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Review

# Penetrating injuries of the inferior vena cava

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ABSTRACT

Inferior vena cava (IVC) injuries occur in 0.5-5% of cases of penetrating abdominal injury. Uncommonly encountered in general surgical and trauma practice, they remain extremely lethal despite advances in resuscitation and critical care. Important factors determining treatment outcomes are the hemodynamic status of the patient at presentation, the level and extent of injury, and the presence of associated injuries. Operative approaches and techniques for definitive repair are to be tailored to the condition of the patient, type of injury, and available expertise. In a patient with severe hemodynamic compromise, damage control principles take priority to stop bleeding and save life. The most commonly employed strategies are venorrhaphy or ligation. Retro-hepatic and supra-hepatic caval injuries are particularly challenging in terms of exposure and repair, and are associated with high fatality. Endovascular approaches are being used in select cases with success. This paper reviews in detail the epidemiology, injury patterns, management protocols, and outcomes of IVC injuries due to penetrating abdominal trauma.

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## Introduction

Inferior Vena Cava (IVC) injuries represent 30-40% of all intra-abdominal vascular injuries and are associated with high mortality. The majority of IVC injuries are secondary to penetrating injuries, as its retroperitoneal location shields the vessel from injury in blunt abdominal trauma. Penetrating injuries to the IVC carry an estimated mortality of 20–66%, with more than one-third of patients not surviving to reach a hospital and another third dying within 24 h of treatment [1]. The alarmingly high mortality can be attributed to exsanguination from a high-flow, low-pressure system, difficulty in attaining quick operative access with adequate exposure, and in achieving vascular control. Associated injuries are common, due to the proximity of the vessel to adjacent visceral and vascular structures. Even after initial control of haemorrhage, patients succumb to delayed complications and mortality due to multi-organ failure, venous insufficiency, shock, acidosis, coagulopathy, reperfusion injuries, and their sequelae. The mortality trends have not improved over the past 30 years [2], despite advances in pre-hospital trauma support and surgical therapy. This may be explained by improved paramedical care bringing patients with serious injuries alive to trauma centres, thus resulting in a reduction in field mortality but an increased in-hospital mortality.

## Incidence

Injuries to the IVC are thought to be rare, perhaps deceptively low, owing to the significant mortality at the scene of injury. The incidence of IVC injury has been reported as 0.5–5 and 0.6–1% of penetrating and blunt abdominal trauma respectively [3]. Bordoni et al. reported an analysis of 1888 forensic autopsies of patients who died from abdominal trauma. Among the 1487 cases of death from penetrating abdominal trauma, there were 312 cases of major arterial and venous injuries (20.9%) [4]. In a retrospective 6-year review of data at a high-volume trauma centre, 302 patients presented with abdominal vascular injuries; IVC injuries accounted for 25% of all vessels damaged and 31% of all venous injuries. Eighty-eight percent were the result of penetrating trauma. Isolated IVC injuries were associated with a mortality rate of 70%, while those combined with other venous injuries recorded a mortality rate of 77% [5]. The PROspective Observational Vascular Injury Treatment (PROOVIT) registry data on vascular injuries [6] captured 542 vascular injuries over 1 year, and retro-hepatic and infra-renal IVC injuries were infrequent and documented in a mere 21 cases (3.8%).

## Anatomy

The IVC originates from the confluence of common iliac veins anterior to the body of the fifth lumbar vertebra and posterior to the right common iliac artery. It ascends along the posterior abdominal wall, on the right side of the lumbar vertebral bodies.

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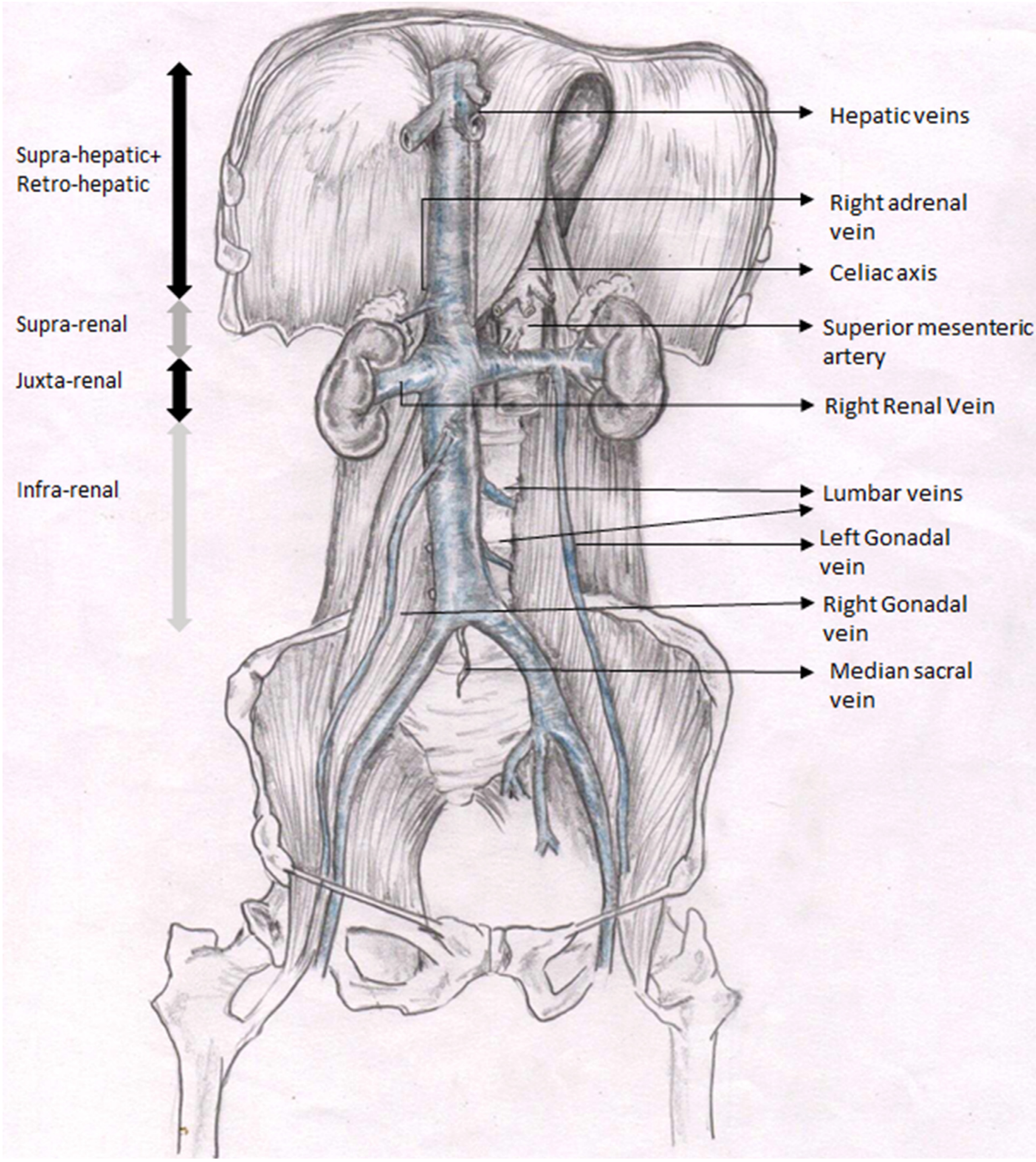


**Fig. 1.** Anatomy and relations of the Inferior Vena Cava (IVC) with major tributaries. Sections of the IVC as indicated: Infra-renal, Juxta-renal, Supra-renal, Supra-hepatic /Retro-hepatic. *Adapted from González, J., & Ciancio, G. (2014). Retroperitoneal Venous Diseases. PanVascular Medicine, 1–42. DOI:10.1007/978-3-642-37393-0_151-1*.

