Visceral Trauma: Principles of Management and Role of Embolotherapy

Peter G. Stratil, M.D., M.B.A.,¹ and Thomas R. Burdick, M.D.^{1,2}

ABSTRACT

Interventional radiology for the treatment of traumatic visceral hemorrhage has emerged as an important adjunct to modern trauma care. This article outlines the general surgical concepts of the acute care of trauma patients as a guideline for catheter-based therapy. Specific considerations are presented for embolizing visceral injuries in the liver, spleen, and kidney. Expected outcomes and follow-up are reviewed.

KEYWORDS: Trauma, hepatic hemorrhage, splenic embolization, hepatic embolization, renal embolization, damage control laparotomy

Objectives: On completion of this article, the reader should (1) understand generalized principles of acute care of trauma patients and the role of interventional radiology; and (2) have a working knowledge of how to approach arterial injuries in the liver, spleen, and kidney.

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In the United States there are 1.9 million trauma-related hospital admissions and ~165,000 trauma-related deaths each year.¹ The associated costs are astounding, with an estimated \$406 billion lifetime costs related to injuries happening in the year 2000 alone.¹ The leading cause of fatal injuries is motor vehicle accidents, followed by firearm-related injuries. Interventional radiology is playing an increasing role in the management of trauma. Having a working knowledge of the principles of trauma care, including a basic understanding of trauma physiology as well as the medical and surgical options available to the patient, facilitates timely and effective collaboration with surgeons and other healthcare providers. A complete review of trauma care is well beyond the scope of this article, but some important concepts of trauma physiology as well as

surgical options available to the patient are presented. Using this information, the interventional radiologist can enhance his or her role as an important member of the trauma team. This article also reviews three specific areas for embolization in which this knowledge can be applied: hepatic, splenic, and renal traumatic injuries.

PHYSIOLOGY OF THE TRAUMA PATIENT AND PRINCIPLES OF MANAGEMENT

Physicians who treat patients suffering from blunt or penetrating abdominal trauma are often fighting the clock. Patients need to be assessed and treated quickly to stabilize life-threatening injuries. The physiology encountered in severe trauma is primarily related to hemorrhage with resulting exsanguination and what

¹Department of Radiology, University of Washington; ²Department of Radiology Harborview Medical Center, Seattle, Washington.

Address for correspondence and reprint requests: Peter G. Stratil, M.D., M.B.A., Radiology Resident, University of Washington, Department of Radiology Box 357115 959 NE Pacific Street, Box 357115, Seattle, WA 98195 (e-mail: pstratil@u.washington.edu).

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has been described as the "lethal triad" of hypothermia, coagulopathy, and acidosis.² These factors should constantly be addressed throughout trauma resuscitation.

Hemorrhage following trauma can lead to hypovolemia and reduced cardiac output. Treating blood loss first and foremost involves locating the site of and arresting subsequent blood loss. This can be accomplished using either surgical or interventional radiology techniques, which are addressed in more detail later in this article.

Hypothermia results from reduced perfusion, excess exposure, immobility, and the administration of resuscitative fluids. To counteract hypothermia, the radiology suite ambient room temperature should be raised to 80°F, the patient should be kept covered and dry, resuscitation fluids should be warmed, and warming blankets should be applied to the patient.³ If necessary, peritoneal lavage with warm fluid or extracorporeal rewarming can be used.⁴

Coagulopathy results from several factors, including dilutional coagulopathy from resuscitative fluids, as well as hypothermia and acidosis, which both affect the coagulation cascade.⁴ Strategies for treating coagulopathy include actively replenishing the needed coagulation factors with whole blood, fresh frozen plasma (FFP), platelets, and cryoprecipitate; it is generally addressed via institutional massive transfusion protocols. In addition, the underlying hypothermia and acidosis should be treated accordingly. Acidosis results from anaerobic metabolism in the setting of inadequate oxygen delivery. The best way to treat this is to stop active hemorrhage and restore oxygen delivery. Hypothermia, coagulopathy, and acidosis are interrelated and should be constantly monitored and addressed throughout the resuscitation period.

