

Liver Trauma – Operative Management

JJ Morrison¹, KE Bramley², AG Rizzo³

¹Specialty Registrar in General Surgery (West of Scotland) and Academic Department of Military Surgery and Trauma, Royal Centre for Defence Medicine, Birmingham; ²Specialty Registrar in Anaesthesia and Critical Care (West of Scotland), Dept of Anaesthesia, Glasgow Royal Infirmary; ³Attending Surgeon in Trauma Surgery and Critical Care, Inova Fairfax Hospital, VA, USA.

Abstract

Civilian liver trauma is generally sustained by blunt injury, with management strategies increasingly focusing on selective non-operative strategies and endovascular intervention. Military liver trauma is more often ballistic in nature and almost always requiring operative intervention. This article reviews established and evolving surgical techniques in the operative management of liver trauma.

Introduction

The liver is the most commonly injured organ following abdominal trauma [1,2], with haemorrhage being the surgeon's primary concern. The degree of injury is graded by increasing severity from I to VI (Table 1) [3,4]. Prior to the 1990s, almost all patients with suspected liver trauma underwent operative management; many were diagnosed by peritoneal lavage and thus the extent of injury was unknown. With increased access to computed tomography (CT), a number of studies have demonstrated the safety of selective non-operative management (SNOM) of initially blunt [4,5] but subsequently, penetrating liver injury [6,7] in haemodynamically stable patients. This has been brought about in conjunction with the wider availability of axial imaging and endovascular techniques aiding diagnosis and haemorrhage control in stable patients (Figure 1 and 2) [8,9]. Battlefield liver trauma is still almost always managed operatively [10,11], although SNOM of battlefield liver injury has also been reported recently [12-14], but has yet to become accepted practice.

There is evolving concern that some patients, especially those with higher grade injury, are being inappropriately selected for non-operative management thereby incurring unnecessary morbidity [15]. This has been ascribed to a lack of hepatic operative experience, the techniques of which have been learned throughout most of the 20th century with many lessons learned on the battlefield, not being applied to civilian cases. Surgeons managing liver trauma need to remain conversant with all available strategies, thus this paper is a review of the civilian and military literature on the operative management of liver trauma.

Incidence and Outcomes

Civilian Liver Trauma

The civilian world has seen significant changes to not only the common mechanisms of liver trauma, but also to the

Maj JJ Morrison, Academic Department of Military Surgery and Trauma, Royal Centre for Defence Medicine, Birmingham Research Park, Vincent Drive, Edgbaston, Birmingham B15 2SQ
Tel: + 44 (0) 7917 180 486
E-mail: jonny_morrison@doctors.org.uk

	Grade ^a	Description
I	Haematoma	Subcapsular, <10% surface area.
	Laceration	Capsular tear, <1cm parenchymal depth
II	Haematoma	Subcapsular, 10-50% surface area, intraparenchymal, <10cm in diameter.
	Laceration	1-3cm parenchymal depth, <10cm in length.
III	Haematoma	Subcapsular, >50% surface area or expanding; ruptured subcapsular or parenchymal haematoma. Intraparenchymal haematoma >10cm or expanding.
	Laceration	>3cm parenchymal depth.
IV	Laceration	Parenchymal disruption involving 25-75% of hepatic lobe or 1-3 Couinaud's segments within a single lobe.
V	Laceration	Parenchymal disruption involving >75% of hepatic lobe or >3 Couinaud's segments within a single lobe.
	Vascular	Juxtahepatic venous injuries; ie, retrohepatic vena cava/central major hepatic veins.
VI	Vascular	Hepatic avulsion.

^a Advance one grade for multiple injuries, up to Grade III.

Table 1: The American Association for the Surgery of Trauma Liver Injury Scale (1994 Revision) [3]

management strategies employed. In North America over the past 50 years, firearms and knife assaults have decreased substantially, whilst blunt injury following automobile crashes has risen. In 1969-70 one Detroit trauma centre saw 235 penetrating and 14 blunt injuries, but by 1997-98 this trend had reversed to 61 penetrating and 55 blunt injuries [16]. This was coupled with reductions in the median Grade of injury from III to II, rates of operative intervention from 100% to 68% and liver related

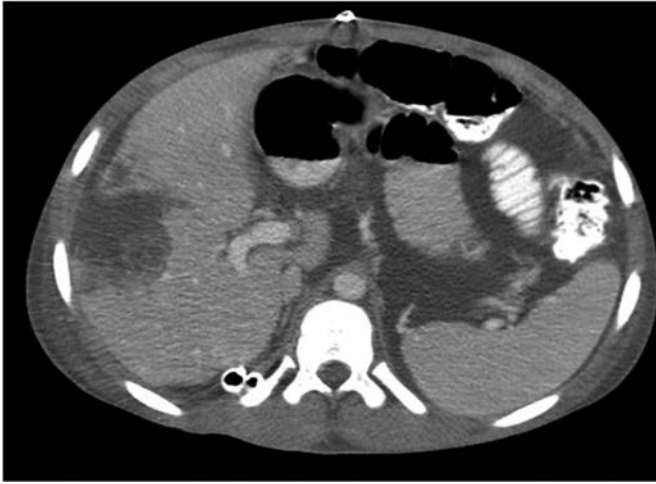


Figure 1: A Computed Tomography scan of a blunt liver injury. (Picture credit: Surg Capt MJ Midwinter RN.)



Figure 2: Liver angiography showing active contrast extravasation illustrating ongoing bleeding. (Picture credit: Lt Col Anne Rizzo USAF.)

