Western Trauma Association Critical Decisions in Trauma: Management of abdominal vascular trauma

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This is a recommended management algorithm from the Western Trauma Association (WTA) addressing the management of abdominal vascular injuries in adult patients. Because there are no published prospective randomized clinical trials that have generated Class I data, the recommendations herein are based on published observational studies and the expert opinion of WTA members. The two algorithms (Figs. 1 and 2), two tables (Tables 1 and 2),[1–9] and accompanying comments represent a safe and sensible approach that could be followed at most trauma centers. We recognize that there will be patient, personnel, institutional, and situational factors that may warrant or require deviation from the recommended algorithm and encourage institutions to use this guideline to formulate their own local protocols.

The algorithms contain letters at decision points, and the corresponding paragraphs in the text elaborate on the thought process and cite the pertinent literature. The annotated algorithms are intended to (a) serve as a quick bedside reference for clinicians, (b) foster more detailed patient care protocols that will allow for prospective data collection and analysis to identify best practices, and (c) generate research projects to answer specific questions concerning decision making in the management of adults with abdominal vascular injuries.

HISTORICAL PERSPECTIVE

Injuries to the abdominal vessels are caused by penetrating wounds in 90% to 95% of patients. When reviewing series of US military vascular injuries from World War II, the Korean War, and the Vietnam War, the incidence of abdominal vascular injuries was 2%, 2.3%, and 2.9%, respectively.[10–12] This reflects the high kinetic energy of military weapons and the delays in transport to definitive care. The incidence of only 2.4% in one report from the recent Iraqi War is presumably a reflection of the body armor worn by US military personnel in the field.[13]

Civilian trauma centers in the United States treat much higher numbers of patients with abdominal vascular wounds as compared with facilities in combat zones. This is a reflection of the lower wounding power of civilian weapons and the lack of body armor. In one review of patients undergoing laparotomies after sustaining gunshot wounds of the abdomen at Ben Taub General Hospital in Houston in 1988, 24.6% of patients had an injury to a named abdominal vessel.[14]

ANATOMY

Abdominal vessels are described based on a modification of the Zone I (midline retroperitoneum), Zone 2 (upper lateral retroperitoneum), and Zone 3 (pelvic retroperitoneum) classification used in many trauma textbooks. This modification divides Zone I into supramesocolic and inframesocolic areas as well as adding an area encompassing the portal vein and the retrohepatic vena cava.

PRESENTATION

The hemodynamic status of a patient with an abdominal vascular injury depends on whether a partially or completely contained hematoma or active hemorrhage is present.[15,16] When a completely contained hematoma is present, the patient may have only modest hypotension on arrival in the emergency department. This is particularly true if an abdominal venous rather than an abdominal arterial injury is present. Such a patient will be a "responder" to the infusion of crystalloid solutions and blood, and the hypotension may not recur till the hematoma is opened at the time of laparotomy.

When hemorrhage from a vascular injury is occurring through a perforation in the retroperitoneum or directly into the peritoneal cavity upon the patient's arrival in the emergency department, the patient is hypotensive and a "nonresponder." This is particularly true if an arterial injury is present. Some of these patients may have a distended abdomen, as well.

Figure 1: Approach to Hematoma at Laparotomy

A. A hypotensive patient with torso trauma should have an identification bracelet applied and blood drawn for type and cross-match and coagulation studies/thromboelastography. The blood bank is notified that the "massive transfusion protocol" should be initiated. A cephalosporin antibiotic is administered intravenously in the operating room before the midline abdominal incision is made. All gastrointestinal perforations are clamped or stapled shut. In the patient with a nonexpanding hematoma, gastrointestinal perforations are rapidly sutured or stapled shut to eliminate further contamination and bulky clamps in the operative field. When the hematoma is expanding rapidly, the clamps on gastrointestinal perforations are left in place, and the hematoma is approached as described later.

B. When there is not an operating room in the emergency department and it is geographically distant, an emergency department left anterolateral thoracotomy can be considered in the profoundly hypotensive patient (systolic blood pressure < 70mm Hg) who is clinically deteriorating.[17,18] This will allow for cross-clamping of the descending thoracic aorta and improved flow to the coronary and carotid arteries in the patient with a cardiac rhythm. In addition, it may lower the incidence of cardiac arrests that often occur when a tamponaded abdominal hemoperitoneum/clot is suddenly released at laparotomy. These potential benefits must be balanced against the time required to perform the procedure and the loss of heat and blood that invariably follows.