Controlling hemorrhage in a timely fashion is one of the cornerstones of trauma care, and is vital to slowing the progression of hypothermia, coagulopathy, and acidosis. The past 15 years have seen a gradual trend favoring damage control laparotomy (DCL) over conventional repair of abdominal trauma. The term *damage control* originates from a concept of military naval repair; the ability of a warship to withstand damage while maintaining mission integrity. The damaged hull of the ship undergoes rapid assessment and an adequate temporary patch allowing it to return to the controlled environment of port for definitive repair.⁵ The principal behind DCL is that the time required for definitive surgical repair of abdominal and visceral injuries permits the aforementioned lethal triad of hypothermia, coagulopathy, and acidosis to proceed unchecked. The role of DCL is to control life-threatening hemorrhage and contamination quickly, whereas definitive repair is postponed until the patient is stable. This approach has been proved to be effective in reducing mortality. In their landmark article, Rotondo et al demonstrated the effec-

tiveness of this technique in high-risk patients who presented with vascular as well as visceral injuries, and found a mortality rate of 89% in patients who underwent definitive laparotomy and 23% in those treated with the damage control approach.⁶ Treatment is generally divided into three phases: (1) initial surgery to achieve complete control of hemorrhage and contamination; (2) resuscitation in the intensive care unit focusing on rewarming, hemodynamic stabilization, and correction of metabolic derangements; and (3) reexploration and definitive repair with abdominal closure.⁷

The extent and type of injury a patient has, as well as the hemodynamic stability of the patient, should dictate what type of intervention is most appropriate to control hemorrhage. Certain injuries are amenable only to surgical intervention. Others may be treated effectively with catheter-based interventions in the angiography suite. Finally, many patients can be safely monitored with no intervention. These varying treatment options necessitate a multidisciplinary evaluation and treatment plan.

The interventional radiologist has become an important member of the trauma team by playing a vital role in the control of hepatic, splenic, and renal hemorrhage. The surgical options in each of these areas and the interventional radiology technique are discussed in the following sections.

HEPATIC TRAUMA

Overview of Management

The management of hepatic trauma has greatly evolved over the past 30 years. As described by Richardson et al, the treatment has moved from extensive hepatic resection, to surgical ligation of the hepatic artery, to DCL with the more widespread use of nonoperative techniques.⁸ Although embolization of hepatic hemorrhage has emerged as an important adjunct to damage control laparotomy,⁹ initial surgical management remains the standard of care. There have been recent reports of unstable hepatic injuries being treated initially with embolization,¹⁰ but this method is not currently widely accepted. Surgeons may gain immediate control of hepatic bleeding by performing a Pringle maneuver: clamping the portal triad at the hepaticoduodenal ligament. Alternatively, surgical control of hepatic arterial bleeding may involve ligation of the left or right main hepatic artery. Ligation distal to this point is difficult surgically, as is identification of hepatic vascular variants. Continued bleeding is generally controlled with hepatic packing to apply additional tamponade to quell portal venous and hepatic venous bleeding.

Hepatic arterial bleeding can also be controlled with embolization, and patients with hepatic trauma generally are directed to the interventional radiology

suite in two scenarios. The first is when a patient continues to hemorrhage after DCL. In their study of 22 patients with complex hepatic injuries, Asensio et al sent 15 of 22 patients to angiography for persistent bleeding following DCL. Embolization successfully stopped the bleeding in all of these patients.¹¹ A more recent series by Asensio et al of 103 patients with grades 4 and 5 hepatic injuries demonstrated that early hepatic embolization was an independent predictor of decreased mortality.¹²