As it courses cephalad, it receives 4 or 5 pairs of lumbar veins, the right gonadal vein, renal veins, right adrenal veins, hepatic and phrenic veins. It then crosses through the diaphragm at the level of the eighth thoracic vertebra, to reach the right atrium. The IVC is a thin-walled vessel, 2.5 to 3.75 cm in diameter, and valveless throughout its course except for a variable non-functional valve in the ostium at the right atrium [7]. The intraluminal pressure is approximately 5 cm of $H_2O$, and it is a high flow system; therefore, it is a source of torrential haemorrhage when injured.

The IVC may be divided into 4 portions, each of which has anatomical features that affect surgical exposure and subsequent control of injuries in that section (Fig. 1).

- Infra-renal
- Juxta-renal
- Supra-renal/ Infra-hepatic
- Retro-hepatic and Supra-hepatic

The *infra-renal portion* is the site of abundant collateral circulation, mainly constituted by the lumbar veins. They form part of a rich anastomotic network along with branches from the common iliac, hypogastric, iliolumbar, and renal veins. The presence of this network may complicate efforts at attaining proximal and distal vascular control of injuries in this area. However, relative ease of access and tolerance to ligation imparts the best results for injuries of this area.

The *juxta-renal segment* of the IVC extends approximately 2 cm superior and inferior to the renal veins, and lies posterior to the pancreatic head and duodenum. An injury to this section would require control of both renal veins to facilitate repair.

The *supra-renal/infra-hepatic IVC* is a short segment that extends anatomically from the juxta-renal segment to the level of the right adrenal vein. The portal vein lies immediately anterior to this portion.

The *retro-hepatic and supra-hepatic segment of the IVC* is the most unique anatomical segment of the IVC, and the most challenging as far as operative management is concerned because of complicated access. It lies in a groove on the posterior aspect of the liver, within its bare area. This portion of the vein is encased by the peritoneal reflections of the liver onto the diaphragm posteriorly and the liver anteriorly. The retro-hepatic IVC drains a variable number of accessory/inferior hepatic veins and is joined by the major hepatic veins shortly before it enters the thorax and drains into the right atrium. Exposure of caval injuries in this zone is perilously difficult, and may even be avoided if there is adequate tamponade by the surrounding liver and hepatic ligaments.

The IVC develops between the 6th and 8th gestational weeks and is derived from the growth, regression, and fusion of three pairs of embryonic veins (posterior cardinal, subcardinal and supracardinal). A detailed review of embryology and anomalies in IVC development is beyond the scope of this review. Although infrequent, the presence of certain variations is especially relevant for trauma surgeons. A left IVC results when there is abnormal persistence of the left supracardinal vein and regression of its right-sided counterpart. The left moiety usually joins the left renal vein, leading thereon to a normal suprarenal anatomy [8]. Other common variations are duplicate IVC, retroaortic left renal vein, and circumaortic (renal) venous rings. An audit of 500 trauma CT scans to assess the suitability of anatomy to place IVC filters picked up a giant IVC (> 28 mm diameter) and the above anomalies in 47 (9.4%) patients [9]. Awareness of these anomalies helps in achieving proper vascular control and avoiding secondary injuries. The left-sided component of duplicate IVC should not be mistaken for the left gonadal vein joining the left renal vein. Ligation of this segment can lead to deep vein thrombosis (DVT) in the left lower limb. Patients with a hypoplastic infra-renal segment of IVC are also more prone to DVT [10]. A circumcaval ureter is a rare variant that occurs due to abnormal persistence of the right posterior cardinal vein. The IVC itself is orthotopic, but the right ureter spirals around it, coursing posterior, then wrapping around and descending on its anterior surface [8]. Unless identified, it may be injured during attempts at dissection of the infra-renal IVC.

## Mechanism, patterns of injury and classification

With the exception of the retro-hepatic vena cava, which may be injured by blunt trauma as well, virtually all IVC injuries are caused by penetrating injury. Guns shot wounds (GSWs) are more likely than stab wounds to lacerate the IVC, and also result in more tissue destruction. They are usually high-energy injuries, producing large tangential areas of tissue avulsion or vessel transection, as opposed to stab wounds which tend to be linear lacerations that are more likely to spontaneously tamponade.

Penetrating IVC injuries are almost invariably associated with injuries to other viscera and major vessels. Among intra-abdominal organs, the liver, duodenum, pancreas, small bowel, and colon tend to be more commonly injured. Degiannis et al. reported the small bowel and renal vein as the most commonly injured non-vascular and vascular structure respectively, along with penetrating trauma to the IVC [11]. Combined arterial and venous injuries have also been described, with mortality for combined aortic and IVC injury being as high as 93% [5]. There are also reports of acute traumatic aorto-caval fistulae, caused by combined penetration of the IVC and aorta [12].

**Table 1**
American Association for the Surgery of Trauma—organ injury scale for abdominal vascular injury [14].

| Grade | Description |
|---|---|
| **Grade 1** | Non-named superior mesenteric artery or superior mesenteric vein branches<br>Non-named inferior mesenteric artery or inferior mesenteric vein branches<br>Phrenic artery or vein<br>Lumbar artery or vein<br>Gonadal artery or vein<br>Ovarian artery or vein<br>Other non-named small arterial or venous structures requiring ligation |
| **Grade 2** | Right, left, or common hepatic artery<br>Splenic artery or vein<br>Right or left gastric arteries<br>Gastroduodenal artery<br>Inferior mesenteric artery or inferior mesenteric vein, trunk<br>Primary named branches of mesenteric artery or vein<br>Other named abdominal vessels requiring ligation or repair |
| **Grade 3** | Superior mesenteric vein, trunk<br>Renal artery or vein<br>Iliac artery or vein<br>Hypogastric artery or vein<br>Vena cava, infra-renal |
| **Grade 4** | Superior mesenteric artery, trunk<br>Celiac axis proper<br>Vena cava, suprarenal and infra-hepatic<br>Aorta, infra-renal |
| **Grade 5** | Portal vein<br>Extra-parenchymal hepatic vein<br>Vena cava, retro-hepatic or supra-hepatic<br>Aorta, suprarenal, sub-diaphragmatic |

*Increase one grade for multiple grade 3 or 4 injuries involving >50% vessel circumference. Downgrade one grade if <25% vessel circumference laceration for grades 4 or 5.

As a consequence of its location, the surrounding retroperitoneal tissues can offer a considerable degree of containment of any haemorrhage from the IVC. Owing to this capacity for self-tamponade, most IVC injuries may cease to bleed, especially when the inducing injury is low-velocity, such as oblique GSWs or stab wounds. Spontaneous tamponade is also likely to occur in caval wounds that are posterior to the pancreas, duodenum, and liver, provided the overlying viscera are not extensively disrupted. Survival is definitely more likely in patients in whom spontaneous cessation of bleeding has occurred, but they may still exsanguinate at surgical decompression of the retroperitoneal tamponade unless the haemorrhage is rapidly controlled.

