Injuries to the Great Vessels of the Abdomen

David V. Feliciano, M.D., F.A.C.S.

In patients who have injuries to the great vessels of the abdomen, the findings on physical examination generally depend on whether a contained hematoma or active hemorrhage is present. In the case of contained hematomas around the vascular injury in the retroperitoneum, the base of the mesentery, or the hepatoduodenal ligament, the patient often has only modest hypotension in transit or on arrival at the emergency center; the hypotension can be temporarily reversed by the infusion of fluids and may not recur until the hematoma is opened at the time of laparotomy. This is usually the situation when an abdominal venous injury is present. In the case of active intraperitoneal hemorrhage, the patient typically has significant hypotension and may have a distended abdomen on arrival. Another physical finding that is occasionally noted in association with an injury to the common or external iliac artery is intermittent or complete loss of a pulse in the ipsilateral femoral artery; this finding in a patient with a transpelvic gunshot wound is pathognomonic of an injury to the iliac artery.

Injuries to the great vessels of the abdomen are caused by penetrating wounds in 90% to 95% of cases; accordingly, they are often accompanied by injuries to multiple intra-abdominal organs, including those in the gastrointestinal tract. The general principles governing the sequencing of repairs of injuries to the great vessels and the GI tract are outlined elsewhere. A hematoma or hemorrhage associated with an injury to a great vessel of the abdomen occurs in one of the three zones of the retroperitoneum or in the portal-retrohepatic area of the right upper quadrant. The magnitude of injury is usually described according to the Abdominal Vascular Organ Injury Scale, devised in 1992 by the American Association for the Surgery of Trauma. Injuries in Zone 1

**Supramesocolic**

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posterior left renal artery as the maneuver is performed; and the anatomic distortion that results when the left kidney and the left renal artery are rotated anteriorly. When the hematoma is near the aortic hiatus of the diaphragm, it may be advisable to leave the left kidney in its fossa, thereby eliminating potential damage to the structure as well as the distortion resulting from rotation. Because of the density of the celiac ganglia and nerve plexus and the lymphatic vessels surrounding the upper abdominal aorta, this portion of the aorta is difficult to visualize even when left medial visceral rotation has been performed. It is frequently help-

**Figure 2** Algorithm illustrates management of intra-abdominal hematoma found at operation after blunt trauma.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>AAST Abdominal Vascular Organ Injury Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>Characteristics of Injury</td>
</tr>
<tr>
<td>I</td>
<td>Unnamed superior mesenteric artery or superior mesenteric vein branches</td>
</tr>
<tr>
<td>I</td>
<td>Unnamed inferior mesenteric artery or inferior mesenteric vein branches</td>
</tr>
<tr>
<td>I</td>
<td>Phrenic artery or vein</td>
</tr>
<tr>
<td>I</td>
<td>Lumbar artery or vein</td>
</tr>
<tr>
<td>I</td>
<td>Gonadal artery or vein</td>
</tr>
<tr>
<td>I</td>
<td>Ovarian artery or vein</td>
</tr>
<tr>
<td>I</td>
<td>Other unnamed small arterial or venous structures requiring ligation</td>
</tr>
<tr>
<td>II</td>
<td>Right, left, or common hepatic artery</td>
</tr>
<tr>
<td>II</td>
<td>Splenic artery or vein</td>
</tr>
<tr>
<td>II</td>
<td>Right or left gastric arteries</td>
</tr>
<tr>
<td>II</td>
<td>Gastroduodenal artery</td>
</tr>
<tr>
<td>II</td>
<td>Inferior mesenteric artery, trunk, or inferior mesenteric vein, trunk</td>
</tr>
<tr>
<td>II</td>
<td>Primary named branches of mesenteric artery (e.g., ileocolic artery) or mesenteric vein</td>
</tr>
<tr>
<td>II</td>
<td>Other named abdominal vessels requiring ligation or repair</td>
</tr>
<tr>
<td>III</td>
<td>Superior mesenteric vein, trunk</td>
</tr>
<tr>
<td>III</td>
<td>Renal artery or vein</td>
</tr>
<tr>
<td>III</td>
<td>Iliac artery or vein</td>
</tr>
<tr>
<td>III</td>
<td>Hypogastric artery or vein</td>
</tr>
<tr>
<td>III</td>
<td>Vena cava, infrarenal</td>
</tr>
<tr>
<td>III*</td>
<td>Superior mesenteric artery, trunk</td>
</tr>
<tr>
<td>III*</td>
<td>Celiac axis, proper</td>
</tr>
<tr>
<td>III*</td>
<td>Vena cava, supraparenal and infraportal</td>
</tr>
<tr>
<td>III*</td>
<td>Aorta, infrarenal</td>
</tr>
<tr>
<td>IV</td>
<td>Portal vein</td>
</tr>
<tr>
<td>IV</td>
<td>Extraparenchymal hepatic vein</td>
</tr>
<tr>
<td>IV</td>
<td>Vena cava, retrohepatic or suprahepatic</td>
</tr>
<tr>
<td>IV</td>
<td>Aorta, supraprenal and subdiaphragmatic</td>
</tr>
</tbody>
</table>

Note: This classification is applicable to extraparenchymal vascular injuries. If the vessel injury is within 2 cm of the parenchyma of a specific organ, one should refer to the injury scale for that organ.