28-day mortality from 7% to 4%, although the overall mortality remained at 16% [16].

In Europe, penetrating trauma is a relatively infrequent occurrence, with automobile crashes accounting for the majority of trauma admissions. One UK study [17] analysing 52 admissions from 1991-2001 found that half of patients required operative management for liver lacerations of greater grade and haemodynamic instability than their conservatively managed counterparts. Within the non-operative group, 23% eventually required operation, but the indications were not explicit. The operative mortality was 31% compared to 16% in the SNOM group.

A similar study from Spain [18] described 143 patients admitted between 1992 and 2008 and found that surgery was required in 38% with 15% of the SNOM group eventually requiring operation. Haemodynamic instability was the main indication for operation following failure of SNOM in 9 out of 11 patients. The mortality of patients selected for initial operative

management was 29% compared to 16% in the SNOM group, which including two late deaths from ARDS and sepsis in the group who failed SNOM.

Military Liver Trauma

In contrast to civilian trauma, battlefield trauma is generally the result of fragmentation or gunshot wounds (GSW) [19]. The resultant wounds are usually the result of high energy transfer associated with large volumes of tissue destruction, multi-cavity involvement [20] and gross bacterial contamination [21].

During World War I, all major liver trauma was managed expectantly with a corresponding mortality of 66% [22]. During World War II, advances in surgical equipment and techniques meant that such patients were managed operatively with a mortality of 27% [22]; in Korea, mortality fell further to 14% [10]. In Vietnam, the incidence of liver injury in patients with penetrating abdominal war wounds was between 20% and 27%, second only to intestinal perforation [23,24]. The right lobe was involved in two thirds of patients, with left lobe injury associated with concomitant inferior vena cava (IVC) injury [23]. Mortality for liver trauma during this period varied from 4.5% in the military population to 12% when other combatants and civilians were included [24].

During the 1982 Lebanon War, a small study reported 11 liver wounds in a cohort of 37 consecutive laparotomies [25] whereas the conflict in Yugoslavia during the 1990s, involved substantially larger casualty numbers. Two retrospective studies, analysing military and civilian casualties, reported 17% and 28% of patients with abdominal wounding to have liver involvement [10,11]. These studies reported a median injury grade of III with increasing grade associated with escalating mortality between 0% for Grade I to 100% for Grade VI.

The trend of injury amongst serving personnel in the recent and current conflicts of Iraq and Afghanistan reflects the increased use of personal and vehicular ballistic protection by western militaries. There are several studies examining exclusively military populations which quote rates of abdominal injury of 1.7 - 1.9% [26,27]. If native forces, motor vehicle crashes and civilian injuries are included this rises to 8- 17% [14,28]. The liver is second only to the intestines as the most commonly injured organ (13-27%) [13,14,28].

Patient Selection for Operative Management

There are two major determinants to consider when making decisions in suspected liver trauma: haemodynamic stability and mechanism of injury. In general, haemodynamic instability or peritonism makes decision-making in trauma more straightforward, although ultimately, the surgical procedure required may be complex. Management decisions are more challenging when patients are haemodynamically stable as the array of potential therapeutic modalities are substantial and the patient's future clinical course is unknown [8,9].

Concomitant injury, either extra- or intra-abdominal, and high grade liver injury are predictors of outcome in liver trauma [1,29]. It has been a constant observation through time that most Grade I and II injuries require little or no intervention [15]. The most useful tool to help guide decision making in stable cases is CT scanning which is generally available in most western hospitals and becoming so in most mature deployed field hospitals [13,14]. A recent study used CT to evaluate several patients with blunt abdominal trauma who were initially unstable, but who

responded to resuscitation, without mishap [17]. The numbers involved were small and we would not advocate this approach for all unstable trauma cases. There is also emerging literature about the pitfalls of multiple scans delaying definitive treatment and the additional radiation exposure increasing the risk of carcinogenesis in trauma patients [18].

Liver-related failure of SNOM (ie secondary liver haemorrhage) is associated with higher grades of injury, and the management of Grades IV and V merit particular scrutiny with a low threshold for operative intervention [5,6,17]. In the civilian literature, delayed intervention is not associated with additional morbidity or mortality [7,30]. This has yet to be clarified in the military literature as only one study reports a failure of battlefield SNOM in a patient with a Grade III liver injury [14].

Overall, all civilian and military patients who are unstable following abdominal trauma should undergo a laparotomy. All stable patients should be evaluated by CT scanning. Operative management should be considered for grades III to V who become unstable, peritonitic, septic or have multiple additional injuries. SNOM should only be considered in the military environment if CT scanning, critical care facilities and the provision for serial observation are available; otherwise, surgery is the default strategy.

Operative Strategies

General Principles

From the outset the surgeon needs to be aware of not only the anatomical pattern of injury, but also the physiological state of the patient. In the context of haemodynamic instability and physiological derangement then a damage control approach of abbreviated surgery should be adopted early [28]. Damage control surgery is now considered a component within a wider resuscitation paradigm termed damage control resuscitation [31]. This utilises aggressive, early use of blood product to restore tissue oxygenation, limit acidosis and coagulopathy, coupled with active warming, has been associated with improved survival [32].

