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Damage Control Surgery for Liver Trauma

Ioannis A. Ziogas, Ioannis Katsaros and Georgios Tsoulfas

Abstract

The liver is one of the most commonly injured organs of the abdomen after major trauma and may lead to the extravasation of major amounts of blood. Damage control surgery (DCS) as a concept exists for over one hundred years but has been more widely optimized and implemented over the past few decades. Minimizing the time from the trauma scene to the hospital and recognizing the patterns of injury and the “lethal triad” (acidosis, hypothermia, coagulopathy) is vital to understand which patients will benefit the most from DCS. Immediate patient resuscitation, massive blood transfusion, and taking the patient to the operating room as soon as possible are the critical initial steps that have been associated with improved outcomes. Bleeding and contamination control should be the priority in this first exploratory laparotomy, while the patient should be transferred to the intensive care unit postoperatively with only temporary abdominal wall closure. Once the patient is stabilized, a second operation should be performed where an anatomic liver resection or other more major procedures may take place, along with permanent closure of the abdominal wall.

Keywords: liver trauma, hypothermia, acidosis, coagulopathy, perihepatic packing

1. Introduction

Despite its well-protected position, the liver is the most frequently affected abdominal organ by blunt or penetrating trauma [1, 2]. Over the past decades, the improvements in the assessment and management of hepatic injury have evolved significantly, thus resulting in better outcomes for affected patients [3]. The majority of such injuries develop following high-energy traffic accidents or violent behaviors [4]. Industrial and farming accidents also consist of a significant percentage of liver trauma. Blunt injuries are the majority of cases in Europe, Australia, and Asia, whereas penetrating injuries (stab and gunshot wounds) are most frequently encountered in North America and South Africa [5, 6].

Blunt trauma, as a result of traffic accident or fall from a height, may lead to deceleration injury due to the inertia of the liver [4]. The affected sites usually involve the attachments to the diaphragm and abdominal wall. These types of injury typically involve the right lobe, especially the posterior segments, and the caudate lobe, while a vascular injury may also be present with the respective hepatic arteries, portal and hepatic veins being affected [4, 7, 8]. The site of connection between inferior vena cava and hepatic veins is vulnerable to blunt traumas and may lead to serious venous injuries and a significant blood loss. Penetrating injuries are more frequently associated with significant vascular injuries at the liver site inflicted [4].

In this chapter, we aimed to describe the classification and appropriate investigations of liver injuries and elaborate on the use of damage control surgery (DCS) in this setting.

2. Liver anatomy

The liver is a wedge-shaped abdominal organ and is located in the right hypochondrium and epigastrium and may extend into the left hypochondrium [9, 10]. It is covered by fibrous Glisson's capsule and is attached to the surrounding structures and the abdominal wall by several ligaments (falciform, coronary, triangular, hepatoduodenal and hepatogastric ligaments). It is divided into two lobes (right and left) by the falciform ligament, while two "accessory" lobes, the caudate and quadrate lobe, arise from the right lobe. The liver has unique double blood supply from the proper hepatic artery (25%) and portal vein (75%). Venous drainage is achieved through hepatic veins (right, middle, left) to the inferior vena cava.

3. Liver functional anatomy – Couinaud classification system

The Couinaud classification is the most widely used classification for functional liver anatomy [11]. It divides the liver into eight functionally independent segments, which have their own individual vascular supply and biliary drainage (**Figure 1**) [12]. A branch of the portal vein, hepatic artery, and bile duct are centrally located in each segment, while the vascular outflow to hepatic veins is located peripherally. Due to their functional independence, each segment can be safely resected without damaging the remaining liver parenchyma [13]. Nevertheless, the Couinaud classification system does not take into account the influence of vascular variations and does not provide liver surface landmarks for segment separation [14].

