18 Abdominal Aortic Trauma, Iliac and Visceral Vessel Injuries

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Introduction

Major vascular injuries may be seen in up to 25% of abdominal trauma and are associated with a high mortality.[1,2] Following penetrating abdominal trauma, vascular injuries are the most common causes of death.[3] Intra-abdominal hemorrhage can be catastrophic due to the difficulty of rapidly accessing the retroperitoneal vessels. It is for this reason that early recognition of a possible vascular injury is essential and transfer to a center capable of early surgical intervention is vital. The early diagnosis of these injuries has been facilitated with the increasing use of computed tomography (CT) angiography and with its availability close to the resuscitation room.

Civilian vascular injury comprises approximately 1% to 5% of all trauma[4,5] with data from the PROOVIT (PROspective Observational Vascular Injury Treatment) registry revealing the incidence of abdominal arterial injuries to be 7.8% of all of vascular trauma.[6] The relative rarity therefore makes it difficult for a trauma center and its surgeons to accumulate large caseloads of specific arterial injuries. Although blunt trauma is the most common mechanism of all vascular injury in the PROOVIT registry, there are huge variations in the role of penetrating trauma causing abdominal vascular injury. In urban US trauma centers this is reported to be as high as 88%,[7] whereas in Germany, over a 16-year period, the incidence of penetrating trauma was only 5% in 760 patients with abdominal vascular injury.[2] The incidence of injuries differs between military and civilian trauma. During the Vietnam War and World War II, the incidence of penetrating abdominal vascular injuries was less than 3%,[8] but in the recent conflicts in Iraq and Afghanistan, iliac injuries were found in 3.9% of injuries, and aortic injuries in a further 2.9%.[9] In civilian populations with a high incidence of knife crime, the incidence approaches 10%; and this figure doubles to more than 20% in populations with gun crime.[10] For aortic penetrating injuries, the incidence still remains low, and it is less than 3% for penetrating trauma.[11]

Mechanism of Injury

PENETRATING INJURY

In the context of noniatrogenic injuries, penetrating injuries usually occur either from stab wounds or firearms. Injuries resulting from explosions (e.g., bomb blast) are complex, resulting in mixed patterns of penetrating and blunt trauma.

Stab wounds (e.g., knife wounds) result in localized injuries whereby the path of injury follows the track of the weapon. The type of injury that results from firearms is variable depending on the nature of the firearm. Gunshot wounds may be high velocity or low velocity. Low-velocity gunshot wounds are defined as wounds caused by projectiles such as bullets or missiles with speeds of less than 600 m/s.[12] Low-velocity gunshot wounds such as those that occur with handguns cause localized injury to the structures that lie in the paths of the projectiles. They are associated with a lower transfer of energy compared with high-velocity gunshot wounds. Military wounds are more often a result of high-velocity (greater than 600 m/s) projectiles. A high-velocity projectile carries with it a significant amount of kinetic energy that is transferred to the surrounding tissue and results in extensive injury around the path of the projectile as well as the immediate damage to any tissue in the path of the projectile. The amount of energy transferred to the patient will be decided by a combination of factors including the energy carried by the missile, the cross-sectional area of the missile that comes into contact with the tissue, and the degree of retardation of the missile within the patient, that is, whether the missile passes through the tissue (delivering less energy) or comes to rest within the tissue (delivering all of its kinetic energy). When military weapons are used in civilian settings with no body armor, mortality from abdominal vascular injury may approach 100%.[13]

The injury that results from shotgun wounds is dependent on the range at which the shotgun is fired. If the range is less than 5 m, the chance of survival is approximately 10%. At this range, although the shotgun cartridge contains multiple pellets (shot), the pellet mass has yet to disperse and thus acts as a more focused mass on impact with tissue. When the shotgun is fired from a greater distance (e.g., 5–15 m) the shot has spread, with each pellet carrying lower kinetic energy secondary to retardation from the air – behaving as a low-energy missile, generally resulting in less destruction to tissue. At close range, vascular injuries tend to be multiple, complex, and frequently contaminated either with bowel contents or external contaminants such as the victims clothing.[14]

BLUNT INJURY

Blunt abdominal vascular injury is rarely isolated, is often associated with high injury severity scores (ISS) in competing injured body regions, and incurs significant mortality.[2] The mechanism by which blunt trauma results in vascular injury is either by severe deceleration, by crush injuries, or by direct laceration from a fractured bone fragment. Severe deceleration can occur in the context of high-speed road traffic accidents or falls from significant heights. Crush injuries also occur in road traffic accidents and may result in an anteroposterior crush injury as seen in a seatbelt-restrained passenger. This can also be associated with shearing injuries of the aortic branches. Fractures of the spine or pelvis can result in direct laceration to the aorta and iliac vessels, respectively. Renal vessels may be damaged with acceleration – deceleration-type injuries causing shearing forces to be applied to the renal pedicle.

Whereas the adventitia is the most durable part of the arterial wall, the intima remains the least elastic and therefore most likely to be torn during blunt injury. Hence the artery is frequently injured from "inside to outside," and the adventitia may remain intact. This creates a thrombogenic environment within the artery resulting in thrombosis and occlusion. Alternatively, the intima may be sheared resulting in a dissection. If the adventitia remains intact, the artery may still be weakened, contributing to delayed aneurysmal degeneration. Total transmural injury can lead to perforation, hemorrhage, and false aneurysms.

Anatomy

Vascular injuries in the abdomen are classified according to geographical location (Fig. 18.1). These are usually defined within three zones, albeit a fourth zone is occasionally included.

Zone I begins at the point of entry of the aorta through the diaphragm (i.e., the aortic hiatus) and extends down to the sacrum. The aorta enters the abdomen at the level of the twelfth thoracic vertebra passing behind the median arcuate ligament of the diaphragm. The aorta descends to the level of the fourth lumbar vertebra where it bifurcates into the left and right common iliac arteries. Zone I includes the central retroperitoneal area and the base of the mesentery. The area is further divided into the supramesocolic and inframesocolic areas. The supramesocolic and inframesocolic areas are defined by the levels of the renal arteries. The suprarenal aorta, celiac axis, superior mesenteric artery (SMA), renal arteries, inferior vena cava (IVC), and superior mesenteric vein all lie within this supramesocolic area. The inframesocolic area contains the infrarenal aorta, the inferior mesenteric artery, and the IVC.

Zone II exists either side of zone I and contains the paracolic gutters, kidneys, and renal vessels. It is also referred to as the upper lateral retroperitoneum.

Zone III, containing the iliac vessels, is also known as the pelvic retroperitoneum.

The hepatic artery, portal vein, retrohepatic IVC, and hepatic veins all lie within an area occasionally referred to as zone IV.

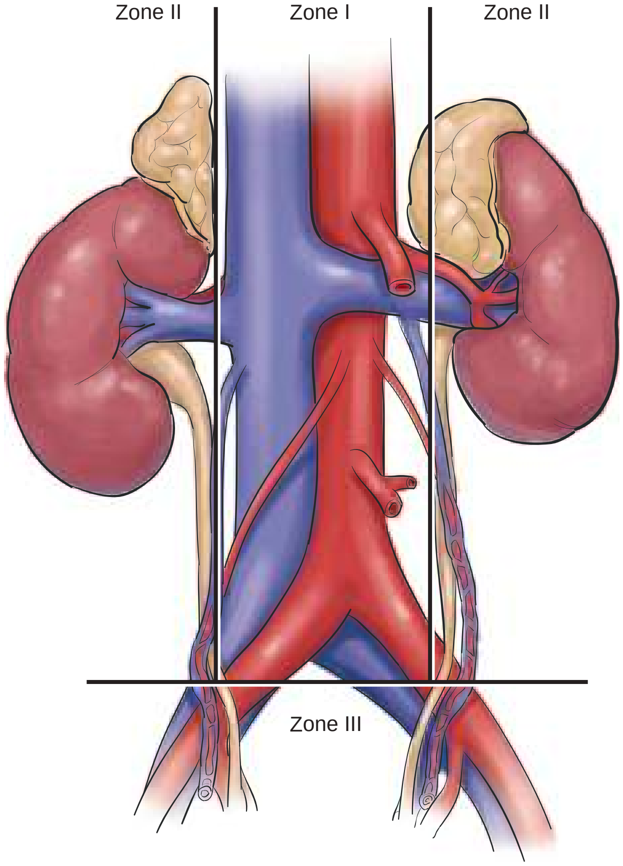

Fig. 18.1 The three anatomical zones of the retroperitoneum used to describe the locations of vascular injuries presenting as retroperitoneal hematomas. Zone I extends from the aortic hiatus to the sacrum and includes the midline vessels and origins of the visceral branches. Zone II exists on either side of Zone I and includes the kidneys, renal vessels, and paracolic gutters. Zone III lies inferior to the level of the sacral promontory and includes the iliac vessels and pelvic retroperitoneum. Zone IV is not depicted in the diagram.