The most frequently injured segment of the IVC is the infra-renal segment (39%), followed by the retro-hepatic segment (19%), infra-hepatic (18%), juxta-renal (17%) and finally the supra-hepatic segment(7%) [13]. The American Association for the Surgery of Trauma (AAST) classifies injuries to the IVC in the Organ Injury Scale for Abdominal Vascular Trauma [14]. Infra-renal caval injury is Grade 3 trauma; supra-renal injuries are classified as Grade 4 trauma, and retro-hepatic or supra-hepatic injuries are labelled as Grade 5 trauma. An additional determinant in classifying the severity of the injury is the circumference of the vessel damaged (Table 1).

## Clinical presentation and diagnosis

IVC injuries must be suspected in patients presenting with penetrating injuries to the right side of the abdomen, and with suggestive wound trajectories. Clinical presentation is dependent on whether the injury has resulted in tamponade or free intraperitoneal rupture. Most of these patients present with some degree of global hypoperfusion. If ruptured, patients have signs of profound hemodynamic compromise, with likely failure to respond to initial volume replacement. Rare presentations of caval injury include acute caval-duodenal fistula with hypotension and hematemesis, or aorto-caval fistula, characterized by wide pulse pressure and abdominal bruit. Patients, in whom early containment occurs, may be normotensive at presentation or be transient responders to resuscitation.

Some patients with major vascular injury may be candidates for further evaluation with computed tomography (CT), if hemodynamically stable. The most common finding identified is a retroperitoneal hematoma localized around the ascending colon and duodenum with only 33% showing active contrast extravasation [15]. Other findings suggestive of caval injuries include contour abnormalities, intimal flap, IVC thrombosis, intra-caval fat, and hemopericardium [16–20]. Forewarning of the severity and location of the caval injury allows for planning the best management approach with adequate preparation of multidisciplinary teams.

Occasionally, the presence of a major vascular injury may not even be suspected preoperatively, and may be encountered while exploring the abdomen for another associated injury. The retroperitoneum is divided into three zones for vascular trauma purposes. Zone 1 includes the midline retroperitoneum extending from the aortic hiatus to the sacral promontory and contains the IVC as well as the aorta and its major branches. The presence of a central retroperitoneal hematoma to the right of the midline should raise suspicion of a caval injury. An injury may be detected during retroperitoneal exposure after mobilization of either right colon, duodenum, or liver for associated injury.

## Initial resuscitation and management

It is of utmost importance to have a high index of suspicion about the presence of possible IVC injury in all patients presenting with penetrating abdominal trauma, especially GSWs. Effective management depends upon rapid transfer from the site of injury to a centre equipped to deal with major abdominal trauma, prompt resuscitation, expert assessment, decision making on the need for surgery, and an on-table strategy that quickly and safely controls bleeding. Pre-hospital care and speedy transfer are variables most often not in the control of the treating team, but play a very important part in determining the ultimate outcome.

It is good practice to notify the surgical team immediately whenever there is an unstable patient with penetrating abdominal trauma, providing valuable lead time to anaesthetic teams and the blood bank to prepare themselves. Initial assessment and management are as per advanced trauma life support (ATLS) protocols. It is of paramount importance to obtain supra-diaphragmatic vascular access as IVC injuries can preclude adequate vascular containment of infused volumes [21]. A hypoperfused state at arrival and need for multiple blood product transfusions are indicative of serious injury and ongoing bleed. Shock and absence of hemodynamic response to initial volume replacement protocols is a significant predictor of mortality consistently reported in all major series of penetrating IVC trauma [1,3,11].

### *Damage control resuscitation (DCR)*

Once circulation is restored, mild hypotension is preferred, as per the strategy of (DCR). The goal is to maintain organ perfusion and prevent acidosis. Maintaining a mean blood pressure of 60-65 mm Hg is a reasonable target. Over-aggressive fluid resuscitation can result in further bleeding whereas delay of aggressive fluid resuscitation in this cohort of patients, until arrival to the operating room, may be the preferred strategy [22]. Large volume resuscitation is postulated to enlarge the vena cava, including the injured region, possibly leading to increased intraluminal pressure and loss of tamponade. Active warming measures to prevent hypothermia should be initiated early in the emergency room (ER).

### *Imaging*

A Focused Abdominal Sonogram in Trauma (FAST) will detect the presence of significant hemoperitoneum, and associated solid organ injury, especially to the liver. However, it may fail to detect an isolated retroperitoneal hematoma; hence it is desirable to have a contrast-enhanced CT scan of the abdomen and pelvis whenever possible to diagnose IVC injury and formulate a treatment strategy. Perhaps the only absolute contraindication is a hemodynamically unstable patient. Other instances where one might forego a CT scan are the presence of frank peritonitis, eviscerated bowels, or renal failure. A careful assessment is made for the presence and nature of other extra-abdominal injuries. The assessment and treatment of these injuries follow standard guidelines and are beyond the scope of the current review.

### *Decision making in the ER*

A simple dictum to follow is that an unstable patient with evidence of ongoing bleed has to reach the operating room (OR) early. Time from arrival to ER to OR can be an important quality indicator in trauma; most centres report 30–150 min [11]. Control of bleed before the onset of the deadly triad of acidosis, coagulopathy, and hypothermia will prevent organ dysfunction and mortality. While in an unstable patient, the decision to shift to OR is straight forward, in a stable patient the underlying principle should be to avoid harm by doing unnecessary surgery. CT scans can be of immense value in this situation. The presence of bowel injury or evidence of active contrast extravasation from vessels becomes an indication for intervention. It is important to remember that the tamponade effect of the retroperitoneum will be lost with possible sudden massive uncontrollable bleeding if the planes are opened during surgery. Almost all series of IVC injuries report a significant proportion of patients who die on-table (50–75%) [1,11,23]. Therefore, it is prudent to take a step back and carefully consider if surgery is really needed or careful observation and reassessment might be a safer option at this stage. Successful non-operative management of IVC injuries has been reported [24], and should be considered in the hemodynamically stable patient with no associated injuries mandating surgery.

### *Resuscitative thoracotomy*

Resuscitative thoracotomy has been advocated as a life-saving measure for trauma patients in extremis, who deteriorate too rapidly for admission to the OR. The American College of Surgeons (ACS) Committee on Trauma [25] recommends that ER thoracotomy be utilized for patients with penetrating exsanguinating abdominal vascular injury who experience traumatic arrest or unresponsive hypotension. The rationale is to ensure adequate cerebrovascular and cardiovascular perfusion and decreasing distal haemorrhage by cross-clamping the thoracic aorta; the patient, in the meantime, is shifted to the OR for definitive management. This approach is currently thought to be more harmful than beneficial, due to the inherent physiological sequelae involved in the additional insult of a thoracotomy. A meta-analysis by Rhee et al. reported a survival rate of 4.5% after ER thoracotomy for exsanguinating abdominal trauma [26]. There is a paucity of evidence regarding the utility of this technique for penetrating injuries to the IVC barring anecdotal reports [27]. In a series of aorta and IVC trauma, there were no survivors among 4 patients with IVC injury that were treated with resuscitative thoracotomy [28]. In a series of 74 IVC injuries, 5 of the 6 patients who required this procedure succumbed [11]. From a practical point of view, emergency thoracotomy in an unstable patient with ongoing abdominal bleed might be counter-productive.