*Increase grade by I if there are multiple injuries involving > 50% of vessel circumference.
*Reduce grade by I if laceration is < 25% of vessel circumference.

AAST—American Association for the Surgery of Trauma  
AIS—Abbreviated Injury Scale  
ICD—International Classification of Diseases
ful to transect the left crus of the aortic hiatus in the diaphragm at the 2 o’clock position to allow exposure of the distal descending thoracic aorta above the hiatus. Visualization of this portion of the vessel is much easier to achieve than visualization of the diaphragmatic or visceral abdominal aorta below, and an aortic cross-clamp can be applied much more quickly at this level.

Active hemorrhage from the midline supramesocolic area is controlled temporarily by packing with laparotomy pads or using an aortic compression device [see Figure 5]. A definitive approach is to divide the lesser omentum manually, retract the stomach and esophagus to the left, and manually dissect in the area just below the aortic hiatus of the diaphragm to obtain rapid exposure of the supraceliac abdominal aorta. An aortic cross-clamp can then be applied. Distal control of the upper abdominal aorta is difficult to obtain because of the presence of the anteriorly located celiac axis and superior mesenteric artery. In young trauma patients who are otherwise healthy, ligation and division of the celiac axis allow easier application of the distal aortic clamp and better exposure of the supraceliac area for subsequent vascular repair.

Small penetrating wounds to the supraceliac abdominal aorta are repaired with a continuous 3-0 or 4-0 polypropylene suture. If two small perforations are adjacent to each other, they can be connected and the defect closed in a transverse fashion. If closure of a perforation would result in significant narrowing of the aorta or if a portion of the aortic wall is missing, patch aortoplasty with polytetrafluoroethylene (PTFE) is indicated. On rare occasions, in patients with extensive injuries to the diaphragmatic or supraceliac aorta, resection of the area of injury and insertion of a vascular conduit are indicated. Even though many of these patients have associated gastric, enteric, or colonic injuries, the most appropriate prosthesis with such a life-threatening injury is a 12 mm or 14 mm Dacron or PTFE graft [see Figure 6]. Provided that vigorous intraoperative irrigation is performed after repair of GI tract perforations, that proper graft coverage is ensured, and that perioperative antibiotics are appropriately employed, it is extraordinarily rare for a prosthesis inserted in the healthy aorta of a young trauma patient to become infected.

The aortic prosthesis is sewn in place with a continuous 3-0 or 4-0 polypropylene suture. Both ends of the aorta are flushed before the distal anastomosis is completed, and the distal aortic cross-clamp is removed before the final knot is tied to eliminate air from the system. The proximal aortic cross-clamp is removed very slowly as the anesthesiologist rapidly infuses fluids and intra-
venous bicarbonate to reverse so-called washout acidosis from the previously ischemic lower extremities. The retroperitoneum is then irrigated with an antibiotic solution and closed over the graft in a watertight fashion with an absorbable suture.

Cross-clamping of the diaphragmatic or supraceliac abdominal aorta in a patient with hemorrhagic shock results in severe ischemia of the legs. Restoration of flow through the repaired abdominal aorta may then cause a reperfusion injury in addition to the ischemic edema that develops in the muscle compartments below the knee. In a patient who is hemodynamically stable after repair of the suprarenal abdominal aorta and other injuries, measurement of compartmental pressures below the knees should be performed before the patient is moved from the operating room. Pressures in the range of 30 to 35 mm Hg are likely to rise in the intensive care unit; accordingly, at many centers, bilateral below-the-knee two-incision four-compartment fasciotomies would be performed in this situation.

The survival rate in patients with injuries to the suprarenal abdominal aorta had been 30% to 35% but was lower than 10% in one 2001 review. Injuries to branches of the celiac axis are often difficult to repair because of the amount of dissection required to remove the dense neural and lymphatic tissue in this area. Because most patients have excellent collateral flow in the upper abdomen, major injuries to either the left gastric or the proximal splenic artery generally should be ligated. Because the common hepatic artery may have a larger diameter than either of these two arteries, an injury to this vessel can occasionally be repaired by means of lateral arteriorrhaphy, an end-to-end anastomosis, or the insertion of a saphenous vein graft. One should not worry about ligating the common hepatic artery proximal to the origin of the gastroduodenal artery: there is extensive collateral flow to the liver from the midgut. When the entire celiac axis is injured, it is best to ligate all three vessels and forgo any attempt at repair.

Injuries to the superior mesenteric artery are managed according to the anatomic level of the perforation or thrombosis. On rare occasions, in patients with injuries beneath the neck of the pancreas, one may have to transect the pancreas to obtain proximal control. Another option is to perform left medial visceral rotation (see above) and apply a clamp directly to the origin of the superior mesenteric artery. Injuries to the superior mesenteric artery in this area or just beyond the base of the mesocolon are often associated with injuries to the pancreas. The potential for a postoperative leak from the injured pancreas near the arterial repair has led numerous authors to suggest that any extensive injury to the artery at this location should be ligated (see Figure 7).