C. A supramesocolic midline hematoma may harbor an injury to the diaphragmatic or visceral abdominal aorta, one of the visceral vessels, or the suprarenal inferior vena cava. An injury to the inferior vena cava at this level, however, is more likely to present with a right-sided hematoma beneath the porta hepatis and surrounding the right kidney. In the patient with a true midline supramesocolic hematoma, a left medial visceral rotation should be performed.[19–21] The line of Toldt is divided in the left colic gutter and extended around the spleen. A combination of sharp (by the assistant on the left) and blunt (by the surgeon on the right) dissection is used to elevate the left colon, left kidney, spleen, and tail of the pancreas toward the midline. Adhesions from the posterior
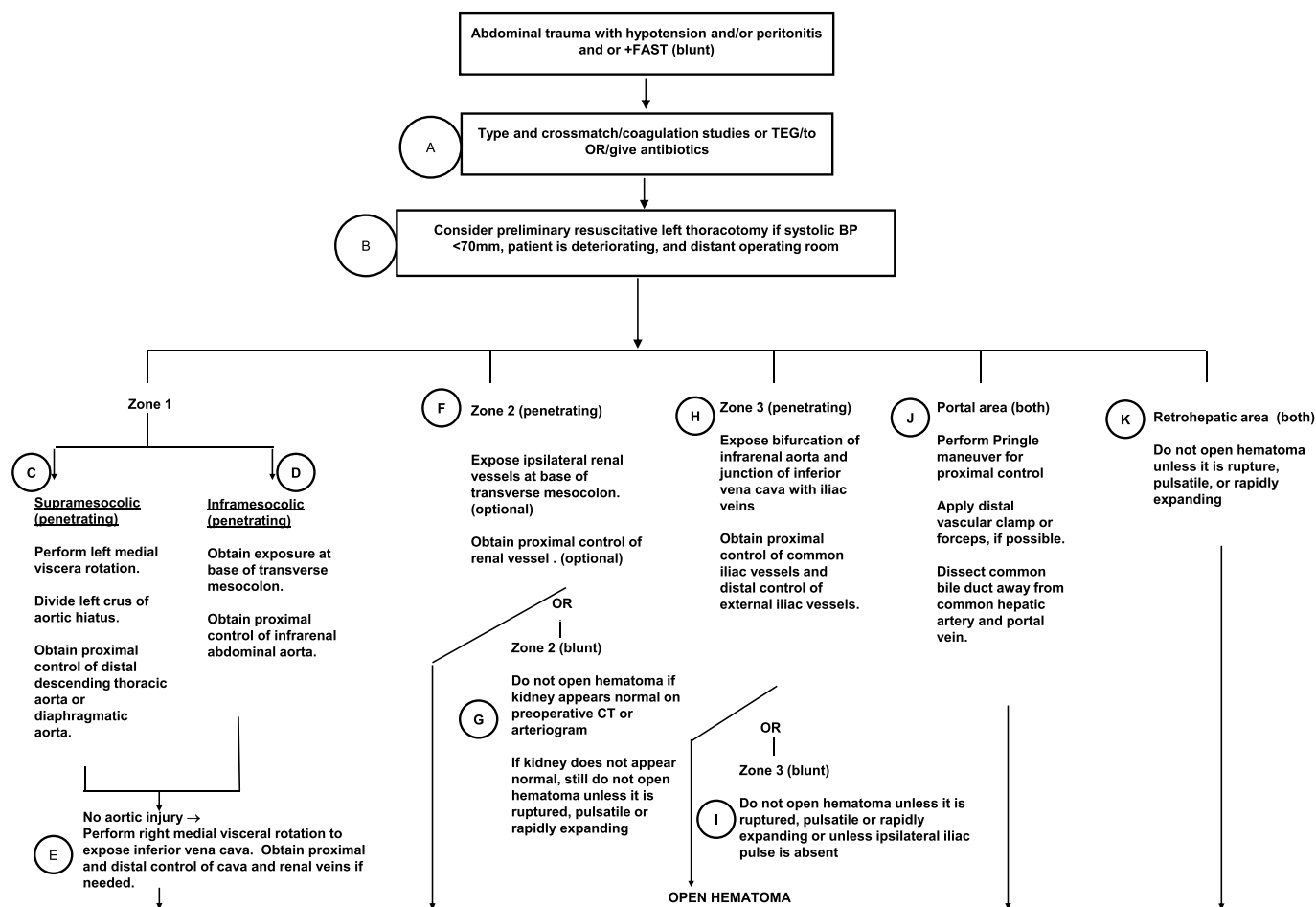
Figure 1. Abdominal vascular trauma: Approach to hematoma at laparotomy.

aspect of the fundus of the stomach to the retroperitoneum are divided, as well. Some authors recommend that the left kidney be left in the retroperitoneum, but this is only helpful if a wound is found in the juxtarenal aorta or proximal left renal artery. Because of the dense lymphatic tissue and celiac ganglia in the suprarenal periaortic area, it is very helpful to divide the left crus of the aortic hiatus of the diaphragm at the 2-o'clock position with the electrocautery.[15] The distal descending thoracic aorta will then be readily visualized and can be clamped for proximal control. Further dissection inferiorly on the diaphragmatic aorta will lead to the celiac axis and then the superior mesenteric artery. These vessels are quite close and usually assume a "V" conformation at their origins.

D. An inframesocolic midline hematoma may cover an injury to the infrarenal abdominal aorta, inferior vena cava, or the left renal vein at the midline. An injury to the cava, however, is more likely to present with a right-sided hematoma elevating the mesentery of the ascending colon. If present, the aortic injury is located under the highest point of the hematoma—the "Mount Everest phenomenom."[15] The transverse colon is elevated on to the lower chest wall, and the small bowel is eviscerated to the right. The midline retroperitoneum at the base of

the transverse mesocolon and to the left of the duodenum at the ligament of Treitz is divided longitudinally without entering the hematoma. Sharp and blunt dissection will allow for visualization of the infrarenal abdominal aorta inferior to the crossover left renal vein, and it can be clamped for proximal control. Further dissection inferiorly on the infrarenal abdominal aorta avoiding the left-sided origin of the inferior mesenteric artery will allow for visualization of an aortic injury.

E. If no injury to the suprarenal or infrarenal abdominal aorta is present under a large midline hematoma through the exposures described in C and D, the transverse colon and small bowel are placed back in the abdomen. A right medial visceral rotation, which includes elevation of the right colon after division along the line of Toldt and of the C-loop of the duodenum by an extended Kocher maneuver, is performed.[15] This allows for a visualization of the infrahepatic inferior vena cava from the confluence of the iliac veins to the liver.

F. After penetrating trauma and when preoperative imaging with a contrast-enhanced computed tomography (CT) scan has been performed, nonoperative management may be chosen. This is appropriate with a small perirenal hematoma covering a peripheral parenchymal injury with

minimal or no extravasation of the contrast agent.[22,23] Otherwise, a larger Zone 2 perirenal hematoma noted at operation may cover an injury to the renal artery or renal vein or a more significant injury to the kidney. If a left-sided hematoma is unruptured and not expanding, the surgeon may choose to obtain central control of the renal artery and vein.[24,25] The midline retroperitoneum at the base of the transverse mesocolon and to the left of the duodenum at the ligament of Treitz is divided longitudinally. The left renal vein is exposed as it crosses over the juxtarenal abdominal aorta and encircled with a vessel loop. After further dissection to elevate the vein, careful dissection on the left posterolateral aorta at the 4-o'clock position will allow for exposure and subsequent placement of a vessel loop around the left renal artery. If a right-sided hematoma is present, looping of the crossover left renal vein and rightward traction on the juxtarenal inferior vena cava will allow for exposure and looping of the posterolateral right renal artery. The right renal vein is usually not controlled until the perirenal hematoma is opened. A rapidly expanding hematoma is approached as in 2G.

G. After blunt trauma, a contrast-enhanced CT will occasionally document the presence of an intimal flap in or blunt thrombosis of the renal artery. Endovascular stenting of this injury is appropriate in hemodynamically stable patients.[26] Otherwise, a Zone 2 perirenal hematoma noted at a laparotomy after blunt trauma for other indications is not opened if the kidney appears normal on a preoperative CT or arteriogram. If no preoperative imaging has been performed, a perirenal hematoma is opened only if it is partially ruptured, pulsatile, or rapidly expanding.

