Vol 5 | Issue 1 | Pages 67-76

Journal of Gastrointestinal and Hepatic Surgery
ISSN: 2689-8721

Review Article

DOI: 10.36959/879/385

Liver Trauma: Review of Management, and Patient Outcomes at Our Major Trauma Centre

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Introduction

"Whenever you encounter massive bleeding, the first thing to remember is that it is not your blood..."

Raphael Adar

The liver is the largest solid organ in the body, has two blood supplies and performs around 500 functions. It has an unrivalled capacity to regenerate in response to injury - a feature described in Greek mythology and one that has evolved in response to damage from the very toxins it is meant to clear. Its complexity however, can also be its downfall. It is one of the only organs whose functions cannot be artificially replicated and for this reason liver failure is often a fatal event. In spite of residing under the right costal margin, it is the most frequently injured organ during abdominal trauma [1,2] and despite advances in non-operative management [1,3,4], uncontrolled haemorrhage and delayed complications are associated with a mortality rate of 10-15%.

Over the past 40 years, there has been a shift from invasive operative management of liver trauma to a more "conservative" approach. This was driven largely by a rapid improvement in imaging techniques and the emergent use of CT scanners, which permitted the non-invasive serial assessment of trauma patients and their injuries [5,6].

The introduction of transarterial angioembolization in the 1970's offered a potential viable option for the treatment of acute arterial hepatic haemorrhage [7,8] and became the mainstay of therapeutic intervention in patients with hemodynamic stability by the late 90's [9-12]. Despite undoubtedly saving lives, the selection of patients for non-operative management is critical, not only because some have questioned its overuse [13] but also because failure and the subsequent need for surgery leads to a higher mortality rate [4].

The aim of this review is to discuss the management of hepatic trauma and associated vascular injuries from the perspective of one Europe's most active hepatobiliary and liver transplant centres. We will discuss how anatomical and physiological factors impact upon these injuries and discuss how lessons learnt from liver surgery and transplantation can improve the management of traumatic liver injury.

Applied Anatomy

The adult liver weighs approximately 2% of body weight and resides in the right upper quadrant under the diaphragm behind the costal margin and extends into the left upper abdomen. The superior surface is percussed as high as the 5th intercostal space - an important factor when dealing with blunt or penetrating trauma to the right hemithorax. The antero-inferior border is normally palpated on deep inspiration below the costal margin. The gallbladder is attached to the inferior surface, which in turn is closely related to the hepatic flexure and transverse colon, right kidney and adrenal gland, duodenum, pancreas and stomach. Also on the inferior surface, the inflow to the liver enters through the porta hepatis. The common hepatic artery from the coeliac trunk gives rise to the gastroduodenal artery and continues as the hepatic artery proper passing anteriorly over the portal vein and to the left of the common bile duct. These three main structures lie in the free edge of the lesser omentum behind which is the opening of the lesser sac. At the level of the hilum, the hepatic artery divides into right and left branches that run alongside the right and left branches of the portal vein. Atypical vascular anatomy is however common. Michels described 10 main variations in hepatic arterial supply based on the dissection of 200 cadaveric donors [14]. The most common include a middle hepatic artery arising from either the right or left hepatic (55%), a left hepatic arising from the left gastric artery (20%) and the right hepatic arising from the superior mesenteric artery (20%). Within a 10 cm^2 area, the coeliac trunk and its branches, portal vein, IVC, pancreaticoduodenal arcade, superior mesenteric vessels and right renal pedicle converge. Trauma to this area can therefore be catastrophic. Vascular anatomy is important when considering the intervention of radiologists and will be discussed later.

