



Vascular Injury During Urologic Surgery: Somebody Call My Mother

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Abstract

Purpose of Review To provide the critical elements to effectively manage hemorrhage from vascular injuries sustained during planned urological interventions.

Recent Findings The frequency of intraoperative vascular injuries is increasing. However, literature concerning the management of iatrogenic operative vascular injuries is scarce.

Summary Although rare, intraoperative vascular injuries may be associated with potential catastrophic complications and death. The decision-making process following a potential life-threatening intraoperative vascular injury occurs in a very short time frame. Appropriate knowledge of the critical elements to identify the source of bleeding, initiate first-line hemostatic measures, select the candidate for damage control strategies, and perform the indicated operative repairing maneuvers and techniques have been proved crucial to ensure hemodynamic stability and bleeding cessation. The key surgical principles to counteract the impact of exsanguinating bleeding, and the aim to obtain the best achievable outcomes after definitive repair, are described in detail in this review.

Keywords Urologic surgery · Vascular injury · Hemorrhage · Vascular exposure · Damage control

Introduction

“The only weapon with which the unconscious patient can immediately retaliate upon the incompetent surgeon is hemorrhage.”

William Stewart Halsted,

Bulletin of the Johns Hopkins Hospital, 1912; 23: 191

“In a wound that is perfectly dry, and in tissues never permitted to become even stained by blood, the opera-

tor, unperturbed, may work for hours without fatigue. The confidence gradually acquired from masterfulness in controlling hemorrhage gives to the surgeon the calm which is so essential for clear thinking and orderly procedure at the operating table.”

William Stewart Halsted,

The Johns Hopkins Hospital Reports, 1920; 19: 71

Surgeons are occasionally involved in the management of patients with vascular injuries sustained during elective operations. Although serious injuries are relatively rare, they are associated with potential catastrophic complications and risk for death. This is especially true for injuries sustained in major vascular structures, particularly in low-pressure and high-flow vessels. Injuries in these locations span the spectrum of urologic interventions, and can pose a formidable challenge to the surgeon [1••].

As the interest in aggressive oncologic resection increases, it can be expected that iatrogenic vascular injuries will continue to occur, becoming even more frequent. However, a paucity of literature exists concerning the management of iatrogenic vascular injuries sustained intraoperatively, mostly devoted to the description of selected cases with specific patterns of injury [2••]. Conversely, what the treating surgeon probably

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misses is the description of a systematic approach to deal with intraoperative vascular complications. Therefore, the purpose of this review is to provide the reader with the critical elements to effectively manage hemorrhage from vascular injuries sustained during planned urological interventions.

Epidemiology of Vascular Injury and Sources of Complications

Control of hemorrhage has been of prime concern to man since his beginning. Although the first arteriorrhaphy was performed more than two centuries ago, it is only in the past 5 decades that vascular surgery has been routinely practiced with anticipation of good results. Since the days of Ambrose Paré, major advances in the surgery of vascular trauma have occurred at war, when it was necessary to treat large numbers of severely injured patients, often under far from ideal conditions [3] (Table 1).

Nowadays, it is estimated that nearly 25% of adverse events in surgery are related to technical complications [15]. Such an incidence is responsible for 5–75% of all vascular injuries [16–20]. Nevertheless, the overall incidence of vascular injuries is relatively low (0.9–2.3/100,000 population) [16], a number that varies according to the type of practice (referral bias), specific disease nature, and surgical approach. Conversely, this incidence is rising in recent years due to the increasing number of iatrogenic injuries [17–20]. According to a survey conducted between 2003 and 2008, intraoperative hemorrhage was responsible for 33% and 47% of the reported cardiac arrests and deaths, respectively [21]. Although two thirds of those hemorrhagic deaths occurred in emergency operations, the remaining one third was sustained during elective surgical procedures.

