



Special Issue: Technical Considerations for Hemorrhage Control

## Abdominal vascular hemorrhage

David V. Feliciano, MD, FACS, MAMSE \*

University of Maryland School of Medicine, Shock Trauma Center/Department of Surgery, University of Maryland Medical Center, Baltimore, MD



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### ABSTRACT

Major abdominal vascular injuries are noted in 5%–10% of patients undergoing laparotomy for blunt trauma. In contrast, injuries to named abdominal vessels are present in 20%–25% of patients undergoing laparotomy after gunshot wounds and in 10% after stab wounds. Hence, all surgeons performing laparotomies after abdominal trauma must be familiar with techniques for exposure and management of these injuries.

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### INTRODUCTION: TWO PATIENTS WITH TWO DIFFERENT PRESENTATIONS

A 29-year-old man was shot with a handgun to the right paraumbilical area. At an emergency laparotomy, there is a mostly midline inframesocolic hematoma which also elevates the mesentery of the cecum and ascending colon. The ideal operative approach would be?

A 29-year-old man was shot with a handgun to the left lower quadrant. At an emergency laparotomy, there are left pelvic hematoma and active arterial and venous hemorrhage into the pelvis. The ideal operative approach would be?

### TRAUMA LAPAROTOMIES AND ABDOMINAL VASCULAR INJURIES

**Incidence.** Major abdominal vascular injuries are noted in 5%–10% of patients undergoing laparotomy for blunt trauma. In contrast, injuries to named abdominal vessels are present in 20%–25% of patients undergoing laparotomy after gunshot wounds and in 10% after stab wounds [1,2]. Hence, all surgeons performing laparotomies after abdominal trauma must be familiar with techniques for exposure and management of these injuries.

**Skin Preparation and Draping.** Wide skin preparation and draping are mandatory in all patients about to undergo a trauma laparotomy. This extends from the chin to the knees bilaterally and to the operating table laterally. This wide exposure allows for the following: (1) extension into a median sternotomy or the addition of an anterolateral thoracotomy; (2) exposure of the proximal common femoral artery in the groin after an injury to the distal external iliac artery in the pelvis; and

(3) retrieval of the greater saphenous vein in the groin and thigh for use as an interposition graft for repair of an abdominal vascular injury.

### CONDUCT OF OPERATION

**General.** A xiphoid-to-pubis midline abdominal incision is made, and all free blood, clot, and gastrointestinal or biliary contents are suctioned or swabbed out of the abdomen with laparotomy pads. In patients with blunt trauma, many surgeons pack all four quadrants with laparotomy pads and then sequentially remove these to assess where all injuries are. With penetrating trauma, the area of the knife or missile track is inspected first as this is where the injuries will be. Abdominal vascular injuries present with contained hematomas, free bleeding, or a combination of the two.

**Patient With a Contained Hematoma.** A patient with a retroperitoneal (midline supramesocolic, midline inframesocolic, lateral perirenal, lateral pelvic), mesenteric, or portal hematoma, particularly from a venous injury, may be remarkably stable as the incision for a laparotomy is performed. This allows the surgeon to rapidly control associated perforations of the gastrointestinal tract by placing noncrushing clamps (Allis, Babcock, Glassman, DeBakey, Cooley, Satinsky, Glover) across the hole before suturing or placing a staple line under the hole. The abdomen is then irrigated with a saline-cephalosporin antibiotic solution before the surgeon's gloves and drapes are changed, and the hematoma is approached.

Much as with a cervical, thoracic, or peripheral vascular injury presenting with a contained hematoma, proximal and distal vascular control is obtained before the hematoma is opened. On occasion, very experienced trauma vascular surgeons may enter a massive retroperitoneal hematoma directly when it may overlap the usual locations to obtain proximal and distal control. A classic example would be when a penetrating injury to the infrarenal abdominal aorta causes a large midline inframesocolic hematoma. As the highest point of the hematoma is

\* University of Maryland Medical Center, 22 S Greene St, S4D07, Baltimore, MD 21202-1595. Tel.: +1 410-328-7611 (office), 404-550-3506 (cell).

E-mail address: [davidfelicianomd@gmail.com](mailto:davidfelicianomd@gmail.com) (D.V. Feliciano).

over the perforation in the vessel (the "Mt. Everest" phenomenon), a direct approach through this site will bring the surgeon to the area of injury [1]. The hematoma is spread manually, and when bleeding is encountered at the base, the injured vessel is compressed and occluding vascular clamps are placed around the perforation. This is a rapid technique that works best on arteries with a rigid wall.