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Accepted: November 07, 2022

Published online: November 09, 2022

Citation: Laing RW, Edwards M, Faulkner T, et al. (2022) Liver Trauma: Review of Management, and Patient Outcomes at Our Major Trauma Centre. J Gastrointest Hepat Surg 5(1):67-76

The liver can be divided into 8 "Couinaud" segments [15]. The right lobe (segments 5-8) is usually 20% larger than the left (segments 1--4) although this can vary. The liver is anchored in the abdominal cavity by several peritoneal attachments and reflections that form 'ligaments'. The falciform ligament, the free-edge of which contains the ligamentum teres (the obliterated umbilical vein), attaches the anterosuperior surface of liver to the anterior abdominal wall and diaphragm. The liver is attached to the diaphragm posteriorly by two reflections of peritoneum, the anterior and posterior coronary ligaments which converge laterally to form the right and left triangular ligaments. In the centre of these points of attachment (posteriorly and to the right of the IVC) is the bare area of the liver - the only surface without a covering of peritoneum. There are also attachments to the right kidney, lesser curvature of the stomach and the first part of the duodenum.

Mechanisms of Injury

The relevance of these attachments is evident when considering the two principal mechanisms of blunt trauma, deceleration and crush injuries. The former occur in falls from height or road traffic collisions when high energy transfer causes movement of the liver relative to its diaphragmatic attachments [16]. This mechanism can produce lacerations in the hepatic parenchyma, most commonly between the right posterior section (segments 6 and 7) and the right anterior section (segments 5 and 8) and can also involve hepatic veins and the juxtahepatic vena cava. In contrast, crush injuries typically damage the central portion of the liver (segments 4, 5 and 8 - see Figure 1) or compress the liver between the lower ribs and spine injuring the caudate lobe (segment 1). Blunt trauma can also rupture the liver's capsule leading to haematoma formation.

Penetrating trauma is less common in the UK and Western Europe than in other countries such as the United States or South Africa [17-20]. Knife and gunshot wounds are the predominate cause, the latter of which create the greatest degree of parenchymal damage due to cavitation.

Classification of Liver Injury

The severity of liver trauma ranges from a minor capsular tear without parenchymal injury to hepatic avulsion. The American Association for the Surgery of Trauma adopted the classification of liver injury originally described in 1989 by Moore, et al. which was revised in 1994 (Table 1 and Table 2) [21,22]. For the purposes of this review, injuries have been divided into lacerations, haematomas and vascular injuries. The grade is usually calculated using information derived from imaging, operative findings or post-mortem. Multiple liver injuries warrant an increase of classification by one grade.