Clinical Presentation

The patient should be inspected for signs of penetrating injury. Stab wounds in the abdomen should be obvious but be aware that stab wounds in the chest, back, and gluteal regions can result in injury to abdominal and pelvic vessels. With both penetrating and blunt trauma, examine for bruising in the flanks. This can be a sign of a retroperitoneal bleeding. With gunshot wounds, examine the patient for entry and exit wounds. An attempt to predict the trajectory may provide some idea of the vessels and organs injured. Do not assume that the injury is localized to the missile path. The presentation of arterial injuries may be early or late depending on the artery involved, as well as the type and mechanism of injury.

Early presentation is usually in the form of hemorrhage and hypovolemic shock. Urgent laparotomy will reveal either blood in the peritoneal cavity or a retroperitoneal hematoma. The zone should be defined according to Fig. 18.1. Some patients may respond to resuscitation but presentation with a distended abdomen should raise the suspicion of a vascular injury. Patients who are stabilized and taken for trauma CT of the abdomen revealing vascular injury may also be included as early presenters. Thrombosis, dissections, and occlusions may present with lower limb ischemia (absent or diminished femoral pulses; cold, pale limbs). This should be considered in the context of blunt injury resulting in pelvic fractures or abdominal crush. Be aware that the presentation may not be immediate with intimal tears, and repeated examinations are mandatory. Injuries to the renal pedicles may present with hematuria. Anuria as a result of bilateral renal artery thrombosis is rare.

Both penetrating and blunt trauma can result in vascular injuries that present late. With the increasing use of CT angiography, arterial injuries are being detected early, reducing the incidence of late presentation. Pseudoaneurysms frequently present late. They may each present as a pulsatile mass compressing adjacent structures. Compression of the duodenum may present as bowel obstruction. The false aneurysm may erode into the bowel resulting in massive gastrointestinal hemorrhage. Similarly, internal iliac pseudoaneurysms have presented with rectal bleeding.[15,16] Pseudoaneurysm of the renal artery can present with hematuria. Arterial fistulas have been seen with hepatic artery injuries and penetrating liver injuries. These fistulas may present with hemobilia, right upper quadrant pain, and upper gastrointestinal hemorrhage. Injuries involving both arteries and veins can cause arteriovenous fistulas. The clinical manifestation may be obvious or subtle. Aortocaval fistulas are associated with lower limb edema and an abdominal bruit. Other arteriovenous fistulas may present later with high-output cardiac failure and lower limb chronic venous skin changes.

Investigations

The choice of investigation will depend on the patient's physiologic status and the available local facilities. CT has become the gold standard investigation. Availability close to the resuscitation room is an important factor in the planning of a major trauma center. Catheter angiography still maintains an important role in trauma and has the advantage of being coupled with therapeutic options such as stenting and embolotherapy. Early availability of experienced interventional radiologists and the location of the radiology suite often limit use to the hemodynamically stable patient. The use of ultrasound in trauma has increased in the form of focused assessment with sonography for trauma (FAST) scans. Bedside ultrasonography is able to detect intraabdominal free fluid, facilitating the decision for early exploratory laparotomy. The exploratory trauma laparotomy remains an important diagnostic tool and is coupled with the techniques of damage control surgery. Duplex scanning is less useful in the acute trauma presentation. It has a role in assessing neck trauma and can be used for surveillance to detect late pseudoaneurysms and arteriovenous fistulas. In the context of abdominal vascular injuries, its use is limited.

Surgical Techniques

The operative approach will be dependent on the location of the hematoma and the degree of urgency. The latter is dictated by the degree of hemodynamic shock.

When a decision is made to proceed to surgery, the patient should be prepared with sterile drape application allowing exposure of the abdomen, chest, and groins. This allows for incisions to be extended into the chest; and, if deemed necessary, a left anterolateral thoracotomy can be utilized to gain control of the descending aorta prior to entry to the abdomen. To facilitate distal control, exposure of the common femoral arteries may be required. The initial incision is a long midline laparotomy from the xiphisternum to the pubis. If further access is required, the incision may be extended in the midline to include a median sternotomy or through the sixth or seventh intercostal spaces for a lateral thoracotomy.

On initiating the laparotomy the surgeon may be presented with an abdominal cavity containing free blood. At this stage it may be difficult to establish the source of bleeding and the principles of damage control surgery should be applied. In order to identify the source of bleeding, the surgeon should proceed with small bowel evisceration and packing of the abdominal cavity, using large packs to either stop or slow the bleeding. These packs are then removed from each compartment until the source of bleeding is identified. The four-quadrant packing technique requires packs to be placed in the right upper quadrant over the right lobe of the liver, the left upper quadrant, the infracolic compartment (elevate the greater omentum and pack either side of the small bowel mesentery), and the pelvis. Pelvic packing is performed by lifting the small bowel out of the pelvis before applying the packs into the pelvis.

Exposure of the aorta and its branches is best achieved using the technique of a medial visceral rotation. This can be performed from either the left or right side; the decision will be dependent on which vessels need to be exposed. The medial visceral rotation can be a time-consuming technique, even in experienced hands, and temporary control may be required, especially if active hemorrhage is occurring from the supramesocolic aorta. Direct manual compression of the aorta against the spine may control the bleeding but frequently restricts exposure of the aorta and therefore subsequent repair. It can be a useful technique to control the inflow, but the ultimate aim should be to apply a clamp.

Division or creation of a window within the lesser omentum enables exposure of the supraceliac aorta. This technique is aided by retracting the stomach and the esophagus to the left. The liver is retracted in a cephalad direction. Division of the diaphragmatic crura further aids exposure, and then a supra celiac aortic clamp can be applied. This is the quickest way to apply a supraceliac clamp and to gain control of the bleeding abdominal aorta. Although inflow will be controlled, back-bleeding from the visceral vessels and lumbar arteries may be significant. The presence of visceral branches can make distal control challenging.

In order to perform a left-sided medial visceral rotation, the peritoneal attachments of the sigmoid and the descending colon are divided. The incision is started in the lateral avascular peritoneal reflection of the sigmoid colon and is continued proximally along the left paracolic gutter. The plane is developed by mobilizing the sigmoid colon and the descending colon to the midline. The retroperitoneal attachments of the left kidney, pancreatic tail, and spleen can be divided, mobilizing these organs to the midline and hence facilitating complete exposure of the abdominal aorta from its origin at the diaphragm to its bifurcation at the level of the fourth lumbar vertebra (Figs. 18.2 and 18.3). This technique carries a significant risk of damage to the spleen, left kidney, and left renal vessels. Developing a dissection plane anterior to the left kidney can reduce the risk of intraoperative renal injury.

If rapid proximal control of the abdominal aorta is required before the medial visceral rotation, a clamp can be applied to the distal descending thoracic aorta. This is

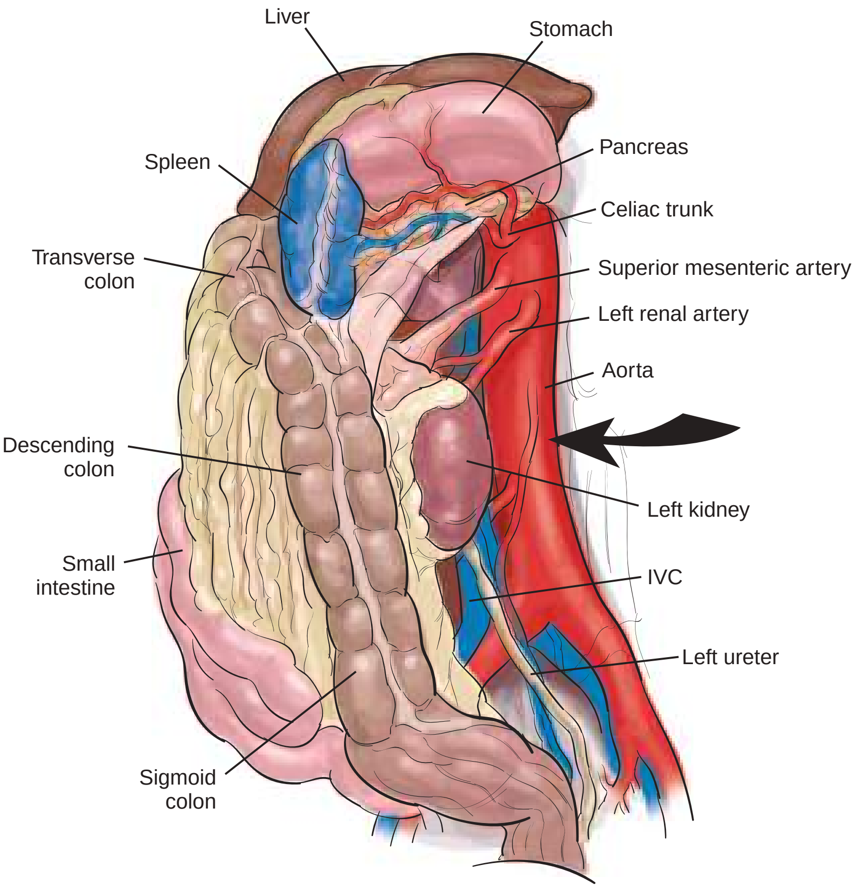

Fig. 18.2 Left-sided medial visceral rotation. The peritoneum is incised lateral to the descending colon allowing the colon, left kidney, and spleen to be mobilized to the right. This allows exposure of the left renal artery, the superior mesenteric artery, and the celiac artery. *IVC*, Inferior vena cava.

especially useful with an expanding zone I hematoma. The aorta is exposed by division of the left crus of the diaphragmatic aortic hiatus. Incision is made at the 2 o'clock position exposing the descending thoracic aorta and hiatal aorta. This is the quickest way to achieve proximal control during a medial visceral rotation. The presence of celiac nerves and lymphatic tissue around the aorta, together with dense diaphragmatic muscle fibers, makes careful dissection of the most proximal abdominal aorta difficult, time consuming, and hence unsuitable for the severely hypotensive patient.