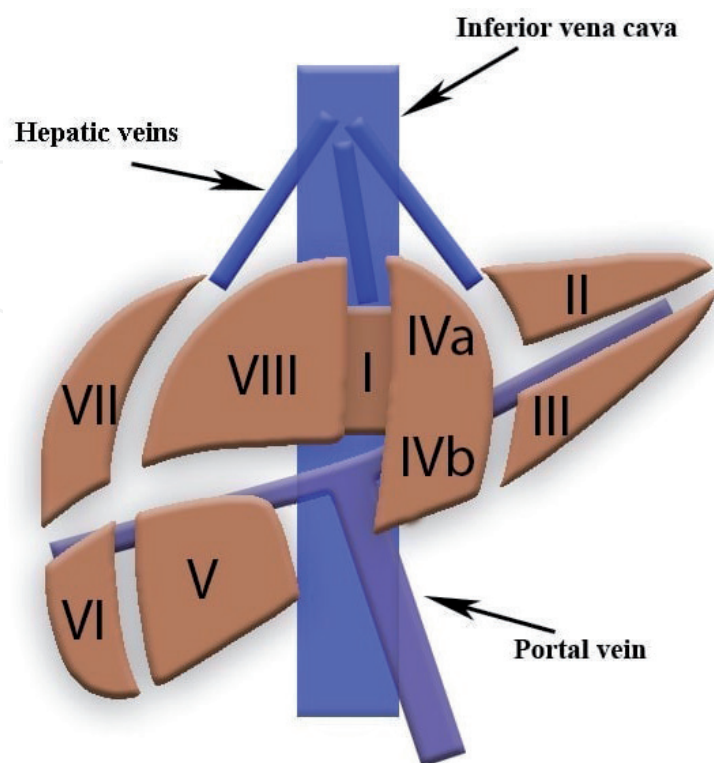


Figure 1.
Liver functional anatomy – Couinaud classification system.

The liver segments are divided by portal vein branches and hepatic veins and are numbered clockwise [12]. The portal vein bifurcates at hepatic hilum into the left and right branches, which separate the liver into upper and lower segments. The right and left lobes are divided by middle hepatic vein, which runs along the Cantlie's line from the inferior vena cava to the gallbladder fossa [15]. Furthermore, the right hepatic vein divides the right lobe into anterior and posterior segments and left hepatic vein divides the left lobe into medial and lateral parts.

The Caudate lobe (segment 1) is located posteriorly and often drains directly to inferior vena cava, while it can be supplied by both the right and the left portal vein branches, while segments II (superiorly) and III (inferiorly) are located medial to the left hepatic vein [16]. Segment IV (quadrate lobe) is located between the left and middle hepatic veins and is further divided by Bismuth into IVa (superiorly) and IVb (inferiorly) [17]. The anterior segments of the right hemiliver, V (inferiorly) and VIII (superiorly) lie between the middle and right hepatic veins, while the posterior right hemiliver segments, VI (inferiorly) and VII (superiorly), are located lateral to the right hepatic vein.

4. Liver trauma classification

The American Association for the Surgery of Trauma (AAST) grading scale is widely utilized for the classification of liver injury severity (**Table 1**) [18, 19]. However, it does not take into consideration the hemodynamic status of patients and the associated injuries. Thus, the World Society of Emergency Surgery (WSES) proposed a novel classification for the proper management of hepatic injuries involving AAST grade (1994 revision), hemodynamic stability, and mechanism of injury (**Table 2**) [2, 20].