Because of the intense vasoconstriction of the distal superior mesenteric artery in patients who have sustained exsanguinating hemorrhage from more proximal injuries treated with ligation, the collateral flow from the foregut and hindgut is often inadequate to maintain the viability of the organs in the distal midgut, especially the cecum and the ascending colon. Therefore, it is safest to place a saphenous vein or PTFE graft on the distal infrarenal aorta, away from the pancreatic injury and any other upper abdominal injuries. Such a graft can be tailored to reach the side or the anterior aspect of the superior mesenteric artery, or it can be attached to the transected distal superior mesenteric artery in an end-to-end fashion without significant tension (see Figure 8). Soft tissue must be approximated over the aortic suture line of the graft to prevent the development of an aortoenteric fistula in the postoperative period.

In patients with severe shock from exsanguination caused by a complex injury to the superior mesenteric artery, damage-control laparotomy is indicated (see Damage-Control Laparotomy, below): the injured area should be resected and a temporary intraluminal Argyle, Javid, or Pruitt-Inahara shunt inserted to maintain flow to the midgut during resuscitation in the surgical intensive care unit.

Figure 6 A 22-year-old man with a gunshot wound to the right upper quadrant had injuries to the prepyloric area of the stomach and to the suprarenal abdominal aorta. The aortic injury was managed by means of segmental resection and replacement with a 16 mm polytetrafluoroethylene (PTFE) graft. The patient went home 46 days after injury.

Figure 7 An 18-year-old man experienced a gunshot wound to the head of the pancreas and the proximal superior mesenteric artery. A Whipple procedure was performed, and a 6 mm PTFE graft was placed in the artery. The artery-graft suture line dehisced secondary to a pancreatic leak on day 30 after injury, and the patient died on day 42.
When ligation is indicated for more distal injuries to the superior mesenteric artery, segments of the ileum or even the right colon may have to be resected because of ischemia.

The survival rate in patients with penetrating injuries to the superior mesenteric artery is approximately 50% to 55% overall [see Table 2] but only 20% to 25% when any form of repair more complex than lateral arteriorrhaphy is necessary.1-4,15,17

An injury to the proximal renal artery may also be present under a supramesocolic hematoma or bleeding area. When active hemorrhage is present, control of the supraceliac abdominal aorta in or just below the aortic hiatus must be obtained. When only a hematoma or a known thrombosis of the proximal renal artery is present, proximal vascular control can be obtained by elevating the transverse mesocolon and dissecting the vessel from the lateral aspect of the abdominal aorta. Options for repair of either the proximal or the distal renal artery are described elsewhere [see Injuries in Zone 2, below].

The superior mesenteric vein is the other great vessel of the abdomen that may be injured in the supramesocolic or retromesocolic area of the midline retroperitoneum. Because of the overlying pancreas, the proximity of the uncinate process, and the close association of this vessel with the superior mesenteric artery, repair of the superior mesenteric vein is quite difficult. As with injuries to the superior mesenteric artery (see above), one may have to transect the neck of the pancreas between noncrushing vascular or intestinal clamps to gain access to a perforation of the superior mesenteric vein. An injury to this vein below the inferior border of the pancreas can be managed by compressing it manually between one's fingers as an assistant places a continuous 5-0 polypropylene suture to complete the repair. When a penetrating injury to the vein has a posterior component, one must ligate multiple collateral vessels entering the vein in this area to achieve proper visualization.

There is excellent evidence that young trauma patients tolerate ligation of the superior mesenteric vein well when vigorous postoperative fluid resuscitation is performed to reverse the peripheral hypovolemia that results from splanchnic hypervolemia.18,19 Typically, ligation is followed almost immediately by swelling of the midgut and discoloration suggestive of impending ischemia. In such cases, temporary coverage of the midgut with a silo, followed by early reoperation, may be necessary to reassure the operating surgeon that the ischemia has not become permanent.

The survival rate in patients with injuries to the superior mesenteric vein ranges from 36% to 71%, depending on whether other vascular injuries are present [see Table 3].1-4,18

**INFRAVESICAL**

The lower area of the midline retroperitoneum in zone 1 is known as the midline infravesical area. Injuries to either the infrarenal abdominal aorta or the inferior vena cava occur in this area.

An injury to the infravesical abdominal aorta that is under a hematoma is controlled by performing the same maneuvers used to gain proximal control of an infrarenal abdominal aortic aneurysm. The infrarenal abdominal aorta is exposed by pulling the transverse mesocolon up toward the patient's head, eviscerating the small bowel to the right side of the abdomen, and opening the midline retroperitoneum until the left renal vein is exposed. A proximal aortic cross-clamp is then placed immediately inferior to this vessel [see Figure 9]. When the entire infravesical area is distorted by the presence of a large pulsatile hematoma, the inexperienced trauma surgeon should remember that the hole in the infrarenal abdominal aorta is under the highest point of the hematoma (the so-called Mt. Everest phenomenon). When there is active hemorrhage from this area, rapid proximal control is obtained in the same fashion or, if necessary because of the need
to apply compression, by dividing the lesser omentum and applying the cross-clamp just below the aortic hiatus of the diaphragm. Distal control of the infrarenal abdominal aorta is obtained by dividing the midline retroperitoneum down to the aortic bifurcation, taking care to avoid the origin of the inferior mesenteric artery on the left side.