**Patient with Hemorrhage.** A patient with *hemorrhage* from an injured vessel in the retroperitoneum is approached by eviscerating the transverse colon and small bowel and covering these structures with towels or enclosing them in a clear plastic bowel bag. When the bleeding is from the mesentery, the bowel is left in situ and the area of injury approached directly. Bleeding from an associated injury to a solid organ is controlled with packing with laparotomy pads until the vascular injury is managed.

Manual or laparotomy pad compression is applied to the area of hemorrhage. With injuries to the common or external iliac vessels, the surgeon may actually be able to grab the injured artery or vein with a hand to temporarily control exsanguinating hemorrhage. The time-honored technique of compression of the infrarenal inferior vena cava with spongosticks until a perforation is precisely located can always be considered. It is often disappointing, however, because of the difficulty in keeping the spongosticks in place. Balloon catheter tamponade through a perforation in an abdominal vessel is used when compression is ineffective, there is scarring from previous surgery around the area of injury, or there is a perforation at a bifurcation or major branch of the vessel (ie, aortoiliac junction, common iliac bifurcation, or venous confluence, etc). After insertion of a 5-mL or 30-mL Foley balloon catheter into the perforation, the balloon is inflated and pulled tight against the edges of the injury. Once formal and distal vascular control has been obtained around the area of injury, the balloon is deflated and the catheter removed. Another technique for control of hemorrhage particularly applicable to perforations in major veins (inferior vena cava, renal, common or external iliac, superior mesenteric, splenic, portal) is the application of a row of Allis clamps. Suture venorrhaphy can then be performed as the clamps are removed sequentially. A less ideal option is to pass a continuous suture (basting stitch) underneath the tips of the Allis clamps as this will obviously narrow the involved vein.

After the vascular injury is repaired or ligated, the abdomen is irrigated with a saline-cephalosporin antibiotic solution. The site of vascular repair or ligation is covered with retroperitoneal or mesenteric tissue or a viable pedicle of omentum. Antibiotic-soaked laparotomy pads are then placed over this, and repairs of the gastrointestinal tract and solid organs are completed.

## OVERVIEW OF MANAGEMENT OF ABDOMINAL VASCULAR INJURIES

**Complexity.** Abdominal vascular injuries are more complex to manage than peripheral vascular injuries for the following reasons: (1) patients are more often hemodynamically unstable; (2) tamponaded hematomas are larger; (3) volume of hemorrhage is greater; (4) associated injuries to the gastrointestinal tract are common; (5) exposure of vessels in the retroperitoneum is more difficult; and (6) many vessels have limited mobility when transected or when segmental resection is performed.

**Basic Principles of Managing Abdominal Vascular Trauma.** All retroperitoneal hematomas (midline supramesocolic, midline inframesocolic, upper lateral (perirenal), lower lateral (pelvic), and the portal-retrohepatic areas—see below) from *penetrating trauma* are explored. Exceptions would be those lateral to the ascending or descending colon or a nonexpanding and nonpulsatile hematoma deep in the male pelvis.

After *blunt trauma*, only midline supramesocolic and midline inframesocolic hematomas are explored. Hematomas in the upper lateral (perirenal) retroperitoneum, lower lateral (pelvic) retroperitoneum,

and portal-retrohepatic areas are explored only if ruptured, pulsatile, or rapidly expanding. One added principle for the blunt perirenal hematoma is that the normal appearance of a kidney on a preoperative CT would also preclude opening the hematoma. Another added principle for the blunt pelvic hematoma is opening is appropriate if the ipsilateral pulse in the common or external iliac artery is absent ... particularly when there is no local endovascular capability.

A "geographic" approach to management is ideal and includes the following areas of injury: (1) midline supramesocolic, (2) midline inframesocolic, (3) upper lateral (perirenal), (4) lower lateral (pelvic), and (5) portal-retrohepatic [3] (Table 1).

## MIDLINE SUPRAMESOCOLIC HEMATOMA OR HEMORRHAGE

Either presentation may be caused by an injury to the diaphragmatic aorta, supraceliac aorta, visceral aorta, a visceral artery (celiac axis, superior mesenteric artery, renal artery), or the suprarenal inferior vena cava.