The immediate operative goal of the surgeon is to control haemorrhage followed by debridement or resection of devitalised liver, control of any bile leak and appropriate drainage [33]. In general, this can be achieved through a generous midline laparotomy which can either be extended into a right sub-costal incision or substituted for a bilateral sub-costal incision if the injury is known to be confined to the supra-colic compartment. The liver can be fully mobilised by dividing the triangular and coronary ligaments to permit full evaluation of injuries. This is contra-indicated when a retrohepatic venous injury is suspected as decompression of a critical vascular injury can result.

Inflow Control (Pringle's Manoeuvre)

This valuable technique (Figure 3) involves compression of the portal triad, either digitally or by a non-crushing bowel clamp, occluding vascular inflow from the hepatic artery and portal vein. It was first described by Pringle in 1908 [34] and can be both diagnostic and therapeutic. Application of inflow control will stem haemorrhage from an arterial or portal source, permitting thorough evaluation of the injury and allowing the anaesthetist time to restore intravascular volume. Should haemorrhage from a liver injury not be controlled by Pringle's Manoeuvre, an aberrant arterial supply or major IVC injury should be suspected [33]. Care should be taken during the application of compression not to injure the common bile duct. The risk of prolonged



Figure 3: A line drawing of Pringle's Manoeuvre, where the portal triad is digitally compressed to reduce vascular inflow. (From: Hirschberg A, Mattox KL. *Top Knife: the Art and Craft of Trauma Surgery*. 1st Edn. Berlin: Springer, 2006. Reproduced with kind permission.)

occlusion relates to the sequelae of ischemic hepatitis such as liver insufficiency and encephalopathy, thus occlusion time should generally be less than 1 hour [35].

Liver Packing

The use of gauze packing in trauma to effect the tamponade of haemorrhage is well known to surgeons, but has gone through periods of both favour and disfavour. Liver packing was used for first time on a large scale during World War II where it was eventually abandoned due to a variety of serious complications. Packing became associated with haemorrhage following pack removal, abscess, hepatitis and biliary peritonitis [22]. This continued through the Vietnam War and civilian practice where operative management focused on resectional and vascular isolation techniques [23].

There was a resurgence of interest in temporary packing during the 1980s following the identification of coagulopathic patients where discrete bleeding vessels had been ligated, but the raw hepatic surface continued to ooze [36]. Packing was only advocated in critical case however, as it was still associated with septic morbidity [37]. In an effort to reduce this infective burden, omental pack [38] or Gerota's fascia flap [39] have been advocated to pack into hepatic wounds. This carries the benefit of autologous tissue use and helps reduce dead-space, however; omentum is not always available and flaps are time consuming to mobilise. With improvements in resuscitation and the use of antibiotics, subsequent studies have been unable to demonstrate an increased burden of sepsis with gauze packs [40].

The main pitfalls relate to the technique of packing - packs must be placed around the liver to reconstitute its anatomical shape. Packs placed in the hepatic wound risk further bleeding by tearing tissue. Excessive packing can compress the IVC increasing the

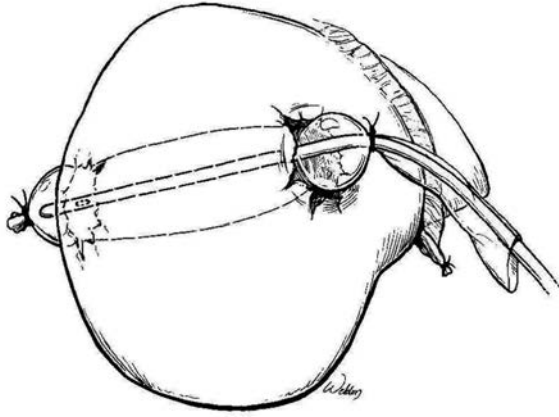


Figure 4: A line drawing of intrahepatic balloon tamponade using a Penrose drain and urinary catheter. (From: Hirshberg A, Mattox KL. *Top Knife: the Art and Craft of Trauma Surgery*. 1st Edn. Berlin: Springer, 2006. Reproduced with kind permission.)

risk of compartment syndrome and multi-organ failure [33,41]. Conversely under-packing is associated with increased transfusion requirements and unplanned re-look laparotomies [41]. It is felt that the optimum time for pack removal is between 36 and 72 hrs, following the correction of a patient's physiology - earlier removal is associated with secondary haemorrhage [40]. In general, the liver should be mobilised (except when there is a suspicion of retro-hepatic venous injury) to permit the systematic placement of packs posteriorly, round to the anterior surface of the liver to achieve antero-posterior compression. Packs can be placed in Morison's Pouch to support the inferior surface. Packing directly under the diaphragm can cause respiratory embarrassment, but may be required depending on the location of wounds.

Mesh Wrapping

Mesh wrapping uses an absorbable mesh to encapsulate the liver under tension, compressing the parenchyma to achieve haemostasis. It has the benefits seen with gauze packing - simplicity and the avoidance of resection - but avoids extra-hepatic compression of the IVC, portal vein and diaphragm. There are several techniques depending on the injury pattern, from complete [42] to partial [43] encapsulation. A cholecystectomy is required if the right lobe is completely wrapped to avoid necrosis of the gall bladder [33]. This technique is attractive for the reasons detailed above and has not been associated with an increase in hepatic complication although the evidence base is limited to a number of small series and reports [42,43].