H. After penetrating trauma, a Zone 3 lateral pelvic hematoma may cover an injury to the iliac artery, iliac vein, or ureter. After mobilization of the cecum and evisceration of the small bowel to the right, the midline lower retroperitoneum over the bifurcation of the infrarenal abdominal aorta is divided longitudinally. Cautious medial and lateral dissection (especially in older patients) around the ipsilateral proximal common iliac artery will allow for placement of a vessel loop for proximal control.[15] Further dissection around the common iliac vein at the same level will allow for placement of a vessel loop for distal control. The hematoma is left intact, and the distal external iliac artery is palpated beneath the retroperitoneum after it rises out of the pelvis and passes beneath the inguinal ligament. The retroperitoneum at this location is opened, dissection around the distal external iliac artery and proximal external iliac vein is performed, and both vessels are encircled with vessel loops.

I. After blunt trauma, a Zone 3 lateral pelvic hematoma presumably related to an adjacent pelvic fracture is not opened unless it is partially ruptured, pulsatile, or rapidly expanding or unless the ipsilateral iliac pulse is absent.[27] Should any of these be present but only venous hemorrhage is noted after the hematoma is opened, preperitoneal packing is appropriate.[28]

J. After penetrating or blunt trauma, a portal hematoma (in the hepatoduodenal ligament) may cover an injury to the portal vein, hepatic artery, or common bile duct. A finger is placed into the foramen of Winslow, and all structures in the porta hepatis are encircled. An angled DeBakey clamp is then placed across all three structures just above the duodenum (Pringle maneuver).[29] Depending on the length of the portal structures, it may be possible to place a distal clamp across all three structures at the liver, as well. The hematoma is then opened, the common bile duct is encircled with a vessel loop and pulled to the right, and the portal vein and common hepatic artery are exposed.

K. After penetrating or blunt trauma, a retrohepatic hematoma may cover an injury to the retrohepatic vena cava or an extrahepatic vein. As injuries to these low-pressure structures may heal, this hematoma is not opened unless it is partially ruptured, pulsatile, or expanding.[1] Should the hematoma encompass the right kidney as well, the surgeon should follow the guidelines in F and G.

Figure 2: Approach to Hemorrhage at Laparotomy

A. Same as Figure 1.

B. Same as Figure 1.

C. Hemorrhage from the supramesocolic midline may come from an injury to the diaphragmatic or visceral abdominal aorta, one of the visceral vessels, or the suprarenal inferior vena cava. If an aortic compressor is not available, manual compression is applied to the area of hemorrhage by the assistant. The same assistant then manually retracts the distal esophagus and the lesser curve of the stomach to the patient's left. The lesser omentum is opened manually, and the surgeon places his or her fingers in the aortic hiatus of the diaphragm. A stripping motion on either side of the diaphragmatic aorta frees this structure from the adherent hiatal muscle fibers. The surgeon then leaves the left second and third fingers on either side of the diaphragmatic aorta as a guide and places a DeBakey aortic clamp from anterior to posterior until the tips touch a vertebra.[15] The clamp is then closed to obtain proximal control. Because of the visceral vessels, the overlying pancreas, and the transverse mesocolon, only manual distal aortic control is obtained at this level. Another option is to cross-clamp the infrarenal abdominal aorta inferior to the transverse mesocolon.

D. Hemorrhage from the inframesocolic midline may come from an injury to the infrarenal abdominal aorta, inferior vena cava, or the left renal vein at the midline. Manual compression is applied to the area of hemorrhage by the assistant. Then, follow guidelines in 1D.

E. If an aortic injury is not the source of hemorrhage, manual compression is maintained as the transverse colon and small bowel are returned to the abdomen. A right medial visceral rotation maneuver is performed. As the right colon and duodenum are elevated, manual compression is switched from anterior to the mesentery of the ascending colon to the retroperitoneum directly. An area of hemorrhage just inferior to the liver is likely to be coming from the suprarenal inferior vena cava or one of the renal veins.
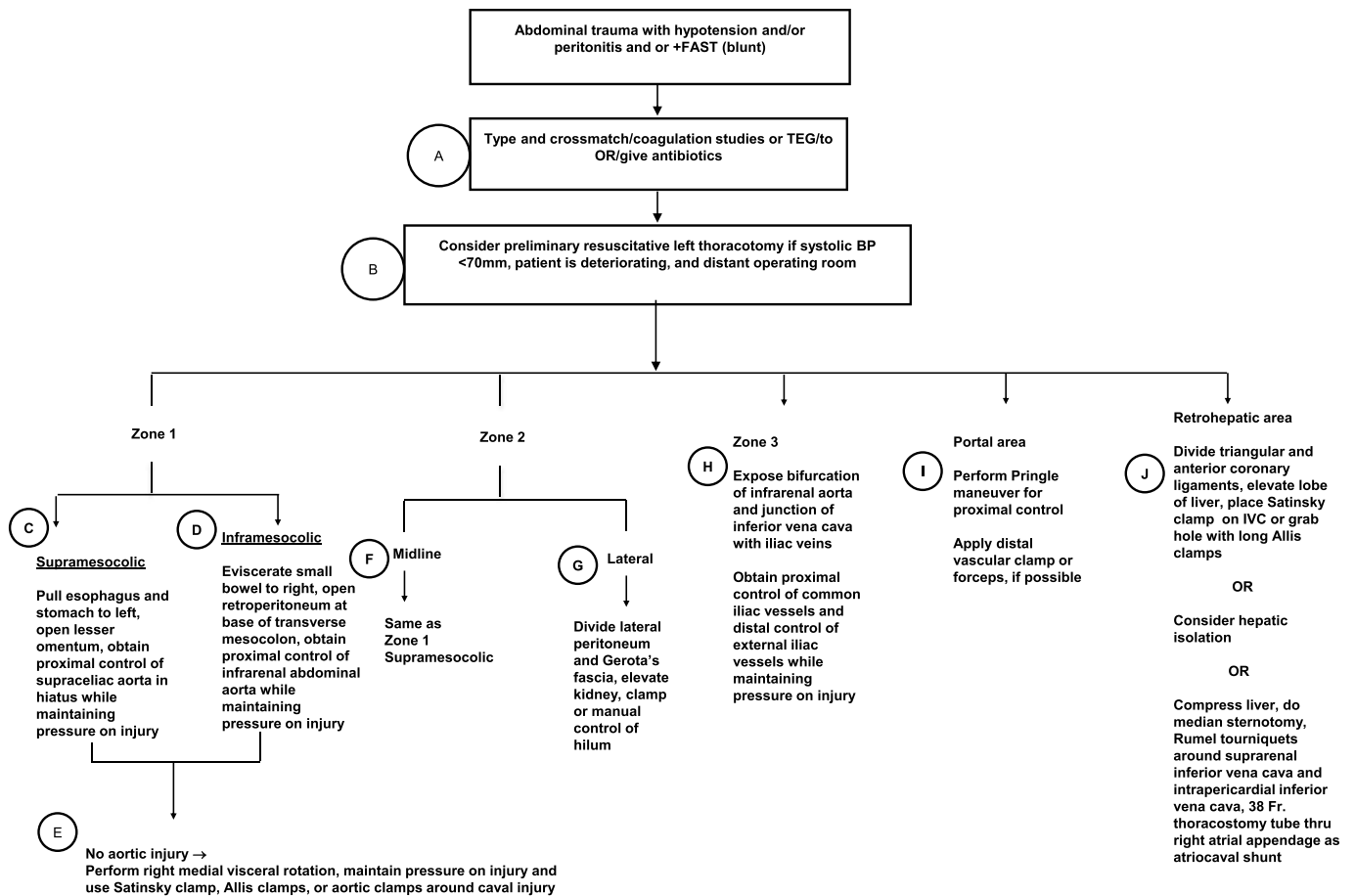
Figure 2. Abdominal vascular trauma: Approach to hemorrhage at laparotomy.