The patient with a *hematoma* is approached with a left medial mobilization maneuver. This elevates the descending colon, splenic flexure, left kidney (if the location of injury mandates this), spleen, tail and body of pancreas, and fundus of stomach. When the hematoma extends into the area of the diaphragmatic aorta, more proximal exposure is obtained by dividing the left crus of the aortic hiatus of the diaphragm with the electrocautery at the 2-o'clock position over a Kelly clamp. Cross-clamping of the distal descending thoracic aorta is considerably easier than when the supraceliac or visceral abdominal aorta is involved as these areas are covered with the celiac ganglia and dense lymphatic tissue. Once a proximal cross-clamp is placed on the descending thoracic or proximal supraceliac abdominal aorta, dissection proceeds distally until the injury is visualized or the celiac artery is encountered. It should be noted that the celiac axis and origin of the superior mesenteric artery have a "V" conformation (proximity).

The patient with *hemorrhage* is approached by manually tearing through the lesser omentum as the assistant retracts the distal esophagus and lesser curve of the stomach to the left. The surgeon's left hand is inserted through the defect in the lesser omentum until the pulsations of the supraceliac aorta are felt. An attempt is made to insinuate the second and third fingers inside the aortic hiatus of the diaphragm immediately adjacent to the aorta. A curved DeBakey aortic cross-clamp is then inserted vertically across the aorta following the left second and third fingers. With proximal aortic control in place, distal dissection will determine whether the injury is in the supraceliac aorta, visceral aorta, or one of its branches.

Repair of a solitary perforation of the diaphragmatic, supraceliac, or visceral aorta is with interrupted or continuous 4-0 polypropylene sutures. Adjacent perforations are connected, and an attempt is made to close the defect in a transverse or oblique fashion. When significant narrowing of the aorta will result, a thin-walled polytetrafluoroethylene (PTFE) patch is sewn in place. Loss of a significant portion of the aortic wall or near transection mandates segmental resection. Because of the lack of mobility of the abdominal aorta at all levels (lumbar arteries are attached), a woven Dacron or PTFE (12–16 mm) interposition graft will have to be inserted. To prevent a postoperative aortoduodenal fistula, both suture lines and the graft should be covered with a viable pedicle of omentum passed into the retroperitoneum before closure of the incision.

A significant injury to the celiac axis, splenic artery, or left gastric artery is ligated. On rare occasions, a significant injury to the proximal hepatic artery proper may be managed with segmental resection and an end-to-end anastomosis or insertion of a saphenous vein graft (see below).

Division of the neck of the pancreas between Glassman intestinal clamps or DeBakey vascular clamps may occasionally be necessary to expose the proximal superior mesenteric artery (SMA). An injury to this vessel in Fullen zone I (trunk proximal to inferior pancreaticoduodenal artery), zone II (between inferior pancreaticoduodenal and middle colic arteries, and proximal zone III (beyond middle colic artery) is NEVER

**Table 1**  
Operative approaches to major abdominal vascular injuries

Zone	Major arterial branches	Major venous branches	Operative maneuvers*
1 (Supramesocolic)	Suprarenal aorta Celiac axis Superior mesenteric artery Proximal renal artery	Superior mesenteric vein	Left medial visceral rotation Midline suprarenal aortic exposure
1 (Inframesocolic)	Infrarenal aorta	Infrahepatic inferior vena cava	Midline infrarenal aortic exposure Right medial visceral rotation
2	Renal artery	Renal vein	Lateral control of the renal hilum
3	Common, external, and internal iliac arteries	Common, external, and internal iliac veins	Midline control of iliac arteries and veins Isolation and control of common iliac vein/vena caval confluence
4	Hepatic artery	Portal vein Retrohepatic vena cava	Total pelvic isolation Portal exposure Exposure and control of retrohepatic inferior vena cava

Adapted from Feliciano DV, Asensio JA. Abdominal vessels. In: Feliciano DV, Mattox KL, Moore EE (eds). *Trauma. Ninth Edition*. New York, NY: McGraw Hill; 2021: 747–71.

LIGATED WITHOUT PERFORMING A SEPARATE AORTO-SMA BYPASS [4]. In patients with an associated injury to the head, neck, or body of the pancreas that may result in a postoperative pancreatic leak, the aorto-SMA bypass originates from the infrarenal abdominal aorta inferior to the transverse mesocolon. The saphenous vein interposition graft is then attached to the posterior or lateral SMA once the posterior mesentery is opened.