Intrahepatic Tamponade

Perforating wounds of the liver that are actively bleeding leave the surgeon with a management dilemma: performing a tractotomy to gain access may require substantial tissue disruption and risks further bleeding, yet the need for haemostasis remains paramount. For this infrequently encountered injury, an elegant solution exists in the form of intra-hepatic balloon tamponade (Figure 4). A device can either be fashioned from a Foley catheter and Penrose drain [44] or a Sengstaken-Blakemore tube. The device is gently delivered into the length of the tract and then inflated, often with a radio-opaque contrast fluid so integrity and position can be later confirmed radiologically if required. The inflated balloon tamponades any bleeding vessels and once the patient is haemodynamically stable with normal clotting, the balloon can

be emptied and withdrawn. This can be achieved at re-laparotomy or through a pre-prepared abdominal wall tract.

Hepatorrhaphy (Deep Liver Suture)

This is an older technique which involves passing deep parenchymal sutures to bring disrupted tissue together compressing bleeding vessels and reducing dead space. Unfortunately, in the pursuit of haemostasis, it has been reported that large areas of tissue can become ischaemic progressing to infarction, becoming a nidus for infection [45]. Thus, hepatorrhaphy has largely been superseded by hepatotomy with direct ligation of vessels. However, some advocate hepatorrhaphy for "hard-to-reach" areas such as the dome and posterior portion of the right lobe [46].

Hepatotomy (Finger Fracture Technique)

Hepatotomy is the counter-intuitive alternative to hepatorrhaphy, originally described in 1958, which involves initially making the liver wound larger [47]. This can be done using the fingers [48] (hence the term "finger fracture"), scalpel handle [47] or electrocautery (Figure 5) [33]. This provides access to vessels embedded in the parenchyma, allowing for direct suture or clip ligation. The largest consecutive series reports 75 patients with median injury Grade of III, where finger fracture was used in conjunction with Pringle's Manoeuvre, to achieve a morbidity of 8% and mortality of 5%. A more recent study in 1990 reported that hepatotomy was appropriate in 301 of 683 patients with an 87% success rate. Overall, this technique has a low morbidity when compared to hepatorrhaphy and helps reduce the need for resection but most of the evidence presented is in relation to penetrating trauma [33].

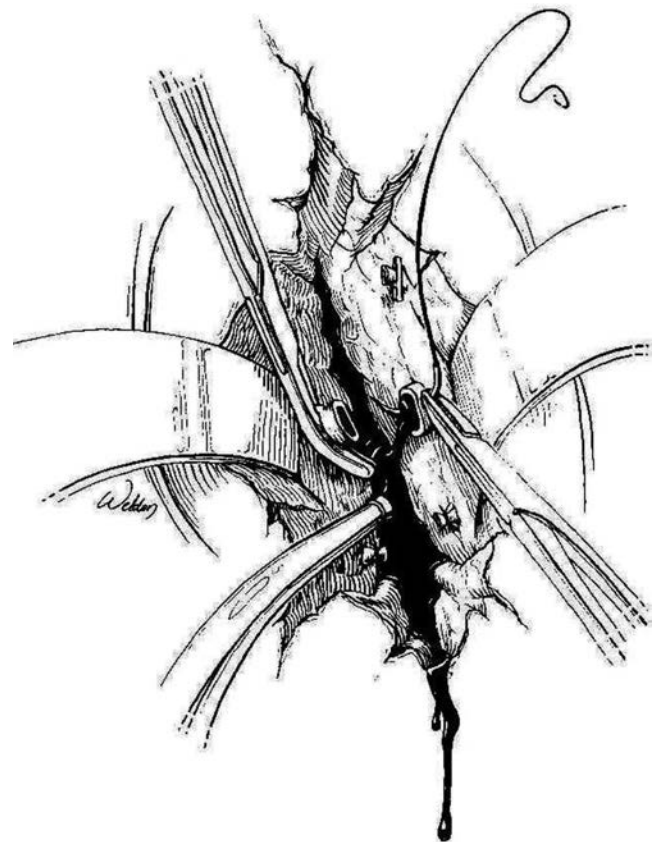


Figure 5: A line drawing of a hepatotomy with direct suture of bleeding vessels. (From: Hirshberg A, Mattox KL. *Top Knife: the Art and Craft of Trauma Surgery*. 1st Edn. Berlin: Springer, 2006. Reproduced with kind permission.)

Debridement (Non-Anatomical Resection)

The removal of all non-viable tissue from a traumatic wound to minimise post-operative sepsis and secondary haemorrhage is a basic tenet of surgery. Debridement is rarely a technique practised in isolation and is frequently used in conjunction with inflow control and hepatotomy. This allows for haemorrhage control prior to resection of all devitalised tissue while usually involves crossing traditional anatomical boundaries hence the term “non-anatomical resection” (Figures 6 and 7).

Debridement is rarely utilised in civilian liver trauma [30,49,50], except in patients injured with firearms [46,51]. This is likely because of the cavitating effect that ballistic wounds inflict on liver parenchyma yielding injuries requiring debridement. This is echoed by a military study reporting debridement in 78% of cases [11] where all patients had sustained high energy transfer penetrating injury.

Lobectomy (Anatomical Resection)

Formal anatomical resection is a procedure associated with substantial mortality and its role in trauma has changed from enthusiasm [52] to a more measured application of last resort [33,53]. The complications seen with intra-hepatic packing, coupled with advances in surgical techniques and instruments, motivated surgeons to explore anatomical resections as a means of primary haemorrhage control in the 1950s and '60s. Initial military experience from the Vietnam War found that one in five patients were suitable for a lobectomy with a mortality rate of 16% [24], although injury severity was not reported in this series. However, throughout the 1960s and '70s, numerous series reported mortality rates of 47% to 59% [54-56].