As manual or spongestick compression continues, the infrarenal inferior vena cava and both renal veins at their junctions with the cava are clamped.[15] This will give the surgeon proximal vascular control, at least. Once compression on the bleeding site is released, an isolated suprarenal perforation can be grabbed with a vascular forceps or long Allis clamp, elevated, and a Satinsky clamp applied underneath. A larger perforation can be controlled by placing a Foley balloon catheter into the hole, inflating the balloon, and placing traction on the catheter until more formal vascular control is obtained.[2] A longitudinal laceration in the cava is grabbed with a series of Judd-Allis clamps to appose the edges and control most hemorrhage.[3] An oblique or transverse laceration can be controlled by applying DeBakey aortic clamps on the inferior vena cava superior and inferior to it. With the use of the exposure technique described in 1E, an injury to the infrarenal inferior vena cava is controlled as described later for the suprarenal cava without the addition of looping and/or clamping the renal veins.

F. Same as Figure 2C.
G. Manual compression is applied to the kidney as the retroperitoneum lateral to the injured kidney and Gerota's fascia are divided. The kidney is manually elevated, and

bleeding from a hilar vessel or the kidney itself is controlled manually or by placing a vascular clamp across both vessels in the hilum.
H. Manual compression is applied to the side of the pelvis where hemorrhage is occurring. On occasion, a defect in the pelvic retroperitoneum will allow the surgeon to actually grab and compress the injured vessel with a hand until proximal and distal control has been obtained. Otherwise, follow guidelines in 1H.
I. Same as Figure 1I.
J. Manual compression is applied to the overlying hepatic lobe to allow the surgical team, anesthesia, and blood bank to prepare for a major operation. If manual compression does not control hemorrhage or if preparations for the major operation to follow are completed, the triangular and anterior coronary ligaments of the hepatic lobe thought to overlie the caval injury are divided. The lobe is then manually elevated by the assistant as two suction devices are placed adjacent to the retrohepatic vena cava. A small penetrating wound or venous avulsion can be elevated by a DeBakey vascular forceps or a Judd-Allis clamp. A Satinsky vascular clamp is then placed across the cava and underneath the elevated perforation. A longer laceration not amenable to placement of a Satinsky clamp may

be controlled by placing a row of long Judd-Allis clamps to appose the two sides as previously noted.

Exsanguinating hemorrhage upon elevation of the overlying lobe mandates resuming compression of the lobe down onto the retrohepatic vena cava. Careful, but rapid, dissection of the suprarenal inferior vena is performed to allow for passage of an umbilical tape around the structure. While maintaining compression on the liver, a median sternotomy is performed, and the pericardial sac is opened in a longitudinal direction. An umbilical tape is placed around the intrapericardial inferior vena cava. Both umbilical tapes are then passed through 4-in segments of red Robinson #18F catheters. A Satinsky vascular clamp is placed on the right atrial appendage, a 1-cm perforation is placed at the apex of the atrial wall above the clamp, and a 2-0 silk purse-string suture is placed around the perforation. A so-called *atriocaval shunt* is prepared by placing a clamp on the open (nonperforated) end of a #36 or #38F thoracostomy tube.[1] A large extra hole is cut in the side of the thoracostomy tube 20 cm from the drainage hole most distant from the tip of the tube. With an assistant controlling the purse-string suture in the right atrial appendage, the Satinsky clamp is removed, and the surgeon passes the perforated end of the thoracostomy tube into the atrium. As the tube (shunt) is passed inferiorly, the surgeon's left hand guides the tip of the shunt through the retrohepatic vena cava into the infrarenal inferior vena cava. When the extra large hole cut into the thoracostomy tube is in the right atrium and the drainage hole most distant from the tip of the tube is in an infrarenal position, both umbilical tapes are pulled up tight. Hemostats force the portion of the Robinson catheter around the umbilical tapes down onto the cava. In this way, all venous blood from the lower half of the body and both kidneys passes into the atriocaval shunt and then into the right atrium. Therefore, less blood will enter the injured retrohepatic vena cava. This may allow the surgeon to visualize the injury better and place a large Satinsky clamp under it or a row of long Judd-Allis clamps across it.

Other approaches to injuries in this difficult location include total hepatic vascular isolation without[4] or with[30,31] venovenous bypass.

Table 1: Treatment of Arterial Hemorrhage at Laparotomy or After Hematoma Opened

A. A penetrating wound to the suprarenal or infrarenal abdominal aorta is repaired with 3-0 or 4-0 polypropylene sutures placed in a transverse direction in a continuous or interrupted fashion, depending on the size of the defect, the diameter of the aorta, and preference of the surgeon.[32] A larger injury with the loss of tissue of part of the wall can be treated with a patch aortoplasty with a piece of a polytetrafluoroethylene (PTFE) prosthesis tailored to fit. A more extensive injury that requires a segmental resection cannot be repaired with an end-to-end anastomosis because of the lack of mobility of the ends. An interposition PTFE graft is inserted, even if gastrointestinal contamination has occurred elsewhere in the abdomen.[15] Less

appealing choices in this situation include woven or albumin-coated Dacron grafts. After insertion of the graft, appropriate flushing, and restoration of flow, the retroperitoneal area around the graft is irrigated with a saline solution containing antibiotics. Then, retroperitoneal tissue is closed in a watertight fashion over the graft. Finally, postoperative antibiotics are administered for 1 day to 3 days.