Injuries to the infrarenal aorta are repaired by means of lateral aortorrhaphy, patch aortoplasty, an end-to-end anastomosis, or insertion of a Dacron or PTFE graft. Much as with injuries to the suprarenal abdominal aorta in young trauma patients, it is rarely possible to place a tube graft larger than 12 or 14 mm. Because the retroperitoneal tissue is often thin at this location in young patients, an important adjunctive measure after the aortic repair is to mobilize the gastrocolic omentum, flip it into the lesser sac superiorly, and then bring it down over the infrarenal aortic graft through a hole in the left transverse mesocolon. An alternative is to mobilize the gastrocolic omentum away from the right side of the colon and then swing the mobilized tissue into the left lateral gutter just below the ligament of Treitz to cover the graft. With either technique, it is mandatory to suture the viable omental pedicle superior to the aortic suture line to prevent a postoperative aortoduodenal fistula.20,21

The survival rate in patients with injuries to the infrarenal abdominal aorta had been approximately 45% but was 34% in a 2001 review [see Table 2].1-4

Table 2  Survival after Injuries to Arteries in the Abdomen

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<tbody>
<tr>
<td></td>
<td>Isolated Injury</td>
<td>With Other Arterial Injury</td>
<td></td>
</tr>
<tr>
<td>Abdominal aorta as a whole</td>
<td>21.7% (10/46)</td>
<td>17.6% (3/17)</td>
<td>39.1% (25/64)</td>
</tr>
<tr>
<td>Pararenal to diaphragm</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Infrarenal</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Superior mesenteric artery</td>
<td>52.4% (11/21)</td>
<td>28.6% (2/7)</td>
<td>53.3% (8/15)</td>
</tr>
<tr>
<td>Renal artery</td>
<td>62.5% (5/8)</td>
<td>33.3% (2/6)</td>
<td>56.2% (9/16)</td>
</tr>
<tr>
<td>Iliac artery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common</td>
<td>—</td>
<td>—</td>
<td>55.5% (5/9)</td>
</tr>
<tr>
<td>External</td>
<td>—</td>
<td>—</td>
<td>65.2% (30/46)</td>
</tr>
</tbody>
</table>

*Excludes patients who exsanguinated before repair or ligation.

Injury to the inferior vena cava below the liver should be suspected when the aorta is found to be intact underneath an inframesocolic hematoma, when such a hematoma appears to be more extensive on the right side of the abdomen than on the left, or when there is active hemorrhage coming through the base of the mesentery of the ascending colon or the hepatic flexure. It is certainly possible to visualize the inferior vena cava through the midline retroperitoneal exposure just described (see above); however, most surgeons are more comfortable with visualizing the vessel by mobilizing the right half of the colon and the C loop of the duodenum.1 With this right medial visceral rotation maneuver, the right kidney is left in situ unless there is an associated injury to the posterior aspect of the right renal vein, to the suprarenal vena cava, or to the right kidney itself. Right medial visceral rotation, in conjunction with the Kocher maneuver, permits visualization of the entire vena caval system from the confluence of the iliac veins to the suprarenal vena cava below the liver [see 7:6 Operative Exposure of Abdominal Injuries and Closure of the Abdomen]. Local exposure of the iliac vein–vena cava junction in the lower abdomen and of the renal vein–vena cava junction in the upper abdomen is appropriate before completion of right medial visceral rotation. This measure allows rapid application of proximal and distal vascular clamps on the inferior vena cava in the event that exsanguinating hemorrhage results when the caval injury is exposed.

Table 3  Survival after Injuries to Veins in the Abdomen

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>Isolated Injury</td>
<td>With Other Venous Injury</td>
<td></td>
</tr>
<tr>
<td>Inferior vena cava as a whole</td>
<td>29.3% (12/41)†</td>
<td>22.2% (8/36)†</td>
<td>56% (47/84)</td>
</tr>
<tr>
<td>Pararenal to diaphragm</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Infrarenal</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Superior mesenteric vein</td>
<td>47.4% (9/19)</td>
<td>35.7% (5/14)</td>
<td>71.4% (15/21)</td>
</tr>
<tr>
<td>Renal vein</td>
<td>—</td>
<td>44.1% (15/34)</td>
<td>70% (21/30)</td>
</tr>
<tr>
<td>Iliac vein (all)</td>
<td>62.2% (23/37)</td>
<td>33.3% (5/15)</td>
<td>—</td>
</tr>
<tr>
<td>Common</td>
<td>—</td>
<td>—</td>
<td>81% (17/21)</td>
</tr>
<tr>
<td>External</td>
<td>—</td>
<td>—</td>
<td>74.5% (41/55)</td>
</tr>
</tbody>
</table>