*Resuscitative endovascular balloon aortic occlusion (REBOA)*

In light of significant morbidity and mortality associated with resuscitative thoracotomy, other alternatives for non-compressible torso haemorrhage were sought for. One such technique is REBOA, which is a less-invasive method of rapid infra-diaphragmatic haemorrhage control. First described in 1954 during the Korean War [29], it involves temporary occlusion of aortic flow with an inflatable endovascular balloon, via a peripheral arterial access; this improves proximal cerebral and coronary circulation [30]. REBOA is to be avoided in supra-diaphragmatic trauma, as it may exacerbate bleeding. Evidence for the use of REBOA in trauma is conflicting. A systematic review in 2018 [31] analysed 89 studies, 18 of which concerned traumatic abdomino-pelvic haemorrhage. Mortality among trauma patients was 63%. The meta-analysis showed a significant difference in mortality after the use of REBOA compared with other means of treatment, with a risk difference of 0.27 [0.14–0.49($p < 0.001$)] favouring REBOA. The use of REBOA in hemodynamically unstable caval injuries has been reported, with its use described as a means to immediately increase systolic pressures, decrease vasopressor requirements, and enable exploration of the retroperitoneal hematoma under controlled conditions [32]. Complications include those related to vascular access, worsening of proximal bleeding, dissection or rupture of the aorta (due to over-inflation) and visceral, spinal, pelvic, or lower limb ischemia [30]. The use of REBOA, though promising, is still not universally absorbed into standard trauma protocols for major abdominal vascular injuries such as the IVC; additional data with accurate delineation of specific patient populations, indications and optimal occlusion times is needed.

## Operative management

The importance of an experienced team cannot be overstated. A consultant surgeon experienced in trauma surgery with expertise in vascular surgery should be present in the OR from the beginning. Experience in liver surgery is of great help should liver mobilization or hepatic vascular exclusion become necessary. An experienced anaesthetist will maintain hemodynamics and organ perfusion even in the extremis to the best extent possible. Trained staff nurses will ensure smooth assistance and availability of vascular clamps and sutures. It is always preferable to do the surgery in a hybrid OR with fluoroscopy facilities available should an endovascular approach become necessary. An experienced interventional radiologist should be involved as early as possible for anticipated complex injuries. The surgical approach largely depends on the *condition of the patient, level of injury, and expertise available.* The following section provides a framework for intraoperative management and decision-making based on available literature.

*Condition of the patient*

Management has to be tailored for three broad categories of patients. *First is the patient in extremis* who is hemodynamically unstable and has multiple injuries. There is no time for detailed evaluation or preparation. This category of patients has the highest mortality across all series irrespective of the level of injury [2] or the nature of intervention performed [1]. Active ongoing bleed at laparotomy with a lack of spontaneous tamponade has been reported to be the only independent factor predictive of mortality on multivariate analysis [33]. In this setting, the primary goal should be to stop bleeding and restore hemodynamic stability by damage control surgery. IVC injuries in this category of patients are most commonly dealt with IVC ligation [34] especially if the injury is infra-renal and there is near complete transection. In such injuries, it may be difficult to obtain adequate exposure and quick vascular control [13]. IVC ligation is a good salvage strategy as time-consuming procedures like interposition grafts or even patch venoplasty are likely to result in massive continuing blood loss and possible on-table mortality [23]. For unstable patients with retrohepatic or juxta-hepatic vein injuries, a combination of endovascular and surgical strategies described subsequently may be useful prior to exploring the retroperitoneal hematoma. All sources of active bleeding have to be stopped, even if it means control by packing. Intestinal injures can be over sewn temporarily to prevent peritoneal contamination or a segment resected with staplers without restoring bowel continuity. The abdomen is temporarily closed with a laparostomy and re-exploration is done after 24-48 h for definitive management of intestinal injuries and formal abdominal closure.

The second category of patients is those *who are stable but need surgical exploration* due to contrast extravasation from the IVC or due to associated injuries. In this category of patients, there is adequate time to plan a combined endovascular and surgical approach. This hybrid approach involves performing the procedure in an OR with fluoroscopy and digital subtraction angiography capabilities. Interventional radiologists and surgeons can collaborate seamlessly to ensure the best outcomes for the patient. For hybrid procedures, access has to be planned in advance and groins should be prepped in addition to the chest and abdomen. The importance of good communication and ensuring that vascular surgeons, interventional radiologists are involved as soon as possible cannot be overemphasized. Vascular control above and below the level of injury can be obtained by placing balloons through a trans-femoral approach before the retroperitoneal hematoma is explored surgically. This has the potential to prevent sudden uncontrolled haemorrhage. The third category of patients are those *who are stable and have an isolated IVC injury* or a retroperitoneal hematoma on the CT scan. In such situations, a non-operative approach may be adopted with careful reassessment and expectant management.

*Level of injury*

The most commonly adopted strategies to deal with penetrating IVC injuries are *caval ligation and venorrhaphy*. Before deciding on one of these strategies, the anatomical location of the injury and its extent has to be determined. Assessing the circumference of the caval wall involved will usually mean removing the clots over the site of bleeding; this will invariably involve sudden rapid blood loss. It is therefore imperative to have good exposure and vascular control where ever possible. An extended Cattel-Braasch manoeuvre with duodenal Kocherization will give adequate exposure to the infra-renal and supra-renal IVC (Figs. 2 and 3). As soon as the colon is mobilized, it is prudent to secure vascular control of the infra-renal IVC above the iliac bifurcation. One should be careful to avoid the lumbar veins during this step. Clamping of the IVC here will reduce bleeding during the subsequent steps of the operation. If the patient is extremely unstable, clamping the supra-celiac aorta temporarily at the diaphragmatic hiatus can reduce bleeding.

**For infra-renal injuries**, IVC ligation is a bailout strategy that can save patients. It is useful when the patient is in extremis and there is massive bleeding due to a big laceration or transection. Undue attempts to dissect, define, and control multiple tributaries