With a possible injury to the superior mesenteric vein (SMV) at the base of the mesentery or transverse mesocolon, the area of the hematoma or hemorrhage is opened directly. DeBakey vascular forceps are used to elevate the area of injury so that a large Satinsky vascular clamp can be applied under it. A near or complete transection is controlled with the application of proximal and distal DeBakey angled vascular clamps. Much as with the proximal SMA, an injury to the distal SMV underneath the neck of the pancreas may require transection of this structure. Lateral venorrhaphy of the SMV, segmental resection with an end-to-end anastomosis, or insertion of a saphenous vein graft with 5-0 polypropylene suture is preferred for limited perforations. Ligation, however, is acceptable during a "damage control" laparotomy [5]. As this results in splanchnic hypervolemia and systemic hypovolemia for several days, significant postoperative infusion of crystalloid solutions will be necessary to maintain the patient's hemodynamic status. The splanchnic hypervolemia leads to distension of the midgut and mandates the need for a silo or vacuum-assisted device coverage of the open abdomen. In patients with a prolonged period of hypotension prior to ligation of the SMV during a damage control laparotomy, necrosis of segments of small bowel in the postoperative period is not rare.

Injury to the suprarenal inferior vena cava will be discussed in the next section.

#### MIDLINE INFAMESOCOLIC HEMATOMA OR HEMORRHAGE

Either presentation may be caused by an injury to the infrarenal abdominal aorta and/or the infrarenal inferior vena cava. Because of proximity, injuries to the juxtarenal and suprarenal infrahepatic inferior vena will be discussed as well.

The patient with a *hematoma* or *hemorrhage* in the midline inferior to the transverse mesocolon is approached by opening the retroperitoneum and, if necessary, by mobilizing the ligament of Treitz to the right. Dissection posteriorly will bring the surgeon down to the crossover left renal vein, and if an injury to the infrarenal abdominal aorta is visualized or suspected, a DeBakey aortic cross-clamp is applied at this location. Dissection inferiorly in the midline retroperitoneum along the aorta should avoid the left-sided origin of the inferior mesenteric artery. As previously noted, an experienced trauma vascular surgeon may manually divide a large inframesocolic hematoma at its highest point to come right down on the area of injury. With injuries to the infrarenal abdominal aorta, repairs are similar to those described for the diaphragmatic, supraceliac, or visceral aorta previously. On the

rarest of occasions, a penetrating wound will destroy the aortoiliac arterial bifurcation in a patient with physiologic exhaustion. Management is by the insertion of side-by-side temporary intraluminal shunts into the common iliac arteries [6]. Once the patient is normothermic, is hemodynamically stable, and has a normal thromboelastogram (TEG), a woven (if a residual coagulopathy) Dacron bifurcation prosthesis is inserted at a reoperation.

A "midline" inframesocolic hematoma which also elevates the mesentery of the cecum ascending colon, and/or hepatic flexure should be suspected of causing an injury to the infrarenal, juxtarenal, or suprarenal inferior vena cava (IVC). Any of these injuries should be suspected as well if the dissection of the infrarenal abdominal aorta does not reveal an injury. Exposure of the IVC in the patient with a *hematoma* starts with division of the right line of Toldt inferior to the area of the hematoma. Manual elevation of the cecum and ascending colon is performed until the IVC is visualized below the area of injury. This will allow for the rapid application of a long DeBakey aortic cross-clamp if control of a perforation superiorly is difficult. If the hematoma is truly infrarenal, distal exposure just below the renal veins and possible caval control is obtained by completing a Kocher maneuver with elevation of the C-loop of the duodenum to expose the juxtarenal and suprarenal IVC. Complete elevation of the cecum, ascending colon, and hepatic flexure will expose the entire infrahepatic IVC. An obvious anterior or lateral perforation can be elevated with a DeBakey forceps and a Satinsky clamp applied under this. A larger longitudinal perforation or anterior and posterior perforations may require the application of proximal and distal cross-clamps in the areas described above.

With *hemorrhage* from a presumed injury to the infrarenal IVC, it is still worthwhile to expose the IVC just above the confluence of the common iliac veins to allow for application of a cross-clamp if manual pressure is not effective. In the absence of proximal control of the IVC, a large perforation can be temporarily controlled by inserting a Foley balloon catheter or grabbing the sides of a long laceration with the sequential application of Judd-Allis clamps.