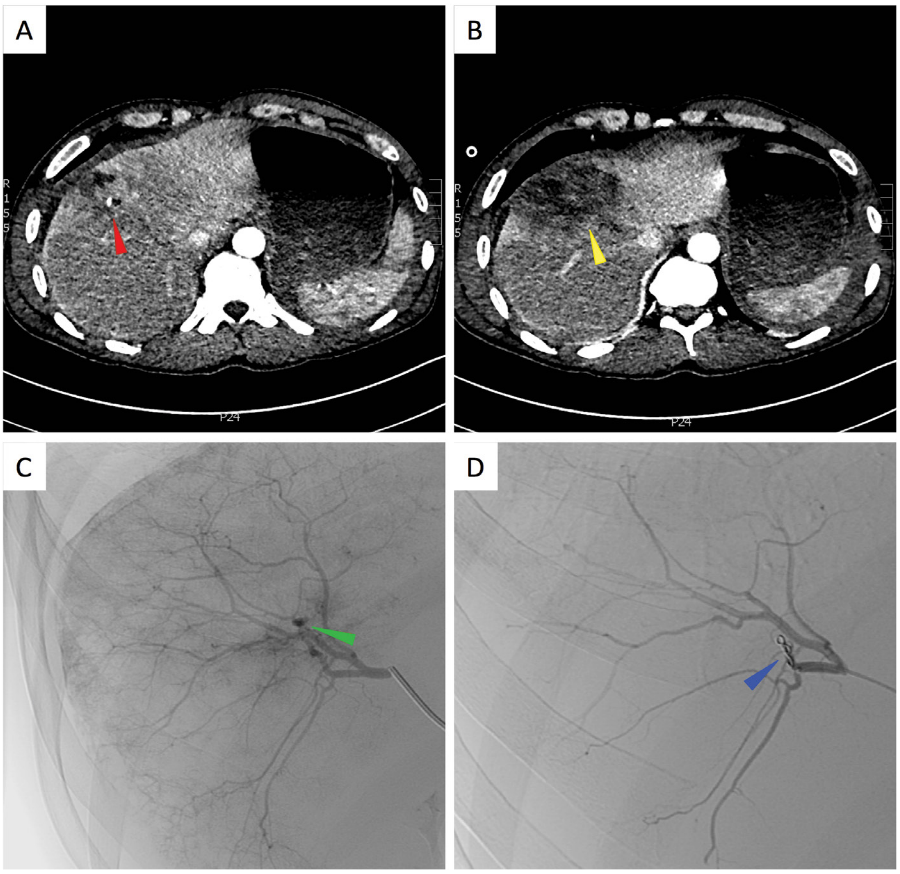

Figure 1: A and B are abdominal CT images of a 47-year-old pedestrian who was struck by a car. He sustained an AAST Grade IV liver injury involving lobes IVa and VIII (yellow arrow). A blush of contrast on the arterial phase was suggestive of active bleeding. The patient underwent hepatic angiography and selective embolisation (C and D) of a pseudoaneurysm (green arrow) using gelfoam and two 2 × 5 mm Vortex coils. He remained stable following the procedure and did not require surgical intervention.

Table 1: Classification of liver injury (adapted from the American Association for the Surgery of Trauma (AAST) guidelines [22].

Grade	Laceration	Haematoma	Vascular Injury
I	**Capsular tear** • < 1 cm depth	**Sub-capsular** • < 10% surface area	
II	**Intra-parenchymal** • < 10 cm diameter • 1-3 cm depth • < 10 cm length	**Sub-capsular** • 10-50% of surface area	
III	**Intra-parenchymal** • > 3 cm depth	**Sub-capsular** • 50% surface area/expanding • ruptured **Intra-parenchymal** • 10 cm/expanding • ruptured	
IV	**Parenchymal disruption** • 25-75% of hepatic lobe • 1-3 Couinaud segments within a single lobe		
V	**Parenchymal disruption** • 75% of hepatic lobe • > 3 Couinaud segments within a single lobe		**Juxta-hepatic venous injuries** • retro-hepatic cava • major hepatic veins
VI			**Hepatic avulsion**

Table 2: Key points.

• 80% of liver trauma is minor and can be managed conservatively
• Independent risk factors for failure of non-operative management include; • Patient age • Need for blood products • Active haemorrhage on CT
• Trauma patients who develop hypothermia require more blood products and have a higher mortality rate.
• Angioembolisation is effective in up to 90% of cases.
• TEG and ROTEM can provide quick identification of bleeding due to trauma-induced coagulopathy (TIC) or hyperfibrinolysis (excessive clot lysis).
• Operative management is usually indicated in patients where initial resuscitation attempts have been futile and interventional radiological management is not available or appropriate.

Grades I and II represent 80-90% of cases and are usually managed conservatively [13]. Grades III to V may require surgical intervention, while grade VI injuries are regarded as fatal.

Initial Management and Triage of Patients

All patients who sustain trauma should be managed according to advanced trauma life support (ATLS) guidelines in an attempt to stabilise them prior to safely ascertaining the degree of injury suffered. Assuming the patient has suffered injury to their liver, it should be remembered that 80% of these cases are minor and can be managed non-operatively [1,23]. Action however, can be taken by clinicians when managing all patients with liver trauma, regardless of the likely course of management, which can reduce the risk of deterioration.

