard of care for most hemodynamically stable patients. NOM eliminates the morbidity of laparotomy and reduces time of hospitalization, transfusion requirements, and cost while preserving splenic function and improving overall survival rates [8].

Intravenous CECT is the imaging modality of choice for determining AAST splenic injury grade, presence and characterization of splenic vascular injuries, extent of hemoperitoneum, and accompanying injuries [9-11]. CECT findings of splenic intravenous contrast extravasation (ICE), pseudoaneurysm (PSA), or arteriovenous fistula (AVF) are risk factors for NOM failure as well as indications for surgical or angiographic management [12]. There is controversy regarding the validity of these predictive findings, however, as several studies have found a low rate of angiographic correlation with CECT findings of splenic vascular injury[13,14].

There are two types of splenic embolization which can be utilized in the trauma setting: proximal main splenic artery occlusion (SAO) and distal splenic branch embolization (SBE). This distinction is not always clearly stated in medical literature and may confound analysis.

SAO is used as an adjunct to NOM and improves the success rate of NOM leading to splenic salvage rates of 89%-97% [9,10]. SAO entails mechanical occlusion of the main splenic artery. This lowers parenchymal blood pressure, which facilitates parenchymal healing and potentially prevents delayed splenic rupture. After SAO, arterial blood flow to the spleen is maintained via several collateral beds including the pancreatic, gastroepiploic, short gastric, and splenic capsular pathways. Collateral perfusion preserves splenic function and avoids splenic infarction.

SAO is indicated in hemodynamically stable patients with one or more of the following CECT findings: AAST injury grade III or higher, moderate or large hemoperitoneum, or splenic ICE/PSA/AVF. CECT findings must be interpreted in light of the patient's clinical status. Falling hematocrit requiring the transfusion of two or more units of packed red blood cells over 12 hours or persistent tachycardia despite resuscitation are additional indications for SAO. In our practice, we perform SAO embolization with metallic coils or vascular plugs placed 2 cm distal to the dorsal pancreatic artery. Completion angiography should confirm occlusion of the main splenic artery with delayed perfusion of the splenic parenchyma via collateral arteries (Figure 1a-1c).

SBE is performed beyond the splenic hilum and entails super selective embolization of injured splenic arterial branches. SBE has been associated with higher post-procedural complication rates, especially splenic infarction, without improved outcomes [15]. In our practice, we reserve SBE for patients with positive angiographic findings (contrast extravasation, PSA, AVF). SBE typically requires the use of a microcatheter and increases procedure time, contrast material use, and radiation exposure. In cases of multifocal high grade injury with splenic branch artery injury by angiography, SAO is performed after SBE. In cases with a single focal splenic injury with angiographic correlate, SBE may be performed without SAO. One advantage of not performing SAO after SBE is maintaining access for repeat parenchymal embolization if continued bleeding occurs.

Complications following splenic embolization occur in approximately 20%. Most of these are minor, requiring only supportive care, and include fever, left upper quadrant pain, and left pleural effusion. Splenic embolization failure requiring splenectomy occurs in 10% [16]. Continued splenic bleeding, splenic infarction, splenic abscess, contrast induced nephropathy, pancreatitis and coil migration are other potential complications [17]. Unless complete splenic infarction occurs, splenic immune function is preserved after embolization making immunization against encapsulated organism's unnecessary [18].

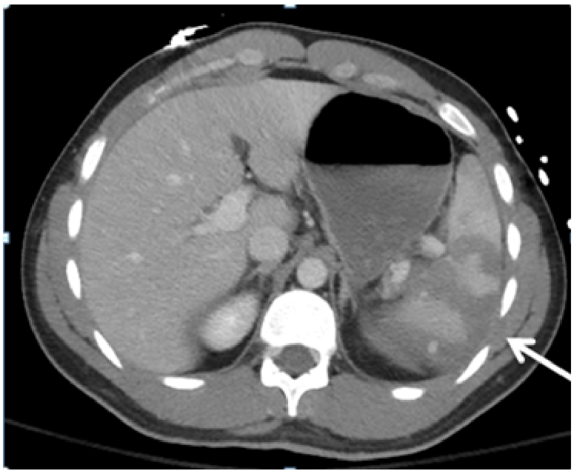

Figure 1a: AAST Grade III splenic laceration in a hemodynamically stable 23 year old male involved in a motorcycle collision. Contrast enhanced CT through the level of the spleen shows multiple splenic lacerations >3 cm (white arrow). Hemoperitoneum was also present (not shown).