Specific sources leading to intraoperative vascular complications may be categorized within three domains: (i) errors due to technical factors, (ii) cognitive factors, and (iii) patient factors [15]. Hence, vascular complication rates vary with the nature of the procedure, patient comorbidities and anatomy, and experience of the surgeon among others. In fact, the incidence of hemorrhage requiring transfusion reported in the urological literature varies from 0.3% for percutaneous nephrolithotomy [22] to 52% in one cohort undergoing radical retropubic prostatectomy [23]. In current series, most of the patients developing hemorrhagic complications due to vascular injuries underwent oncologic operations. Therefore, in a recent study, hostile distorted anatomy was described in 63% of patients suffering from this complication by the operating surgeon. In this report, factors that were seen to increase technical difficulty in the proper identification and correct dissection of the tissue planes were previous operation (48%), tumor recurrence (23%), previous radiation therapy (20%), and chronic inflammatory changes (20%) [1••].

Additional surveys concerning hemorrhagic events revealed that they were complicated by many human factors and then develop into critical hemorrhage [21]. Furthermore, mortality was directly associated with the severity of bleeding. Of no surprise, mortality was higher in patients with massive hemorrhage, hypothermia, acidosis, hypotension, and large fluid requirements [24]. Interestingly, while intraoperative blood loss was strongly inversely correlated with surgeon's experience, major vascular injuries appear to occur with equal frequency in both novice and experienced surgeons [25]. This finding underscores the need for all surgeons, even those with significant experience, to follow key surgical principles to avoid these complications.

Types of Vascular Injuries

The spectrum of vascular injury affects both arteries and veins, and covers a continuum between minor puncture to complete vessel avulsion. Punctures are commonly related to laparoscopic procedures. Lacerations represent the most common form of vessel injury, tend to occur during sharp dissection, and may be repaired primarily in most instances. Conversely, transection and avulsion typically require more complex repair, involving major vascular structures, and requiring extensive mobilization maneuvers and surgical skills [26].

Initial Management of Bleeding

Identification of the Source of Bleeding Vascular injuries must be identified in a quick fashion in order to achieve the best outcomes possible after their repair (Fig. 1). Sometimes, the vascular insult becomes immediately self-evident, since the surgical field is rapidly filled in with blood impairing adequate visualization, or a jet of blood is directly noticed. However, the presence of a pulsatile hematoma may be subtle initially preventing its intraoperative diagnosis [27].

Initial Bleeding Control Once identified, if the source of bleeding is small and clearly visible, the use of cautery may be the first option. Conversely, more important bleedings may require a second suction device in the field to allow visual control while the maneuvers to stop bleeding continue [2••]. In cases of non-life threatening hemorrhage and obscure source of bleeding, compression packing is recommended. Shortly after, the removal of the sponges will improve bleeding.

Hemostasis can be easily obtained by cinching the loop, if the vessel was previously identified with a vessel loop. However, in cases of full transection, the loop may slip off the vessel, and clamping or indwelling a Fogarty catheter inside the vessel may be required for bleeding control. Of note, vascular clamps must be applied over a well-dissected

Table 1 The vascular injury legacy: historical milestones in the development of vascular injury surgery