B. A significant injury to the origin of the celiac axis is treated with ligation.[5,9] This is because collateral arterial flow from the midgut will preserve the liver, stomach, and spleen. An injury to either the proximal left gastric artery or the splenic artery is treated with ligation, as well. In contrast, an injury to the proximal hepatic artery proper or the common hepatic artery may be amenable to lateral arteriorrhaphy or segmental resection with an end-to-end anastomosis on rare occasions.

C. As collateral flow to the midgut is compromised in the patient with shock, ligation of a significant injury to the first, second, or third portions of the superior mesenteric artery is never performed to avoid ischemic necrosis of the midgut in the postoperative period.[6,15,33]

An extensive injury to the proximal superior mesenteric artery in the patient with profound shock is treated with segmental resection and insertion of an appropriately sized temporary intraluminal shunt.[7,8] After passage of a 2-0 silk tie around the proximal stump of the artery, a temporary shunt 4-cm longer than the gap between the two ends and with a hemostat on the opposite end is inserted for a distance of 2 cm. The 2-0 silk is tied tight compressing the proximal arterial stump down onto the shunt, and the hemostat on the shunt is released to verify arterial flow. The shunt is then reclamped. The distal end of the shunt is inserted into the distal arterial stump for a distance of 2 cm, and another encircling 2-0 silk is tied tight to fix the shunt in place. After removal of the hemostat, there should be a pulse in the superior mesenteric artery distal to the shunt. Another option is to insert a Pruitt-Inahara shunt proximally, inflate the proximal balloon, verify arterial flow and reclamp the shunt, and then insert distally and inflate the distal balloon. The side port on this shunt allows for an infusion of heparin or a completion arteriogram. After this "damage-control operation,"

TABLE 1. Treatment of Arterial Hemorrhage at Laparotomy or After Hematoma Opened

Vessel	Management
A. Suprarenal/infrarenal aorta	Lateral repair vs. Dacron or PTFE graft
B. Celiac axis	Repair hepatic artery proper, if possible, otherwise ligate.[1]
C. Superior mesenteric artery	Do not ligate proximal vessel. Shunt if "damage control," then repair unless branch artery.[2–4]
D. Renal artery	Nephrectomy if normal contralateral kidney. Repair if solitary kidney or atrophic contralateral kidney.
E. Common/external iliac artery	Do not ligate. Shunt if "damage control," then repair.[5]
F. Internal iliac artery	Ligate

the patient's hypothermia, acidosis, and coagulopathy are corrected in the intensive care unit.[34] Once this is completed, the patient is returned to the operating room for removal of the shunt. In the absence of any evidence of a pancreatic injury (no fat necrosis around the pancreas or shunt), a saphenous vein interposition graft is inserted. The presence of fat necrosis, however, mandates removal of the shunt and ligation of both ends of the artery at this level to avoid postoperative necrosis of the proximal suture line or graft itself from a posttraumatic pancreatic leak.[15] The proximal end of a saphenous vein graft is then sewn in an end-to-side fashion with 4-0 polypropylene suture to the midaspect of the infrarenal abdominal aorta. If neither the greater nor the lesser saphenous vein is available for the bypass, a ringed PTFE graft can be used. After dissecting out the superior mesenteric artery on the underside of the mesentery of the small bowel and shortening the saphenous vein graft to the appropriate length, it is sewn to the artery in an end-to-side fashion with 5-0 or 6-0 polypropylene suture. A "second look" operation in 12 hours to 24 hours should always be considered after such extensive reconstruction of the superior mesenteric artery, especially if the postoperative metabolic acidosis does not clear.

In patients without profound shock and only a limited injury to the arterial wall, lateral arteriorrhaphy with 5-0 or 6-0 polypropylene suture is most commonly performed on the first, second, or third portions of the superior mesenteric artery.[6,33] Injuries to branch vessels are ligated, and the overlying small bowel or colon is observed for 5 minutes. A dusky blue appearance denotes ischemia, and a segmental resection of the bowel is performed.

D. Each kidney receives 12.5% of the cardiac output and is very sensitive to a period of ischemia. An extensive injury to the renal artery deep in the retroperitoneum is treated with ligation and ipsilateral nephrectomy if there is a palpably normal contralateral kidney and exsanguinating hemorrhage from other intra-abdominal injuries.[15,35] When the contralateral kidney is atrophic or absent, an injury to the wall of the renal artery is treated with lateral arteriorrhaphy with 5-0 or 6-0 polypropylene suture. A more extensive injury outside the hilum (e.g., through-and-through gunshot wound) mandates a segmental resection. The ipsilateral kidney is mobilized out of the retroperitoneum and Gerota's fascia in a medial direction to allow an end-to-end anastomosis to be completed with 6-0 polypropylene suture without tension. If an end-to-end anastomosis cannot be performed, a saphenous vein interposition graft is inserted. Surrounding the kidney with a sterile bag containing ice or saline at 1°C to 3°C during retrieval of the graft and performing the proximal anastomosis are warranted. Another option is to place the interposition graft over a temporary intraluminal shunt and perfuse the kidney as the proximal and two third of the distal anastomoses are performed. Acute tubular necrosis of the involved kidney usually occurs in the postoperative period if there has been a prolonged period of ischemia as the renal artery was repaired.

E. Ligation of the common or external iliac artery in the patient with shock will lead to postoperative ischemic necrosis of the foot, leg, and a portion of or all of the thigh.

Therefore, ligation of either of these vessels is never performed.[36] An extensive injury to the common or external iliac artery in the patient with profound shock is treated with segmental resection and insertion of an appropriately sized temporary intraluminal shunt (Table 1C).[15,36] After insertion of the shunt, there should be palpable or Doppler-audible arterial pulsations in the dorsalis pedis and posterior tibial arteries of the ipsilateral ankle. Once the patient's hypothermia, acidosis, and coagulopathy are corrected in the intensive care unit, the patient is returned to the operating room for removal of the shunt. A patient who had extensive enteric or fecal contamination noted at the original laparotomy after injury is at significant risk for an infection involving the vascular repair performed at the reoperation. Therefore, the surgeon should consider an extraanatomic crossover femorofemoral bypass instead of a complex vascular reconstruction in the contaminated pelvis. The silo or vacuum-assisted device over the patient's open abdomen is left in place, and both groins and the suprapubic area are prepared and draped. Through longitudinal incisions in the groins, proximal and distal control of both common femoral arteries is obtained. A subcutaneous tunnel connecting both groin incisions is made through the suprapubic area inferior to the open midline incision, and a laparotomy pad is then pulled through this tunnel and left in place for venous tamponade as the first groin anastomosis is performed. If the patient's coagulopathy has been corrected, unfractionated heparin at a dose of 100 U/kg is administered intravenously to attain an activated clotting time greater than 200 seconds. The contralateral common femoral artery is clamped proximally and distally. An oblique arteriotomy (10 o'clock to 4 o'clock on the left common femoral artery and 2 o'clock to 8 o'clock on the right common femoral artery) is made, and the beveled PTFE graft is sewn to the artery in an end-to-side fashion using 5-0 polypropylene suture. With the graft clamped off just above the suture line and after appropriate flushing, arterial flow is restored to the contralateral femoral artery. After removal of the laparotomy pad in the suprapubic tunnel, the graft is pulled through to the opposite groin. The graft is then sewn in an oblique beveled end-to-side fashion to the common femoral artery on the side of the iliac injury. After appropriate flushing, flow is restored to the femoral artery on the side of the injury. The groins are then irrigated with saline solution containing antibiotics. Closure of both groins is in layers, the skin incisions are closed with interrupted vertical mattress sutures of 2-0 nylon, and watertight dressings are applied.