Pelvic Embolization

Pelvic fractures occur in 4.0%-9.3% of blunt trauma patients [19]. Lateral compression fractures account for 65% of pelvic fractures, are typically stable without major ligamentous disruption, and require angiography in only 1% [20]. Anteroposterior, vertical shear, and combined type pelvic fractures often result in significant ligamentous injury with increased pelvic volume and require angiography in up to

20% of cases [20]. Pubic symphysis diastasis of 3-cm doubles the volume of the pelvis to 8 liters [21]. Loss of the tamponading effect of an intact pelvis can lead to life-threatening hemorrhage if not treated promptly. In many cases, hemorrhage is of venous origin. Common sources include bone fracture edges, soft tissue, and veins themselves. Venous bleeding sources can be controlled with external stabilization of the pelvis. AE is reserved exclusively for control of pelvic arterial bleeding, with control achieved in up to 95% and acceptably low complication rates [22].

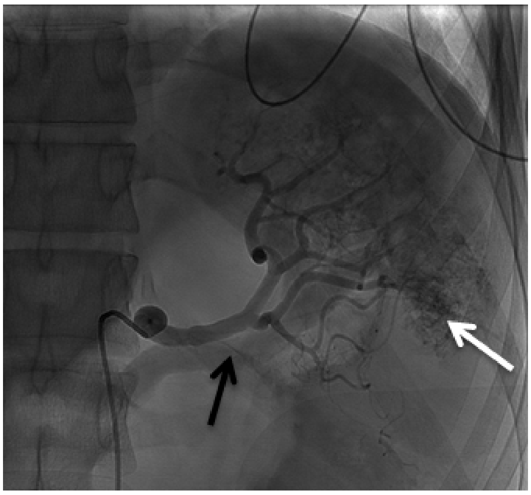

Figure 1b: Selective parenchymal-phase splenic angiogram shows post-traumatic changes in the lower pole (arrow) without contrast extravasation, pseudoaneurysm, or arteriovenous fistula. Note opacification of the splenic vein (black arrow).

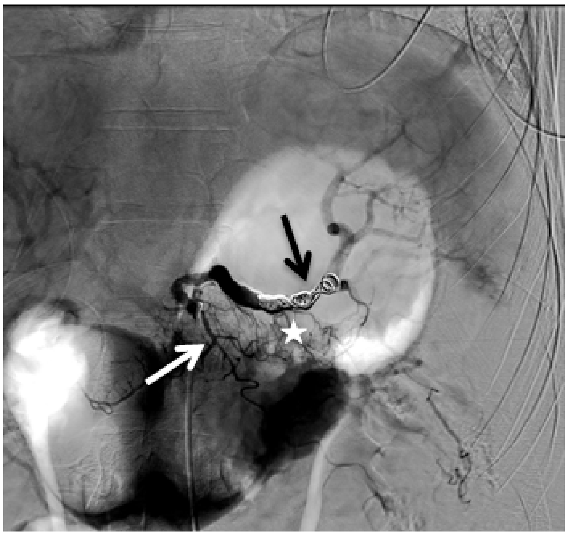

Figure 1c: Late parenchymal phase celiac arteriogram after main splenic artery occlusion (SAO) with 8 mm detachable coils (black arrow). The dorsal pancreatic artery (white arrow) and pancreatic arcade (star) reconstitute the splenic artery at the hilum providing collateral perfusion to the spleen.

A statistically significant survival benefit has been shown in patients with pelvic fracture and arterial bleeding who receive treatment within 3 hours of their injury [23]. While the mortality rate is less than 5% in hemodynamically stable patients, hemodynamically unstable patients have mortality rates approaching 40% [24]. Furthermore, surgical treatment options are limited. For these reasons, rapid and liberal implementation of AE for traumatic pelvic arterial hemorrhage is a common practice.