Date	Author	Contribution
98-117 [3]	Rufus of Ephesus	<ul style="list-style-type: none"> An artery continues bleeding when partially severed, but Complete avulsion of an artery results in contraction of the cuffs and stop of bleeding within a short period
129-210 [3]	Galen	<ul style="list-style-type: none"> Placing a finger in the orifice of a bleeding superficial vessel ignites the formation of thrombus and cessation of bleeding If bleeding comes from a vein, pressure usually suffices Ligation (with linen) is recommended for arterial injuries
1536 [3]	Ambroise Paré	<ul style="list-style-type: none"> Established the use of ligatures for hemorrhage control Developed the “bec de corbin”: a predecessor of the modern hemostat to grasp the vessel before ligation Advanced in the dressing technique during the siege of Turin by using a mix made of egg yolk, rose oil, and turpentine, for better wound care
1616 [3]	William Harvey	<ul style="list-style-type: none"> “Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus”: description of blood circulation
1759 [4]	Hallowell and Lambert	<ul style="list-style-type: none"> Initial reports on arterial repair using the “Farrier’s stitch”: a method to reconstruct an artery after aneurysm excision
1873 [5]	von Eschmarch	<ul style="list-style-type: none"> Discovered, developed, and used the tourniquet for control of bleeding
1889 [6]	Jassinowsky	<ul style="list-style-type: none"> Noticed that arterial wounds could be managed by refreshing and anastomosing its proximal and distal ends The anastomosis maintained its lumen by using a double-layered invaginating cuff suture
1897 [7]	Murphy	<ul style="list-style-type: none"> Arterial repair could be performed with safety when no more than ¼ inch of vascular length had been removed In certain locations where tension between both arterial cuffs may be relieved by moving the surrounding tissue to reapproximate them, even larger defects may be treated by primary anastomosis
1902 [8]	Carrel	<ul style="list-style-type: none"> Nobel Prize in Physiology and Medicine in 1912 with the description of the triangulation method of arterial anastomosis
1912 [9]	Halsted	<ul style="list-style-type: none"> Demonstration of the development of collateral circulation in a dog model by gradually occluding different large arteries including the aorta
1914-1918	World War I	<ul style="list-style-type: none"> The widespread use of high explosives and high-velocity bullets, combined with mass casualties and slow evacuation of the wounded, made arterial repair impractical
1939-1945 [10]	World War II	<ul style="list-style-type: none"> The ligation was not a procedure of choice but a procedure of extreme necessity to obtain hemorrhage control given the location, type, size, and character of most battle injuries of the arteries The average time lag between wounding and surgical treatment was over 10 h (virtually precluding successful arterial repair in most patients)
1950-1953 [11]	Korean War	<ul style="list-style-type: none"> Successful repair of arterial injuries were due to several factors including: <ul style="list-style-type: none"> -progress in surgical techniques (anastomosis, debridement, delayed primary closure) and other areas in medicine (anesthesia, blood transfusion, technology, and antibiotics) -creation of highly specialized army medical corps attending at the site of conflict -rapid evacuation of wounded men (mostly by helicopter with a lag until adequate assistance of 1-2 h in most cases)
1955-1975 [12, 13]	Vietnam War	<ul style="list-style-type: none"> The availability of surgeons experienced in vascular surgery was progressively widespread Time lag between injury and treatment was reduced even further (routine evacuation by helicopter) Major problems still remained: arterial injuries associated with massive damage to soft tissues, major venous obstruction, repeated vascular operations, associated unstable bone fractures, inadequate tissue debridement, and small vessel injury
2001-present [14]	Afghanistan and Iraq Wars	<ul style="list-style-type: none"> New strategies of management have been recently incorporated: <ul style="list-style-type: none"> -Use of different topical hemostatic agents -reemergence of tourniquets -temporary vascular shunts -smarter transfusion and resuscitation strategies -and even catheter-based endovascular techniques

vascular structure. Otherwise, their blind application may add vascular damage.

The same fundamental principles apply for laparoscopic approach. However, actions for bleeding control must be taken immediately to prevent complete visual loss inside the field. Direct compression with a sponge stick or Yankauer blunt tip while the pneumoperitoneum is progressively increased will serve to temporarily tamponade bleeding. Since subsequent

control and repair is often difficult through this approach, the wise surgeon must give consideration to open conversion, particularly if a major vascular structure is compromised.

Decision-Making on Damage Control Surgery Operative repairing maneuvers must ensure hemodynamic stability and bleeding cessation. Substantial hemorrhage must be followed by aggressive fluid resuscitation and intensive care unit (ICU)