*Excludes patients who exsanguinated before repair or ligation.
†Excludes retrohepatic vena cava.
For proper exposure of a hole in a large vein such as the inferior vena cava, the loose retroperitoneal fatty tissue must be dissected away from the wall of the vessel. Active hemorrhage coming from the anterior surface of the inferior vena cava is best controlled by applying a Satinsky vascular clamp. If it is difficult to apply this clamp, one should try grasping the area of the perforation with a pair of vascular forceps or several Judd-Allis clamps; this step may facilitate safe application of the Satinsky clamp. When the perforation in the inferior vena cava is more lateral or posterior, it is often helpful to compress the vessel proximally and distally around the perforation, using gauze sponges placed in straight sponge sticks. On occasion, an extensive injury to the inferior vena cava can be controlled only by completely occluding the entire inferior vena cava with large DeBakey aortic cross-clamps. This maneuver interrupts much of the venous return to the right side of the heart and is poorly tolerated by hypotensive patients unless the infrarenal abdominal aorta is cross-clamped simultaneously.

There are two anatomic areas in which vascular control of an injury to the inferior vena cava below the liver is difficult to obtain: (1) the confluence of the common iliac veins and (2) the junction of the renal veins with the inferior vena cava. One interesting approach to an injury to the inferior vena cava at the confluence of the iliac veins is temporary division of the overlying right common iliac artery, coupled with mobilization of the aortic bifurcation to the patient’s left. This approach yields a better view of the common iliac veins and the proximal inferior vena cava and makes repair considerably easier than it would be if the aortic bifurcation were left in place. Once the vein is repaired, the right common iliac artery is reconstituted via an end-to-end anastomosis. The usual approach to injuries to the inferior vena cava at its junction with the renal veins involves clamp or sponge-stick compression of the infrarenal and suprarenal vena cava, as well as control of both renal veins with Silastic loops to facilitate the direct application of angled vascular clamps. As noted, medial mobilization of the right kidney may permit the application of a partial occlusion clamp across the inferior vena cava at its junction with the right renal vein as an alternative approach to an injury in this area. Another useful technique for controlling hemorrhage from the inferior vena cava at any location is to insert a 5 ml or 30 ml Foley balloon catheter into the caval laceration and then inflate it in the lumen. Once the bleeding is controlled, vascular clamps are positioned around the perforation, and the balloon catheter is removed before repair of the vessel.

Anterior perforations of the inferior vena cava are managed by means of transverse repair with a continuous 4-0 or 5-0 polypropylene suture. Much has been written about visualizing posterior perforations by extending anterior perforations, but in my experience, opportunities to apply this approach have been rare. It is often easier to roll the vena cava to one side to complete a continuous suture repair of a posterior perforation. When both anterior and posterior perforations have been repaired, there is usually a significant degree of narrowing of the inferior vena cava, which may lead to slow postoperative occlusion. If the patient’s condition is unstable and a coagulopathy has developed, no further attempt should be made to revise the repair. If the patient is stable, there may be some justification for applying a large PTFE patch to prevent this postoperative occlusion (see Figure 10).

Ligation of the infrarenal inferior vena cava is appropriate for young patients who are exsanguinating and in whom a complex repair of the vessel would be necessary. After the damage-control abdominal procedure has been completed and a silo has been used to cover the midgut, it is, once again, worthwhile to measure the compartmental pressures below the knees before the patient is moved from the OR. Below-the-knee two-incision four-compartment fasciotomies are performed when pressures exceed 30 to 35 mm Hg. Three-compartment fasciotomies in the thighs have proved necessary in some surviving patients after caval liga-

Figure 9 Shown is a gunshot wound to the infrarenal abdominal aorta viewed through standard inframesocolic exposure. Patient’s head is at the bottom of the photograph.

Figure 10 Shown is PTFE patch repair of an injury to the infrarenal inferior vena cava.
tion. Patients who have undergone ligation of the infrarenal inferior vena cava require vigorous resuscitation with crystalloid solutions in the postoperative period; in addition, both lower extremities should be wrapped with elastic compression wraps and elevated for 5 to 7 days after operation. Patients who have some residual edema during the later stages of hospitalization despite the elastic compression wraps should be fitted with full-length custom-made support hose. Ligation of the suprarenal inferior vena cava is occasionally necessary when the patient has an extensive injury at this location and appears to be in an irreversible shock state during operation. If the patient’s condition improves during a brief period of resuscitation in the SICU, reoperation and reconstruction with an externally supported PTFE graft are usually necessary to prevent renal failure.

The survival rate in patients with injuries to the inferior vena cava depends on the location of the injury; in the past, it ranged from 60% for the suprarenal vena cava to 78% for the infrarenal vena cava but decreased to approximately 33% to 56% if injuries to the retrohepatic vena cava were included. Current studies indicate survival rates of 22% to 56% for inferior vena cava injuries taken as a whole. A 2001 review reported survival rates of 46.1% for the infrarenal inferior vena cava and 40.3% for more superior injuries.

Injuries in Zone 2

Hematoma or hemorrhage in zone 2 is cause to suspect the presence of injury to the renal artery, the renal vein, or the kidney. In patients who have sustained blunt abdominal trauma but in whom preoperative intravenous pyelography, renal arteriography, or abdominal CT confirms that a reasonably intact kidney is present, there is no justification for opening a perirenal hematoma if one is found at a subsequent operation [see Figure 11].