Minor (WSES grade I) and moderate (WSES grade II) liver injuries concern hemodynamically stable patients after either blunt or penetrating trauma with AAST grade I-II or III lesions, respectively. Severe hepatic injuries include

AAST grade	Injury description
I	Subcapsular hematoma <10% of surface
	Parenchymal laceration or capsular tear <1 cm depth
II	Subcapsular hematoma 10–50% of surface area; intraparenchymal hematoma, <10 cm diameter
	Parenchymal laceration 1–3 cm in depth or < 10 cm in length
III	Subcapsular hematoma >50% of surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma >10 cm in diameter
	Parenchymal laceration >3 cm in depth
	Any liver vascular injury or active bleeding contained within liver parenchyma
IV	Parenchymal disruption 25–75% of hepatic lobe
	Active bleeding extending beyond the liver parenchyma into the peritoneum
V	Parenchymal disruption >75% of hepatic lobe
	Juxtahepatic venous injury including retroheaptic vena cava and major hepatic veins

Grade is based on highest grade assessment made during imaging, intraoperatively or pathologic specimen. Advance one grade for multiple injuries up to grade III.

Table 1.
 The American Association for the Surgery of Trauma (AAST) liver injury scale (2018 revision).

	WSES grade	AAST grade*	Mechanism of Injury	Hemodynamic status	CT-scan	First-line treatment
MINOR	I	I-II	Blunt/penetrating	Stable	YES + local exploration in stab wounds	NOM + clinical/laboratory/radiological evaluation
MODERATE	II	III	Blunt/penetrating	Stable		
SEVERE	III	IV-V	Blunt/penetrating	Stable		
	IV	I-VI	Blunt/penetrating	Unstable	NO	Surgery

NOM: non-operative management.

**American Association for the Surgery of Trauma (AAST) liver injury scale (1994 revision).*

Table 2.
The World Society of Emergency Surgery (WSES) classification and management of liver trauma.

hemodynamically stable, AAST grade IV-VI lesions following penetrating or blunt trauma (WSES grade III) (**Figure 2**) or any hemodynamically unstable lesion (WSES grade IV).

The importance of the WSES classification and management approach is highlighted by the fact that patients suffering from high-grade AAST lesions, which are hemodynamically stable, can be successfully treated non-operatively [21]. On the contrary, “minor” AAST injuries combined with hemodynamic instability must be treated operatively in order to control the intrabdominal bleeding [20].

5. Initial assessment and investigation

A liver injury should always be suspected in all patients suffering from a blunt or penetrating thoracoabdominal trauma, especially at the right site. Initial management of these patients should be based on the Advanced Trauma Life Support (ATLS) guidelines with fluid resuscitation and close monitoring being the first priorities [22]. Depending on the underlying injury mechanism, other concurrent injuries should also be evaluated and treated accordingly. The management of multi-trauma patients should take into consideration all the affected organs, and a multidisciplinary team is essential for the optimal treatment approach of these patients.

As far as hepatic trauma is concerned, in hemodynamically unstable patients, despite adequate fluid resuscitation, an immediate operation for bleeding control is indicated, whereas in stable patients, an appropriate workup protocol using ultrasonography or computerized tomography scanning (CT) can be followed. Hemodynamic instability is characterized by the following: heart rate > 120 bpm, systolic blood pressure < 90 mmHg, low urine output, increased respiratory rate (>30 respirations/minute), signs of skin vasoconstriction and altered level of consciousness [22]. Non-operative management necessitates medical centers capable of an accurate injury severity diagnosis, intensive management of patients, and prompt access to diagnostic modalities, interventional radiology, operation theater, and blood–blood products [20, 23].