The advantage of this technique is that, after mobilizing the spleen and the tail of the pancreas, the anterior midline visceral branches of the aorta are well exposed and can be controlled, repaired, or ligated.

A right-sided medial visceral rotation is performed by dividing the peritoneal reflection lateral to the ascending colon (Fig. 18.4). A dissection plane is developed anterior to the kidney, facilitating mobilization of the colon and terminal ileum to the midline. This allows exposure of the duodenum, which can then be kocherized. The duodenum and the pancreatic head are mobilized to the left, and the retroperitoneal tissue left of the IVC is divided to expose the suprarenal aorta, the celiac axis, and the SMA. If exposure of the diaphragmatic hiatal aorta is required, this technique should be avoided.

If injury is isolated to the infrarenal aorta, exposure to this part of the aorta can be achieved via an anterior approach that resembles that for an infrarenal abdominal aortic aneurysm. Peritoneal incision is made left of the duodenojejunal flexure, the peritoneum dissected off the aorta, and an infrarenal aortic clamp applied. More proximal application of an infrarenal aortic clamp can be facilitated by ligation and division of the left renal vein, preferably preserving its adrenal and gonadal tributaries.

Surgical exposure of the celiac artery is either via a medial visceral rotation or via a direct dissection through the lesser sack. Fullen's anatomical classification can be used for the purpose of describing injuries to the SMA. Exposure of the proximal SMA (Fullen's zone I) is via a left medial visceral rotation. If severe bleeding dictates very rapid exposure, this part of the SMA can be exposed by dividing the neck of the pancreas. The easiest and quickest way of doing this is by using a stapling device, but, if this is not available, intestinal clamps should be applied before the division of the pancreatic neck to control any bleeding. The proximal infrapancreatic SMA can be exposed through root of the small bowel mesentery, and this may be facilitated further by mobilization of the duodenum and retraction of the pancreas. The more distal SMA may be exposed directly in the bowel mesentery.

The inferior mesenteric artery origin is easily exposed via an infrarenal approach to the aorta. The renal arteries can be exposed through respective medial visceral rotation techniques. In the presence of a large retroperitoneal hematoma, the application of a supraceliac aortic clamp should be used for proximal control. If the renal artery is bleeding from a more distal point (e.g., renal hilum), the renal artery can be exposed at its origin without the need for a visceral rotation. The small bowel is eviscerated to the right, and the aorta is approached anteriorly. The duodenojejunal flexure is mobilized

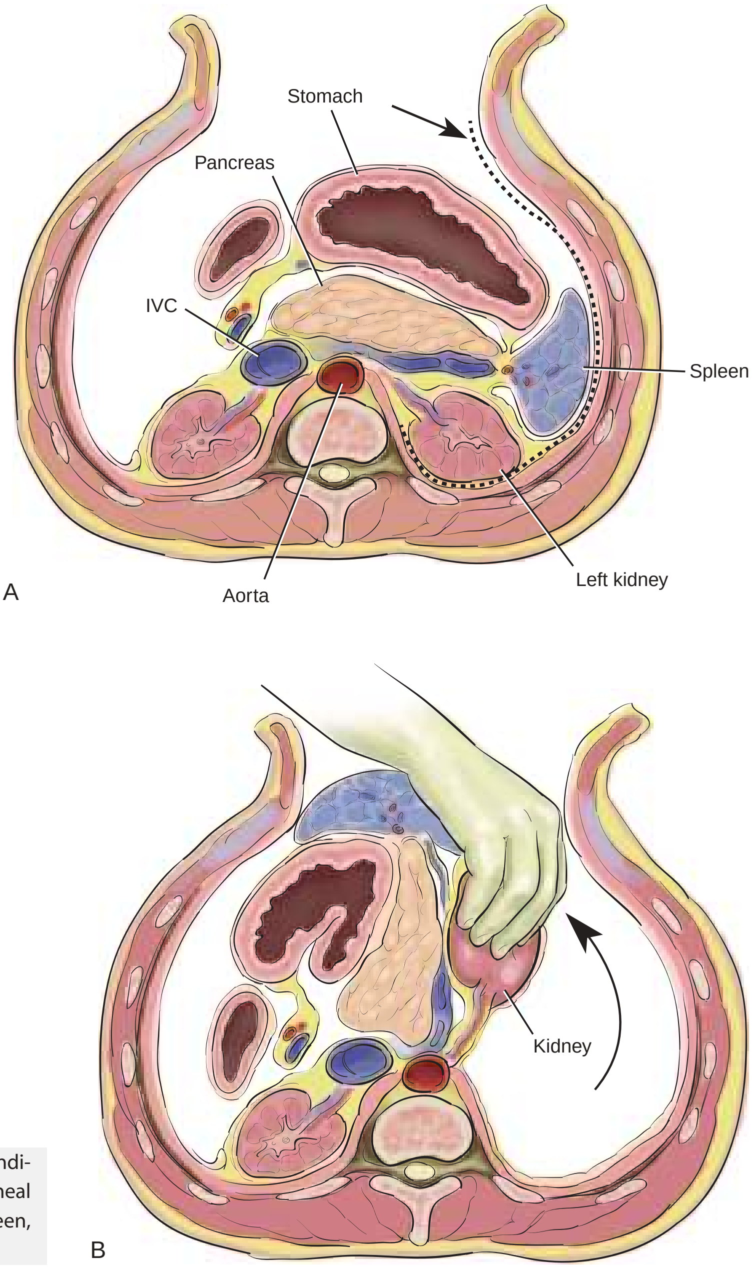

Fig. 18.3 (A) Plane of dissection for left-sided visceral rotation indicated by the arrow and dotted line. (B) The lateral retroperitoneal attachments are divided to facilitate medial mobilization of the spleen, descending colon, and kidney. *IVC*, Inferior vena cava.

as previously described. The left renal vein can be either divided as previously described or retracted proximally. The latter can be facilitated by division of the left gonadal and adrenal veins. This will allow exposure of the origin of the renal arteries.

The left renal artery can be seen following dissection of the surrounding peritoneal tissue. The right renal artery may require lateral retraction of the IVC to identify its origin. Additionally, medial rotation of the duodenum and then of the pancreas may be required to visualize the right renal vein, which will need to be looped and retracted before the remaining right renal artery can be exposed. The presence of a large retroperitoneal hematoma around the right kidney and juxtarenal IVC can make this a challenging dissection. Identifying the IVC distally and then dissecting in a proximal direction along the course of the IVC through the hematoma is an alternative approach.

Although the focus of this chapter is on arterial injuries due to their close proximity, the veins may be injured with the artery in the patient with multiple injuries. Achieving hemostasis during combined venous and arterial bleeding can be challenging. The application of clamps to a large vein can further tear the vein and therefore should be avoided or used with extreme caution. Using mounted sponges or swabs to apply pressure above and below the injury can achieve hemorrhage control and is less likely to damage the vein. With the aid of an experienced assistant, the surgeon can repair or ligate the vein. An alternative technique is using Foley catheters within large veins to control the inflow and back-bleeding.

Aortic Injuries

The majority of injuries to the aorta are consequences of penetrating traumas. Blunt injuries are rare and may be associated with seatbelt injuries and thoracolumbar