After appropriate skin preparation and draping of the abdomen, the silo or vacuum-assisted device is removed. The operative field is irrigated with saline solution containing antibiotics. After clamping the iliac artery around the shunt, the silk ties are cut, and the shunt is removed. Both ends of the iliac artery are oversewn with 4-0 polypropylene suture and buried beneath the pelvic retroperitoneum.

In the absence of extensive enteric or colonic contamination, an injury to the common or external iliac artery is treated with lateral arteriorrhaphy with 5-0 polypropylene

suture. A more extensive injury is treated with a segmental resection and an end-to-end anastomosis or insertion of a saphenous vein or PTFE interposition graft.[15,37] An injury involving the proximal common iliac artery may be treated with oversewing of the proximal stump at the aortic bifurcation and transposition of the distal end to the side of the contralateral common iliac artery. A pedicle of viable omentum is created to cover any suture line, graft, or site of iliac arterial ligation if any enteric or colonic contamination has been present.

F. An extensive injury to the internal iliac artery is ligated.

Table 2: Treatment of Venous Hemorrhage at Laparotomy or After Hematoma Opened

A. A perforation of the suprarenal inferior vena cava isolated above a Satinsky vascular clamp is oversewn with a continuous suture of 4-0 polypropylene. A longer laceration partially controlled by the row of Judd-Allis clamps is oversewn by placing a continuous suture row of 4-0 polypropylene as each clamp is removed in succession. A large defect in the lateral wall is repaired with a thin-walled PTFE patch venoplasty using 4-0 polypropylene suture. A more extensive injury mandates segmental resection and insertion of an 18-mm to 22-mm ringed PTFE venous interposition graft. On occasion, the intraoperative sequelae of shock are so profound that the surgeon must ligate the suprarenal inferior vena cava around the injury. After a 2-hour to 4-hour period in the intensive care unit to correct some of the hypothermia, acidosis, and coagulopathy, the patient is returned to the operating room. After proximal and distal control around the ties used for venous ligation is obtained, the cava is debrided and an interposition graft as described earlier is inserted. Permanent ligation of the suprarenal inferior vena cava is not performed because irreversible renal failure results in most patients.

B. Once control of the injury to the infrarenal inferior vena cava is obtained, a decision must be reached on ligation versus repair. Ligation of the infrarenal inferior vena cava is performed in patients with profound shock and loss of the wall of the cava or a long laceration.[38] It is helpful to place an O-silk or O-polypropylene suture ligature outside an occluding clamp on the cava. In this way, the engorged cava does not have to be tied directly where there is a risk

of the tie lacerating the vessel. After ligation of both ends of the cava around the extensive injury, an abdominal silo or vacuum-assisted device is used to cover the edematous open abdomen. Compartment pressures are measured in both legs in the operating room. A pressure greater than 30mm Hg in the anterior compartment of either leg mandates a below-knee two–skin incision four-compartment fasciotomy.[39] When the patient has profound hypothermia, acidosis, or a coagulopathy, this procedure may be deferred to the intensive care unit in 2 hours to 4 hours. The vigorous resuscitation with blood and crystalloid solutions that is needed in the postoperative period to maintain blood pressure may cause a progressive increase in the compartment pressures of the thighs. Therefore, it is worthwhile to measure the pressure in the anterior (extensor) compartment of both thighs in the intensive care unit after 4 hours to 6 hours of resuscitation and then every 12 hours for the first 3 days, as well. On occasion, the patient will have to be returned to the operating room for a bilateral two- or three-compartment thigh fasciotomy. In the intensive care unit, both lower extremities are elevated on four pillows to decrease edema. Elastic wraps are applied with modest tension to the feet, legs, and thighs, as well.

The same techniques of repair described for repair of the suprarenal inferior vena cava in 2A are used for the infrarenal inferior vena cava.[40] Should there be significant narrowing at the site of the repair ("hourglass" appearance), postoperative gradual thrombosis of the cava is likely. This may cause a subsequent pulmonary embolus. To lower the incidence of this complication, the aforementioned elevation and elastic wraps are applied. In addition, postoperative anticoagulation with heparin is started with a goal of a partial thromboplastin time or activated partial thromboplastin time of 1.5 to 2.5 times normal. A decision on long-term out-of-hospital anticoagulation is based on surgeon preference because no data are available on its value in this clinical situation. If there is a contraindication to anticoagulation, a filter can be placed in the infrarenal or, if necessary, suprarenal inferior vena cava via a transjugular approach.

C. Once control of the injury to the superior mesenteric vein is obtained, a decision must be reached on ligation versus repair. An extensive injury to the superior mesenteric vein in a patient with profound shock from any injury more complex than a lateral defect is ligated.[41,42] Ligation is performed because it is rapid, well tolerated, and "damage control."[15,34] The midgut will rapidly become engorged and somewhat dusky after ligation. A clear genitourinary irrigation bag or x-ray cassette bag is placed over the open abdomen as a silo. This will significantly decrease the risk of a postoperative abdominal compartment syndrome and allow for observation of the discolored midgut. The splanchnic hypervolemia and systemic hypovolemia that occur after ligation are treated with large infusions of crystalloid solutions during the patient's first several days in the intensive care unit.[42]

If there is progressive darkening of segments of the midgut visible under the silo, the patient is returned to the operating room for a "second look" procedure and possible insertion of a venous interposition graft to restore flow through

TABLE 2. Treatment of Venous Hemorrhage at Laparotomy or After Hematoma Opened

Vessel	Management
A. Suprarenal vena cava	Repair vs. temporary ligation, then repair.
B. Infrarenal inferior vena cava	Ligate if large injury and "damage control."[6] Otherwise, repair.
C. Superior mesenteric vein	Ligate if "damage control."[7,8] Otherwise, repair.
D. Renal vein	If ligate right, do nephrectomy. Otherwise, repair.
E. Common/external iliac vein	Ligate if "damage control."[9] Otherwise, repair.
F. Internal iliac vein	Ligate
G. Portal vein	Ligate if "damage control."[8] Otherwise, lateral repair.
H. Retrohepatic vena cava	Repair

the ligated vein. Some surgeons choose to do this within 12 hours of the "damage-control laparotomy" whether the appearance of the midgut has changed or not. While ischemic necrosis of segments of the small bowel or right/transverse colon is rare in patients who are likely to survive, it does occur. Segmental resection without a bowel anastomosis is performed, should this complication of ligation occur.