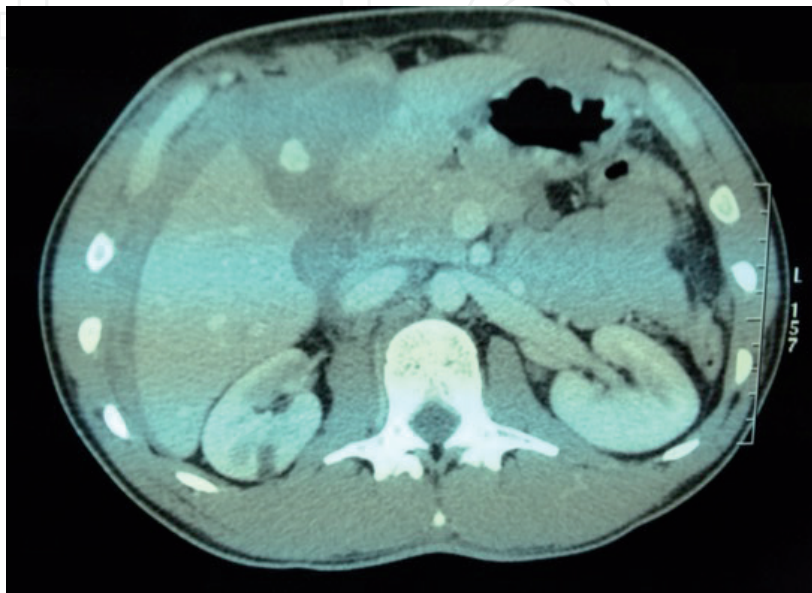


Figure 2.
Computed tomography scan demonstrating a severe liver injury.

Ultrasound plays a significant role in the proper investigation of abdominal injuries. Focused Assessment with Sonography for Trauma (FAST) can be performed immediately at the emergency department and can help assess the pericardium, hepatorenal space (Morison's pouch), perisplenic space and Douglas pouch to identify the presence of free fluid [22]. More detailed ultrasonography by an experienced radiologist is necessary for a more accurate investigation of liver parenchyma. Ultrasonography has widely replaced diagnostic peritoneal lavage (DPL) and has a high specificity of 95–100% [24]. Nevertheless, ultrasound examination is highly operator-dependent and should be performed by experienced clinicians.

Computerized tomography (CT) scan is a valuable tool for the evaluation of stable patients with an abdominal injury [25]. A contrast-enhanced, multi-slice CT scan is reported to have a sensitivity and specificity of over 95% for detecting liver injuries [26, 27]. Subscapular and intraparenchymal hematomas, lacerations, and vascular injuries can be recognized. Furthermore, an active hemorrhage can be visualized as an extravasation of contrast medium. A CT scan can also successfully elucidate other abdominal injuries involving the spleen, kidneys, and bowel [26]. Finally, a follow-up CT scan can be utilized for the detection of delayed liver injury complications, including delayed hemorrhage, bile leak, biloma, arteriovenous malformations, and liver abscesses [4, 28].

6. Damage control surgery - general

Damage control surgery refers to the immediate steps taken in order to reduce blood loss, the risk of sepsis, morbidity, and mortality instead of a thorough patient workup in the intensive care unit (ICU) [29]. DCS has significantly improved the outcomes of patients presenting at the hospital with severe organ injuries, including liver injuries, and hemodynamic instability due to maneuvers to control the bleeding [1]. Uncontrolled bleeding can lead to coagulopathy secondary to the dilution and depletion of the coagulation factors, hypothermia, and acidosis, the so-called “lethal triad” or “medical bleeding” [21]. The onset of this series of events may necessitate the need for DCS, including temporary (perihepatic) packing of the bleeding sites, where physiological recovery is prioritized over anatomical repair [30].

7. Damage control surgery – history

The earliest report on perihepatic packing to prevent uncontrolled bleeding from injuries to the liver dates back to 1908 by James Pringle [31], while later in 1913, Halstead described the use of a rubber sheet between the injured liver and the gauze packs [32]. Despite the improvements in outcomes, perihepatic packing was sparsely described in the literature [33] until Stone et al. [34] reported a survival rate of 76% in patients managed with “truncated laparotomy” compared to 7% in patients managed with definitive surgical repair. Rotondo et al. [35] introduced the term “damage control laparotomy” and demonstrated that this approach could improve survival in hemorrhaging trauma patients (requiring transfusion of >10 units of packed red blood cells) with multiple visceral penetrating injuries and major vessel injuries. The authors described the three steps of their approach, and the same research group later modified it by introducing a fourth pre-operative phase (**Table 3**) [36]. Since then, DCS has been successfully implemented for the management of major liver injury with optimal outcomes. The use of angioembolization in more recent series has been proposed as the logical augmentation