The liver receives 30% of cardiac output and therefore significant blood loss can ensue. Poorly managed haemorrhagic shock can trigger the lethal triad of progressive metabolic acidosis, coagulopathy and hypothermia, promptly followed by circulatory and multi-organ failure. Initial management of patients with the possibility of liver trauma and those who are actively bleeding should involve the definitive control of airway and ventilation which expedites safe transfer to CT and onward to possible angiography or the operating theatre, secure vascular access that permits rapid infusion and order blood products according to local protocols for massive haemorrhage. ATLS guidelines state that immediate infusion with up to 2 L of crystalloid should take place during the initial phases of assessment. Repeated administration of crystalloid to maintain blood pressure in haemorrhagic shock [24-26] should be avoided as excessive use can dilute the haematocrit and clotting factors which exacerbates bleeding prior to definitive control [27-29]. Cannon was the first to describe the deliberate hypotensive resuscitation of patients with abdominal trauma because, in his words, prior to definitive control "blood that is sorely needed may be lost" [30]. Since then, many have shown his sentiments were correct and permissive hypotension in conjunction with haemostatic resuscitation has been shown to improve survival in animal and human models of abdominal trauma with uncontrolled haemorrhage [31-34]. Fluid resuscitation therefore should be initiated to maintain a systolic blood pressure of close to 80 mmHg and given concerns over use of crystalloids, unstable patients should be resuscitated with a "whole blood" regime i.e. equal volumes of packed red cells, fresh frozen plasma and platelets. Plasma is generally required after loss of 30-40% of circulating volume (1.5-2 L) and platelets will be required shortly after. Rapid transfusion of blood products can trigger hypocalcaemia due to citrate toxicity and hyperkalaemia can occur as a result of release from lysed RBCs and ongoing metabolic acidosis. Fibrinogen levels should also be checked and cryoprecipitate administered as required. Hypothermia reduces platelet function, clotting cascade enzyme activity and induce fibronolysis [35,36]. Trauma patients who develop hypothermia require more blood products and have a higher mortality rate [37] - techniques such as the use of re-warming blankets and heat exchange rapid infusion pumps should therefore be employed to prevent patients developing it [38,39].

Computerised Tomography (CT)

If a patient with suspected liver injury can be stabilised, they should be transferred to CT to undergo assessment of the injury [40,41]. Triple phase multi-slice CT can identify vascular injury, differentiate source (arterial, portal venous, venous) and has a reported sensitivity and specificity of 92-97% and 98.7% respectively [42]. Multi-plane reconstruction can also be performed to aide radiologist and surgeon. In addition to being able to categorise the injury, CT can be used to estimate volume of haemoperitoneum, localise the original source by pinpointing the "sentinel clot" [43] and even detect active extravasation [44]. The latter is a strong predictor of failure of non-operative management [45,46]. Haemoperitoneum volume has been used as a predictor of need for laparotomy [47-49] however due to discrepancies between CT and operative findings [50] and improvements in non-operative management, more onus is now on the haemodynamic stability of the patient. Concomitant injuries can also be identified on CT and would increase the likelihood of failure of a conservative approach [51]. Monitoring of liver injuries using serial CT's is controversial but is generally only recommended in grade IV or V injuries 7-10 days post injury [52] or when clinical signs dictate repeat investigations [53]. Figures 1A and Figure 1B show arterial phase CT images from a 47-year-old man who was hit by a car. The patient sustained a Grade IV injury of segments VIII and IVa with a blush of arterial contrast suggestive of active bleeding.

Non-Operative Management

Protocols can help categorise those patients who can be managed non-operatively [54]. The criteria for identifying suitable candidates for non-operative management are, however, constantly changing [55]. The evolution has been driven by several factors; the improvements in outcome observed following use of non-operative management in the paediatric population [56-58], the fact spontaneous hemostasis occurs in approximately 50% of patients, the liver's tremendous capacity to regenerate and the vast improvements in radiological modalities. This approach has not only improved outcomes in patients with grade III and IV injuries by up to 23.5% [59] but it has even been used effectively in certain patients with penetrating liver trauma [60,61]. Important criteria include haemodynamic stability after resuscitation, absence of signs of visceral or retroperitoneal injuries that necessitate surgery, and the presence of a multidisciplinary team that are experienced in dealing with liver trauma [17,47,62-67]. It is true that the failure rate of non-operative management is higher in those patients with injuries grade IV or worse [68]. The need however, for surgical intervention is rarely due to complications arising from the liver injury such as delayed haemorrhage, it is usually due to a collateral injury to the spleen or kidney [51]. Independent risk factors for failure on non-operative management include patient age, the need for blood products and active haemorrhage on CT [23,51,69]. Patients with grade IV injuries or worse should be followed up closely using CT to detect any evidence of secondary complications or re-bleeding that may require surgical or radiological intervention [70].