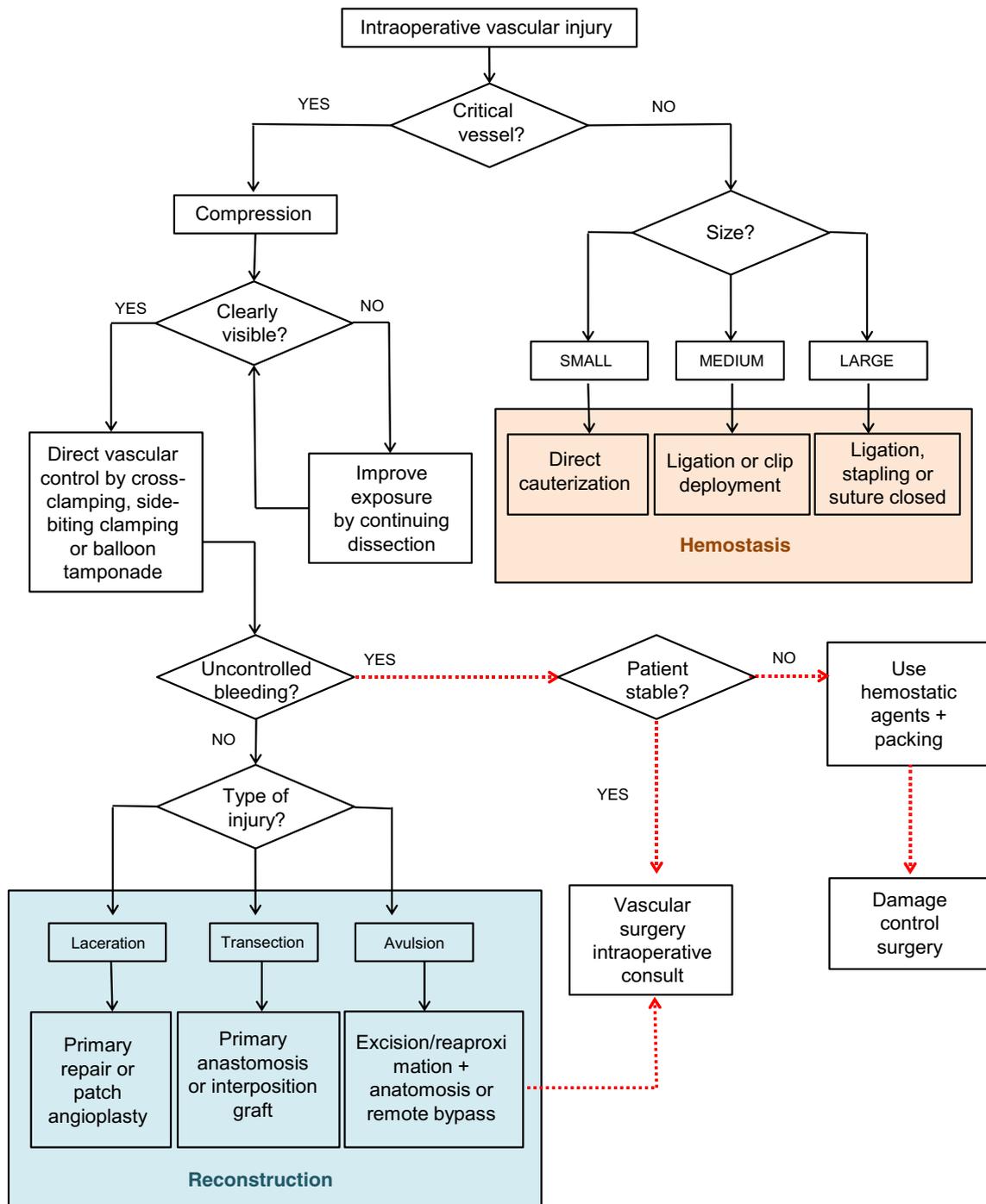


Fig. 1 Algorithm describes management of vascular injury sustained during a planned surgical intervention

transfer until acidosis and coagulopathy are corrected (damage control surgery), particularly if concern for hypovolemic shock exists. Recent evidence from trauma literature supports restrictive blood product transfusion strategies, although they remain still unproved for the intraoperative hemorrhage setting. Once the patient is stabilized, further operative reassessment for definitive repair may be performed in better conditions [28].

Damage Control Surgery

Damage control is well recognized as a surgical strategy (series of operations) that sacrifices the completeness of the immediate repair in order to address the combined physiological impact of hemorrhage, assuming that patients are more likely to die from the “lethal triad” (hypothermia, coagulopathy, and

metabolic acidosis), rather than from a failure to complete operative repair [29].