Currently, civilian literature supports the use of lobectomy in patients with deep fractures or major hepatic venous bleeding [57,58], which are all features generally seen with blunt trauma [59]. Military experience is small, with anatomical resection being utilised in 0-5% with a mortality of 67% [10,11].

Selective Hepatic Artery Ligation

This has largely been superseded by the techniques detailed above as a method for haemorrhage control [60]. Initially, there was a concern that arterial ligation would produce ischaemic liver dysfunction, however, this was not borne out clinically as portal venous blood is sufficiently oxygenated to support hepatic metabolism. It appears to have a role when the source of arterial bleeding cannot be identified at hepatotomy and packing has failed, but can be controlled by Pringle's Manoeuvre. It is contraindicated when a major venous injury is suspected.

Local Haemostatic Adjuncts (Topical Agents and Tissue Adhesives)

This comprises a heterogeneous group of compounds where the end result of application is haemostasis, generally by a combination of augmenting the clotting cascade in conjunction with a structural effect [61]. They are considered as topical agents, tissue adhesives or novel surgical implements.

Examples of topical agents include oxidised cellulose (Surgicel®, Nu-Knit®) which can be packed into a bleeding laceration [62]. Cellulose products stimulate clotting while providing an apparatus that supports clot formation. Importantly, they provide no clotting factors and rely upon an existing functioning cascade. Other products include novel compounds such as zeolite and chitosan; however, the safety of these compounds utilised

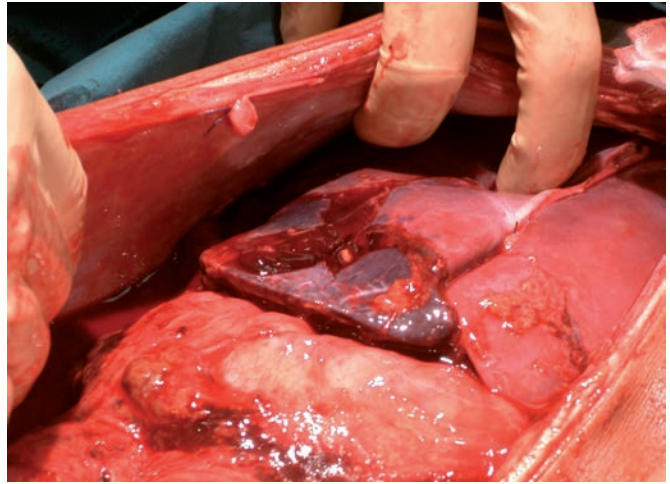


Figure 6: A photograph of a gunshot wound to the right lobe of the liver. (Picture credit: Lt Col J Jansen RAMC (V).)

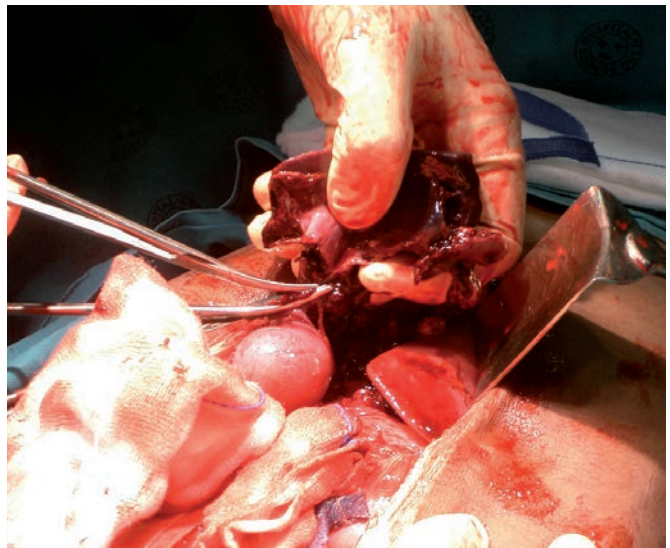


Figure 7: The same patient as Figure 6, having had a non-anatomical resection of devitalised tissue. (Picture credit: Lt Col J Jansen RAMC(V).)

internally has yet to be fully elucidated in human studies and are generally confined to external use [63,64].

Tissue adhesives are substances which polymerize on application, sealing blood vessels and raw surfaces, or helping to hold tissue together, facilitating haemostasis by tamponade [65]. The most common are fibrin-based products which results from a mixture of thrombin and fibrinogen producing a clot, although other synthetic compounds are becoming available. Such compounds have been used in elective liver and vascular surgery [66], but preparation time can be lengthy, reducing their applicability to trauma.

The evidence base for local haemostatic agents in liver trauma is limited to case reports [62] and animal experiments [67-69]. Several authors have commented that a cellulose material packed into a laceration which is then “sealed” shut with fibrin adhesive appears to be an effective technique [62,65]. Currently, there are no trials comparing such a technique with conventional surgery, although these will be likely forthcoming with time.

Additional surgical implements like the cavitron ultrasonic surgical aspirator (CUSA) or Argon beam laser have been employed effectively to control local bleeding and raw edge surfaces [15].

Special Circumstances

Angio-Embolisation as an Adjunct to Surgery

The use of angio-embolisation (AE) is well known in the management of liver trauma [70] and is frequently used to increase the rate of successful non-operative management [71]. In the case of operative management, there are two strategies available to surgeons.

AE can be used immediately after a damage control laparotomy as part of the primary haemorrhage control strategy [72]. Alternatively, AE can be used in post-operative patients to manage ongoing bleeding not associated with haemodynamic compromise [73]. This can involve the not only AE, but also the placement of stents to reconstruct vasculature [74]. The group where this appears most efficacious are in high grade liver injuries associated with complex vascular trauma.