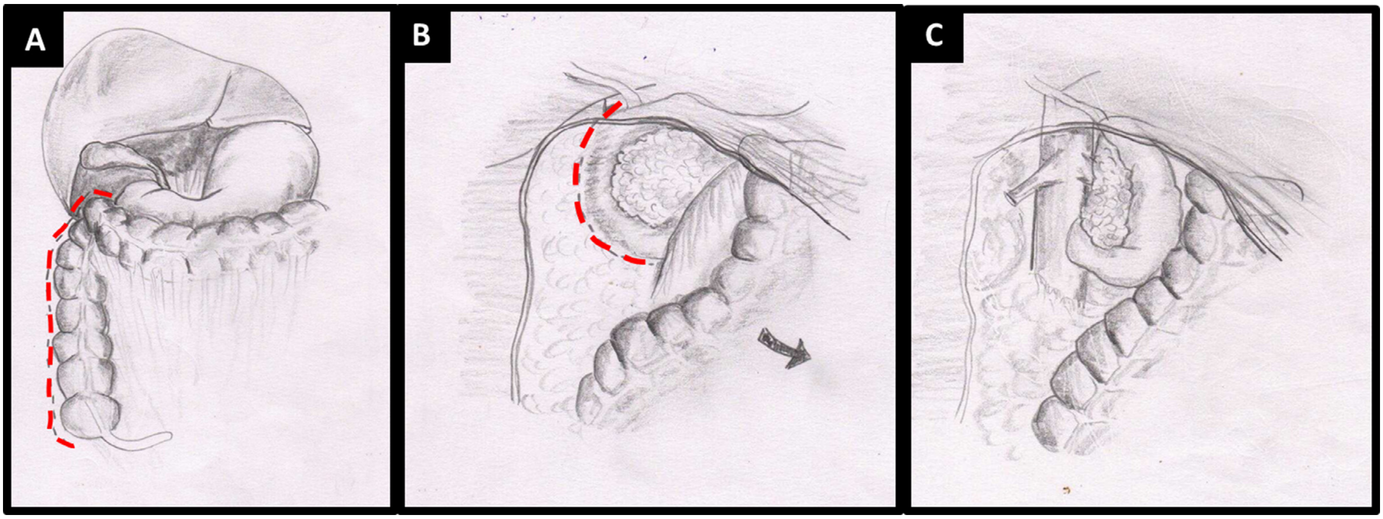


**Fig. 2.** Steps of exposure of IVC. Panel A: Red dashed line indicates the line of mobilization of the right colon, along the white line of Toldt. The cecum, ascending colon and proximal transverse colon are mobilized cephalad and towards the midline, exposing the infra-renal IVC. Panel B: Red dashed line shows the line of mobilization for the Kocher's manoeuvre and medial mobilization of the duodenum. Panel C: On adequate Kocherization, the juxta-renal and proximal portion of the supra-renal IVC are exposed.

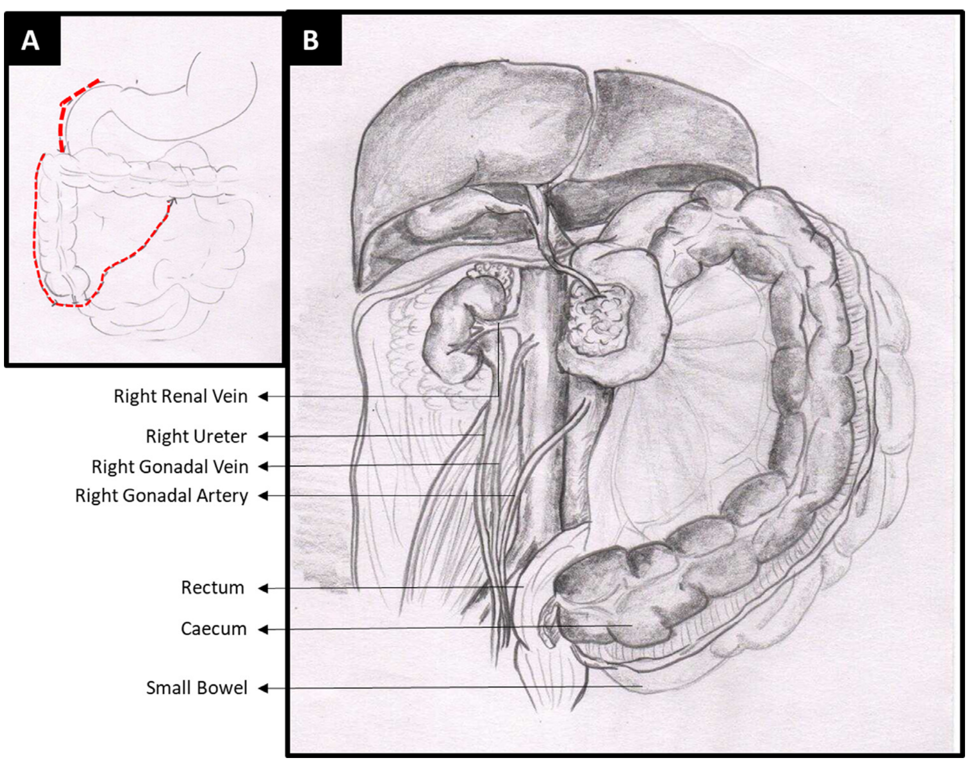


**Fig. 3.** Cattell Braasch manoeuvre. On extension of the line of peritoneal division along the line of attachment of the small bowel mesentery (Panel A: red-dashed line), the small bowel and right colon are rotated to the left, exposing the length of the IVC from the bifurcation.

can result in losing the patient on-table. If the patient is relatively stable, proximal and distal control can be obtained, and if the edges of the laceration are defined clearly, a venorrhaphy can be performed with running 4.0 polypropylene sutures (Fig. 4-A, B). If it is difficult to obtain vascular control, the assistant can apply manual pressure using a large folded gauze held by a sponge holding forceps to compress the cava against the vertebral bodies above and below the level of injury to reduce bleeding. Small Langenbeck retractors have been described as better devices to compress the IVC [35]. Holding up the edges of the laceration with stay sutures will facilitate quick suturing. Even if there is back bleeding from the lumbar veins, suturing can be accomplished with good suctioning and irrigation by an expert assistant. Traction on vascular clamps and sutures should be gentle to avoid extension of the laceration. Rarely, to access injuries near the posterior aspect of the iliocaval junction, the right common iliac artery may have to be transected for proper access and repaired after venorrhaphy [11].

**For supra-renal injuries and retro-hepatic IVC injuries**, the patient's condition dictates the approach. In an unstable patient, packing may give some brief respite while the anaesthetist can catch up with the blood loss. IVC ligation is generally not performed for supra-renal and retro-hepatic injuries. At this stage, if expertise is available, a venogram can be done through the femoral