A lateral defect in the superior mesenteric vein is repaired with interrupted or continuous 5-0 or 6-0 polypropylene suture. A more extensive injury is treated with segmental resection and an end-to-end anastomosis. Tension on the end-to-end anastomosis as it is being performed is decreased by having an assistant push the entire midgut superiorly or even placing the patient in a partial Trendelenburg position.

D. Once control of the injury to the renal vein is obtained, a decision must be reached on ligation versus repair. An extensive injury to the right renal vein in a patient with profound shock is treated with ligation if there is a palpably normal left kidney. A nephrectomy is performed at a subsequent reoperation. An extensive injury to the left renal vein in a patient with profound shock is treated with ligation if there is a palpably normal right kidney. Ligation medial to the entrance of the left gonadal and adrenal veins is tolerated in approximately 70% of patients.[43] Therefore, a left nephrectomy should not be performed at the initial laparotomy.

A lateral defect in the renal vein is repaired with interrupted or continuous 5-0 or 6-0 polypropylene suture. A more extensive injury on the left side can be treated with segmental resection and an end-to-end anastomosis. Much as with the rarely performed end-to-end anastomosis of the renal artery, medial mobilization of the ipsilateral kidney out of the retroperitoneum and Gerota's fascia will decrease tension as the venovenostomy is performed.

E. Once control of the injury to the common or external iliac vein is obtained, a decision must be reached on ligation versus repair. An extensive injury to the common or external iliac vein in a patient with profound shock from any injury more complex than a lateral defect is ligated. Ligation is performed because it is rapid, well tolerated, and "damage control."[15,34] After ligation, an abdominal silo or vacuum-assisted device is used to cover the edematous open abdomen. Much as with ligation of the inferior vena cava, a compartment pressure is measured in the ipsilateral leg before the patient is moved out of the operating room. A pressure greater than 30mm Hg mandates a below-knee two–skin incision four-compartment fasciotomy.[39] Once again, the timing and location of this procedure will depend on the patient's condition. It is worthwhile to measure the pressure in the anterior (extensor) compartment of the ipsilateral thigh in the intensive care unit after 4 hours to 6 hours of resuscitation, as well.

A lateral defect in the common or external iliac vein is repaired with interrupted or continuous 5-0 or 6-0 polypropylene suture.[37] A more extensive injury can be treated with segmental resection and an end-to-end anastomosis. This rarely performed procedure may require ligation and division of the ipsilateral internal iliac vein to allow for mobilization of the two ends of the vein. In the absence of gastrointestinal contamination, a longer segmental defect can be repaired with a ringed 8-mm to 12-mm PTFE venous interposition graft. In patients with narrowed or complex repairs, the ipsilateral lower extremity is elevated on four pillows, elastic wraps are applied with modest tension, and anticoagulation with unfractionated or fractionated heparin is started.[15] A decision on long-term out-of-hospital anticoagulation is based on surgeon preference because no data are available on its value in this clinical situation.

F. Exposure of an injury to the internal iliac vein may mandate ligation and division of the overlying internal iliac artery.[44] Once exposed, the venous injury is ligated.

G. Same as Table 2C.[45]

H. Same as Table 2A without ligation.

REFERENCES

1. Burch JM, Feliciano DV, Mattox KL. The atriocaval shunt. Facts and fiction. *Ann Surg*. 1988;207:555–568.
2. Ball CG, Wyrzykowski AD, Nicholas JM, Rozycki GS, Feliciano DV. A decade's experience with balloon catheter tamponade for the emergency control of hemorrhage. *J Trauma*. 2011;70:330–333.
3. Taylor DC. Two cases of penetrating wounds of the abdomen involving the inferior vena cava. *Lancet*. 1916;2:60–61.
4. Nicoluzzi JE, von Bahten LC, Laux G. Hepatic vascular isolation in treatment of a complex hepatic vein injury. *J Trauma*. 2007;63:684–686.
5. Kavic SM, Atweh N, Ivy ME, Possenti PP, Dudrick SJ. Celiac axis ligation after gunshot wound to the abdomen: case report and literature review. *J Trauma*. 2001;50:738–739.
6. Accola KD, Feliciano DV, Mattox KL, Burch JM, Beall AC Jr, Jordan GL Jr. Management of injuries to the superior mesenteric artery. *J Trauma*. 1986;26:313–319.
7. Reilly PM, Rotondo MF, Carpenter JP, Sherr SA, Schwab CW. Temporary vascular continuity during damage control: intraluminal shunting for proximal superior mesenteric artery injury. *J Trauma*. 1995;39:757–760.
8. Subramanian A, Vercruysse G, Dente C, Wyrzykowski A, King E, Feliciano DV. A decade's experience with temporary intravascular shunts at a civilian level I trauma center. *J Trauma*. 2008;65:316–326.
9. Asensio JA, Petrone P, Kimbrell B, Kuncir E. Lessons learned in the management of thirteen celiac axis injuries. *South Med J*. 2005;98:462–466.
10. DeBakey ME, Simeone FA. Battle injuries of the arteries in World War II; an analysis of 2,471 cases. *Ann Surg*. 1946;123:534–579.
11. Hughes CW. Arterial repair during the Korean War. *Ann Surg*. 1958;147:555–561.
12. Rich NM, Baugh JH, Hughes CW. Acute arterial injuries in Vietnam: 1,000 cases. *J Trauma*. 1970;10:359–369.
13. Dua A, Patel B, Kragh JF Jr, Holcomb JB, Fox CJ. Long-term follow-up and amputation-free survival in 497 casualties with combat-related vascular injuries and damage-control resuscitation. *J Trauma Acute Care Surg*. 2012;73:1517–1524.
14. Feliciano DV, Burch JM, Spjut-Patrinely V, Mattox KL, Jordan GL Jr. Abdominal gunshot wounds. An urban trauma center's experience with 300 consecutive patients. *Ann Surg*. 1988;208:362–370.
15. Dente CJ, Feliciano DV. Abdominal vascular injury. In: Mattox KL, Moore EE, Feliciano DV, eds. *Trauma*. 7th ed, New York, NY: McGraw-Hill; 2013:632–654.
16. Feliciano DV. Management of traumatic retroperitoneal hematoma. *Ann Surg*. 1990;211:109–123.
17. Feliciano DV, Bitondo CG, Cruse PA, Mattox KL, Burch JM, Beall AC Jr, Jordan GL Jr. Liberal use of emergency center thoracotomy. *Am J Surg*. 1986;152:654–659.
18. Burlew CC, Moore EE, Moore FA, Coimbra R, McIntyre RC Jr, Davis JW, Sperry J, Biffl WL. Western Trauma Association critical decisions in trauma: resuscitative thoracotomy. *J Trauma Acute Care Surg*. 2012;73:1359–1363.