Biliary Injury and the Role of Drainage

The presentation of injury to the biliary tree varies from identification at initial laparotomy to a biloma weeks after injury [58]. In the context of operatively managed patients, the usual presentation is bile in drains, more commonly after major resection, which occurs in 4- 7% [59,75]. There was a vogue for prophylactic T-tube placement to facilitate early biliary de-compression in the 1960s [76], although no advantage was forthcoming in subsequent studies [77]. Most bile leaks from the intra-hepatic biliary tree will stop within weeks [75] provided there is no distal biliary obstruction, although up to three months is not unknown [33]. In the case of extra-hepatic leaks, percutaneous or endoscopic treatment with stent placement is preferred [78], although occasionally Roux-en Y hepaticojejunostomy or formal lobectomy is required [58].

Juxta-Hepatic Venous Injury

This is frequently a catastrophic injury complex where the surgeon is greeted with torrential dark red haemorrhage from an inaccessible posterior venous injury. Two injury patterns have been described: type (A) are intra-parenchymal injuries that bleed through fractured tissue and type (B) where veins are avulsed from the IVC and bleed posteriorly around the liver [79]. Surgical strategy has focused on the premise that such veins need direct exposure and repair or ligation. Techniques to obtain control to facilitate this have included total vascular exclusion [80], atrio-caval shunting [81], veno-veno bypass and deep hypothermic circulatory arrest [82]. All of which have been associated with high mortality rates of between 50% and 90% [79]. As described previously, formal resection also has similarly poor results when used for primary haemorrhage control. Hence, in the past decade, there has been a move towards tamponade and containment with temporary packs, with reports of a 25% mortality rate in some series [83]. Adjuvant angio-embolisation offers these patients an additional option .

Liver Transplantation

This remains a therapy of last resort limited to specialist centres with the literature limited to occasional case reports and series [84]. Transplantation has been reported in both the acute setting as well as following the chronic sequelae of some injuries [85] but is not required or possible in the vast majority.

Laparoscopic Surgery

Laparoscopy in trauma remains controversial due to rates of missed injury [86,87]. Blunt trauma does not lend itself as

well to laparoscopy due to its diffuse pattern as opposed to the more defined nature of penetrating injuries. There are a number of series describing the successful haemostasis of minor liver injuries, in both the civilian [88,89] and military setting [90], although it is likely that these were self-limiting injuries anyway.

In the elective literature, laparoscopic hepatic resection in oncology is established as a safe approach with less morbidity than open resection [91]. While cancer surgery is very different to trauma surgery, the tools exist so that one day laparoscopy may feature in the trauma surgeon's algorithm for the management of haemodynamically stable hepatic trauma.

Post-Operative Complications

Liver trauma is a morbid injury with complication rates from recent series ranges from between 8.1% to 30% [92,93]. This relates to the complexity of the organ and the multi-cavity nature of trauma that often adds to the morbidity burden.

Post-operative Haemorrhage

Primary exsanguinating haemorrhage is a major source of mortality, but most studies report secondary haemorrhage occurring in 3- 6% of survivors with no significant difference between blunt and penetrating mechanisms [46]. Surgical haemorrhage (ie discrete bleeding) and disseminated intravascular coagulation account for the majority of causes in even proportions. In patients managed by peri-hepatic packing, patients who had packs removed at <36hrs had more episodes of haemorrhage requiring re-packing than those with removal between 36hrs and 72hrs [40].

Sepsis and Abscess

Post-operative sepsis occurs in 12-32% of patients. Minor morbidity occurs with urinary tract, surgical wound and respiratory tract sepsis. More serious are intra-abdominal abscesses which occur in up to 24% of patients and are associated with concomitant bowel injury, higher grades of liver injury (IV and V) and massive transfusion [94]. In the same study, 38% of Grade V injuries died of sepsis compared with 24% for all other grades. In such patients, a clinician must have a low threshold for further abdominal imaging in the event of pyrexia or leucocytosis, with CT providing the greatest diagnostic yield. Percutaneous drainage is usually possible, although a minority of patients will require a laparotomy and marsupialization.

Conclusion

In civilian practice the predominant mechanism of injury is blunt trauma where the majority of minor to moderate injury (Grades I and II) can be managed non-operatively. More severe injury Grades (III to IV) can also be managed non-operatively, but are more likely to require operative intervention. Military trauma is mostly penetrating in nature with patients almost always managed operatively. The majority of patients requiring operative intervention can be managed with temporary inflow occlusion, hepatotomy with direct vessel ligation and temporary packing. Formal anatomical resection carries a high morbidity when used for haemorrhage control, although in an experienced centre this may be appropriate. Hepatorrhaphy has become discouraged due to complications of sepsis and bleeding, but may be a useful technique in penetrating trauma where the liver is difficult to access. In time, novel haemostatic agents such as

fibrin tissue adhesives may play a larger role in haemorrhage control. In military surgery the same operative principles apply although debridement is used more extensively due to the larger cavitation effect seen with battlefield wounds.