The two difficult areas of exposure of the IVC are for wounds at the confluence of the common iliac veins and in the juxtarenal area. Wounds at the confluence mandate cross-clamping of both common iliac veins. As the right common iliac artery overlies this area, it may have to be divided and the aortoiliac bifurcation mobilized to the left to visualize the right common iliac vein [7]. After venous repair or ligation, the right common iliac artery is reconstituted with an end-to-end anastomosis. Wounds in the juxtarenal or suprarenal IVC usually mandate cross-clamping of the infrarenal and suprarenal IVC, along with the application of angled DeBakey vascular clamp to both renal veins.

The newest approach to controlling hemorrhage from the IVC at all levels is the insertion of a transfemoral vein balloon catheter. This can be inserted before or as soon as the perforation in the IVC is visualized, and inflation of the balloon at this site will then control hemorrhage. Formal vascular control with a Satinsky clamp or aortic cross-clamps can then be obtained to allow for repair of the IVC.

Perforations of the IVC are closed with 4-0 polypropylene sutures in a transverse or oblique fashion. With simultaneous anterior and posterior perforations, the time-honored technique is to repair the posterior perforation through an enlarged anterior perforation. This is followed by repair of the anterior perforation. Unfortunately, this approach often significantly narrows the IVC, and a better approach is to repair the posterior perforation from the outside by rolling the collapsed IVC to one side. Ligation and division of a lumbar vein or two may be necessary for complete exposure of the posterior IVC.

When there is loss of a portion of the wall of the IVC and the patient does not have physiologic exhaustion, the defect can be covered by sewing a thin-walled PTFE patch into place with a 4-0 or 5-0 polypropylene suture.

Ligation of the infrarenal IVC is appropriate in patients presenting with near-exsanguination, physiologic exhaustion, and an extensive longitudinal laceration or near-transection [8]. Ligation is accomplished with a 0-silk tie on an uninjured section of IVC collapsed between 2 vascular clamps to prevent the tie from tearing through the wall of the vein. Temporary cross-clamping of the infrarenal abdominal aorta and vigorous resuscitation with packed red blood cells will be necessary if ligation of the infrarenal IVC causes persistent hypotension.

Ligation of the juxtarenal, suprarenal, retrohepatic, or suprahepatic IVC causes unrelenting hypotension, postoperative renal failure, and, theoretically, hepatic congestion and failure. There have been, however, occasional survivors after ligation of the suprarenal IVC when the renal failure resolves presumably due to the dilatation of retroperitoneal venous collaterals. One option after ligation of the suprarenal IVC during a "damage control" laparotomy is to rapidly correct hypothermia, metabolic acidosis, and coagulation abnormalities detected on a TEG in the intensive care unit. The patient is then returned to the operating room, and the suprarenal IVC is reconstructed with a ringed PTFE graft.

#### UPPER LATERAL (PERIRENAL) HEMATOMA OR HEMORRHAGE

Either presentation may be caused by an injury to the renal artery, renal vein, both, and/or the kidney. For the patient with a *hematoma* over the track of the renal vessels rather than in a perirenal location, mobilization of the splenic flexure, descending colon, spleen, and tail of pancreas medially will allow for direct access to the renal vessels on the left side. On the right side, mobilization of the hepatic flexure medially and a Kocher maneuver will accomplish the same. When *hemorrhage* is occurring over the track of the renal vessels, manual compression is applied and as much visceral mobilization is performed as needed until the injured vessel is visualized.

For the patient with a *perirenal hematoma* or *hemorrhage*, data over the years have not demonstrated any improvements in renal salvage or in patient survival with preliminary control of the renal artery (and renal vein on the left side) at the midline. Rather, the retroperitoneum lateral to the kidney and the area of hematoma/hemorrhage is sharply divided as pressure is applied if bleeding is present. The kidney is manually elevated, and bleeding from a hilar vessel is controlled with a vascular clamp and from the kidney itself by continuing manual pressure.

The renal artery with a limited laceration or partial transection is difficult to repair because of vasospasm, but repair should be attempted with 5-0 polypropylene sutures. With a destructive injury to the artery, combined injuries to both the renal artery and vein, combined injuries to the artery and ipsilateral kidney, and need for "damage control," a nephrectomy is performed if the contralateral kidney is palpably normal.