While there are many different components to damage control, abdominal packing has historically been considered the foundation principle. There are five critical stages in damage control surgery:

- Stage I. Prompt recognition of the potential need for damage control is crucial. Hence, this stage includes rapid initiation of resuscitation maneuvers and hemorrhage control. Hemodynamic instability, coagulopathy, hypothermia, acidosis, inability to control bleeding, transfusion > 10 units of packed red blood cells, and operative time > 90 min are important indicators for damage control approach [30].
- Stage II. This stage implies control of hemorrhage with ligation, suturing, or temporal shunting of vascular injuries in addition to rapid techniques of intraabdominal packing and temporary abdominal closure [29]. The technique of packing should take less than 5 min to be completed. The packs are shortly thereafter removed, beginning in the quadrant farthest away from the greatest amount of hemorrhage. If non-surgical bleeding continues ongoing, the packs should be replaced and maybe left in the abdomen for further reassessment in a second-look approach. No attempt should be made to accomplish the definitive objective of the intervention if this was not previously completely finished.
- Stage III. At this stage, the patient is transferred to the ICU for rewarming, correction of coagulopathy, reversal of acidosis, minimized crystalloid infusion, and decision on blood transfusion. Endpoints include a systemic lactate concentration of less than 2.5 mmol/L, base deficit greater than -4 mmol/L, core temperature greater than 35 °C, hemoglobin level > 10 g/dL, and hematocrit > 30% [31].
- Stage IV. A laparotomy for reassessment purposes is performed at this stage. It consists of removal off the packing, definitive repair of vascular venous injury/s, accomplish the main objective of the intervention that was planned, and temporary close of the laparotomy once the patient has been fully resuscitated, is warm, and the coagulopathy has been restored; usually 24–48 h (optimal from 12 to 96 h) after the initial intervention. However, timing for reoperation is governed by the indication for damage control, spectrum of injuries, as well as the physiologic response of the patient in the ICU [28].
- Stage V. Abdominal definitive closure of the laparotomy is performed (preferably within 8 days after initial intervention) [32].

Definitive Management of Vascular Injuries

General Principles The construction of a wide lumen, water-tight, and tension-free anastomosis represents the main objective of any vascular repair. Before attempting anastomosing sutures, both vascular cuffs must be refreshed, spatulated in case of low diameter (below 4 mm), and intimal flaps must be excised to prevent turbulence in flow after repair. Sutures must be perpendicularly placed across the full thickness (all layers) of the vessel wall, maintaining approximately 1 mm interval among two consecutive needle passes. Atherosclerosis should be raffled, passing the needle through a place where it can be done safely depending on plaques location [2••].

Different options are available for vascular repair given the nature and location of the injury. While most veins can be permanently interrupted (by ligation, clipping, stapling, or suturing), arterial injuries involving arteries ≥ 2 mm in diameter, providing end-tissue perfusion, or in which interruption becomes unsuitable because inadequate collateral circulation is anticipated, will require reconstruction.

In cases of small defects and uncompromised vessel edges, a simple re-approximation with sutures would work well enough. However, lumen narrowing must be avoided by cuff spatulation to prevent stenosis and subsequent thrombosis. When the size of the defect precludes primary approximation, or simple repair will result in stenosis, a patch angioplasty is warranted. A number of different materials for patching are currently available. Its choice still depends entirely on surgeon's preference and accessibility. Autologous vein, bovine pericardium, and parietal peritoneum may be counted among the biologic materials, while Dacron or extended-polytetrafluoroethylene (ePTFE) represents the most commonly used synthetic materials for vascular patching [33•].

If severe vascular damage makes patch angioplasty unsuitable, edge excision and reanastomosis becomes the procedure of choice. This approach requires further mobilization of both vascular cuffs, thus providing the adequate length to ensure a tension-free anastomosis. However, if significant tension is anticipated, an interposition graft should be used to bridge the gap.

In cases of unfeasible or previously failed open repair, an endovascular stenting approach may represent the best option still available [34].