References

- Sikhondze WL, Madiba TE, Naidoo NM, Muckart DJJ. Predictors of outcome in patients requiring surgery for liver trauma. *Injury* 2007; **38**:65-70.
- Coughlin PA, Stringer MD, Lodge JPA, Pollard SG, Prasad KR, Toogood GJ. Management of blunt liver trauma in a tertiary referral centre. *Br J Surg* 2004; **91**:317-21.
- Moore EE, Cogbill TH, Jurkovich GJ, Shackford SR, Malangoni MA, Champion HR. Organ injury scaling: spleen and liver (1994 revision). *J Trauma* 1995; **38**:323.
- Pachter HL, Knudson MM, Esrig B, et al. Status of nonoperative management of blunt hepatic injuries in 1995: a multicenter experience with 404 patients. *J Trauma* 1996; **40**:31.
- Croce MA, Fabian TC, Menke PG et al. Nonoperative management of blunt hepatic trauma is the treatment of choice for hemodynamically stable patients. Results of a prospective trial. *Ann Surg* 1995; **221**:744.
- Demetriades D, Gomez H, Chahwan S et al. Gunshot injuries to the liver: the role of selective nonoperative management. *JACS* 1999; **188**:343-8.
- Navsaria PH, Nicol AJ, Krige JE, Edu S. Selective nonoperative management of liver gunshot injuries. *Ann Surg* 2009; **249**:653-6.
- MacKenzie S, Kortbeek JB, Mulloy R, Hameed SM. Recent experiences with a multidisciplinary approach to complex hepatic trauma. *Injury* 2004; **35**:869-77.
- Sriussadaporn S, Pak-art R, Tharavej C, Sirichindakul B, Chiamanantapong S. A multidisciplinary approach in the management of hepatic injuries. *Injury* 2002; **33**:309-15.
- Mimica Z, Biocic M, Bacic A et al. The problems and characteristics of hepatic War trauma management in Central Dalmatia during the 1991-1995 War in Croatia. *Mil Med* 2000; **165**:173-177.
- Milotić F, Uravić M, Raguz K et al. Penetrating liver war injury: a report on 172 cases. *Mil Med* 2003; **168**:419-21.
- Wood AM, Trimble K, Loudon MA, Jansen J. Selective nonoperative management of ballistic abdominal solid organ injury in the deployed military setting. *JR Army Med Corps* 2010; **156**:21-4.
- Beekley AC, Blackbourne LH, Sebesta JA, McMullin N, Mullenix PS, Holcomb JB. Selective nonoperative management of penetrating torso injury from combat fragmentation wounds. *J Trauma* 2008; **64**:S108-16; discussion S116-7.
- Morrison JJ, Clasper JC, Gibb I, Midwinter M. Management of Penetrating Abdominal Trauma in the Conflict Environment: The Role of Computed Tomography Scanning. *World J Surg* 2011; **35**:27-33.
- Trunkey D. Hepatic trauma: contemporary management. *Surg Clin North Am* 2004; **84**:437-450.
- Lucas CE; Ledgerwood AM. Changing times and the treatment of liver injury. *Am Surg* 2000; **66**:337.
- Brammer RD, Bramhall SR, Mirza DF, Mayer AD, McMaster P, Buckels JAC. A 10-year experience of complex liver trauma. *Br J Surg* 2002; **89**:1532-7.
- Bernardo C, Fuster J, Bombuy E, Al E. Treatment of Liver Trauma: Operative or Conservative Management. *Gastroenterol Research* 2010; **3**:9-18.
- Champion HR, Holcomb JB, Lawnick MM et al. Improved characterization of combat injury. *J Trauma* 2010; **68**:1139-50.
- Morrison JJ, Midwinter MJ, Jansen JO. Ballistic Thoracoabdominal Injury: Analysis of Recent Military Experience in Afghanistan. *World J Surg* 2011, *in press*.
- Mahoney PF, Ryan JM, Brooks AJ, Schwab CW. *Ballistic Trauma: A Practical Guide*. 2nd Edn. London: Springer; 2005.
- Madding G, Lawrence K. Wounds of the liver and the extrahepatic biliary tract (829 casualties). *Surgery* 1955; :275.
- Carroll CP, Cass KA, Whelan TJ. Wounds of the liver in Vietnam: a critical analysis of 254 cases. *Ann Surg* 1973; **177**:385-92.
- Pilcher D. Penetrating injuries of the liver in Vietnam. *Ann Surg* 1969; **170**:793.
- Hashmonai M, Schramek A, Kam I, Torem S. Treatment of liver trauma in the Lebanon War, 1982. *Israel J Med Sci* 1984; **20**:327-329.
- Zouris JM, Walker GJ, Dye J, Galarneau M. Wounding patterns for U.S. Marines and sailors during Operation Iraqi Freedom, major combat phase. *Mil Med* 2006; **171**:246-52.
- Galarneau MR, Hancock WC, Konoske P et al. The Navy-Marine Corps Combat Trauma Registry. *Mil Med* 2006; **171**:691-7.
- Sambasivan CN, Underwood SJ, Cho SD et al. Comparison of abdominal damage control surgery in combat versus civilian trauma. *J Trauma* 2010; **69** Suppl 1:S168-74.
- Schnüriger B, Inderbitzin D, Schafer M, Kickuth R, Exadaktylos A, Candinas D. Concomitant injuries are an important determinant of outcome of high-grade blunt hepatic trauma. *Br J Surg* 2009; **96**:104-10.
- Malhotra AK, Fabian TC, Croce MA et al. Blunt hepatic injury: a paradigm shift from operative to nonoperative management in the 1990s. *Ann Surg* 2000; **231**:804.
- Duchesne JC, McSwain NE, Cotton BA, et al. Damage control resuscitation: the new face of damage control. *J Trauma* 2010; **69**:976-90.
- Duchesne JC, Kimonis K, Marr AB et al. Damage control resuscitation in combination with damage control laparotomy: a survival advantage. *J Trauma* 2010; **69**:46-52.
- Parks RW, Chrysoe E, Diamond T. Management of liver trauma. *Br J Surg* 1999; **86**:1121-35.
- Pringle P. Notes on the arrest of hepatic hemorrhage due to trauma. *Ann Surg* 1908; **48**:541-549.
- Heriot AG, Karanjia ND. A review of techniques for liver resection. *Ann Roy Coll Surg Engl* 2002; **84**:371-80.
- Svoboda JA, Peter ET, Dang CV, Parks SN, Ellyson JH. Severe liver trauma in the face of coagulopathy. A case for temporary packing and early reexploration. *Am J Surg* 1982; **144**:717-21.
- Ivatury, RR, Nallathambi, M, Gunduz, Y, Constable, R, Rohman, M, Stahl WM. Liver packing for uncontrolled hemorrhage: a reappraisal. *J Trauma* 1986; **26**:744.
- Stone H, Lamb J. Use of pedicled omentum as an autogenous pack for control of hemorrhage in major injuries of the liver. *J Trauma* 1975; **15**:1038.
- Catani M, De Milito R, Romagnoli F, Modini C. Gerota's fascia flap: a technique for autogenous packing in major liver injuries. *J Trauma* 2010; **69**:720-1.
- Caruso DM, Battistella FD, Owings JT, Lee SL, Samaco RC. Perihepatic packing of major liver injuries: complications and mortality. *Arch Surg* 1999; **134**:958.
- Aydin U, Yazici P, Zeytunlu M, Coker A. Is it more dangerous to perform inadequate packing? *World J Emerg Surg* 2008; **3**:1.
- Brunet C, Sielezneck I, Thomas P, Thirion X, Sastre B, Fariße J. Treatment of hepatic trauma with perihepatic mesh. 35 cases. *J Trauma* 1994; **37**:200.