When the contralateral kidney is absent or atrophic, a segmental resection of the injured renal artery and an end-to-end anastomosis or insertion of a saphenous vein interposition graft are options. If the ipsilateral kidney is injured as well, a simultaneous renorrhaphy is appropriate. On rare occasions, removal of the injured solitary kidney attached to an injured renal artery is necessary, followed by "back bench" surgery and a renal autotransplant into the contralateral pelvis.

In patients with blunt thrombosis of the renal artery detected on an admission contrast-enhanced CT of the abdomen, there has been diminished enthusiasm for operative repair (segmental resection of intimal flap causing thrombosis, end-to-end anastomosis) ever since endovascular stenting of the renal artery became available [9]. Should the diagnosis be made early when there is a solitary kidney and endovascular stenting cannot be performed or is not available, then operative repair is mandatory.

Exposure of a laceration or perforation of the posterior renal vein mandates a medial mobilization maneuver including the kidney on either side. Repair is accomplished by a transverse or oblique venorrhaphy with 5-0 polypropylene suture. In a patient with a destructive injury of the renal vein and the need for a "damage control" operation, ligation on the left side is usually well tolerated if the left adrenal and gonadal veins near the kidney are preserved. On the right side, ligation of the renal vein mandates a nephrectomy at the original operation or at a first reoperation.

#### LATERAL PELVIC HEMATOMA OR HEMORRHAGE

Either presentation may be caused by an injury to the common, external, or internal iliac artery; vein; both; and/or the ureter. A *hematoma* from penetrating trauma is approached by eviscerating the transverse colon superiorly and the small bowel to the right. The retroperitoneum over the aortoiliac arterial bifurcation is divided, and the ipsilateral common iliac artery is encircled with a vessel loop or clamped directly if there is associated arterial bleeding from the hematoma. The ipsilateral common iliac vein is then visualized and looped unless there is dense adherence with the common iliac artery. As noted previously, exposure of the right common iliac vein may require temporary ligation and division of the right common iliac artery. The distal external iliac artery and proximal external iliac vein are then looped in the distal lateral pelvis proximal to the inguinal ligament. The hematoma is opened, the ureter and vascular injury are identified, and the vessel loops are elevated to allow for the application of vascular clamps around the injury. Continued bleeding after the application of vascular clamps suggests that there is an injury to the ipsilateral internal iliac artery or vein. Elevation of the vessel loops or vascular clamps on the common and external iliac vessels will help localize an injury to an internal iliac vessel which aims down into the deep pelvis. Exposure of an injury to an internal iliac artery is obtained by ligation and division of the overlying internal iliac vein. *Hemorrhage* from the lateral pelvis after penetrating trauma is controlled with manual pressure from laparotomy pads until proximal and distal vascular control is obtained as described above.

Options for repair of the common or external iliac artery in the absence of extensive gastrointestinal contamination in the pelvis or the need for damage control include the following: lateral arteriorrhaphy; segmental resection with an end-to-end anastomosis or insertion of a saphenous vein or PTFE interposition graft; mobilization of the ipsilateral internal iliac artery for segmental replacement of the proximal external iliac artery; or transposition of the origin of one common iliac artery to the side of the contralateral one.

When *extensive* gastrointestinal contamination is present, there is a risk of a postoperative rupture of any complex repair of a common or external iliac artery. A surgeon who is uncomfortable with ligation of the artery around the area of injury and an immediate or delayed extra-anatomic femorofemoral bypass should first complete the appropriate arterial repair. Then, after vigorous irrigation with a saline-cephalosporin antibiotic solution, the area of the arterial repair should be covered circumferentially with a vascularized pedicle of greater omentum or the pelvic retroperitoneum closed over it. A surgeon with experience in vascular surgery, however, should ligate the artery around the area of injury and cover the stumps with omentum or pelvic retroperitoneum. Then, an extra-anatomic crossover femorofemoral bypass graft of 8-mm ringed PTFE should be performed. The extra-



anatomic track in the suprapubic area should be inferior to the midline abdominal incision to avoid any contamination from the abdomen.

During a damage control operation, an extensive injury to the common or external iliac artery is NEVER LIGATED [10]. Rather, a temporary intraluminal shunt is inserted, and a formal arterial repair is performed at the first reoperation. This approach is based on the 50% ipsilateral amputation rate (54% common iliac; 47% external iliac) reported by Michael E. DeBakey and Fiorindo A. Simeone after ligation of these vessels in World War II [11].