AE of the internal iliac artery to control arterial hemorrhage associated with pelvic fracture was first described in 1972 [25]. Emergent pelvic AE is indicated in hemodynamically unstable patients with pelvic fracture and no other source of bleeding [26]. Other indications include evidence of arterial injury by CECT regardless of hemodynamic status, and ongoing hemorrhage with suspicion of a pelvic arterial source after previous pelvic AE. CT arteriography (CTA) is useful for localization and characterization of pelvic hemorrhag as well as assessment for other injuries [27]. Concomitant injuries are seen in up to 50% of pelvic fractures [28]. Pelvic CTA can be readily integrated into trauma CT imaging of the thorax and abdomen [29]. Brasel et al. correlated ICE on CTA with angiographic findings as the gold standard and found a sensitivity of 90.5% and specificity of 96.1% for arterial bleeding [30].

Pelvic fracture patients often arrive to the angiography suite with a pelvic binder in place. At our institution the T-POD (Pyng Medical, Richmond, BC, Canada) is commonly used. A notch can be cut in the device to allow a window for femoral arterial access without compromising the binder's compressive effect. Alternative access via the brachial or radial artery can be utilized if the femoral arteries are inaccessible. Femoral access contralateral to the side of injury provides favorable catheterization angles and reduces catheter overlap which can obscure areas of interest.

Pelvic angiography for trauma should include an infrarenal aortogram and selective angiography of each internal iliac artery. Pelvic arterial injury most commonly involves internal iliac branches, however selective external iliac angiography has been advocated [31]. In our opinion, external iliac angiography has a role in the setting of negative internal iliac angiography with suspicion of ongoing pelvic arterial hemorrhage or as directed by CECT findings. External iliac artery branches including the external pudendal, deep circumflex iliac, inferior epigastric, and circumflex femoral may uncommonly be injured. The most commonly injured pelvic vessels in order of frequency are the superior gluteal, internal pudendal, obturator, inferior gluteal, lateral sacral, iliolumbar, external iliac, deep circumflex iliac, and inferior epigastric arteries [20]. Visceral pelvic vessels including the vesical, uterine, and middle rectal arteries are rarely injured in trauma. Lower lumbar, gonadal, and inferior mesenteric artery branches are other rare sources of traumatic pelvic hemorrhage.

Angiographic findings in pelvic trauma include contrast extravasation, PSA, AVF, dissection, transection, and occlusion. The goal of AE is to occlude the injured vessel. In most cases this can be achieved with gelfoam; however PSA and AVF management requires coils or plugs in many cases. In the setting of AVF, the potential for coil migration through the fistula to the pulmonary circulation must be considered. Findings of an occluded arterial branch may reflect spasm of the vessel in response to a more distal injury. Arterial spasm may resolve with time and resuscitation leading to delayed hemorrhage if left untreated. Angiographic false positives include bowel and ureteral peristalsis and normal uterine or cavernosal blush. These must be differentiated from vascular injury. Review of un-subtracted angiographic images is helpful for this purpose.

In the hemodynamically unstable patient with hemorrhage from an internal iliac artery source, embolization of the bilateral internal iliac arteries with gelfoam pledgets or slurry should be performed [13]. This can be performed rapidly and is very effective in achieving hemostasis. In hemodynamically stable patients with up to a few foci of pelvic arterial bleeding, we perform a selective embolization, typically with coils and/or gelfoam delivered through a coaxial microcatheter. In such cases, contralateral internal iliac arteriography after embolization is useful to exclude continued bleeding from embolized vessel via anastomoses with contralateral pelvic arteries. In patients with positive CECT findings without angiographic correlate, nonselective embolization of the corresponding anterior or posterior internal iliac artery division can be performed if the patient's clinical status suggests ongoing hemorrhage.

Early reports of male impotence and gluteal necrosis due to pelvic embolization have been largely disproven [32,33]. Continued hemorrhage after pelvic AE is the most dreaded adverse outcome, occurring in 15%-20% and associated with increased mortality [34].