Interventional Radiology in Liver Trauma

A crucial adjunct in the management of patients is radiological intervention [71]. Angiography for liver trauma was first described in 1973 [72,73] with subsequent selective arterial embolization in 1977 [74]. Poletti, et al. developed CT-based criteria including; injury grade, presence of arterial injury or pseudoaneurysm and venous involvement to select patients who should undergo angiography with or without embolization [75]. Angioembolisation has many advantages; it is minimally invasive, it can reach vessels that are difficult to access surgically [76], it is effective in up to 90% of cases [77,78], has a low risk of re-bleeding and can be used in addition to surgical intervention either before or after surgery [79-81]. Johnson, et al. went further and argued that hepatic angiography should be used in all patients following damage-control laparotomy and packing for high grade injuries (> grade III) [82].

Liver-related techniques used in the trauma setting include; hepatic artery embolization or infusion, and portal or systemic vein embolization. Arterial bleeding can cause haemobilia, haematoma or haemoperitoneum and can be difficult to manage surgically due to the rich collateral supply within the liver. Once the source is identified, selective catheterisation and vessel isolation using a coaxial catheter can isolate the vessel prior to embolization using prothrombotic metal coils. Gaining proximal and distal control, the so-called "sandwich technique", overcomes the problem of distal reconstitution due to collateral supply. Crossing the injury can be difficult in cases of vessel transection but is easier when isolating a traumatic pseudoaneurysm. Larger vessels usually require coils whereas particles, gelatin sponge or microcoils can be used for smaller vessels [83]. Complications after transcatheter arterial embolization (TAE) include fever, delayed haemorrhage, hepatic necrosis, sepsis, and biliary fistula detected either by CT or ultrasound [84,85]. Figures 1B and Figure 1C show selective images of the embolization procedure carried out in the patient previously described. A pseudoaneurysm was identified and the vessel embolised using gelfoam and coils.

Anaesthetic Management

If surgery is required, the patient will require a general anaesthetic with tracheal intubation and appropriate wide bored intra venous access. The theatre should have a rapid infusor including both a blood warming and cell salvage system as per the current Royal College of Anaesthetists guidelines [86]. In view of likely delayed gastric motility due to the recent trauma, rapid sequence induction (RSI) or modified RSI is recommended.

Invasive arterial monitoring enables better haemodynamic control and monitoring of peri-operative permissive hypotension and allows regular blood sampling. Central venous access is important for both central venous pressure (CVP) measurement and vasopressor/inotrope infusions but also large wide bored access can be established through the placement of a Swann sheath. Cardiac output monitoring is advised especially for patients with a past medical history of cardiovascular disease where trans-oesophageal echocardiography, pulmonary artery catheterization and arterial waveform based techniques have all been described. Placement of a nasogastric tube enables gastric drainage and post-operative enteral feeding if required. A urinary catheter is needed to assess urine output and aid in fluid resuscitation and maintenance of renal function. Temperature monitoring is essential as active warming of trauma patients reduces the risk of trauma induced coagulopathy and a core temperature of > 36.0 °C is advised [87]. Blood components should be warmed to at least 37.0 °C using an infusor. Permissive hypotensive haemostatic resuscitation (with limited crystalloid use) and ratio-based blood product administration should be implemented [88,89].