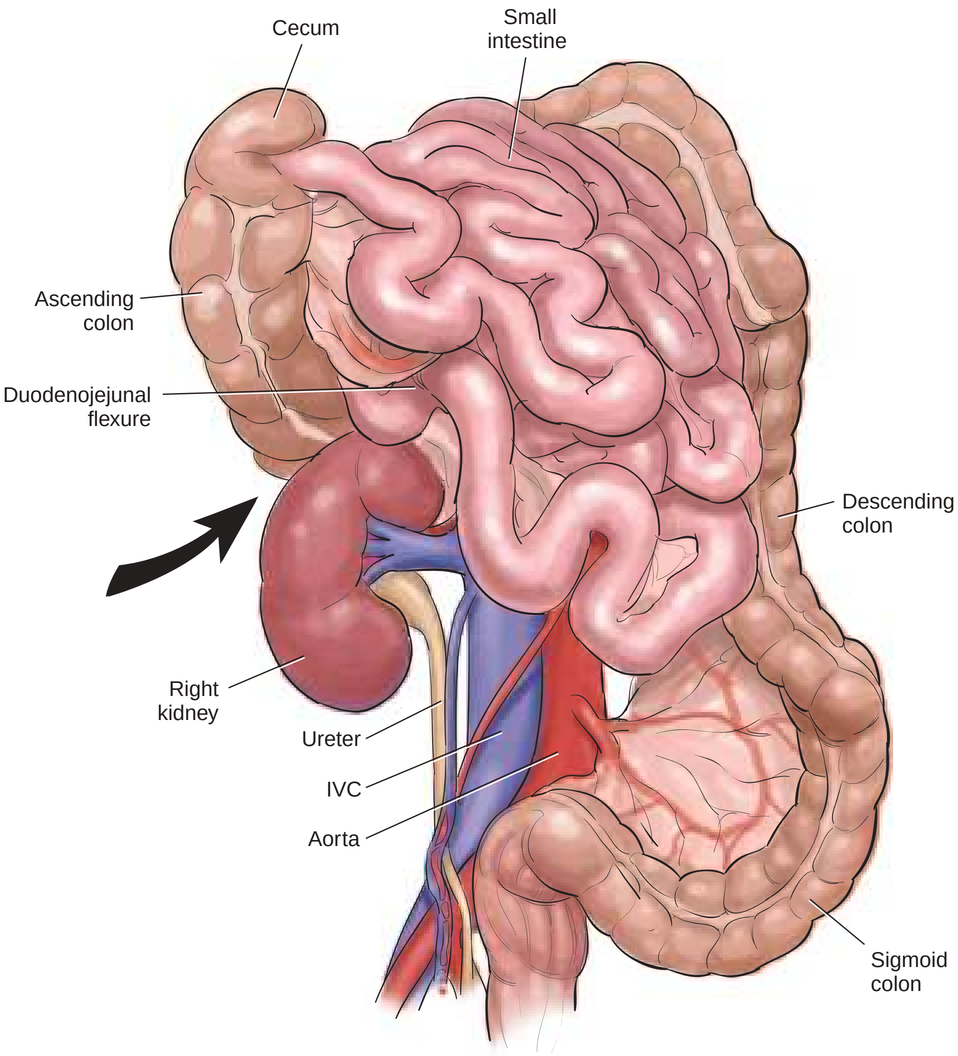

Fig. 18.4 Right-sided medial visceral rotation. This shows the Kocher and Cattell-Braasch maneuvers. The retroperitoneal attachment of the cecum, ascending colon, duodenum, and small bowel mesentery are divided. This allows exposure of the inferior vena cava (IVC), the right renal vessels, and the right iliac vessels.

fractures of the spine. The majority of patients who experience a rupture do not survive transport to hospital.

The complex forces that are associated with blunt trauma can damage the aortic intima resulting in aortic dissection, thrombosis, and consequently end-organ ischemia or limb ischemia. This may not be apparent at the initial presentation, and a high index of clinical suspicion is vital. Less commonly, patients may have delayed presentation with a pseudoaneurysm or arteriovenous fistula.

An aortic branch may be avulsed and present as a large retroperitoneal hematoma during the trauma laparotomy. Gunshot wounds appear to be associated with a higher incidence of aortic injuries than knife wounds.[17] The clinical presentation will be dependent on a number of factors. If the injury results in bleeding into the peritoneal cavity, the patient presents in severe shock with peritonitis and a distended abdomen. Frequently these patients do not survive transfer to the hospital. If the injury is to the lateral wall and bleeding is confined to the retroperitoneum, hemorrhage may tamponade temporarily within the retroperitoneum.

INVESTIGATIONS

Physiologically abnormal patients who do not respond to initial resuscitation should be taken immediately to the operating room for a trauma laparotomy. Patients whose physiology allows can be investigated with a trauma CT scan. This will identify significant bleeding or retroperitoneal hematomas. With the increasing availability of CT angiography, the use of catheter angiography as a diagnostic tool has diminished. Catheter angiography does, however, offer the possibility of combining both diagnostic and therapeutic options with the use of endovascular stents, occlusion balloons, and embolization techniques.

TREATMENT

The choice of treatment is dependent on patient factors and institutional factors. Patient factors include physiologic status, injuries to other intra-abdominal organs, and degree of intra-abdominal contamination. Institutional factors include the availability of local facilities (e.g., interventional radiology, CT imaging, and medical expertise).

Injuries to the infrarenal aorta have been successfully treated with endovascular techniques. These include endovascular stent grafts for dissection flaps and aortocaval fistulas, as well as embolization (e.g., coiling) of aortic visceral branches.

The trauma laparotomy may reveal a retroperitoneal hematoma. Central hematomas require exploration, and the principles of gaining both proximal and distal arterial control should be applied. Exposure of the aorta and its branches has been previously described. Small aortic lacerations may be closed with a 3-0 or 4-0 Prolene suture using the technique of lateral aortorrhaphy. If there is a defect in the aorta and lateral aortorrhaphy is likely to narrow the aorta, consideration should be given to repairing the defect using a prosthetic patch or tube graft (Fig. 18.5). Consideration must always be given to the principles of damage control surgery. The surgeon should avoid prolonged complex arterial repairs in the patient who is acidotic, hypothermic, and coagulopathic.

The decision to use prosthetic grafts will be affected by the degree of intraabdominal contamination from other injuries. Many surgeons will opt for an extraanatomical bypass in the presence of abdominal contamination. Some surgeons do not consider mild contamination as a contraindication to the use of prosthetic grafts in the trauma patient. Instead, the contamination is dealt with, the peritoneum is washed out, and a graft is used if needed. Like many controversies in vascular trauma there is a lack of evidence in the literature to either support or negate the use of prosthetic grafts in this setting.

FOLLOW-UP

Young patients treated with endovascular stents will need to be in a long-term surveillance program, as the durability of these grafts in young patients remains unknown. If there has been abdominal contamination and a prosthetic graft used, the patient should be followed up for signs of graft infection.

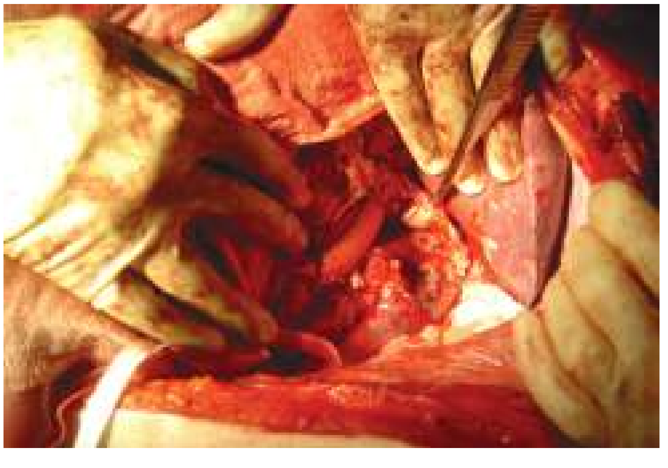

Fig. 18.5 Exposure of the suprarenal aorta through a left-sided medial visceral rotation and replacement with a Dacron prosthetic graft. This was to repair a pseudoaneurysm of the aorta at the level of the SMA after a penetrating aortic injury. *SMA*, Superior mesenteric artery.

Injuries to the Visceral Arteries

CELIAC ARTERY AND BRANCHES

Isolated injuries to the celiac artery are rare.[6] The majority of patients have other vascular injuries. It is for this reason that these injuries are associated with a high mortality. The majority of injuries to the celiac artery are a consequence of penetrating trauma.

Bleeding from the celiac trunk or its branches close to their origin can be difficult to control. This is because of the small size of the vessel, especially in a shocked patient where vasoconstriction makes exposure all the more difficult. The surrounding connective tissue and the location of the celiac trunk contribute to a difficult dissection. Urgent control may be needed with a supraceliac aortic clamp. This is best achieved as previously described via a window through the lesser omentum. Exposure of the celiac axis is best achieved via a left medial visceral rotation but this is time consuming and dependent on the hemodynamic status of the patient.

Injuries to the left gastric or splenic artery should not be repaired as these are small vessels and are better managed with ligation. The surgeon should be aware that the left hepatic artery may arise entirely from the left gastric artery in up to 10% of patients.[18] If there is an injury to the celiac trunk, this can also be managed by ligation provided the SMA is patent and the ligation is proximal to the branches of the celiac trunk. Evidence from elective endovascular aneurysm repairs suggests that the risk of ischemic foregut complications is low in most patients.[19]

If the common hepatic artery is injured, there are a number of options. The artery can be identified in the lesser omentum and its exposure facilitated by retracting the duodenum inferiorly. At the epiploic foramen, it lies anterior to the portal vein and medial to the common bile duct; and hence the Pringle maneuver may facilitate control of bleeding when the injury is at the porta hepatis. Ligation of the common hepatic artery proximal to the origin of the gastroduodenal artery is possible, again dependent on the patency of the inferior pancreaticoduodenal branch of the SMA. The common hepatic artery may have a sufficient diameter so that it is possible to perform arteriorrhaphy. Alternatively, limited resection and an end-to-end anastomosis may be attempted. If end-to-end anastomoses is not possible, reconstruction with autologous vein graft or even prosthetic graft may be considered; however, in the young resuscitated patient with patent SMA, circulation and a well-developed gastroduodenal artery, primary ligation or embolization is unlikely to cause any long-term sequelae.[18]

If the patient's physiology allows it and local facilities and expertise permit, endovascular options may be considered. Catheter angiography can be used to identify bleeding, and this procedure can be combined with coil embolization.