Aortic Injuries Iatrogenic injury to the aorta commonly occurs at the time of laparoscopic access, or during the dissection in upper retroperitoneal surgical cases. Heavy disease adherence to the aortic adventitia and previous treatment with chemo- and/or radiotherapy (producing weakening and melting of the different periaortic tissue layers) are well known factors for this catastrophic mishap. Although exsanguination represents a serious risk, in most (if not all) of these cases, the injury can be identified and repaired intraoperatively.

Initial control of the supraceliac aorta can be gained by means of incising the gastrohepatic ligament (thus entering in the lesser omentum), mobilizing the left lobe of the liver medially (by incising the left triangular ligament), and retracting the stomach in caudal direction. The esophagus and periesophageal fat should be mobilized laterally, thus permitting the identification of the aorta at the level of the diaphragmatic hiatus, where it can be compressed, or encircled and cross-clamped. If the patient is in extremis, aortic occlusion by direct manual compression or using an aortic occluder is recommended until a more favorable situation is reached. While this exposure allows control, it does not provide access for definitive repair [35•, 36••].

Visceral Artery Injuries Although injuries to the superior mesenteric artery (SMA) represent the most common scenario, injuries to the celiac trunk and its components had been also reported [37]. These injuries are commonly sustained during upper retroperitoneal oncologic cases, being the distorted anatomy (commonly related to bulky disease) outlined in the literature as the most frequent predisposing factor [38]. Cautious preoperative review of the diagnostic imaging by the surgical team is of utmost importance to avoid misadventures in these cases.

Once the supraceliac aorta is controlled and bleeding permits adequate visualization, exposure of the supraceliac aorta and the celiac trunk along with its branches is gained by left medial visceral rotation. This maneuver requires the incision of the splenorenal ligament and peritoneal reflection along the paracolic gutter in caudal direction until the distal sigmoid colon is reached. The visceral complex located in the left upper abdominal quadrant is thereafter mobilized towards the midline using a plane anterior to Gerota's fascia [35•, 36••]. Adequate access to the supraceliac aorta, celiac trunk, origin of the superior mesenteric artery, and left iliac system is gained by this approach.

Alternatively, a modification of the left visceral rotation maneuver (the Mattox maneuver) may be used if a magnified access to the takeoff of the main renal artery is required. This maneuver requires a full rotation of the kidney and it envelopes en bloc towards the midline with the rest of the left visceral components, thus a plane of dissection must be developed posterior to the Gerota's fascia. The takeoff of the main renal artery is completely exposed by using this maneuver [35•, 36••, 39•].

If the location of the injury is more distal, a transperitoneal approach to the aorta (by retracting the small bowel to the right hemiabdomen, the transverse colon in cranial direction, and the descending colon laterally) may be used. At this point, the posterior peritoneum can be incised directly over the anterior aortic surface [35•, 36••]. If more exposure is required, the third and fourth portions of the duodenum can be retracted cephalad, and division of the left renal vein accomplished to implement exposure [35•, 36••].

Thoracic and Lumbar Segmental Artery Injuries Paired small arteries emerging from the posterior aortic surface may be lacerated in cases of retroperitoneal lymphadenectomy. A proper plane must be developed far enough of the aortic surface to ensure a proximal arterial stump in case of complete avulsion. This stump may be ligated or clipped. Otherwise, a primary repair over the aortic wall must be tried, ensuring sufficient mobilization of the aorta before attempting the closing suture. The distal stump commonly retracts deeper in the thickness of the muscular wall making simple repair rather difficult. In cases of incomplete bleeding control, the use of synthetic hemostatic agents (Table 2) may favor complete bleeding control [40].

Iliac Artery Injuries External iliac artery (EIA) prompt control and repair is of utmost importance to prevent complications (ischemia and ischemia-reperfusion injuries) requiring amputation. Primary repair or reanastomosis can be used for small tears or uncomplicated transections, respectively. If the defect is larger, the hypogastric artery may be used as a natural bridge, by ligating its distal end, and anastomosing the proximal end to the refreshed distal cuff of the EIA, or simply by retrieving a hypogastric artery whole section graft to replace the defect. Finally, if reconstruction procedures using the hypogastric artery are deemed unsuitable, vascular surgery should be consulted intraoperatively for bypass reconstruction using prosthetic conduits [41].