The second scenario in which embolization may be used is when a hemodynamically stable trauma patient's imaging shows hepatic hemorrhage. At this point, competing injuries are weighed and an embolization procedure may be attempted to obviate the need or extent of a trauma laparotomy. This scenario is part of a growing trend toward nonoperative management of hepatic trauma with supportive embolization. In their study of 230 consecutive patients with grade 3, 4, or 5 hepatic injuries treated with nonoperative management, Kozar et al reported an 11% overall complication rate. Complications included persistent bleeding, biliary tract complications, and abdominal compartment syndrome. Twelve patients with persistent bleeding were treated with embolization, and the bleeding was successfully controlled in all cases.¹³

Hepatic Embolization

An abdominal aortogram is a critical first step before selective hepatic angiography. This allows for a step-wise progression closer to the target vessel and avoids the pitfall of missing a significant bleed from a competing injury or from an unexpected anatomic variant. Knowledge of the hepatic vascular variants is essential

to prevent missing injured branches and to ensure that the entire organ has been examined; classic hepatic arterial anatomy occurs in only 55% of patients. In 1955, Michels described 10 variants of hepatic arterial anatomy.¹⁴ A detailed discussion of these variants is beyond the scope of this article, but the major variants warrant mention here. One can expect either the left hepatic artery replaced to the left gastric artery or the right hepatic artery replaced to the superior mesenteric artery (SMA) in more than 20% of patients. In addition to major trunk variants, several accessory hepatic arteries are commonly found; an accessory left hepatic artery arising from the gastroduodenal artery can be seen in up to 8% of patients, and an accessory right hepatic artery arising from the SMA is found in 7%.^{14,15}

Following aortography, selective celiac and SMA angiography should be performed. Images should be evaluated for the presence of extravasation, pseudoaneurysm, arteriovenous fistula, arteriohepatic fistula, or traumatic occlusion. Extravasation is the most obvious finding of arterial injury. This is recognized by a dense extravascular collection of contrast, which may be seen transiently as the contrast diffuses into the larger hematoma (Figs. 1 and 2). Pseudoaneurysms are well circumscribed collections of contrast that extend beyond the expected vascular wall and in the acute setting are nothing more than contained hematomas (Figs. 3–6). These are unstable and should be treated. Traumatic occlusions may represent dissection without bleeding but cannot be differentiated angiographically from a transected vessel with intermittent bleeding that may resume if the hemodynamic parameters of the patient change. Thus, large truncated vessels should also be considered for embolization.

Figure 1 (A) Initial anteroposterior celiac angiogram on a young trauma patient following high-speed motor vehicle crash. The patient had continuing arterial bleeding despite damage control laparotomy and packing. A vigorous bleed is seen originating from a right hepatic artery branch. (B) Completion celiac angiogram on the patient following subselective catheterization and embolization shows achieved hemostasis.

Figure 2 Right hepatic angiogram in a patient with continuous bleeding following hepatic packing. Active arterial bleeding is noted adjacent to the surgical pack.

Assuming normal anatomy, a diagnostic celiac angiogram through a 4F or 5F catheter is performed followed by subselection of small vessels as the active bleeder is approached. As with any embolization, a sheath at the access site is recommended to avoid losing access if the embolic agent occludes the catheter. The hepatic arteries are prone to spasm (although anecdotally less so in the hyperdynamic trauma setting), and branches distal to the left or right main trunks may be too small to engage without a microcatheter. At our institution, high-flow microcatheters such as the Renegade HI-FLO (Boston Scientific, Watertown, MA) and the Progreat (Terumo, Tokyo, Japan) in 100-cm and 110-cm lengths are preferred for visceral trauma. These catheters accept Gelfoam (Upjohn, Kalamazoo, MI) slurry and large particles with less risk of catheter occlusion. Ideally, solitary sublobar bleeding branches are selected and embolized with 2-to-3-mm coils. The