Damage control (DC) Phase	Description
DC0	<ul style="list-style-type: none"> • Truncated scene times • Recognition of injury pattern • Immediate blood component replacement • Rewarming maneuvers
DCI	<ul style="list-style-type: none"> • Once in the operating room • Immediate exploratory laparotomy • Rapid bleeding and contamination control • Abdominal packing • Temporary wound closure
DCII	<ul style="list-style-type: none"> • Once in the intensive care unit • Physiological and biochemical stabilization • Thorough tertiary examination to identify all injuries
DCIII	<ul style="list-style-type: none"> • Once physiology is normalized • Re-exploration in operating room • Definitive repair of all injuries • May require multiple visits to the operating room if multiple systems are injured

Table 3.
The four Phases of damage control for exsanguinating penetrating abdominal injury by Johnson et al.

of damage control approaches to control bleeding, but particularly in the case of high-grade injuries, it may lead to major hepatic necrosis [37].

8. Damage control surgery – indications

As mentioned earlier, DCS can play a vital role in the setting of the “lethal triad” and thus metabolic acidosis (pH <7.2), hypothermia (<34°C), and coagulopathy (prolonged activated partial thromboplastin time and prothrombin time > two times normal) constitute absolute indications for DCS. Uncontrolled major intra-abdominal bleeding, association with extra-abdominal injury, >10 units of blood transfusion, and hemodynamic instability (low blood pressure and tachycardia) are relative indications for DCS [29].

9. Damage control surgery – phases

9.1 Damage control phase 0 (DC0)

DC0 constitutes the first phase of the DCS process and takes place in the pre-hospital setting and in the emergency room. The most crucial aspects of this phase are injury pattern recognition in order to determine which patients will most likely benefit from DCS according to the absolute and relative indications, and the “scoop and run” concept to truncate scene times. The administration of blood products and tranexamic acid in the pre-hospital setting has been increasingly used [38, 39]. Given the significant improvements in trauma resuscitation strategies aiming at rapid bleeding control, management of coagulopathy, and diversion away from the over-resuscitation with crystalloids, the use of DCS may be required to a lesser extent in the future [40–42]. There is a growing body of evidence that the use of a high plasma to packed red blood cell ratio can lead to a decrease in hemorrhage-related mortality [43]. French lyophilized plasma – manufactured by the French Military

Blood Institute – is a universal therapeutic viro-inactivated plasma that can be reconstituted in <6 min at the point-of-care and is compatible with any blood type [44]. Data suggest that French lyophilized plasma can be used more rapidly correct for the trauma-induced coagulopathy compared to fresh frozen plasma, particularly in the military setting [45]. Its role against normal saline in the management of post-traumatic coagulopathy prevention and correction in the pre-hospital civilian setting is currently under investigation (PREHO-PLYO study) [46], and it is awaited to revolutionize the current state of practice for the management of severe trauma, including liver injury.

Once the patients reach the emergency room, immediate assessment by the trauma team and damage control resuscitation is vital. The surgical and critical care teams should strive towards obtaining vascular access with two large-bore catheters, inserting nasogastric tube and urinary catheter (unless there is blood at the urethral meatus, high riding prostate or prevalent perineal hematoma), rapid induction of anesthesia, drainage of the chest (if needed), intravenous broad-spectrum antibiotics and tetanus prophylaxis (if indicated), rapid rewarming and prevention of further hypothermia, and expedited transport to the operating room for DCS [30].

9.2 Damage control phase I (DCI)

DCI starts with the exploratory laparotomy, which aims to control bleeding and limit contamination, and ends with the temporary closure of the abdominal wall. After the patient is positioned in a “cruciform” lie, the patient is prepped from chin to mid-thighs and a vertical midline incision from the xiphoid process to the pubic symphysis is made [30]. If the suspicion for a severe fracture of the pelvis is high, the incision should be limited just below the umbilicus to facilitate continuous tamponade of the suspected pelvic hematoma. If the patient is unstable, the incision should not be delayed if arterial or venous lines are not in place; these can be inserted during the operation.