Lacerations of the common or external iliac vein are repaired in a transverse or oblique fashion with 5-0 polypropylene suture. When repair results in greater than 50% narrowing or a long narrowed segment or when damage control is necessary, ligation of either of these veins is appropriate. In the patient with a prolonged period of preoperative or intraoperative hypotension, there is an increased risk of an ipsilateral postoperative below-knee compartment syndrome after ligation. Also, even though postoperative pulmonary emboli have been reported after narrowed venous repairs or ligation, there is no consensus on the need for anticoagulation [12].

### PORTAL-RETROHEPATIC HEMATOMA OR HEMORRHAGE

**Portal.** Either presentation may be caused by an injury to the portal vein; common, right, or left hepatic artery; both; and/or the common, right, or left hepatic duct or common bile duct. The key to "safe" management of a vascular injury is to first apply a Pringle maneuver to the hepatoduodenal ligament just superior to the duodenum. Ideally, a DeBakey aortic clamp should be placed across the distal hepatoduodenal ligament as close to the liver as possible to stop all hemorrhage in the porta, but this may not be possible and direct pressure on any bleeding site will need to be used. Then, the common bile duct should be dissected away superiorly and to the right to allow for precise identification of the vascular injury.

A perforation in the portal vein is isolated between DeBakey or Glover clamps or a Satinsky clamp is placed around it. Lateral venorrhaphy is performed with a 5-0 polypropylene suture. A repair that results in 50% narrowing, a longitudinal laceration, or the need for damage control mandates ligation of the vein. As with ligation of the SMV, this will result in postoperative distension of the midgut, splanchnic hypovolemia, and systemic hypovolemia.

As previously noted, repair of the common hepatic artery in the porta hepatis is extraordinarily rare but can be accomplished with lateral arteriorrhaphy or segmental resection with an end-to-end anastomosis or insertion of a saphenous vein graft. During a damage control operation, ligation of an extensively injured common, right, or left hepatic artery is acceptable as long as the portal vein or the ipsilateral branch is intact.

**Retrohepatic.** As previously noted, a hematoma surrounding the retrohepatic vena cava is left in place unless ruptured, rapidly expanding, or pulsatile (most likely from an injury to the right renal artery rather than to the retrohepatic vena cava). Perihepatic packing should be attempted if the hematoma is expanding but is not pulsatile. A ruptured hematoma, however, is usually explored if there is

**Table 2**  
Survival after abdominal arterial injuries (mostly penetrating wounds) [14–16]

Vessel	Mean survival in reviews after 2000
Abdominal aorta	
Overall	32.7%
Infrarenal	46.5%
Superior mesenteric	54.4%
Renal	61.1%
Iliac	58.6%

Adapted from Feliciano DV, Asensio JA. Abdominal vessels. In: Feliciano DV, Mattox KL, Moore EE (eds). *Trauma. Ninth Edition*. New York, NY: McGraw Hill; 2021: 747–71.

**Table 3**  
Survival after abdominal venous injuries (mostly penetrating wounds) [8,14–18]

Vessel	Mean survival in reviews after 2000
Inferior vena cava	
Overall	46.2%
Infrahepatic	48.8%
Infrarenal	52.7%
Superior mesenteric	56.7%
Renal	64.9%
Iliac	
Overall	64.4%
NTDB, 2013, penetrating	74.5%
NTDB, 2018	
Vein repair	91.2%
Vein ligation	81.3%

Adapted from Feliciano DV, Asensio JA. Abdominal vessels. In: Feliciano DV, Mattox KL, Moore EE (eds). *Trauma. Ninth Edition*. New York, NY: McGraw Hill; 2021: 747–71

significant venous hemorrhage. The first step is to apply a Pringle maneuver and then divide the triangular and anterior coronary ligaments of the overlying injured hepatic lobe. Options for control of hemorrhage from the retrohepatic vena cava include the following: (1) application of sequential Judd-Allis clamps to hold the sides of the laceration or perforation together before venorrhaphy, (2) passage of the previously mentioned transfemoral vein balloon to occlude the area of injury, and (3) insertion of an atriocaval shunt (38F thoracostomy tube) through a right atriotomy after placement of Rumel tourniquets around the intrapericardial IVC and the suprarenal infrahepatic IVC. Of interest, one of the largest reviews of use of the atriocaval shunt noted a 19% survival when even including patients who required a resuscitative thoracotomy or hepatic resection [13].