degree of intrahepatic collateralization should not be underestimated. Proximal coil embolization of lobar arteries may lead to backbleeding from adjacent branches. If distal as well as proximal embolization across a bleeding site cannot be performed, Gelfoam or large-particle embolization should be performed before coil embolization to block (1) reversal of flow in the artery distal to the injury and (2) continued backbleeding via these collateral pathways. If the bleeding arises from an artery that allows catheterization distal to the target, precise placement of proximal and distal coils offers an elegant solution.⁷ When using coils, be aware that the coagulation status of the patient may affect the effectiveness of coils, as clotting is needed to achieve hemostasis.¹⁶ Follow-up celiac angiography should always be performed to ensure pan-hepatic hemostasis before leaving the angiography suite.

Specific complications related to hepatic embolization include cystic artery embolization with subsequent gallbladder necrosis.^{13,17} Care should be taken to embolize distal to the cystic artery if this is allowed anatomically. Other complications associated with embolization are contrast reactions and vascular injury/dissection related to the procedure. Published complication rates of angiography in the trauma setting are ~4 to 5%.¹⁸

In 2005, Cox et al published data suggesting there is no need for serial follow-up imaging in patients treated with nonoperative management of hepatic trauma.¹⁹ In this study, 456 patients treated with nonoperative management of hepatic trauma were followed with serial computed tomography (CT) scans with the following results: 86% of patients had no change or improvement, 12% had complete resolution, and 2% worsened. However, all the patients who worsened had obvious clinical symptoms. Thus, in the absence of clinical signs of deterioration, routine imaging adds little useful information.¹⁹

Figure 3 (A) Abdominal computed tomography in a trauma patient following 30-foot fall. There is extensive liver laceration and focal pseudoaneurysm. (B) Abdominal aortogram confirms active bleeding and conventional anatomy. (C) Selective right hepatic angiogram was performed before microcatheter selection and embolization.

Figure 4 A 44-year-old man after crush injury and grade 3 liver laceration resulting in hemobilia. (A) Celiac angiogram demonstrates a 2-cm pseudoaneurysm arising from a small early branch of the right hepatic artery. (B) Angiogram with microcatheter in the pseudoaneurysm showing an outflow vessel. The distal vessel could not be catheterized and thus large particles, 900 to 1100 μm , were slowly delivered to block potential backbleeding. The pseudoaneurysm and inflow branch were then coil embolized.

SPLenic TRAUMA

Overview of Management

The treatment of splenic trauma has also evolved over the past several decades, moving toward more conservative approaches. Splenectomy has long been the treatment of choice in splenic injuries. However, because of the increased incidence of infection and its associated mortality in splenectomized patients, surgical and non-surgical management that attempts splenic preservation has become widespread.²⁰ It is generally accepted that operative management is necessary in splenic injuries when the patient is hemodynamically unstable, has

peritoneal signs, or has additional abdominal injuries that also require operative management.^{21,22} These indications occur in ~40% of splenic trauma.¹ The surgical options for splenic injuries are limited. The most frequently used surgical approach for severely damaged spleens is splenic artery ligation and splenectomy, but attempts to preserve the spleen may include splenorrhaphy with topical agents or partial splenectomy.

Stable patients with isolated splenic injury are candidates for nonoperative management. A trial of

Figure 5 Celiac angiogram demonstrates a traumatic pseudoaneurysm arising from between the left and right hepatic arteries. Selective catheterization is necessary to further diagnose and treat the focal bleed.

Figure 6 Common hepatic angiogram shows two pseudoaneurysms (black arrows) in this trauma patient after high-speed motor vehicle crash. Note variant middle hepatic branch. Treating multiple hepatic targets is difficult because the left and right hepatic arteries require subselective embolization to preserve organ function.

Figure 7 Splenic angiogram shows multiple pseudoaneurysms.

observation with serial physical examination and hematocrit checks may be warranted. However, Haan et al showed that higher grade splenic injuries often fail observation.²³ In higher grade injuries, splenic artery embolization can maximize splenic salvage rates.