The Inferior Vena Cava and Its Branches Bleeding from the IVC is one of the most frightening conditions a surgeon can be involved with. For a small venous tear, simple pressure with a finger usually suffices to decrease the loss of volume. Thereafter, a side-biting (Satinsky) clamp may be applied (partially occluding the IVC) to isolate the defect, and primary repair used to close the orifice with 4-0/5-0 polypropylene sutures [42]. If a clamp cannot be placed in a first instance, proximal and distal compression with gauze sponges around the orifice may result in being useful to decrease bleeding. Alternatively, gentle grasping with Judd-Allis clamps may facilitate the reapproximation of the IVC wall edges, or a Fogarty catheter used to tamponade the vessel cuff by temporary occlusion while maneuvers for control are ongoing.

However, on certain occasions, extensive injuries in the IVC can only be controlled by cross-clamping with DeBakey clamps. If this is the case, simultaneous cross-clamping of the aorta or rapid crystalloid infusion should be used to maintain the cardiac preload. Otherwise, the abrupt decline in cardiac output will induce severe hypoperfusion carrying devastating consequences [43].

Injuries located at the major hepatic veins of the retrohepatic IVC segment will necessitate posterior compression of the right lobe of the liver to minimize blood loss [44]. Thereafter, Pringle maneuver should be applied, and the

Table 2 Commercially available hemostatic agents by category

Category	Name	Description
Passive mechanical agents	Gelfoam (gelatin)	Porcine hydrocolloid: highly absorbent and malleable
	Surgicel (oxidized cellulose)	Cellulose mesh: platelet adhesion, coagulation intrinsic pathway activation, and vasoconstriction
	Collagen	Scaffold: clot formation, platelet activation
	Polysaccharide microspheres	Microspheres: remove water and concentrate platelets and procoagulant factors
Active biologic agents	FloSeal (Thrombin)	Fibrinogen to fibrin conversion (no inhibition by urine). May be used in arterial bleeding
	Tisseel (Fibrin)	Solution of fibrinogen, factor XII, thrombin, and calcium. May be used in arterial bleeding. Risk of immune reaction
Other agents	HemCon	Chitosan-based polymer: red cell aggregation and platelet activation (contraindicated in shellfish allergy)
	Dermabond	Cyanoacrylate: free radical polymerization (cannot be used in mucosa)
	Bioglue	Glutaraldehyde/albumin: can be used in moderate arterial bleeding
	Coseal	Polyethyleneglycol polymerization: fast acting product
	Cyklokapron	Tranexamic acid: blockade of plasminogen and fibrinolysis

surgical team notified for convenient arrangements. Exposure of the retrohepatic segment of the IVC requires liver mobilization. Aggressive volume infusion should start upon liver mobilization maneuvers commence. Liver mobilization begins with the ligation and division of the round ligament in the midline, and followed by taking down the falciform ligament over the anterior aspect of the liver to its major extent. The right lobe may be mobilized medially after incising the right triangular and coronary ligaments. The Kocher maneuver provides additional exposure of the IVC at a level immediately below the liver caudal margin. Once the injury is exposed, reapproximation of venous edges or clamping may be used [35•, 36••, 39•]. The surgeon must change these strategies after one or two direct unsuccessful attempts. A chest or endotracheal tube may be used for atriocaval shunting under these circumstances. Shunting will decrease blood loss by 40–60%, but substantial hemorrhage will continue until complete control of the orifice is obtained [45].