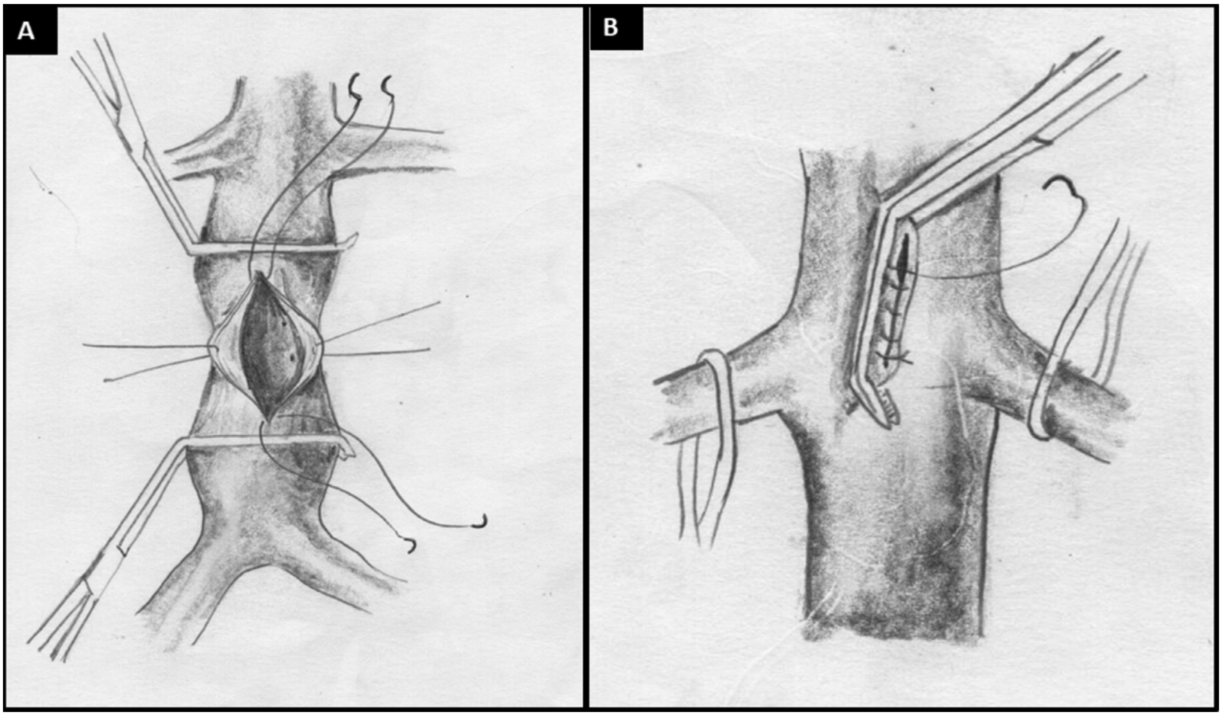


**Fig. 4.** Panel A: Proximal and distal control of the IVC is achieved with vascular clamps. Stay sutures at the lateral edges of the freshened laceration help in optimal venorrhaphy. Fine monofilament double-armed sutures are taken at each corner of the defect, and repair is done in a continuous fashion. Panel B: Small lateral injuries may be held in a vascular clamp, and sutured over in a continuous manner. It is important to gain adequate control of renal veins to control haemorrhage and aid a quick and robust repair. *Adapted from Major Abdominal Veins. https://plasticsurgerykey.com/major-abdominal-veins.*

approach or through direct IVC puncture to assess the site of the leak. If the contrast extravasation is from the segment of IVC between the renal and hepatic vein ostia, a covered metal stent can be deployed to stop the bleeding. Another strategy is to occlude the IVC temporarily above the site of injury with a balloon while mobilization and surgical control can be achieved. There are successful case reports of the use of these strategies in literature [36,37]. Although this is an off-label indication of using arterial stents in veins, medium-term results have been good in select patients. In situations where the endovascular approach is not available or feasible, it is important to attempt control of haemorrhage on-table. To obtain control of the cava superiorly, the right hemiliver has to be mobilized by dividing the right triangular and coronary ligaments. Inferior hepatic veins, retrohepatic tributaries to the liver, and the right adrenal vein can be divided. Once vascular control is obtained, venorrhaphy can be performed as described. Cavoatrial shunting is described as an option to divert blood from the IVC below the site of injury to the right atrium using a synthetic graft. This requires a midline sternotomy and expertise in cardiac surgery. It is a morbid procedure and has not found wide acceptance because of the chances of air embolism and catastrophic bleeding due to the procedure itself.

**Juxta-hepatic vein IVC injuries** can be challenging even for experienced surgeons. Access can be difficult. A Pringle manoeuvre will reduce bleeding from a concomitant liver laceration. Suprahepatic IVC control can be obtained by freeing the diaphragmatic attachments of the cava and circumferentially dissecting the intra-abdominal IVC above the hepatic veins. Phrenic veins have to be divided to access this part of the cava. Total vascular exclusion of the liver is achieved by clamping the hepatoduodenal ligament, the superior and inferior cava (Fig. 5). This will reduce bleeding and permit visualization but an unstable patient will not tolerate loss of venous return for too long. So, the venorrhaphy has to be accomplished swiftly and accurately. Digital compression, finger pinching, and surface-to-surface suturing have been described in

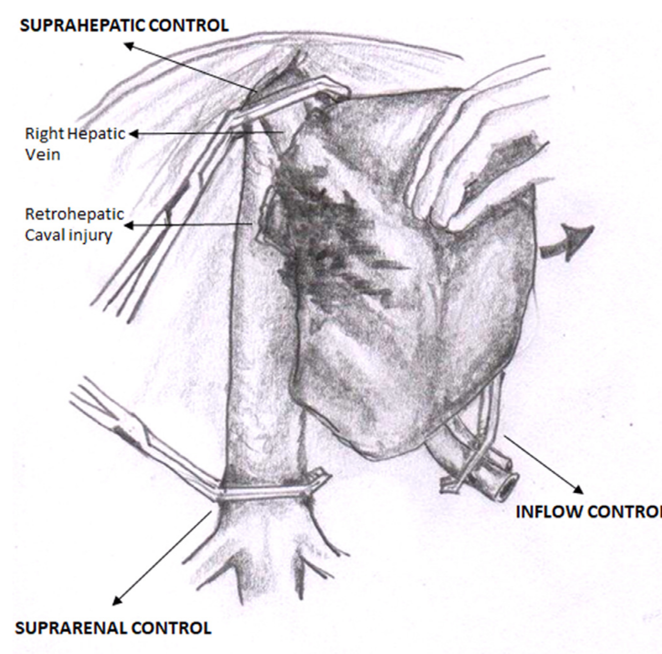


**Fig. 5.** Total hepatic vascular exclusion. In severe retro-hepatic injuries with uncontrolled haemorrhage, supra-hepatic and infra-hepatic vascular clamps may be applied along with a Pringle manoeuvre to control torrential bleed. *Adapted from Balbina M, Araujo D, Romao A, et al. Retrohepatic vena cava lesion: which we cannot forget? World J Adv Res Rev. 2019;03(01):27-034. DOI:10.30574/wjarr.*

the management of retro-hepatic IVC injury during hepatic resection [38]. Some of these principles can be applied in the setting of penetrating trauma as well. Once the vein laceration is repaired, the area is packed and resuscitation is continued. The patient is