SUPERIOR MESENTERIC ARTERY

The most common mechanism of injury to the SMA is penetrating trauma. This is frequently associated with other injuries. With the exception of the renal artery, the SMA is the most commonly injured aortic visceral branch following blunt trauma.[20] Rapid deceleration can result in either avulsion of the SMA at its origin (Fig. 18.6), or alternatively deceleration

Fig. 18.6 Superior mesenteric artery (SMA) disruption after a rapid deceleration injury. The image indicates a central hematoma and hemorrhage into the small bowel mesentery.

Table 18.1 Fullen's Classification of SMA Injuries.

Fullen's Zones	SMA Region
I	From the SMA origin to the inferior pancreatico-duodenal artery
II	From the inferior pancreaticoduodenal artery to the middle colic artery
III	Distal to the middle colic artery
IV	Segmental branches

SMA, Superior mesenteric artery.

injuries may present as an intimal tear, dissection, and thrombosis. This comes as no surprise when consideration is given to the mobility of the small bowel and its mesentery. These injuries can present either early or late as intestinal ischemia.

Injuries may occur at any level. When describing the management of SMA injuries, it is useful to consider Fullen's classification whereby four zones are described (Table 18.1).

Exposure of the SMA has been previously described. The decision to perform a rapid left medial visceral rotation will depend on the state of the patient and the experience of the surgeon. The presence of a large expanding central hematoma during a trauma laparotomy may require a supraceliac clamp in the severely hypotensive patient. Time permitting, the medial visceral rotation will provide the best exposure of the SMA at its origin. Ligation of the SMA at any point between its origin and the middle colic branch is likely to result in massive ischemia of the small bowel, the cecum, and the ascending colon. Consequently, injuries to this part of the SMA (Fullen's zones I and II) should be repaired. Penetrating injuries resulting in a partial transection may be amenable to primary repair with 6-0 Prolene suture. If a direct repair is not possible, an interposition graft using saphenous vein or a prosthetic graft should be used.

If the overall condition of the patient dictates that a damage control procedure is required, prolonged reconstruction can be avoided by the placement of a temporary intraluminal shunt. This will allow for a delayed reconstruction after a period of appropriate resuscitation and correction of hypothermia, acidosis, and coagulopathy. If there is significant small bowel necrosis, consideration may be given to ligation of the proximal SMA. Collateral flow may preserve the proximal jejunum. However, this decision should not be taken lightly as it is not without its complications, including short bowel syndrome.

When considering definitive repair of the SMA using an interposition graft, the distal anastomosis is to the distal stump of the SMA and the proximal anastomosis is to the anterior surface of the disease-free infrarenal aorta. If there are associated pancreatic injuries or small-bowel contamination, the graft should be covered with either omentum or surrounding soft tissue to protect the graft from pancreatic enzymes and to reduce the risk of enteral-arterial fistulas. Aim to pass the graft to the posterior surface of the small bowel mesentery and to ensure the graft does not kink when the bowl is returned to the abdomen.

Injuries to the SMA distal to the middle colic artery (Fullen's zone III) may be treated with ligation but are likely to result in segmental bowel ischemia. Hence the decision to ligate will be dependent on how proximal the injury is. More proximal injuries should be revascularized to avoid significant midgut ischemia. Injuries to the segmental SMA branches (Fullen's zone IV) are treated by ligation and bowel resection.

A low threshold for a second-look laparotomy at 24 hours should be maintained. If temporary intraluminal shunts are used, the surgeon must always consider the possibility of shunt occlusion or dislodgement when a patient fails to improve or clinically deteriorates. When segmental SMA branches are ligated, a second-look laparotomy should be considered mandatory. If damage control techniques are applied at the primary surgery, small-bowel resections can be anastomosed at the time of the second-look laparotomy provided the physiology permits.

INFERIOR MESENTERIC ARTERY

Injuries to the inferior mesenteric artery are rare and certainly far less common than those to the SMA or celiac trunk. They are almost always a consequence of penetrating trauma.

Exposure of the inferior mesenteric artery is easy compared with the exposure of the SMA or the celiac trunk. Injuries are managed by ligation; and in the absence of associated injuries to the SMA or internal iliac arteries, ischemic complications are rare. There are no reports of ischemic colon in trauma cases although this is possible if there is coexisting occlusive arterial disease. Any deterioration in the patient postoperatively should warrant a second-look laparotomy and bowel viability confirmed.

RENAL ARTERY INJURIES

There is a slightly higher incidence of injury to the left renal artery compared with the right renal artery. Half of the cases of blunt injury to the renal artery result in thrombosis and/or dissection. Complete avulsion occurs in approximately one in ten cases.[21] Injuries to the distal renal artery may present with a hematoma or hemorrhage in zone II (lateral compartment or perirenal area); most injuries to the proximal renal arteries present with a more central or supramesocolic hemorrhage.

When considering treatment of the injured renal artery, it is important to remember the potential for a solitary functioning kidney and also that one-third of the population have an accessory renal artery. The latter anatomical variation is more commonly to the inferior pole of the kidney.

The diagnosis of renal artery injury may be made following CT scanning, or at laparotomy, with hypertension suggestive of renal ischaemia.

There appears to be some controversy regarding exploration of perirenal hematomas. Most would advocate exploration following penetrating trauma; however, stable lateral perirenal hematomas that do not encroach the midline (i.e., unlikely to involve the hilum) in a patient who is hemodynamically stable can be managed by close surveillance.

Management of injuries resulting from blunt trauma will be dependent on the duration of renal ischemia. Diagnostic delays and late presentation in this group of patients may result in significant loss of function in the affected kidney. A kidney ischemic for more than 6 hours is unlikely to improve with revascularization, although this has been challenged with successful endovascular revascularization reported after 25 days[22]; however, if they present within 4 to 6 hours, revascularization may be attempted, although the majority of stable patients are managed nonoperatively (assuming that contralateral renal function appears sufficient).

Zone II hematomas should always be explored if the hematoma is expanding, if the patient remains hypotensive, or if the kidney has been shown to be nonfunctioning. If the hematoma is significantly lateral, control may be achieved by exposing the proximal renal artery at the aortic origin.

With the left renal artery, proximal exposure can be achieved as previously described by retracting the transverse mesocolon superiorly, eviscerating the small bowel to the right, mobilizing the duodenojejunal flexure, and retracting the left renal vein in a cephalic direction.

The origin of the right renal artery may also be controlled in this way; however, due to the dense retroperitoneal tissue, rapid exposure of the proximal renal artery may not always be possible. Kocherization of the duodenum with lateral retraction of the IVC may be needed to expose the right renal artery. If more rapid control is required in a hypotensive patient with an expanding hematoma or hemorrhage, supraceliac clamping is likely to be the quickest option. Injury to the proximal renal artery should always be considered in patients with expanding central hematoma, and the quickest and safest technique for control of bleeding is to apply a supraceliac clamp.

When a patient presents with multiple injuries and damage control surgery is indicated, ligation of the renal artery and nephrectomy are reasonable options provided the kidney is not solitary. The experienced trauma surgeon should be able to divide the overlying renal fascia, elevate the kidney, and apply a vascular clamp proximal to the hilum to control bleeding from a distal renal artery injury. This may be possible without applying a supraceliac clamp.

If the patient has a single functioning kidney, nephrectomy is contraindicated and repair should be performed. With small lacerations from penetrating trauma, a suture repair may be possible. With larger lacerations, the segment may require resection. Reconstruction with an end-to-end anastomosis or interposition grafting using long saphenous vein prosthetic graft can be performed. Another option is to translocate the splenic artery onto the left renal artery or interpose a graft between the right renal artery and the hepatic artery.

Other options for renal revascularization include a bypass graft directly from the aorta and autotransplantation of the kidney into the pelvis.

If the diagnosis is delayed, nonoperative management for a stable injury is an option and should be considered in patients with multiple injuries.

Overall, the results of revascularization have tended to be poor, which has led to a conservative approach in many centers. The absolute indications for revascularization are solitary functioning kidney injuries or bilateral renal artery injuries. Delayed hypertension remains a problem in up to half of the patients who undergo revascularization. Patients who are managed conservatively can also develop this delayed hypertension, and this has been seen in at least one-third of patients managed conservatively.[23]

ENDOVASCULAR TREATMENT

Stable patients presenting after blunt trauma and identified as having intimal flaps, fistulas, pseudoaneurysm, and occlusion should be considered for endovascular treatment.

If local facilities and expertise allow, stenting should be considered although the long-term outcome remains unknown. These patients will need long-term surveillance. Embolization may be considered as an alternative to nephrectomy. However, delayed nephrectomy may be required because the patient may suffer from resistant hypertension.[24]

MORTALITY

The majority of blunt trauma results in occlusive injuries and consequently isolated renal artery injuries have a low mortality rate. As expected, mortality is higher when associated with other injuries.