Pringle maneuver, followed by circumferential control of the suprahepatic and infrahepatic-suprarenal IVC may also prevent exsanguination. The suprahepatic IVC can only be accessed by performing a median sternotomy (intrapercardial control), or by incising the central tendon of the diaphragm. With the latter, a gentle sustained traction on the IVC allows the temporary relocation of the intrapercardial IVC inside the abdomen, thus facilitating complete control [39•]. Finally, the infrahepatic IVC may be exposed by using the right visceral rotation maneuver (so-called Cattell-Braasch) [35•, 36••, 39•]. The hepatic flexure and peritoneal reflection along the paracolic gutter have to be taken down. Thereafter, the right colon can be mobilized medially (following a plane anterior to Gerota's fascia). Additional exposure can be obtained by continuing the dissection medially until the root of the mesentery

is reached, and even beyond, if the inferior mesenteric vein is sacrificed [35•, 36••].

Once complete vascular control is gained, a definitive repair can be attempted by using the same principles previously described. Temporary interruption (usually by ligation) of the infrarenal IVC may be appropriate for young patients who are exsanguinating, and in whom a complex repair would be required, but proved unfeasible in such conditions (irreversible shock state) [40, 43].

Portal Injuries Injuries to the portal vein are particularly lethal (50% mortality) due to its posterior location inside the hepatoduodenal ligament [46]. If damage of the portal vein is suspected, the performance of a Pringle maneuver with a vascular clamp is recommended. Digital compression for bleeding control usually suffices until the clamp is placed. Thereafter, the hepatoduodenal ligament must be dissected out. Most injuries in the hepatic artery are amenable to lateral repair, although ligation is commonly well tolerated due to the extensive liver collateral circulation. Portal vein control can be obtained by mobilization of the common bile duct to the left and of the cystic duct in cranial direction, coupled with an extensive Kocher maneuver. If the injury extends beyond the neck of the pancreas distally, it would be necessary to divide the pancreas between non-crushing intestinal clamps [35•, 36••].

If suitable, the best definitive repair for injuries located in the portal vein is probably a lateral venorrhaphy, although more complex repairs have been successfully reported. In cases of severe hypovolemic shock, ligation of the portal vein followed by portosystemic shunt is more appropriate. However, hepatic encephalopathy will indefectively occur [47].

Renal Vein Injuries Left renal vein can be ligated in cases of exsanguinating hemorrhage due to the presence of an extensive collateral network. Conversely, the right renal vein is particularly fragile and lacks this venous collateral network. Therefore, if the right renal vein is injured, the main right renal artery should be approached first. The mobilization of the right kidney (via posterior plane of dissection) provides an excellent exposure of the proximal segment of the main right renal artery [39, 48]. In addition, by doing so, a side-biting clamp can be applied at the confluence of the renal vein and IVC. If a sparing procedure was intended, and venous repair proves to be difficult, a quick kidney excision followed by autotransplantation may become a valid alternative [49].

Iliac Vein Injuries Vascular control of an injury located at the confluence of the common iliac veins may be difficult to obtain. A temporary interruption by division of the right common iliac artery may be required for adequate exposure. Once the injury is definitely repaired, the divided artery is reanastomosed back [41].

The circumferential isolation of the internal iliac vein may result in being challenging, and medial mobilization of the common, external, and proximal internal iliac arteries may be required to gain adequate access for repair. Complete avulsion of the hypogastric vein is usually followed by the retraction of the distal cuff into the posterior wall thickness. If this is the case, the vessel can be delivered back into the operative field using a slender clamp, and thereafter sutured closed [41].

Conclusions

Vascular injuries are occasionally sustained during elective surgical operations. Although serious injuries are relatively rare, they are associated with substantial risk for catastrophic complications and death, posing a formidable challenge even for the most experienced surgeons.

Commonly, the decision-making process following a potential life-threatening intraoperative vascular injury occurs in a very short time frame. Appropriate knowledge of the critical elements to identify the source of bleeding, initiate first-line hemostatic measures, select the ideal candidate for damage control strategies, and perform the indicated operative repairing maneuvers and techniques, have been proved crucial to ensure hemodynamic stability and bleeding cessation. By using the key surgical principles described in the preceding lines, the best performance to counteract the impact of exsanguinating bleeding is ensured.

Compliance with Ethical Standards

Conflict of Interest Javier González, Francisco J. Angulo-Morales, and Enrique Lledó-García each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- Of importance
- Of major importance

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