Hepatic Arterial Intervention

NOM is currently the standard of care for blunt hepatic trauma and is successful in over 80% of patients [35]. In the past, numerous clinical factors have been regarded as contraindications to NOM. These include AAST hepatic injury grade III or greater, presence of ICE on CT, moderate or large hemoperitoneum, age >55, impaired neurological status, and requirement of multiple blood transfusions. Currently, however, hemodynamic instability is the only absolute contraindication to a trial of NOM. In the setting of hemodynamic instability, hepatorrhaphy, non-anatomic resection, and peri-hepatic packing via laparotomy are used as the initial approach. Hepatic angiography and embolization (HAE) has a very high success rate in control of arterial hemorrhage and can be used in the setting of NOM or as an adjunct to damage control laparotomy.

Hepatic artery anatomic variants are common, occurring in 24%-49% of patients [36]. The most common variants are a replaced/accessory right hepatic artery arising from the superior mesenteric artery and a replaced/accessory left hepatic artery arising from the left gastric artery. These account for well over 90% of variant anatomy as isolated anomalies or in various combinations. CECT prior to angiography is helpful not only for localization and characterization of sites of injury, but also to assess hepatic arterial anatomy.

The portal vein supplies 75%-80% of the blood flow to the liver and the hepatic artery supplies the remaining 20%-25%. Hepatic arterial embolization is therefore well-tolerated in the presence of a patent portal vein with hepatopedal blood flow. Bile ducts are largely supplied by the hepatic artery, however, so embolization of central hepatic arterial branches carries a risk of subsequent biliary necrosis [37]. In the setting of hemorrhage from the common or proper hepatic artery, endovascular management should consist of covered stent placement, if feasible. The gastroduodenal artery may need to be embolized with coils or a plug beforehand to prevent endoleak. Right hepatic artery embolization should preferably be performed distal to the cystic artery origin to avoid potential complications of cholecystitis or gallbladder ischemia/infarction [38].

The goal of HAE is to achieve hemostasis with as selective an embolization as possible. Unlike arteries of the spleen and kidney, hepatic arteries are not end arteries. Intrahepatic arterial collateralization is well documented [39]. We typically use a coaxial microcatheter system and attempt to embolize both distal and proximal to the site of arterial injury, the so-called "sandwich technique," to prevent distal reconstitution of the injured artery. If the point of injury cannot be crossed, we perform selective distal embolization with gelfoam slurry. In cases of multifocal extravasation we also perform embolization with gelfoam slurry. We reserve coils and plugs for management of arterial fistulas (to the biliary tree, portal vein, or hepatic vein) or PSAs.

Complications are not uncommon following HAE and the complication rate increases with AAST hepatic injury grade [38]. Dabbs et al. [37] reviewed 71 patients who received HAE for traumatic liver injury and found complications in 61%. These included major hepatic necrosis in 42%, abscess in 17%, gallbladder necrosis in 7%, and bile leak in 20%. Major hepatic necrosis did not confer an increased mortality in this study. Mohr et al [38] reported similar findings. Up to 85% of complications can be managed with conservative management, percutaneous drainage, ERCP or other non-operative interventional techniques [40].

Renal Intervention

Renal injury occurs in 10% of blunt abdominal trauma making the kidney the 3rd most commonly injured abdominal organ [41]. Like other blunt traumatic solid organ injuries, NOM is the current treatment paradigm for hemodynamically stable patients. Operative management often requires nephrectomy, so NOM is beneficial both to avoid surgical morbidity and to potentially preserve renal function in the injured kidney.

Most renal injuries are low grade renal trauma (LGRT) consisting of renal contusions (AAST grade I) or lacerations <1 cm deep (AAST grade II). The vast majority of LGRT is managed conservatively with observation [42]. High grade renal trauma (HGRT; AAST OIS grade III-V), while more likely to require intervention or surgery, can also be managed with a trial of NOM in hemodynamically stable patients. Several studies have demonstrated the safety and efficacy of NOM with adjunctive AE for HGRT with encouraging intermediate-term follow-up results [43-46]. AE in the setting of HGRT is performed with the goal of arresting hemorrhage. Embolization should be as selective as possible in order to preserve functional renal parenchyma. Endovascular management of grade V renal injuries is controversial, with reported clinical success rates ranging from 0% to 100% [47,48].