Injuries to the Iliac Artery

ANATOMY

The bifurcation of the abdominal aorta into the left and right common iliac arteries occurs at the level of the fourth lumbar vertebra. The common iliac arteries continue inferolaterally and bifurcate into the internal and external iliac arteries over the sacroiliac joints. It is at this point that the ureter crosses from lateral to medial. The common iliac veins merge to form the IVC posterior to the right common iliac artery at the level of the fifth lumbar vertebra. Whereas the external iliac artery courses beneath the inguinal ligament to become the common femoral artery, the internal iliac artery passes medially and divides into anterior and posterior divisions. Posteromedial to the left common iliac artery courses the left common iliac vein while the right common iliac vein passes inferoposterior to the right common iliac artery bifurcation. The close proximity of the iliac arteries and veins is the reason for the high incidence of combined injuries.

MECHANISM OF INJURY

The most common mechanism of injury is penetrating trauma, usually involving injury to the common iliac arteries, with blunt trauma being a rare cause of arterial injury. With blunt trauma, the injury is more commonly associated with pelvic fractures, causing either direct laceration or intimal tears (associated with thrombosis), and more commonly affects the internal iliac artery and its branches. One-quarter of patients have combined arterial and venous injuries.

CLINICAL PRESENTATION

Injury to the iliac vessels should always be suspected in a severely hypotensive patient with a low-abdominal penetrating injury. The index of suspicion should be raised in the presence of abdominal distension, and, if the femoral pulse is weak or absent, it is almost diagnostic of a common iliac or external iliac arterial injury. The presence of signs suggesting pelvic visceral injuries such as hematuria should also raise the index of suspicion.

The majority of cases will be diagnosed during the trauma laparotomy or, if the patient is sufficiently stable, by trauma CT. Injuries associated with blunt trauma frequently accompany pelvic fractures. Infrequently, they may have delayed presentation with an ischemic leg secondary to an intimal tear and subsequent thrombosis.

INVESTIGATIONS

Not all patients should undergo radiological investigations. This is dictated by the patient's physiology. Physiologically abnormal patients with penetrating injury should be taken immediately for a trauma laparotomy. The pelvic x-ray taken as part of the initial Advanced Trauma Life Support (ATLS) resuscitation series may show fragments suggesting foreign bodies (e.g., gunshot wounds, blast injuries), and consideration should be given to the possibility of iliac vascular injuries.

With blunt injuries, examine the pelvic x-ray for sacroiliac joint disruption, widening of the symphysis pubis, and for bilateral fractures of both superior and inferior pubic rami. These radiological findings are associated with an increased risk of iliac vascular injuries.

The two most-utilized investigations are CT angiography and catheter angiography. CT angiography is performed routinely in most if not all trauma centers. The CT images should be examined for pelvic hematomas, extravasation of contrast, false aneurysms, intimal flaps, and thrombosis (suggested by the absence of contrast within the arterial lumen).

Catheter angiography still has a vital role in the management of pelvic hematomas. It has both a diagnostic role and a therapeutic role. Its use is dependent on the availability of local expertise and is dictated by local facilities. If the interventional radiology suite is close to the operating room or the trauma center has the ability to perform interventional techniques within the operating room (e.g., a hybrid theater), catheter angiography provides an ideal means of identifying the source of arterial bleeding and treating it by using embolization techniques; however, careful consideration must always be given when transferring a patient who is at risk of becoming physiologically decompensated to a radiology department that is remote from the operating room and that lacks optimal resuscitation facilities.

As well as identifying and treating the source of bleeding, angiography is also useful in diagnosing intimal flaps of the common and external iliac arteries. Some of these can be treated with stents. In addition, massive bleeding can be controlled by the proximal placement of intraluminal occlusion balloons, following which the patient can be transferred to the operating room for surgery.

Angiography should be considered early in patients with pelvic fractures subsequent to blunt trauma especially if there is evidence of bleeding. Box 18.1 lists the radiographic findings on pelvic films that are associated with increased risk of vascular injury and should prompt early angiography.

Surgical Management

In the context of penetrating trauma, laparotomy may identify free intraperitoneal bleeding or a large zone III (pelvic) hematoma, or both. Traditionally, all zone III hematomas caused by penetrating injury merited surgical exploration. If the patient is hemodynamically unstable, this is still the recommended action. However, in the patient whose physiology allows it – and if facilities permit – consideration may be given to intraoperative angiography and an endovascular treatment option. Bleeding from branches of the internal iliac artery can be managed by embolization.

The zone III hematoma resulting from blunt injury should not be routinely explored. The exception to this is in the presence of an absent or reduced femoral pulse suggesting either common iliac or external iliac arterial injury. It is important to remember that blunt injuries may be associated with arterial intimal tears and thrombosis, and hence the absence of a zone III retroperitoneal hematoma does not exclude a major vascular injury.

Active bleeding is managed according to the principles of damage control surgery. This involves the application of direct compression and then proximal and distal exposure of the artery to control inflow and back-bleeding.

In the presence of a large pelvic hematoma, it may be difficult to determine the site of bleeding in the iliac artery, and, if rapid proximal control is required, aortic cross-clamping can be achieved as previously described. The clamp may be applied just above the level of the aortic bifurcation. Similarly, if the injury is close to the proximal common iliac artery, control is best achieved by cross-clamping the distal aorta. If the injury is more distal (e.g., external iliac artery), the common iliac artery can be exposed by dividing the overlying peritoneum. Proximal control can be gained by using a nylon vascular tape to encircle the artery, carefully avoiding damage to the neighboring common iliac vein. Exposure of the

Box 18.1 Pelvic Radiographic Findings Associated With Increased Risk of Vascular Injury

Pubic diastasis greater than 2.5 cm
Sacroiliac joint disruption
Butterfly fractures (bilateral superior and inferior rami fractures)

common iliac and external iliac vessels may require mobilization of the cecum or sigmoid colon and care should be taken to avoid overlying ureters. With external iliac injuries, proximal control will also require exposure and control of the internal iliac artery. This is achieved by proximal and distal vascular retraction and by dissecting medially. Distal control may be difficult with a large hematoma. If direct exposure is not possible (e.g., a narrow pelvis), consider either adding a transverse lower abdominal incision or exposing the artery at the groin. Longitudinal incision and division of the inguinal ligament may be required. Exposure of the artery in the groin can be combined with the passage of occlusion balloon catheters to gain proximal control. However, if there is a complete transection of the artery or a large defect, the catheter may pass out of the artery rather than into the artery proximal to the site of injury.

The choice of repair will be dependent on the size and location of the injury and the degree of contamination. Small arterial injuries (e.g., stab wounds) can undergo primary repair with a 5-0 or 4-0 Prolene suture. If a patch is required, either a venous or prosthetic patch may be used (e.g., polytetrafluoroethylene [PTFE]; bovine pericardium). In the presence of contamination, a venous patch is preferred. Complete transection may be repaired by mobilization of the arterial ends and an end-to-end anastomosis.

Most patients with blunt injury or gunshot wounds require end-to-end anastomosis or interposition grafting. Gunshot injuries may be associated with significant intimal damage. The ends of the artery should be carefully examined. Débridement is usually required and an appropriate section of normal artery selected for the anastomosis of the interposition graft. Embolectomy catheters should always be passed distally to remove any residual clot.

It is best to avoid complex arterial reconstructions requiring extra-anatomical bypasses and mobilization of the internal iliac arteries. These are time consuming and are best avoided in the context of major trauma. If the patient is critical and requires damage control, arterial continuity may be temporarily established with the use of intraluminal shunts.

If a vascular shunt is not available, an alternative is to construct one using a wide bore sterile gastric tube, an intravenous tube, or a urethral catheter. These should be secured with distal and proximal ligatures. Later, once the patient's condition has stabilized, a definite arterial reconstruction can be performed. Shunts frequently thrombose, and therefore the limb should be monitored for ischemia. Ideally the patient should be prophylactically anticoagulated. However, the critical patient is frequently coagulopathic, and hence systemic anticoagulation is contraindicated.

Beyond the most critical of situations, the common and external iliac arteries should never be ligated without some means of ensuring distal perfusion (shunt or extraanatomic reconstruction) due to the high incidence of limb loss and the risk that the ischemia will result in general deterioration of the patient. Subsequent reperfusion attempts that cause severe reperfusion injury and organ failure are associated with high mortality.

If the physiology is normal, interposition grafting can be performed. Extraanatomical bypass should be considered if there is significant enteric contamination, purulent peritonitis, or infection in the injured zone. It is worth noting, however, that one case series of 16 patients reported by Burch et al. describes the use of PTFE grafts in the presence of colonic and urological contamination without subsequent graft infection.[25]

Injuries to the internal iliac artery and its branches can be difficult to manage. Due to cross-filling from branches of the contralateral internal iliac artery, ligation of the injured internal iliac artery (or its branches) may not provide hemorrhage control. Additionally the surgical exposure is difficult. If the hematoma is not expanding, do not explore. Angiography and embolization are the best options. Always consider pelvic packing with subsequent angiography and embolization as a potential option.

Bleeding may persist even after vascular repair or ligation of internal iliac branches. This is not infrequent after gunshot wounds. The safest options are to pack the pelvis and arrange angiography with subsequent embolization.