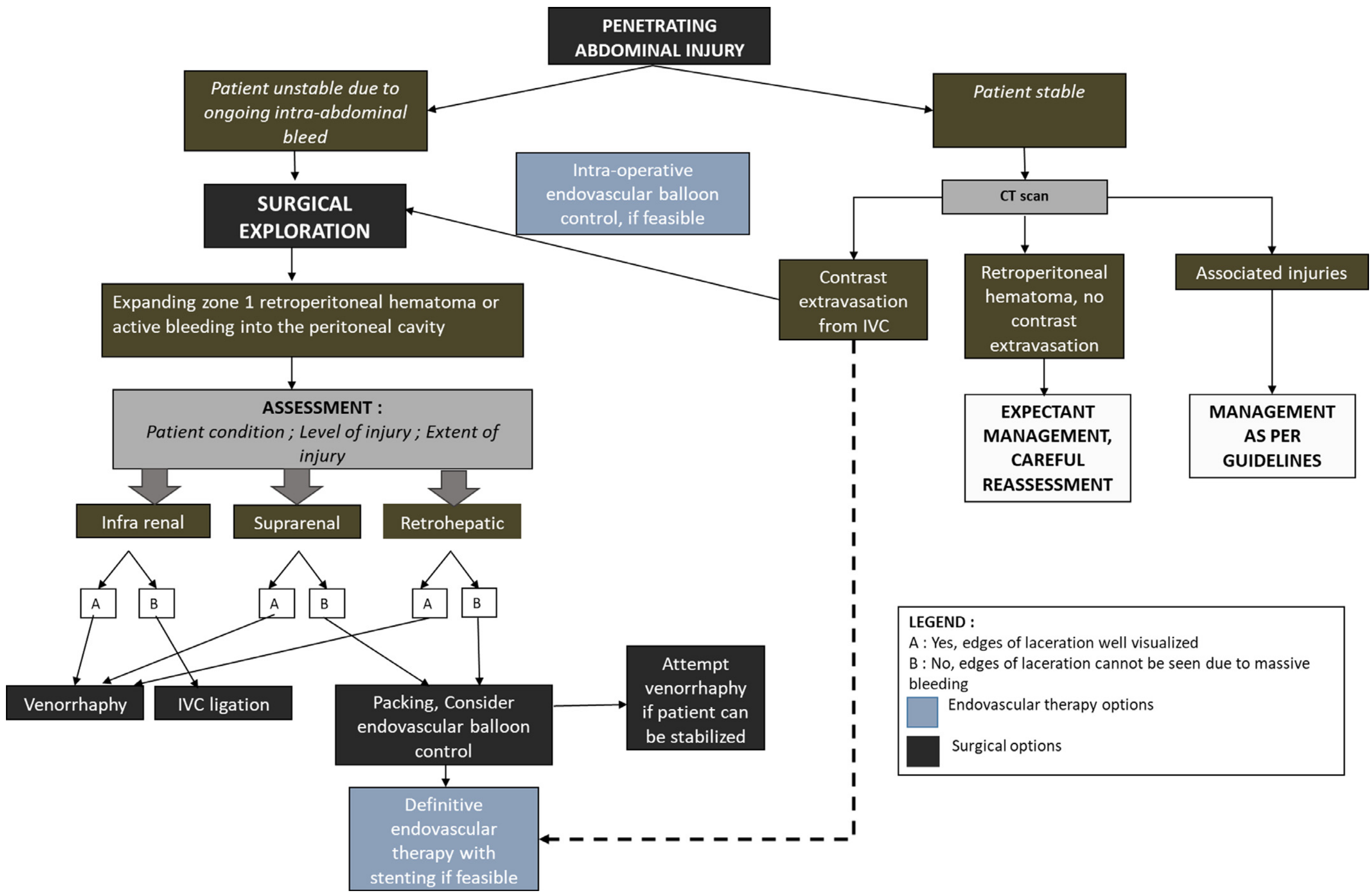


**Fig. 6.** A proposed algorithm for the management of penetrating IVC injuries. The use of endovascular strategies is a useful alternative if expertise and infrastructure is available; however, it is still not standard practice for the treatment of these injuries.

actively rewarmed and managed in a surgical intensive care unit (ICU).

*Endovascular approach in the management of IVC injuries*

A paradigm of integrating an endovascular approach to the standard surgical approach has the potential to manage IVC injury in a minimally invasive manner. With increasing experience in endovascular management, a protocol-based algorithm of a combined or hybrid approach can probably salvage unstable patients who would not tolerate the added insult of a surgery that compounds the problem of hypovolemic shock. The majority of the deaths due to penetrating IVC injury occur on-table as it is not possible to achieve timely haemostasis in the face of massive bleeding. This is especially true for retro-hepatic injuries where the tamponade effect is lost after mobilizing the liver; exploring the hematoma results in uncontrolled haemorrhage before vascular control can be achieved.

In hemodynamically unstable patients where the presence of IVC injury is known prior to surgical exploration, the patient can be taken to a hybrid OR and a balloon placed via a femoral approach in the lower IVC just beyond the bifurcation. A venogram will show the site of contrast extravasation. A balloon can also be placed superior to the site of injury and inflating both balloons will provide vascular control without wading into the 'tiger territory' [39]. The retroperitoneal hematoma can then be explored under more controlled circumstances and venorrhaphy performed. In situations where there is no preoperative diagnosis and an IVC injury is diagnosed intraoperatively, it may be prudent to pack the injury and attempt an endovascular control instead of risking extensive blood loss by surgical exploration. If the area of bleed is between the ostia of the renal and hepatic veins a covered stent can be placed. Having an integrated surgical and endovascular approach may thus minimize blood loss, prevent hypotension and improve perioperative mortality, especially in unstable patients with retrohepatic injures. An algorithm for the management of patients with penetrating IVC injuries is suggested by the authors in Fig. 6. Herein an increasing role for collaborative endovascular treatment is highlighted. Due to the serious nature of the injuries, it is not possible to have very robust evidence-based guidelines for management; however, adhering to general principles of trauma care and focussing on overall patient management and organ perfusion is important while choosing a particular care pathway for an individual patient.

## Post-operative management and complications

Among those patients who survive to post-operative recovery in ICU, a number of complications are to be anticipated, depending on the nature of the repair. Major postoperative complications have been reported in as high as 59% of survivors of surgery [11]. Abdominal compartment syndrome is a complication associated with a prolonged period of hypotension, massive transfusion, hypothermia, and tight abdominal closure [40]. Temporary abdominal closure is a preferred damage-control strategy to avoid this. A frequently reported, but mostly self-limited problem is lower limb oedema, which occurs following both IVC ligation and repair. Leg elevation, elastic bandage wrapping, and sequential compression devices are used to aid venous flow 41,38]. Lower limb compartment syndrome is relatively uncommon and prophylactic

**Table 2**
Major series on IVC injuries, with data on location of injury and mortality.

| Author, Year | IVC injury(n) | Penetrating injury (n) | Mechanism of injury GSW / stab / blunt (n) | Location of injury (n) | | | | | Treatment (n) | | | | Mortality | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *IR* | *Juxta renal* | *SR* | *Retro-hepatic* | *Supra-hepatic* | *Ligation* | *Venorrhaphy* | *Resection, EEA/Patch /Graft* | *Unsuccessful* | *Total (%)* | *On- table / first 48 hrs post-op (n)* |
| **Burch, 1980** [44] | 276 | 257 | 180 / 77 / 19 | 162 | 37 | 32 | 36 | 9 | 13 | 231 | 2 | 27 | 37% | -/90 |
| **Kudsk, 1984** [45] | 70 | 55 | 29/26/15 | 12 | 1 | 10 | 13 (6 HV) | 8 | 3 | - | – | - | 47.1% overall. 36.3% penetrating injury | 9/30 |
| **Wiencek RG, 1988** [46] | 67 | - | - | 14 | 11 | 27 | 15 | - | - | - | - | - | 57% (overall) | - |
| **Degiannis, 1996** [11] | 74 | 74 | 67 / 7 / - | 43 | 17 | 14 | - | - | 4 | 57 | - | - | 39% | 23 / 6 |
| **Coimbra, 1996** [28] | 65 | 47 | -/-/18 | - | - | - | - | - | - | 38 | - | 10 | 59% overall. Isolated IVC 37% | 18 / 5 |
| **Porter, 1997** [42] | 81 | 77 | 60/17/4 | - | - | - | - | - | 7 | 38 | - | - | 56% overall | - |
| **Rosengart, 1999** [47] | 37 | 29 | - | 15 | 2 | 6 | 9 | 3 | - | - | - | - | 51% overall ; 48% penetrating injury | - |
| **Asensio, 2000** [5] | 89 | *88% (overall)* | - | - | - | - | 12 | - | 22 | 34 | - | 33 | 75% overall. Isolated IVC 70.1% | - |
| **Hansen, 2000** [48] | 47 | 31 | -/-/16 | 13 | - | 8 | 9 | - | 4 | 28 | 2 | - | 55% overall | 14 / 8 |
| **Tyburski, 2001** [49] | 144 | - | - | 65 | 14 | 31 | 32 | 2 | - | - | - | - | 57% (overall) | - |
| **Navsaria, 2005** [1] | 48 | 48 | 45 /1 / 2 | 41 | - | 6 | 1 | - | 30 | 18 | - | - | 31% | 6/6 |
| Huerta, 2006 [50] | 36 | 26 | -/-/10 | - | - | - | - | - | 12 | - | - | - | 56% overall | - |
| **Branco, 2010** [2] | 5287 | 1605 | 1130/475/3582 | - | - | - | - | - | 506 | 1759 | 162 | - | 40.5% overall, 34.7% penetrating injury | - |
| **Paul, 2010** [51] | 55 | 44 | - | - | - | - | - | - | - | - | - | - | 44% overall. 36.9% penetrating injury | - |
| **Sullivan, 2010** [34] | 100 | 100 | - | 54 | 21 | - | 15 | 10 | 25 | 57 | - | - | 51% | -/ 54 |
| **Singer, 2012** [43] | 308 | - | - | - | - | - | - | - | 72 | - | - | - | 37.3% overall | - |
| **van Rooyen, 2014** [23] | 27 | 27 | 27 / -/- | 15 | - | 9 | 3 | - | 4 | 16 | 1 | - | 37% | 5 / 4 |
| **Hampton, 2016** [3] | 35 | 33 | 29 / 4 / 2 | 19 | 9 | 3 | 4 | - | 23 | 6 | - | - | 49% overall | 8 /3 |
| **Matsumoto, 2018** [52] | 1316 | 1045 | 696/349/260 | - | - | - | - | - | 447 | 869 | - | - | 38.8% overall | - |