CECT with nephrographic and delayed (excretory) phase image acquisition is the gold standard for assessment of renal and ureteral injury in blunt trauma. In addition to grading the injury according to the AAST OIS, CECT also depicts the extent and location of any devascularized renal parenchyma. Other CECT findings in renal trauma relevant to interventional management include vascular occlusion, ICE, PSA, AVF, and urine leak.

Suggested indications for AE in the setting of renal trauma include ICE, AVF, or PSA, persistent gross hematuria, hemodynamic liability, or falling hematocrit [47].

A flush aortogram prior to renal artery catheterization is useful to evaluate for accessory renal arteries, which are common and may be a source of hemorrhage. Angiographic findings may include extravasation, PSA, AVF, occlusion, dissection, and arterio-calyceal fistula. We embolize only in the presence of angiographic findings. A microcatheter is typically required for subselective catheterization and embolization of the injured branch vessel with coils and/or gelfoam. If the injured branch cannot be catheterized, a less selective embolization with coils or gelfoam slurry can be performed.

Main renal artery injury is rare, occurring in 0.05% of blunt trauma [49]. Treatment options include nephrectomy, surgical or endovascular revascularization, and NOM. In the setting of a hemodynamically stable patient with a functional contralateral kidney, NOM is currently the most widely accepted treatment option due to poor surgical revascularization outcomes and limited evidence supporting a beneficial effect of endovascular therapy [50]. While stent placement for traumatic renal artery occlusion or dissection is a theoretically attractive option, it must be kept in mind that a warm ischemia time of more than 3 hours leads to irreversible loss of renal function [51]. Collateral perfusion via adrenal, renal capsular, peripelvic, and periureteric arteries and patency of the renal vein may extend the ischemic interval, however conservative management is the best option in hemodynamically stable patients if restoration of blood flow cannot be achieved within this time frame [52]. In addition, these patients typically cannot receive intraprocedural anticoagulation or antiplatelet agents after stent placement, which are the standard of care for renal stent placement in the non-trauma setting. This may predispose to stent occlusion and resultant loss of kidney function. Nevertheless, in appropriate cases, endovascular management of main renal artery dissection or transection may be attempted with bare metal or stent graft placement.

Renovascular hypertension (RVH) is an uncommon complication of renal artery occlusion occurring in 5% 49 within 3 months of injury. In refractory cases RVH requires nephrectomy [53]. Complications of AE for renal trauma include fever, pain, non-target embolization, renal artery dissection, and renal abscess. These can typically be managed conservatively, with percutaneous drainage utilized in the setting of renal abscess. New onset hypertension requiring medical therapy occurs in 0.06% of patients within 6 months following blunt renal trauma [54]. Renal AE does not appear to impart an increased risk of acute renal failure [55].

Conclusion

Blunt abdominopelvic trauma is common and results in substantial morbidity and mortality. NOM is widely accepted as a safe and effective first line therapeutic approach for the majority of hemodynamically stable patients. Adjunctive AE and other interventional techniques improve NOM success rates and clinical outcomes with acceptably low post-procedural complication rates and are an integral element of modern trauma management protocols.

Effective integration of interventional radiology into the trauma management paradigm requires adequate and available staffing and equipment, and importantly, rapid multidisciplinary assessment and direct communication. Institutional trauma management algorithms lead to a standardized application of best practices.

Technological developments and customized facilities tailored to evidence-based trauma management algorithms have the potential to expedite patient care and improve outcomes. The hybrid operating room, equipped for patient resuscitation, imaging, angiography, and surgical management, is one example. Initial treatment of the critically ill patient in a single location avoids the obvious risks and treatment delays associated with patient transport. Rapid diagnosis, resuscitation, and, where applicable, angiographic or operative intervention delivered in a streamlined manner represent the goal of modern multidisciplinary management of the trauma patient.

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