Splenic Embolization

Splenic artery embolization for trauma was well described by Sclafani in 1981²⁴ and can be divided into two categories: treatment of focal bleeds or pseudoaneurysms, and global splenic therapy. The types of splenic vascular injury encountered include extravasation, pseudoaneurysm (Figs. 7 and 8), vessel truncation, and arteriovenous fistula. Identification of arteriovenous fistulas is associated with a 60% failure rate of non-operative management despite embolization.²¹ Some authors have advocated superselective splenic embolization if there are less than three focal injuries in the

Figure 8 Splenic angiogram shows innumerable small pseudoaneurysms, too numerous to embolize individually. Proximal coil embolization was performed.

parenchyma noted on the initial angiogram.²⁵ This can be time-consuming and technically challenging given the routinely tortuous path of the splenic artery. As always, when treating potentially unstable trauma patients, time spent preserving end organ function should be balanced against the patient's ability to tolerate ongoing bleeding. Proximal embolization—either at the classic location between the origins of the dorsal pancreatic artery and the pancreaticomagna branches or at the splenic hilum—has been described and is a well-accepted technique for reducing splenic hemorrhage by forcing the spleen to perfuse through short gastric and pancreatic collaterals (Fig. 9). This decreases the systolic pressure seen at the bleeding site without completely depriving the splenic parenchyma of arterial blood flow and inducing infarction. Splenic salvage rates are comparable with all techniques, with the overall splenic salvage rate at 90% as reported by Haan.^{21,23}

The reported complication rate associated with splenic artery embolization varies. The largest multicenter review by Haan et al reviewed 140 patients from four level one trauma centers who received splenic artery embolization. In this series, major complications occurred in up to 19% and included persistent bleeding, infection, and iatrogenic vascular injuries. Persistent bleeding was the most common, occurring in 11% of patients, half of whom proceeded to splenectomy. Four percent of patients developed splenic abscesses, half of whom proceeded to splenectomy. There was no difference in the complication rate between main splenic artery and superselective embolization.²³

Routine follow-up imaging has been a subject of debate. Recent data reported by Weinberg et al suggest delayed pseudoaneurysm presentation warrants routine

Figure 9 Splenic angiogram after proximal coil embolization shows reconstitution of the distal splenic artery via the dorsal pancreatic to the transverse pancreatic to the pancreaticomagna collateral route. This allows healing of the injury without inducing infarction the spleen.

CT follow-up between 24 and 48 hours following admission in patients with splenic trauma undergoing nonoperative management.²⁶ Although splenic salvage rates have been high, the ability of the embolized spleen to effectively assist in the immune response is unclear.²³ Thus, thought should be given to administering standard postsplenectomy immunization to patients who have undergone a splenic artery embolization. Recommended vaccinations for postsplenectomy patients older than the age of 2 years include the pneumococcal vaccine, meningococcal vaccine, and, if not already administered, hemophilus influenza vaccine.

RENAL TRAUMA

Overview of Management

The role of conservative nonoperative management of renal injuries is well established. It is generally accepted that low-grade renal injuries such as contusions, sub-

capsular hematomas, and low-grade lacerations will heal spontaneously with few complications. Surgery generally is indicated in only ~5 to 10% of patients.²⁷ Currently accepted indications for surgery are avulsion of the renal pelvis, injuries to the vascular pedicle, and continued hemodynamic instability. Surgical options for renal vascular injury generally include gaining vascular control at the pedicle followed by wedge resection, partial nephrectomy, and total nephrectomy.¹

Stable patients with renal injury are candidates for observation with serial physical examination and serial hematocrit checks. In the case of persistent bleeding with nonoperative management, embolization has been shown to be effective in treating a wide array of renal injuries, including higher grade injuries.²⁸

Renal Embolization

When intervening on patients with renal trauma, an abdominal aortogram in anterior/posterior projection is

Figure 10 Penetrating trauma to the left flank and hematuria prompted angiographic evaluation. (A) Aortogram shows normal renal artery anatomy and a small inferior pole bleed. (B) Selective left renal angiogram demonstrates the bleed to arise from an interlobar branch. (C) Final angiogram following coil embolization demonstrates cessation of hemorrhage.