Near testing of arterial blood gases for Hb, lactate, base excess, calcium, potassium should be carried out to help guide resuscitation and peri-operative management. Blood sugar should also be closely monitored as massive liver trauma may disrupt glucose metabolism. A Clauss fibrinogen measurement is also important as it is more sensitive in predicting developing coagulopathy in trauma patients than prothrombin time and activated plasminogen TT. Fibrinogen can be replaced using either FFP or cryoprecipitate however fibrinogen concentrate administration is currently not licensed for use in trauma in the UK.

Point of care tests including thromboelastography (TEG) or rotational thromboelastometry (ROTEM) assess *in vitro* clot formation and stability, and are used in both liver transplant anaesthesia and in patients with major trauma. They can provide quick identification of bleeding due to trauma-induced coagulopathy (TIC) or hyperfibrinolysis (excessive clot lysis) which can result from massive transfusion in trauma patients [90,91]. Recent observational studies have shown that goal-directed therapy via TEG leads to decrease in use of blood products [92,93].

The CRASH-2 trial examined the use of tranexamic acid (TXA) in trauma patients and demonstrated that early use (< 3 hours since trauma occurred) of TXA reduced all-cause mortality without increasing the risk of vascular occlusive events [94]. Despite this result, several issues were associated with the trial. Only 5% of the patients died because of bleeding. It had no effect of the need for surgical intervention or blood transfusion. The MATTER study (Military Application of Tranexamic Acid for Trauma Emergency Resuscitation), was more focussed and evaluated military trauma patients who needed at least one unit of blood [95]. The relative reduction in mortality was 6.7% and those who received TXA required fewer blood products. In the CRASH-2 trial TXA patients received the same amount of blood as those who did not receive the drug. TXA administration for patients with isolated liver trauma has not been investigated, however due to the safety profile and cost-effectiveness of TXA, its early use in trauma patients has been widely adopted and is also used in selective liver transplant recipients with coagulopathy.

Operative Management

Detailed management strategies are beyond the scope of this paper, however there are several ways to approach the surgical management of liver trauma. Operative management is usually indicated in patients where initial resuscitation attempts have been futile and interventional radiological management is not available or appropriate. In an ideal world, patients such as this should undergo surgery in a specialist centre with multidisciplinary teams with experience in complex HPB surgery, but in reality is that this is not always the case. Patients who require surgery are often those in dire need and transfer to such a centre is often not possible. In this scenario the job of the surgical team is to control the bleeding without causing further complications. A compromise includes specialist on call liver surgeons travelling to non-specialist hospitals; a practice that has been used successfully in our centre.

The initial approach should be a long midline laparotomy which permits extension into the chest if required, blood and clots should be removed and all 4 quadrants of the abdomen should be packed. At this point the anaesthetist should be given time to attempt to resuscitate the patient with blood products in order to minimise the progression of the 'lethal triad' which will only lead to deterioration of the clinical scenario. The lower quadrant packs should be removed to check the bowel for enterotomies which should be quickly controlled. The spleen should be examined next and removed if damaged. The right upper quadrant packs can finally be removed to assess the degree of liver injury. Most minor bleeds or lacerations can be reduced by returning the liver lobes to their anatomical position i.e. towards the midline. Any manoeuvre that further distracts the injured lobe will only exacerbate bleeding. The assistant can maintain this compression whilst bringing the liver up towards the diaphragm.

If bleeding continues, compression of the structures in the free edge of the lesser omentum - a Pringle manoeuvre (either with the fingers or with an atraumatic vascular clamp whilst being careful not to damage the common bile duct) - can help decrease blood loss by reducing inflow. Under normal circumstances, a liver can tolerate such occlusion for up to 1 hour, however in trauma the prolonged ischemia may propagate the parenchymal damage. Equally, the resulting decrease in cardiac output of up to 10% and increase in left ventricular afterload of 20-30% in an otherwise unstable trauma patient may cause cardiovascular compromise [96]. If haemorrhage continues despite inflow occlusion, hepatic vein or vena cava injury should be suspected and hepatic outflow control may also be required. Total hepatic vascular occlusion would require control of both the infrahepatic and suprahepatic vena cava and even if this is achieved by an experienced surgeon, the 60% reduction in cardiac output would be poorly tolerated by the liver and the patient.