In highly selected stable patients with penetrating wounds to the flank, there are some data to justify performing preoperative CT. On occasion, documentation of an isolated minor renal injury in the absence of peritoneal findings on physical examination makes it possible to manage such patients nonoperatively. In all other patients with penetrating wounds, when a perirenal hematoma is found during initial exploration, the hematoma should be unroofed and the wound tract explored. If the hematoma is not rapidly expanding and there is no active hemorrhage from the perirenal area, one may control the ipsilateral renal artery with a Silastic loop in the midline of the retroperitoneum at the base of the mesocolon [see Figure 12]. Control of the left renal vein can be obtained at the same location; however, control of the proximal right renal vein requires mobilization of the C loop of the duodenum and dissection of the vena cava at its junction with this vessel.

If there is active hemorrhage from the kidney through Gerota’s fascia or from the retroperitoneum overlying the renal vessels, no central renal vascular control is necessary. In such a situation, the retroperitoneum lateral to the injured kidney should be opened, and the kidney should be manually elevated directly into the abdominal incision. A large vascular clamp should then be applied directly to the hilar vessels of the elevated kidney to control any further bleeding until a decision is reached on repair versus nephrectomy.

Occasionally, a small perforation of the renal artery can be repaired by lateral arteriorrhaphy or resection with an end-to-end anastomosis. Interposition grafting and replacement of the renal artery with either the hepatic artery (on the right) or the splenic artery (on the left) have been used on rare occasions, but such approaches ordinarily are not indicated unless the injured kidney is the only one the patient has. In patients who have sustained multiple intra-abdominal injuries from penetrating wounds or have undergone a long period of ischemia while other injuries were being repaired, nephrectomy is the appropriate choice for a major renovascular injury, provided that intraoperative palpation has confirmed the presence of a normal contralateral kidney.

The role of renal revascularization in patients who have intimal tears in the renal arteries as a result of deceleration-type trauma remains controversial. If a circumferential intimal tear is noted on preoperative arteriography but flow to the kidney is preserved, the decision whether to repair the artery depends on whether laparotomy is necessary for other injuries and whether the opportunity for anticoagulation is available. If there are no other significant injuries and flow to the kidney is preserved despite the presence of an intimal tear, anticoagulation and a repeat isotope renogram within the first several days may be justified. An alternative approach involves insertion of an endovascular stent in the renal

Figure 11 A right perirenal hematoma was not opened at operation, because preoperative abdominal CT documented a reasonably intact kidney.

Figure 12 Midline looping of respective renal vessels is performed before entry into any perirenal hematoma.
Failure to properly dissect out the structures in the porta hepatitis after a penetrating wound led to the creation of an iatrogenic hepatic artery–portal vein fistula, which was corrected after the arrival of the attending surgeon.

The survival rate in patients with isolated injuries to the renal veins is approximately 70% [see Table 3].

**Injuries in Zone 3**

Hematoma or hemorrhage in either lateral pelvic area is suggestive of injury to the iliac artery or the iliac vein. When lateral pelvic hematoma or hemorrhage is noted after penetrating trauma, compression with a laparotomy pad or the fingers should be maintained as proximal and distal vascular control is obtained. The proximal common iliac arteries are exposed by eviscerating the small bowel to the right and dividing the midline retroperitoneum over the aortic bifurcation. In young trauma patients, the common iliac artery usually is not adherent to the common iliac vein, and Silastic loops can be passed rapidly around these vessels to provide proximal vascular control. Distal vascular control is most easily obtained where the external iliac artery and vein come out of the pelvis proximal to the inguinal ligament. Even with proximal and distal control of the common or the external iliac artery and vein, there is often continued back-bleeding from the internal iliac artery. Such bleeding is controlled by elevating the Silastic loops on the proximal and distal iliac artery and then either clamping or looping the internal iliac artery, which is the only major branch vessel that descends into the pelvis.

For transpelvic bilateral iliac vascular injuries resulting from a penetrating wound, a technique of total pelvic vascular isolation has been described. Proximally, the abdominal aorta and the inferior vena cava are cross-clamped just above their bifurcations, and distally, both the external iliac artery and the external iliac vein are cross-clamped, with one clamp on each side of the distal pelvis. Back-bleeding from the internal iliac vessels is minimal with this approach.

Ligation of either the common or the external iliac artery in a hypotensive trauma patient leads to a 40% to 50% amputation rate in the postoperative period; consequently, injuries to these vessels should be repaired if at all possible. The standard options for repair—lateral arteriorrhaphy, completion of a partial transection with an end-to-end anastomosis, and resection of the injured area with insertion of a conduit—are feasible in most situations [see Figure 13]. On rare occasions, it may be preferable either to mobilize the ipsilateral internal iliac artery to serve as a replacement for the external iliac artery or to transpose one iliac artery to the side of the contralateral iliac artery. When a patient is in severe shock from exsanguination caused by a complex injury to the common or the external iliac artery, damage control laparotomy [see Damage Control Laparotomy, below] is indicated. The injured area should be resected and a temporary intraluminal Argyle, Javid, or Pruitt-Inahara shunt inserted to maintain flow to the ipsilateral lower extremity during resuscitation in the SICU.