Figure 11 (A) Left renal angiogram in a patient with an accessory lower pole artery. Note lack of parenchymal enhancement of the lower pole when studying the upper pole artery. (B) Microcatheter selective angiogram shows active bleeding originating from an arcuate branch. This was selectively coil embolized from this position.

mandatory. Accessory renal arteries are common, occurring 25% of the time, and thus early selective angiography may miss major bleeding. Identification of actively bleeding vessels (Figs. 10 and 11), pseudoaneurysms (Figs. 12 and 13), and traumatic arteriovenous (AV) fistulas may require selective angiography in multiple projections. Selective catheterization is usually with either a recurve catheter such as a Sos (AngioDynamics, Queensbury, NY) or a double angle curve catheter such as a C2 (Boston Scientific, Watertown, MA). Once a culprit vessel has been identified, embolization may be performed proximally to the target due to the paucity of intrarenal arterial collateralization. Backbleeding is distinctly uncommon as most renal artery branches are strictly end organ. Although the primary goal in these patients is to stop hemorrhage, an important secondary goal is renal preservation. Care should be taken to limit

nontarget embolization. In most cases, subselective microcatheter techniques and careful coil embolization will accomplish both goals elegantly. Detachable coils may be useful when embolizing near major branch points. In cases of renal injuries with bleeding from proximal vessels in the hilum, superselective techniques are often not necessary as a 4F or 5F catheter can be advanced into the target vessel. Wide embolization is generally not recommended due to the effect on renal function; however, in the case of the traumatized nonfunctioning kidney, embolization of the entire organ can be performed using coils, Gelfoam, particles, or vascular plugs.

The reported success rate of controlling hemorrhage with embolization is high, in many cases reaching 100%.²⁸⁻³⁰ Complications associated with embolization of the renal arteries include renal infarction,

Figure 12 (A) Left renal angiogram in this young patient with intermittent large-volume hematuria 1 week after penetrating trauma to the left flank. A pseudoaneurysm with early filling of the renal vein (arrows) was discovered. (B) Selective angiogram on the same patient demonstrates the aneurysm. (C) Catheter is seen positioned through the pseudoaneurysm into a portion of the fistula and renal vein. This complex lesion was treated with coil embolization, which resolved the hematuria.

Figure 13 Selective left renal angiogram shows a subtle pseudoaneurysm (arrow).

iatrogenic vascular injury, and postembolization syndrome. The most feared complication is renal infarct and subsequent decreased renal function; however, superselective technique limits the amount of tissue infarction and is likely to preserve more tissue than the surgical alternatives. In their study of patients undergoing superselective embolization for iatrogenic and traumatic renal vascular injury, Chatziioannou et al reported an initial ischemic area of 12%, with resulting infarcted area of 6%.³⁰ Postembolization syndrome with associated pain, malaise, and low-grade fever may be mistaken for infection of a perirenal hematoma or urinoma. No report has proved an increased incidence of hypertension following selective renal artery embolization.^{28,31}

CONCLUSION

Modern trauma care in patients with abdominal visceral injury centers on principles of damage control, whereby life-threatening hemorrhage is controlled quickly allowing resuscitation to continue. The prompt control of hemorrhage allows the trauma team to focus on preventing and controlling the deadly cycle of hypothermia, coagulopathy, and acidosis. Although surgery is the mainstay of hemorrhage control in unstable patients, there has been a growing trend toward nonoperative management in stable patients with visceral injury. The embolization techniques employed by interventional radiologists are ideally suited for the damage control pathway, as hemorrhage can be controlled quickly in a minimally invasive fashion.

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