Peri-hepatic packing may be the most appropriate management option if compression has been successful, but must be done well to be effective without causing further complications such as failure to control haemorrhage, renal vein compression or abdominal compartment syndrome [97]. If available, caval pressure monitoring can be employed to allay fears. The technique should aim to mimic the actions of the assistant, bringing the parenchyma together using sequential dry packs and compressing the injury itself to tamponade the bleeding. Patients should return to theatre after 48 hours for pack removal and injury reassessment [98].

If bleeding continues despite manual compression of the injury, surgical haemostasis may be required. Haemostatic agents such as thrombin or fibrin aggregates can be useful adjuncts and the argon beam coagulator has advantage over diathermy of not sticking to the liver tissue. Liver sutures can be used to approximate the ruptured parenchyma. Sutures should be large diameter round bodied needles and gentle tension will be enough to treat the majority of haemorrhage. Due to the risks of cavitating haematomas, re-bleeding, bile leaks and ischaemia, the injury should be explored, however, wherever possible to identify the source of bleeding to enable definitive haemostasis and to rule out other issues that would otherwise need attention.

Resectional debridement, the removal of tissue along the demarcated lines of injury, is best performed at the re-look after initial packing. Anatomical resection as a primary procedure is not usually performed due to difficulties that can arise in the presence of coagulopathy, shock and coexistent visceral injury. It may be necessary however in cases that involve significant devascularisation, major venous injury or shattered parenchyma and as with most complex surgical approaches, the best results are obtained in high-volume centres with experienced teams [99-101].

Total hepatectomy and liver transplantation for trauma, either at the time of initial surgery or due to subsequent liver failure, is rare. A review of 34 cases in the literature between 1987 and 2012 by Patrono, et al. demonstrated an overall patient survival rate of 65% (79% since 2002). Indications

Table 3: Summary of 2019 admissions with liver injury to Queen Elizabeth Hospital Birmingham (UHB NHSFT).

	Polytrauma						Isolated Injury								
	Conservative Management			Radiological/Surgical Management			Conservative Management			Radiological/Surgical Management					
Grade	Number	Number died	Av LOS (days)	Number	Number died	Av LOS (days)	Number	Number died	Av. LOS (days)	Number	Number died	Av. LOS (days)	Total Grades	Total Deaths	Average LOS (days)
1	18	3	31	-	-	-	3	0	15	-	-	-	21	3	29
2	8	1	15	2(S)	1	68	4	0	9	2	0	34	16	2	23
3	7	0	29	2(R)	0	9	4	0	13	1(R) 2(S)	0	8	16	0	25
4	1	0	25	2(S)	0	117	1	0	5	1(R) 1(S)	0	35	6	0	56
5	-	-	-	1(S)	1	1	-	-	-	-	-	-	1	1	1
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	34	4	27	7	2	55	12	0	12	7	0	23	60	6	

were acute liver failure (59%), haemorrhage (26%), biliary fistula (6%), secondary biliary cirrhosis (6%) and total liver necrosis (3%). Seventy-nine percent (79%) were performed as a direct consequence of the injury or due to acute liver failure after the initial treatment and 74% were performed as a single-stage procedure (no significant anhepatic phase) [102]. A more recent review demonstrated similar results in 46 patients and concluded this surgical approach had its place in the management of severe hepatic trauma [103].