One unique problem associated with repair of the common or the external iliac artery is the choice of technique when significant enteric or fecal contamination is present in the pelvis. In such cases, there is a substantial risk of postoperative pelvic cellulitis, a pelvic abscess, or both, which may lead to blowout of any type of repair. When extensive contamination is present, it is appropriate to divide
the common or external iliac artery above the level of injury, close
the injury with a double row of continuous 4-0 or 5-0 polypropylene
sutures, and bury the stump underneath uninjured retroperitoneum.

If a stable patient has obvious ischemia of the ipsilateral lower ex-
tremity at the completion of this proximal ligation, one may perform
an extra-anatomic femorofemoral crossover bypass with an 8 mm
externally supported PTFE graft to restore arterial flow to the ex-
tremity.

Injuries to the internal iliac arteries are usually ligated even if
they occur bilaterally, because young trauma patients typically
have extensive collateral flow through the pelvis.

The survival rate in patients with isolated injuries to the exter-
nal iliac artery exceeds 80% when tamponade is present. If the
injury is large and free bleeding has occurred preoperatively, how-
ever, the survival rate is only 45%. Current studies report overall
survival rates of approximately 45% to 55% for injuries to the
common iliac artery and 62% to 65% for injuries to the external
iliac artery [see Table 2].

Hemorrhage from injuries to the iliac veins can usually be con-
trolled by means of compression with either sponge sticks or the
fingers. As noted, division of the right common iliac artery may
be necessary for proper visualization of an injury to the right com-
mon iliac vein. Similarly, ligation and division of the internal iliac
artery on the side of the pelvis yield improved exposure of an
injury to an ipsilateral internal iliac vein.

Injuries to the common or external iliac vein are best treat-
ated by means of lateral venorrhaphy with continuous 4-0 or 5-0
polypropylene sutures. Significant narrowing often results, and a
number of reports have demonstrated occlusion on postoperative
venography. For patients with narrowing or occlusion, as well as
for those in whom ligation was necessary to control exsanguinat-
ing hemorrhage, the use of elastic compression wraps and eleva-
tion for the first 5 to 7 days after operation is mandatory.

In some centers, once the patient’s perioperative coagulopathy
has resolved, anticoagulation with a low-molecular-weight hepar-
in is initiated to prevent progression or migration of a venous
thrombus. The patient is then discharged on a regimen of oral
warfarin sodium, and serial measurement of the international
normalized ratio (INR) is continued for 3 months.

The survival rate in patients with injuries to the iliac veins
ranges from 33% to 81%, depending on whether associated vas-
cular injuries are present [see Table 3].


Injuries in the Porta Hepatis or Retrohepatic Area

PORTA HEPATIS

Hematoma or hemorrhage in the area of the portal triad in the
right upper quadrant is cause to suspect the presence of injury to
the portal vein or the hepatic artery or of vascular injury com-
bined with an injury to the common bile duct.

If a hematoma is present, the proximal hepatoduodenal liga-
ment should be occluded with a vascular clamp (the Pringle
maneuver) before the hematoma is entered. If the hematoma is
centrally located in the porta, one may also be able to apply an
angled vascular clamp to the distal end of the portal structures at
their entrance into the liver.

If hemorrhage is occurring, compression of the bleeding vessels
with the fingers should suffice until the vascular clamp is in place.
Once proximal and distal vascular control is obtained, the three
structures in the hepatoduodenal ligament must be dissected out
very carefully because of the danger of blindly placing sutures in
proximity to the common bile duct [see Figure 14].

Injuries to the hepatic artery in this location are occasionally
amenable to lateral repair, though ligation without reconstruction
is ordinarily well tolerated because of the extensive collateral arte-
rial flow to the liver. If an associated hepatic injury calls for
extensive suturing or debridement, ligation of the common
hepatic artery or artery to the injured lobe will certainly lead to
increased postoperative necrosis of the hepatic repair. Moreover,
ligation of the common hepatic artery, the right or left hepatic
artery supplying the injured lobe, and the portal vein branch to
that lobe will lead to necrosis of the lobe and will necessitate
hepatectomy. Finally, ligation of the right hepatic artery to con-

Retrohepatic hematoma or hemorrhage is cause to suspect the
presence of injury to the retrohepatic venous cava, a hepatic vein, or
a right renal blood vessel. In addition, hemorrhage in this area
may signal injury to the overlying liver [see 7.7 Injuries to the Liver,
Biliary Tract, Spleen, and Diaphragm].

If there is a hematoma that is not expanding or ruptured and
clearly has no association with the right perirenal area, a tampon-
aded injury to the retrohepatic venous cava or a hepatic vein is pres-
ent. Perihepatic packing around the right lobe of the liver for 24
to 48 hours has been shown to prevent further expansion and
should be considered.