### SURVIVAL AFTER ABDOMINAL VASCULAR INJURIES

See Tables 2 and 3.

#### Author Contribution

Dr. Feliciano wrote and edited all components of this manuscript.

#### Conflict of Interest

Dr. Feliciano has no conflicts of interest to declare.

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#### References

- [1] Feliciano DV, Asensio JA. Abdominal vessels. In: Feliciano DV, Mattox KL, Moore EE, editors. *Trauma*. 9th ed. New York, NY: McGraw Hill; 2021. p. 747–71.
- [2] Feliciano DV. Abdominal vascular hemorrhage: more than just clamp and sew. In: Ball CG, Dixon E, editors. *Treatment of ongoing hemorrhage. the art and craft of stopping severe bleeding*. Cham, Switzerland: Springer; 2018. p. 99–113.
- [3] Feliciano DV, Moore EE, Biffi WL. Western Trauma Association critical decisions in trauma: management of abdominal vascular trauma. *J Trauma Acute Care Surg*. 2015;79:1079–88.
- [4] Accola KD, Feliciano DV, Mattox KL, Burch JM, Beall Jr AC, Jordan Jr GL. Management of injuries to the superior mesenteric artery. *J Trauma*. 1986;26:313–9.
- [5] Asensio JA, Petrone P, Garcia-Nuñez L, Healy M, Martin M, Kuncir E. Superior mesenteric venous injuries: to ligate or to repair remains the question. *J Trauma*. 2007;62:668–75.
- [6] Moldovan S, Granchi TS, Hirschberg A. Bilateral temporary aortoiliac shunts for vascular damage control. *J Trauma*. 2003;55:592.

- [7] Salam A, Stewart M. New approach to wounds to the aortic bifurcation and inferior vena cava. *Surgery*. 1985;98:105–8.
- [8] Sullivan PS, Dente CJ, Patel S, Carmichael M, Srinivasan JK, Wyrzykowski AD, et al. Outcome of ligation of the inferior vena cava in the modern era. *Am J Surg*. 2010; 199:500–6.
- [9] Lee JT, White RA. Endovascular management of blunt traumatic renal artery dissection. *J Endovasc Ther*. 2002;9:354–8.
- [10] Ball CG, Feliciano DV. Damage control techniques for common and external iliac artery injuries: have temporary intravascular shunts replaced the need for ligation? *J Trauma*. 2010;68:1117–20.
- [11] DeBakey ME, Simeone FA. Battle injuries of the arteries in World War II. An analysis of 2471 cases. *Ann Surg*. 1946;123:534–79.
- [12] Burch JM, Richardson JR, Martin RR, Mattox KL. Penetrating iliac vascular injuries: experience with 233 consecutive patients. *J Trauma*. 1990;30:1450–9.
- [13] Burch JM, Feliciano DV, Mattox KL. The atriocaval shunt. Facts and fiction *Ann Surg*. 1988;207:555–68.
- [14] Davis TP, Feliciano DV, Rozycki GS, Bush JB, Ingram WL, Salomone JP. Results with abdominal vascular trauma in the modern era. *Am Surg*. 2001;67: 565–71.
- [15] Asensio JA, Chahwan S, Hanpeter D, Demetriades D, Forno W, Gambaro E, et al. Operative management and outcome of 302 abdominal vascular injuries. *Am J Surg*. 2000;180:528–34.
- [16] Tyburski JG, Wilson RF, Dente C, Steffes C, Carlin AM. Factors affecting mortality rates in patients with abdominal vascular injuries. *J Trauma*. 2001;50:1020–6.
- [17] Lauerman MH, Rybin D, Doros G, Kalish J, Hamburg N, Eberhardt RT, et al. Characterization and outcomes of iliac vessel injury in the 21<sup>st</sup> century: a review of the National Trauma Data Bank. *Vasc Endovascular Surg*. 2013;47: 325–30.
- [18] Magee GA, Cho J, Matsushima K, Strumwasser A, Inaba K, Jazaeri O, et al. Isolated iliac vascular injuries and outcome of repair versus ligation of isolated iliac vein injury. *J Vasc Surg*. 2018;67:254–61.