Liver Trauma at QEHB

In 2019 there were 60 patients admitted with trauma to the liver (Table 3). 43 patients (72%) were male with an age distribution as follows - 18% < 20 years, 48% 20-39 years, 25% 40-59 years and 8% 60 years and above. 68% of patients had multiple injuries and the overall mortality rate was 10%. All deaths were secondary to combinations of injuries and there were no deaths of patients with isolated liver injuries. Seven patients underwent surgical intervention (grade II injuries required other intrabdominal injuries to be assessed at laparotomy, grade II and above for isolated liver injuries in patients who were haemodynamically unstable), 4 patients (2 of which were isolated injuries, grade II and IV) underwent radiological angioembolisation. The need for intervention, either radiological or surgical, was associated with a doubling in the average length of stay for patients (polytrauma 27 to 55 days and isolated liver injuries 12 to 23 days).

Conclusion

In summary, the management of liver trauma has evolved greatly over several decades (Figure 2). Non-operative management is the mainstay of treatment for the majority of patients, however failure of non-operative management is associated with a high morbidity and mortality. Centralisation of trauma services means that most major trauma patients should be managed at high-volume centres with hepatobiliary experience however it is still important to understand the pitfalls associated with treating these patients, should you care for one at a smaller general hospital. A multi-disciplinary approach, through engaging with other specialties such as anaesthetics and radiology, is important in order to give these patients an optimal standard of care and the best chance of recovery.

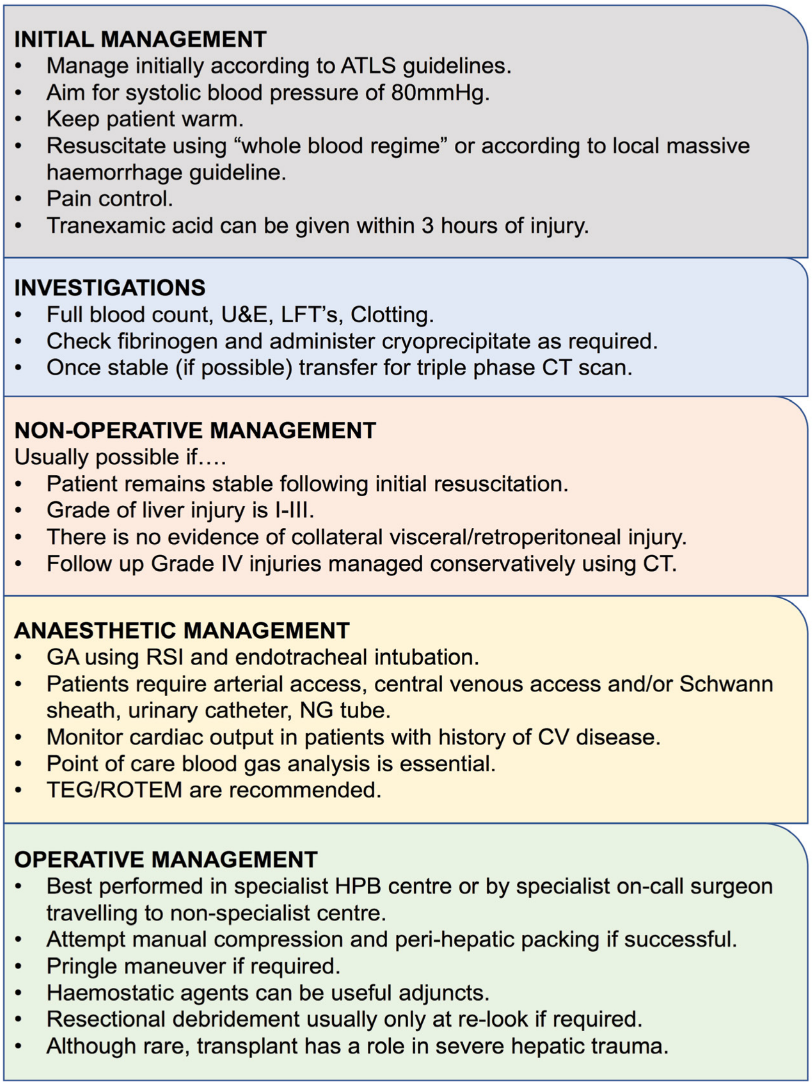

Figure 2: Summary of management of the liver trauma patient.

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DOI: 10.36959/879/385