If the observed intra-abdominal bleeding is not considered to be major, compression on its own or the use of topical hemostatic agents, bipolar devices or electrocautery, argon beam coagulation, omental patching or even simple suturing of the liver parenchyma may be adequate to control the hemorrhage [2, 20, 47–49]. In the case of massive intra-abdominal hemorrhage, more aggressive maneuvers should be adopted, including perihepatic packing and manual compression, or even hepatic vascular isolation (i.e., intrahepatic balloon tamponade) [50, 51]. Injuries to the portal vein should be primarily repaired, while ligation of the portal vein should be considered only as an alternative – provided that the proper hepatic artery is intact – due to the increased risk of hepatic necrosis or massive intestinal edema [47]. Data suggest preferring liver packing or resection over portal vein ligation if only lobar or segmental branches of the portal vein are injured [2, 47, 52]. However, portal vein ligation is safer than arterial ligation regarding biliary complications or hepatic necrosis, and may even prepare the liver for staged extended liver resection [53]. If the surgeon comes across a proper hepatic artery injury, they should shoot for a primary repair; otherwise, selective hepatic artery ligation should be preferred, and if the common or right hepatic artery is to be ligated, cholecystectomy should follow to prevent gallbladder necrosis [1, 52]. When arterial control or the Pringle maneuver is inadequate to control the hemorrhage, the surgeon should suspect that there might be an aberrant hepatic artery [47]. If the bleeding arises from the area behind the liver, the injury is most likely to be found on the hepatic or retro-hepatic caval vein [2, 47, 54]. Inserting vascular shunts (i.e., atrio-caval shunt) might also be useful to control hemorrhage [29, 47]. In case of persistent

bleeding and hemodynamic instability, resuscitative endovascular balloon occlusion of the aorta in the zone I and of the vena cava at the level of the retro-hepatic vena cava can serve as a bridge to more definitive procedures [47]. Liver resection should be avoided at this phase, but if absolutely necessary, non-anatomic resections should be preferred [2, 47, 48, 52], while resection of a hemorrhaging spleen or kidney can be performed, if needed in order to stop the bleeding [29]. Angioembolization should be advocated for either stable patients after the initial surgical hemostatic attempt or adjunctively in case of suspected uncontrolled bleeding despite the surgical hemostatic attempt [2, 47, 55]; data also suggest that its routine implementation immediately after DCS can significantly improve survival in grade IV or V liver injury [56]. Regarding contamination control, intrahepatic abscesses can be managed with percutaneous drainage, and bilomas may either resolve spontaneously or should also be managed with percutaneous drainage potentially with adjunct therapeutic endoscopic retrograde cholangiopancreatography and stent placement [47]. Abdominal wall closure is the final step before transitioning to DCII (transfer to the ICU) and should be only temporary without fascial closure to avoid abdominal compartment syndrome [30].

9.3 Damage control phase II (DCII)

DCII involves taking the patient to the ICU postoperatively, where the goal is to restore the biochemical and physiological derangements. Managing fluid administration to bring the patient back to hemodynamic stability is often achieved through invasive monitoring (i.e., transthoracic echocardiography, transesophageal Doppler, pulmonary artery catheterization, etc.) [30]. Securing adequate oxygenation and aggressive rewarming of the patient are also necessary. The management of coagulopathy is crucial for survival, and the use of rotational thromboelastometry and other tests to assess how the coagulation cascade works along with massive blood transfusion practices have led to an improvement in outcomes and a decrease in blood transfusion requirements [30, 57]. Prevention of potentially fatal complications commonly seen in the ICU, including infection, adult respiratory distress syndrome, and deep vein thrombosis, is also important for patient survival [29]. This is the perfect opportunity for treating physicians to perform a complete reassessment of the patient and a “tertiary survey”, including imaging studies that may help identify previously unknown injuries.