*GSW-gunshot wound; IR- infra-renal; SR-supra-renal; EEA- end to end anastomosis.

fasciotomy is not recommended A retrospective study in 2010 described higher requirement of lower limb fasciotomy in survivors of IVC ligation as compared to IVC repair (77% vs. 4%) [34]. Whereas infra-renal caval ligation is well-tolerated, suprarenal ligation is associated with significant morbidity including congestive nephropathy and renal failure.

When venous repair has been performed, stenosis, thrombosis, and air-embolism may occur. Venorrhaphy may produce significant narrowing, even necessitating revision by patch angioplasty or graft replacement once the patient is stable [41]. However, even if 50% of the lumen is maintained there are no immediate problems; most patients develop collaterals in the long term and do not face any serious consequences of IVC narrowing. Post-operative caval doppler screening is warranted following repair, to document patency before discharge [42]. The reported incidence of DVT following IVC repair and ligation is 2.3-15%, with 0.6-2.5% incidence of pulmonary embolism (PE) [11,43]. The role of prophylactic anticoagulation is debatable and must be weighed against the risk of haemorrhage from associated injuries. Anticoagulation is generally advised for patients with IVC ligation at the time of discharge to prevent DVT, although there is no consensus on the duration of therapy.

## Outcomes and determinants of mortality

Penetrating IVC injuries are associated with a significant risk of mortality, with most series reporting death rates in the range of 31–75% (Table 2) [1,2,3,5,11,23,28,34,42,43,44-52]. Cause of death is most commonly exsanguination and usually occurs within the first 24–48 h. Delayed death is attributed to sepsis, respiratory complications, and hepatic failure. What is noteworthy is that, despite improvement in pre-hospital care, optimized resuscitation protocols, advancement in endovascular techniques, progress in surgical technology, and better postoperative critical care, these injuries remain highly lethal. In 2018, Branco et al. published their 13-year analysis of the US National Trauma Databank (NTDB) with respect to IVC, abdominal aortic and thoracic aortic injuries [2]. There were 1605 cases of penetrating IVC injury, with an overall mortality rate of 34.7%. When compared to single vessel injuries, combined injury (IVC and aorta) carried a significantly higher mortality rate following penetrating trauma (60.4% vs. 30.5%, $p<0.001$). Despite a steady mean Injury Severity Score (ISS) across the study period, there was a significant increase in mortality associated with these injuries, from 40.8% in 2002 to 47.8% in 2014 ($p<0.001$). It could be argued that with progress in patient transportation facilities and pre-hospital resuscitation, more patients with these injuries reach the hospital alive but in dire hemodynamic status, only to succumb there later; several of these patients might not have survived to reach the hospital at all, in the early stage of the study period.

The most important factors that determine the outcome are the hemodynamic condition of the patient on arrival, the occurrence of spontaneous tamponade of the caval injury, and other associated vascular injuries apart from aortic injuries [11,33,45,49,50]. An unrecordable blood pressure at admission was associated with a four times higher mortality rate when compared to those admitted with recordable values; the mortality rate was six times higher in the fraction of patients who failed to respond to initial fluid resuscitation than responders [11]. In the presence of a limiting retroperitoneal tamponade, a 26% mortality rate was reported, while the absence of retroperitoneal tamponade with free intraperitoneal haemorrhage was associated with death in 74% of cases [28]. Injury of more than 2 vessels in addition to the IVC resulted in 100% mortality [11]. In the same series, the presence of associated iliac artery injury was especially dangerous, with a 71.4% mortality rate.

The level of injury understandably has implications on outcomes. An injury to the infra-renal IVC carries the best prognosis, as exposure and haemorrhage control is considerably easier. Numerous authors have reported poor outcomes for retro-hepatic and supra-hepatic caval injury, with mortality for supra-hepatic caval trauma approaching 100% in most series [7,25]. Other factors that may predict mortality include ISS [1], transfusion requirement [3], preoperative serum lactate [47], a low Glasgow Coma Score on arrival [13], number of caval injuries [45], performance of ER thoracotomy [33], and initial base deficit [51]. The mechanism of injury has also been variably related to mortality in penetrating IVC trauma, with GSWs described to be associated with worse outcomes when compared with stab wounds [47].

The operative technique employed may have a bearing on outcomes, i.e. ligation or repair. In the critically-ill patient with IVC injury, ligation is thought to be the appropriate damage-control strategy. A propensity-score matched analysis was performed by Matsumoto et al. [52] based on the NTDB data, to compare the outcomes in patients treated for IVC injury with either ligation as part of a damage-control operative protocol, or repair. The hypothesis was that ligation could be potentially beneficial and yield greater survival benefit. In the cohort of 1316 subjects with IVC injury (80% penetrating trauma), 310 pairs were studied, matched for baseline characteristics, hemodynamic parameters, Abbreviated Injury Scale, and associated intra-abdominal injuries. After matching, both groups displayed similar in-hospital mortality (41.3% vs. 39.0%; OR 1.10; 95% CI 0.80 to 1.52; $p = 0.623$). The ligation group had a higher rate of morbidity such as extremity compartment syndrome, pneumonia, DVT and PE, and also had longer hospital stay and duration of mechanical ventilation. They concluded that ligation offered no survival benefit in IVC injuries when compared to repair, even in physiologically compromised patients.

## Summary

Penetrating IVC injuries pose a great challenge for trauma surgeons. Mortality remains resiliently high, despite developments in rapid pre-hospital transit, and specialized trauma care. The majority of patients still die of hypovolemic shock and exsanguination on-table or within 48 h of arrival to the hospital. Early recognition is crucial and management of these injuries must be guided by fundamental principles of trauma resuscitation, early effective haemorrhage control, and damage-control surgery. Retrohepatic and supra-hepatic injuries represent especially challenging situations for even the most experienced of surgeons and are fraught with extremely high mortality rates. Employing a multidisciplinary approach to the management of these complex injuries may further refine the treatment strategy, including the use of endovascular/hybrid approaches in appropriate cases. The application of selective non-operative management in suitable cases has the potential to salvage an important subgroup of patients.

## Declaration of Competing Interest

The authors have no conflict of interest to declare.

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