Complications of Vascular Trauma

The most common early complication following arterial reconstruction is thrombosis. The use of meticulous surgical technique, embolectomy balloon extraction of clots, intraoperative local heparinization, and angiography can all reduce the incidence of this complication. Postoperative monitoring of the limb is essential. Lower limb compartment syndrome remains a common postoperative problem, and the surgeon should have a low threshold for performing fasciotomies. Some centers advocate prophylactic fasciotomies, but this remains a topic of debate. An awareness of abdominal compartment syndrome should be maintained. Monitoring intraabdominal pressure, urine output, and ventilatory pressure can alert the team of this possibility and the need for abdominal decompression. The use of prosthetic grafts raises the possibility of graft infections. Late complications can also occur, with delayed presentations of pseudoaneurysms, arteriovenous fistulas, and aortoenteric fistulas.

Endovascular Treatment of Intra-abdominal Trauma

Interventional radiological techniques in trauma may include embolization, stent deployment,[26] or balloon occlusion.[27]

CONTROL OF BLEEDING BY EMBOLIZATION

Endovascular embolization techniques are especially useful for hemorrhage control. The decision to embark on an interventional treatment plan will depend on the availability of local expertise and interventional facilities. These factors must also be balanced against the hemodynamic stability of the patient. An unstable patient should not be treated in an interventional radiology suite that is located away from resuscitating facilities or the operating theater. Should physiology become deranged, it is vital that quick and easy transfer to an operating theater is possible. The interventional radiologist should be confident of his or her technical ability to perform selective embolization.

A number of principles need to be considered before embarking on embolization. A detailed understanding of the anatomy is essential, including variations in arterial anatomy. It is important to recognize whether a feeding vessel or an entire vascular bed requires embolization. The presence of anastomoses and collaterals between arterial territories must be appreciated as this will require embolization of both inflow and outflow arteries. Finally the effect on the end organ or vascular territory must also be considered.

Embolization agents used in trauma can be divided into those that result in permanent vessel occlusion or those where occlusion is temporary. Agents can be further divided into mechanical occlusion devices (e.g., coils), particulate agents (e.g., gel foam), and liquid agents (e.g., sclerosants, adhesives).[28] The decision to use a type of agent is dictated by the duration of occlusion required, the number of bleeding points, the size of the artery, and whether an individual feeding vessel or an entire vascular bed is the target.

Gelfoam results in temporary occlusion, which can last up to a few weeks – a useful property in trauma that allows time for the vessel to heal. Gelfoam is available as either a powder or a sheet. The powder form is made up of small particles and hence facilitates occlusion down to the capillary level. The sheet form is more useful for larger vessels and is cut into small pledgets of 1- to 2-mm diameter that are soaked in contrast media before syringing and injecting. Gelfoam is suitable for multiple bleeding points and is frequently the choice in pelvic trauma. Coil embolization results in permanent occlusion through both a mechanical obstruction and a thrombogenic effect. The coils are made from stainless steel or platinum and are available in a range of sizes, usually coated with thrombogenic fibers. To be effective, they must be tightly packed in a stable position within the artery. When using coils it is vital to consider the supply to the bleeding vessel. If the vessel is an end artery (e.g., renal), only inflow requires embolization; but where this is not the case, both inflow and outflow vessels must be embolized to prevent back-bleeding and to gain hemorrhage control.

Before embolization, a preliminary angiogram is always performed. If contrast extravasation is confirmed, the degree of extravasation must be matched to the hemodynamic status of the patient. If the amount of extravasation does not correlate with the shock, other sources of bleeding should be sought before embarking on embolization. The end-organ ischemic effects of embolization should always be anticipated. For instance, embolization of a renal artery should never be performed without confirming the presence of two functioning kidneys. Use of "end-hole only" catheters passed by the shortest and straightest possible path and maintained in a stable position facilitates accurate delivery of the embolization agent to the target vessel and prevents inadvertent occlusion of nontargeted arteries. If using particulate agents, a test injection with contrast is usually sufficient to confirm that the catheter tip is not displaced during the injection. If using coils, passage of a guide wire will allow the operator to see whether the delivery catheter tip is not in a stable position. During delivery of the agent, continuous fluoroscopy is essential, and completion angiography should be performed to confirm the effect on flow. After coil embolization, provided the flow is not too brisk, patience and a delay of a couple of minutes may be all that are required to facilitate vessel thrombosis. If the flow does appear brisk, further coils will need to be packed into the region. Embolization may not always be successful in controlling bleeding. Equally a patient may become hemodynamically compromised during the procedure, necessitating open surgery. If a decision is made to convert to open surgery, a temporary occlusion balloon can be placed in the artery proximal to the injury (e.g., in the common iliac artery or aorta). Care needs to be applied when transferring the patient but this technique is the endovascular equivalent of arterial clamping – restoring blood pressure and providing time for the surgeon to proceed with damage control techniques.

ENDOVASCULAR TREATMENT OF SOLID ORGANS AND PELVIC TRAUMA

Pelvic bleeding as a consequence of blunt trauma is most commonly associated with pelvic fractures. The first-line treatment is to stabilize the fracture through application of a pelvic binder, and this frequently results in cessation of venous bleeding. Continued instability suggests arterial bleeding, and gelfoam angioembolization of the internal iliac arteries is usually indicated. Internal iliac artery embolization carries a risk of pelvic ischemia; if angiography reveals extravasation from isolated branches, selective embolization is preferable as the ischemic burden is lower (Fig. 18.7). Stabilization of the bony pelvis may require urgent external fixation either before or during concomitant laparotomy. Control of pelvic bleeding during the trauma laparotomy can be challenging, and intraoperative hemostasis can be facilitated via the technique of preperitoneal packing in order to facilitate tamponade. Preperitoneal packing can be combined with follow-on embolization to ensure cessation of hemorrhage. Mortality from major pelvic bleeding still remains high, exceeding 30%.[29]

Although this chapter has focused on the management of arterial injuries, the techniques of angioembolization are also applied to the nonoperative management of solid abdominal organ injury, which therefore warrants brief discussion. The spleen remains one of the most commonly injured organs following blunt abdominal trauma.[30] Angiography is indicated for active bleeding (extravasation), pseudoaneurysms, hemoperitoneum on CT (Fig. 18.8), and high-grade splenic injuries. Embolization is required if angiography confirms active bleeding. There is controversy regarding the use of proximal embolization over more distal selective embolization. It has been postulated that distal embolization (Fig. 18.8) may offer benefits with regard to preserving splenic function – coupled with a higher risk of rebleeding – though the authors of a meta-analysis[31] were not able to confirm these differences in outcome. Blunt trauma to the liver results more frequently in parenchymal venous than arterial injury. Liver trauma can usually be managed conservatively in the first instance given patient stability and the absence of a contrast blush or active extravasation on CT.[30] With renal trauma, it is vital to ensure two functioning kidneys before proceeding with any embolization. Renal extravasation, arterial lacerations, pseudoaneurysms, and arteriocalyceal fistulae can be treated with embolization. Selective embolization can facilitate renal salvage and can reduce the volume of renal infarction. Other injuries such as dissection flaps can be managed with endovascular stents.[32]

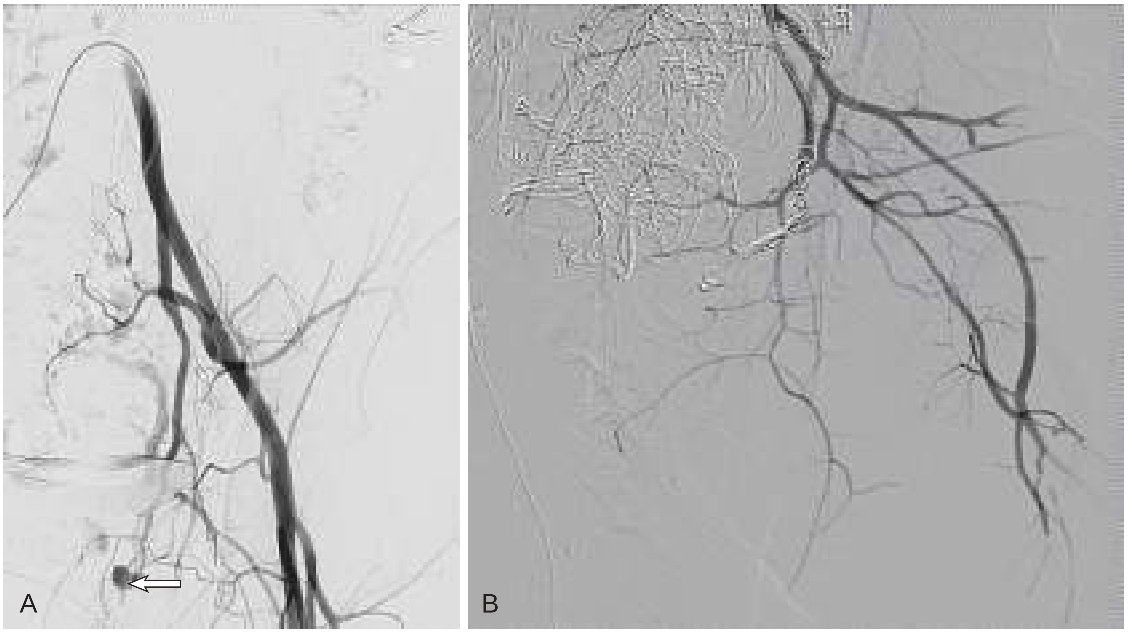

Fig. 18.7 (A) Branch of left internal iliac artery showing extravasation of contrast. This patient presented following a stab injury to the buttock. The arrow shows the extravasation of contrast. (B) Postembolization of iliac artery bleeder.