If hemorrhage is occurring that does not appear to be coming
from the overlying liver, the right lobe of the liver should be com-

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pressed posteriorly to tamponade the caval perforation. The Pringle maneuver is then applied, and the surgical and nursing team, the anesthesiologist, and the blood bank are notified. Once the proper instruments and banked blood are in the OR, the overlying injured hepatic lobe or the lobe closest to the presumed site of injury is mobilized by dividing the triangular and coronary ligaments and then lifted out of the subdiaphragmatic area. On occasion, an obvious perforation of the retrohepatic or suprahepatic vena cava or an obvious area where a hepatic vein was avulsed from the vena cava may be grasped with a forceps or a series of Judd-Allis clamps; a Satinsky clamp may then be applied. Because of the copious bleeding that occurs as the liver is lifted and the hole in the vena cava sought, the anesthesiologist should start blood transfusions as the lobe is being mobilized.

If the retrohepatic hemorrhage is not controlled after one or two direct attempts, another technique must be tried. The most common choice is the insertion of a 36 French chest tube or a 9 mm endotracheal tube as an atriocaval shunt [see 7:6 Operative Exposure of Abdominal Injuries and Closing the Abdomen and 7:7 Injuries to the Liver, Biliary Tract, Spleen, and Diaphragm]. The shunt can reduce bleeding by 40% to 60%, but vigorous hemorrhage persists until full control of the perforation is obtained with clamps or sutures. An alternative approach is to isolate the liver and the vena cava by cross-clamping the supraceliac aorta, the porta hepatis, the suprarenal inferior vena cava, and the intrapericardial inferior vena cava. Because profoundly hypovolemic patients usually cannot tolerate cross-clamping of the inferior vena cava, this approach is rarely employed. Some experienced hepatic surgeons have successfully used extensive hepatotomy to expose and repair the retrohepatic vena cava.

The retrohepatic vena cava is repaired with continuous 4-0 or 5-0 polypropylene sutures. When the atriocaval shunt is removed from the heart after the vessel has been repaired, the right atrial appendage is ligated with a 2-0 silk tie.

The survival rate in patients not in cardiac arrest who undergo atriocaval shunting and repair of the retrohepatic vena cava has ranged from 33% to 50%.

Damage-Control Laparotomy

Patients with injuries to the great vessels of the abdomen are ideal candidates for damage-control laparotomy: they are uniformly hypothermic, acidic, and coagulopathic on completion of the vascular repair, and a prolonged operation would lead to their demise. In such patients, packing of minor or moderate injuries to solid organs, packing of the retroperitoneum, stapling and rapid resection of multiple injuries to the GI tract, and consideration of diffuse intra-abdominal packing are all appropriate, as is silo coverage of the open abdomen, in which a temporary silo made from a urologic irrigation bag is sewn to the skin edges with a continuous 2-0 polypropylene or nylon suture. The patient is then rapidly moved to the SICU for further resuscitation. Priorities in the SICU include rapid restoration of normal body temperature, reversal of shock, infusion of intravenous bicarbonate to correct a persistent pH lower than 7.2, and administration of fresh frozen plasma, platelets, and cryoprecipitate when indicated. It is usually possible to return the patient to the OR for removal of clot and packs, reconstruction of the GI tract, irrigation, and reapplication of silo coverage or application of a vacuum-assisted closure device within 48 to 72 hours.

When massive distention of the midgut persists after 7 days of intensive care and use of the vacuum-assisted closure device (15% to 25% of patients), the safest approach is to convert the patient to an open abdomen (i.e., without closure of the midline incision) and cover the midgut with a double-thickness layer of absorbable mesh. With proper nutritional support and occasional use of Dakin solution to minimize bacterial contamination of the absorbable mesh, most patients are ready for the application of a split-thickness skin graft to the eviscerated midgut within 3 to 4 weeks of the original operation for an injury to a great vessel.

Complications

Besides those already mentioned, major complications associated with repair of injuries to the great vessels in the abdomen include thrombosis, dehiscence of the suture line, and infection. Because of the risk of occlusion of repairs in small vasoconstricted vessels (e.g., the superior mesenteric artery), it may be worthwhile to perform a second-look operation within 12 to 24 hours if the patient’s metabolic state suggests that ischemia of the midgut is present. Early correction of an arterial thrombosis in the superior mesenteric artery may permit salvage of the midgut.

As noted [see Injuries in Zone 1, above], dehiscence of an end-to-end anastomosis or a vascular conduit inserted in the proximal superior mesenteric artery when there is an injury to the adjacent pancreas may be prevented or the incidence lowered by inserting a distal aorta–superior mesenteric artery bypass graft. To prevent adjacent loops of small bowel from adhering to the vascular suture lines, both lines should be covered with soft tissue (retroperitoneal tissue for the aortic suture line and mesenteric tissue for the superior mesenteric arterial suture line). Also as noted [see Injuries in Zone 3, above], when an extensive injury to either the common or the external iliac artery occurs in the presence of significant enteric or fecal contamination in the pelvis, litigation and extra-anatomic bypass may be necessary.

On occasion, vascular-enteric fistulas occur after repair of the anterior aorta or the insertion of grafts in either the abdominal aorta or the superior mesenteric artery. In my experience, such fistulas all occur at suture lines; hence, once again, proper coverage of suture lines with soft tissue should eliminate or lower the incidence of this complication.

References

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