9.4 Damage control phase III (DCIII)

DCIII involves definite repair of the injuries once the patient is stabilized and has returned to his “physiologic normality” and commonly takes place within 24–72 hours after admission to the ICU. The patient is taken back to the operating room for re-exploration and packing removal (preferably after 48 hours) [21]. That is also the stage when an anatomic liver resection may be performed (**Figure 3**), along with the removal of devitalized tissue or vascular shunts, anastomosis of vessels or bowel, or even a feeding jejunostomy. The phase ends with the permanent closure of the abdominal wall. This should be performed with the approximation of the fascial edges if gentle adduction permits; if this is not possible due to retroperitoneal or bowel wall edema, then the abdominal wall should be again only temporarily closed with the fascia left open. In that scenario, the patient is taken back to the ICU and provided the patient is hemodynamically stable, administration of diuretics to decrease the bowel edema should be considered [30]. This situation should then be managed with washouts and re-inspection of the abdomen regularly, while primary closure should be completed within seven days, particularly in the absence of signs

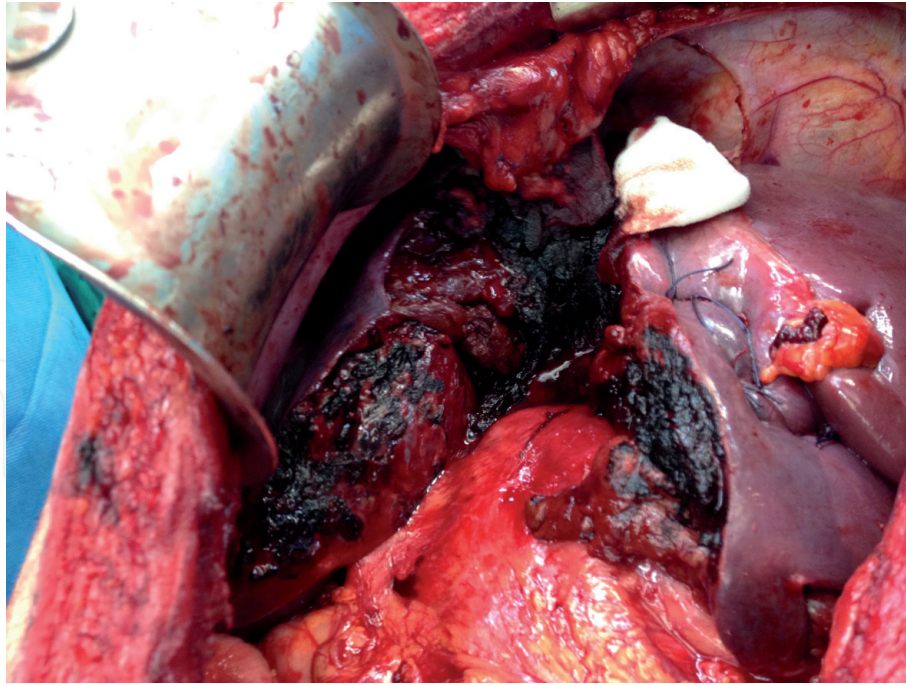


Figure 3.
Surgical management of severe liver injury with active bleeding.

of infection. Other abdominal closure alternatives should be considered if this is not possible. This will lead to a large ventral hernia that will require repair at some future time point [30].

10. Conclusion

Immediate resuscitation and DCS play a critical role in the outcomes of trauma patients in general, and particularly in those with severe liver injuries where the exsanguination of large amounts of blood is common. The decrease in the time from the scene to hospital and taking, the implementation of massive transfusion protocols, and the improvements in the approaches to control bleeding and contamination intraoperatively by leaving major resections for a later phase have revolutionized the outcomes after liver trauma over the past decades. The advents of pre-hospital care are awaited to change the need for DCS in the future.

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