Fig. 18.8 (A) CT imaging of splenic injury following blunt abdominal trauma. The perisplenic hematoma is arrowed. (B) Selective coil embolization of the splenic artery.

COMPLICATIONS OF EMBOLIZATION

Misplacement of coils or gelfoam can result in nontargeted embolization; the consequences will depend on the territory supplied by the misembolized artery. It is feasible to retrieve errant coils, but this is not an option with gelfoam. Embolization of the common or external iliac artery may require urgent bypass in order to restore limb perfusion. Even properly targeted selective embolization may result in unanticipated and massive tissue infarction in solid organs such as the liver. Clinically, the presentation is of early abdominal pain and delayed fever, nausea, and vomiting caused by the release of vasoactive agents. The patient will require analgesia and supportive treatment, but, assuming there is no abscess, the symptoms are usually self-limiting with resolution after about 3 days. Renal embolization can result in hypertension, and, if uncontrollable by antihypertensive medication, it may warrant delayed nephrectomy.

ENDOVASCULAR BALLOON OCCLUSION

Occlusion of the aorta with endovascular balloons for exsanguinating haemorrhage is not new and was first described in the 1950s.[27] In recent years this technique has been championed again, with several reports in the literature. Gaining access via the femoral vessels, the resuscitative endovascular balloon occlusion of the aorta (REBOA) is placed either in the thoracic aorta, or just above the aortic bifurcation depending on the zone of injury. Despite some promising results, no clear mortality benefit has been shown in a systematic review,[33] with some reporting adverse outcomes.[34] Further evidence is likely to be required before there is widespread adoption of the technique, and randomized trials are undwerway.[35]

References

1. Tyburski JG, Wilson RF, Dente C, Steffes C, Carlin AM. Factors affecting mortality rates in patients with abdominal vascular injuries. *J Trauma Acute Care Surg*. 2001;50(6):1020–1026.
2. Heuer M, Hussmann B, Kaiser GM, et al. Abdominal vascular trauma in 760 severely injured patients. *Eur J Trauma Emerg Surg*. 2013;39(1):47–55.
3. Demetriades D, Inaba K. Vascular trauma: abdominal. In: Sidawy AN, Perler BA, eds. *Rutherford's Vascular Surgery and Endovascular Therapy*. Philadelphia: Elsevier; 2019:2391–2409.e2.
4. Williams TK, Fox C, Rasmussen TE. Epidemiology and natural history of vascular trauma. In: Sidawy AN, Perler BA, eds. *Rutherford's Vascular Surgery and Endovascular Therapy*. Philadelphia: Elsevier; 2019. 2350-2364.e3.
5. Perkins ZB, De'Ath HD, Aylwin C, Brohi K, Walsh M, Tai NRM. Epidemiology and outcome of vascular trauma at a british major trauma centre. *Eur J Vasc Endovasc Surg*. 2012;44(2):203–209.
6. DuBose JJ, Savage SA, Fabian TC, et al. The American Association for the Surgery of Trauma PROspective Observational Vascular Injury Treatment (PROOVIT) registry. *J Trauma Acute Care Surg*. 2015;78(2):215–223.
7. Asensio JA, Chahwan S, Hanpeter D, et al. Operative management and outcome of 302 abdominal vascular injuries. *Am J Surg*. 2000;180(6):528–533, discussion 533.
8. 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.
9. White JM, Stannard A, Burkhardt GE, Eastridge BJ, Blackbourne LH, Rasmussen TE. The epidemiology of vascular injury in the wars in Iraq and Afghanistan. *Ann Surg*. 2011;253(6):1184–1189.
10. Asensio JA, Forno W, Roldán G, et al. Abdominal vascular injuries: injuries to the aorta. *Surg Clin*. 2001;81(6):1395–1416.
11. Demetriades D, Theodorou D, Murray J, et al. Mortality and prognostic factors in penetrating injuries of the aorta. *J Trauma*. 1996;40(5):761–763.
12. Lichte P, Oberbeck R, Binnebösel M, Wildenauer R, Pape H-C, Kobbe P. A civilian perspective on ballistic trauma and gunshot injuries. *Scand J Trauma Resusc Emerg Med*. 2010;18:35.
13. Tresson P, Touma J, Gaudric J, et al. Management of vascular trauma during the Paris terrorist attack of November 13, 2015. *Ann Vasc Surg*. 2017;40:44–49.
14. Botha A, Brooks A, Loosemore T, eds. *Gunshot, Fragment and Blast Injuries*. London: Royal College of Surgeons of England; 2002.
15. Mokoena T, Robbs JV. Surgical management of mycotic aneurysms. *S Afr J Surg*. 1991;29(3):103–107.
16. Robbs J. *Abdominal Vascular Injuries.* 2nd ed. London: Hodder Arnold; 2005.
17. Davis TP, Feliciano DV, Rozycki GS, Bush JB. Results with abdominal vascular trauma in the modern era/Discussion. *Am Surg*. 2001;67(6):565.
18. Burdick TR, Hoffer EK, Kooy T, et al. Which arteries are expendable? The practice and pitfalls of embolization throughout the body. *Semin Intervent Radiol*. 2008;25(3):191–203.
19. Mehta M, Darling III RC, Taggert JB, et al. Outcomes of planned celiac artery coverage during TEVAR. *J Vasc Surg*. 2010;52(5):1153–1158.
20. Mattox KL, Feliciano DV, Burch J, Beall AC, Jordan GL, De Bakey ME. Five thousand seven hundred sixty cardiovascular injuries in 4459 patients. Epidemiologic evolution 1958 to 1987. *Ann Surg*. 1989;209(6):698–705, discussion 706.
21. Clark DE, Georgitis JW, Ray FS. Renal arterial injuries caused by blunt trauma. *Surgery*. 1981;90(1):87–96.
22. Springer F, Schmehl J, Heller S, Claussen CD, Brechtel K. Delayed endovascular treatment of renal artery dissection and reno-vascular hypertension after blunt abdominal trauma. *Cardiovasc Intervent Radiol*. 2011;34(5):1094–1097.
23. Haas CA, Spirnak JP. Traumatic renal artery occlusion: a review of the literature. *Tech Urol*. 1998;4:1–11.
24. Shoobridge JJ, Corcoran NM, Martin KA, Koukounaras J, Royce PL, Bultitude MF. Contemporary management of renal trauma. *Rev Urol*. 2011;13(2):65–72.
25. Burch JM, Richardson RJ, Martin RR, Mattox KL. Penetrating iliac vascular injuries: recent experience with 233 consecutive patients. *J Trauma*. 1990;30(12):1450–1459.
26. Zealley IA, Chakraverty S. The role of interventional radiology in trauma. *BMJ*. 2010;340:c497.
27. Borger van der Burg BLS, van Dongen TTCF, Morrison JJ, et al. A systematic review and meta-analysis of the use of resuscitative endovascular balloon occlusion of the aorta in the management of major exsanguination. *Eur J Trauma Emerg Surg*. 2018;44(4):535–550.
28. Kessel D, Robertson I. Embolization. In: Kessel D, Robertson I, eds. *Interventional Radiology: a Survival Guide*. Philedelphia: Elsevier; 2005.
29. Thorson CM, Ryan ML, Otero CA, et al. Operating room or angiography suite for hemodynamically unstable pelvic fractures? *J Trauma Acute Care Surg*. 2012;72(2):364–372.
30. Yao DC, Jeffrey RB, Mirvis SE, et al. Using contrast-enhanced helical CT to visualize arterial extravasation after blunt abdominal trauma: incidence and organ distribution. *AJR Am J Roentgenol*. 2002;178(1):17–20.
31. Schnüriger B, Inaba K, Konstantinidis A, Lustenberger T, Chan LS, Demetriades D. Outcomes of proximal versus distal splenic artery embolization after trauma: a systematic review and meta-analysis. *J Trauma Acute Care Surg*. 2011;70(1):252–260.
32. Chabrot P, Cassagnes L, Alfidja A, et al. Revascularization of traumatic renal artery dissection by endoluminal stenting: three cases. *Acta radiol*. 2010;51(1):21–26.
33. Morrison JJ, Galgon RE, Jansen JO, Cannon JW, Rasmussen TE, Eliason JL. A systematic review of the use of resuscitative endovascular balloon occlusion of the aorta in the management of hemorrhagic shock. *J Trauma Acute Care Surg*. 2016;80(2):324–334.
34. Joseph B, Zeeshan M, Sakran JV, et al. Nationwide analysis of resuscitative endovascular balloon occlusion of the aorta in civilian trauma. *JAMA Surg*. 2019;154(6):500–508.
35. Jansen JO, Pallmann P, MacLennan G, Campbell MK. Investigators U-RT. Bayesian clinical trial designs: another option for trauma trials? *J Trauma Acute Care Surg*. 2017;83(4):736–741.