19. DeBakey ME, Creech O Jr, Morris GC Jr. Aneurysm of thoracoabdominal aorta involving the celiac, superior mesenteric, and renal arteries; report of four cases treated by resection and homograft replacement. *Ann Surg.* 1956;144:549–573.

20. Elkins R, DeMeester TR, Brawley RK. Surgical exposure of the upper abdominal aorta and its branches. *Surgery.* 1971;70:622–627.

21. Mattox KL, McCollum WB, Jordan GL Jr, Beall AC Jr, DeBakey ME. Management of upper abdominal vascular trauma. *Am J Surg.* 1974; 128:823–828.

22. McAninch JW, Federle MP. Evaluation of renal injuries with computerized tomography. *J Urol.* 1982;128:456–460.

23. Voelzke BB, McAninch JW. Renal gunshot wounds: clinical management and outcome. *J Trauma.* 2009;66:593–600.

24. McAninch JW, Carroll PR. Renal trauma: kidney preservation through improved vascular control—a refined approach. *J Trauma.* 1982;22:285–290.

25. Carroll PR, Klosterman P, McAninch JW. Early vascular control for renal trauma: a critical review. *J Urol.* 1989;141:826–829.

26. Lee JT, White RA. Endovascular management of blunt traumatic renal artery dissection. *J Endovasc Ther.* 2002;9:354–358.

27. Cestero RF, Plurad D, Green D, Inaba K, Putty B, Benfield R, Lam L, Talving P, Demetriades D. Iliac artery injuries and pelvic fractures: a national trauma database analysis of associated injuries and outcomes. *J Trauma.* 2009;67:715–718.

28. Cothren CC, Osborn PM, Moore EE, Morgan SJ, Johnson JL, Smith WR. Preperitoneal pelvic packing for hemodynamically unstable pelvic fractures: a paradigm shift. *J Trauma.* 2007;62:834–839.

29. Jurkovich GJ, Hoyt DB, Moore FA, Ney AL, Morris JA Jr, Scalea TM, Pachter HL, Davis JW. Portal triad injuries. *J Trauma.* 1995;39:426–434.

30. Rogers FB, Reese J, Shackford SR, Osler TM. The use of venovenous bypass and total vascular isolation of the liver in the surgical management of juxtahepatic venous injuries in blunt hepatic trauma. *J Trauma.* 1997; 43:530–533.

31. Biffl WL, Moore EE, Franciose RJ. Venovenous bypass and hepatic vascular isolation as adjuncts in the repair of destructive wounds to the retrohepatic inferior vena cava. *J Trauma.* 1998;45:400–403.

32. Accola KD, Feliciano DV, Mattox KL, Bitondo CG, Burch JM, Beall AC Jr, Jordan GL Jr. Management of injuries to the suprarenal aorta. *Am J Surg.* 1987;154:613–618.

33. Asensio JA, Britt LD, Borzotta A, Peitzman A, Miller FB, Mackersie RC, Pasquale MD, Pachter HL, Hoyt DB, Rodriguez JL, et al. Multiinstitutional experience with the management of superior mesenteric artery injuries. *J Am Coll Surg.* 2001;193:354–365.

34. Rotondo MF, Schwab CW, McGonigal MD, Phillips GR 3rd, Fruchterman TM, Kauder DR, Latenser BA, Angood PA. 'Damage control': an approach for improved survival in exsanguinating penetrating abdominal injury. *J Trauma.* 1993;35:375–382.

35. Knudson MM, Harrison PB, Hoyt DB, Shatz DV, Zietlow SP, Bergstein JM, Mario LA, McAninch JW. Outcome after major renovascular injuries: a Western Trauma Association multicenter report. *J Trauma.* 2000;49: 1116–1122.

36. 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;68:1117–1120.

37. Burch JM, Richardson RJ, Martin RR, Mattox KL. Penetrating iliac vascular injuries: recent experience with 233 consecutive patients. *J Trauma.* 1990;30:1450–1459.

38. Sullivan PS, Dente CJ, Patel S, Carmichael M, Srinivasan JK, Wyrzykowski AD, Nicholas JM, Salomone JP, Ingram WL, Vercruysse GA, et al. Outcome of ligation of the inferior vena cava in the modern era. *Am J Surg.* 2010;199:500–506.

39. Dente CJ, Wyrzykowski AD, Feliciano DV. Fasciotomy. *Curr Probl Surg.* 2009;46:779–839.

40. Burch JM, Feliciano DV, Mattox KL, Edelman M. Injuries of the inferior vena cava. *Am J Surg.* 1988;156:548–552.

41. Donahue TK, Strauch GO. Ligation as definitive management of injury to the superior mesenteric vein. *J Trauma.* 1988;28:541–543.

42. Stone HH, Fabian TC, Turkleson ML. Wounds of the portal venous system. *World J Surg.* 1982;6:335–341.

43. Samson RH, Lepore MR Jr, Showalter DP, Nair DG, Lanoue JB. Long-term safety of left renal vein division and ligation to expedite complex abdominal aortic surgery. *J Vasc Surg.* 2009;50:500–504.

44. Vitelli CE, Scalea TM, Philips TF, Sclafani SJ, Duncan AO. A technique for controlling injuries of the iliac vein in the patient with trauma. *Surg Gynecol Obstet.* 1988;166:551–552.

45. Pachter HL, Drager S, Godfrey N, LeFleur R. Traumatic injuries of the portal vein. The role of acute ligation. *Ann Surg.* 1979;189:383–385.