43. Marshall M, Vinh D, Evans SR. An alternative technique for the use of absorbable mesh in an isolated liver injury. *Injury* 1996; **27**:445-6.
44. Poggetti RS, Moore EE. Balloon tamponade for bilobar transfixing hepatic gunshot wounds. *J Trauma* 1992; **33**:694.
45. Mays ET. The hazards of suturing certain wounds of the liver. *Surg, Gyn & Obs* 1976; **143**:201-4.
46. Degiannis E, Levy RD, Sa FCS, Velmahos GC, Mokoena T, Daponte A. Gunshot injuries of the liver : The Baragwanath experience. *Surgery* 1995; **1**:359-364.
47. Lin T, Tsu K, Mien C, Chen C. Study on lobectomy of the liver. *J Formosa Med Assoc* 1958; **57**:742-59.
48. Pachter HL, Spencer FC, Hofstetter SR, Coppa GF. Experience with the finger fracture technique to achieve intra-hepatic hemostasis in 75 patients with severe injuries of the liver. *Ann Surg* 1983; **197**:771.
49. Cox EF, Flancbaum L, Dauterive AH, Paulson RL. Blunt trauma to the liver. Analysis of management and mortality in 323 consecutive patients. *Ann Surg* 1988; **207**:126.
50. Veroux M, Cillo U, Brolese A et al. Blunt liver injury: from non-operative management to liver transplantation. *Injury* 2003; **34**:181-6.
51. Gonullu D, Koksoy FN, Ilgun S et al. Treatment of penetrating hepatic injuries: a retrospective analysis of 50 patients. *Euro Surg Research* 2009; **42**:174-80.
52. Ackroyd FW, Pollard J, McDermott Jr WV. Massive hepatic resection in the treatment of severe liver trauma. *Am J Surg* 1969; **117**:442.
53. Piper GL, Peitzman AB. Current Management of Hepatic Trauma. *Surg Clin N Am* 2010; **90**:775-785.
54. Trunkey DD, Shires GT, Mc Clelland R. Management of liver trauma in 811 consecutive patients. *Ann Surg* 1974; **179**:722-8.
55. Defore, WW Jr. Mattox, K L. Jordan, G L Jr. Beall ACJ. Management of 1,590 consecutive cases of liver trauma. *Arch Surg* 1976; **111**:493-7.
56. Levin A, Gover P, Nance FC. Surgical restraint in the management of hepatic injury: a review of Charity Hospital experience. *J Trauma* 1978; **18**:399.
57. Beal SL. Fatal hepatic hemorrhage: an unresolved problem in the management of complex liver injuries. *J Trauma* 1990; **30**:163.
58. Hollands M, Little J. Post-traumatic bile fistulae. *J Trauma* 1991; **31**:117.
59. Feliciano DV, Mattox KL, Jordan GL et al. Management of 1000 consecutive cases of hepatic trauma (1979-1984). *Ann Surg* 1986; **204**:438-45.
60. Faris TD, Winegarner FG, Eiseman B. Controversies in the management of liver trauma. *J Trauma* 1971; **11**:915.
61. Recinos G, Inaba K, Dubose J, Demetriades D, Rhee P. Local and systemic hemostatics in trauma: a review. *Turkish J Trauma & Emerg Surg* 2008; **14**:175-181.
62. Theuer CP, Imagawa DK. Use of knitted oxidized cellulose (Nuknit) for the definitive packing of grade III liver fracture. *Injury* 1999; **30**:137-40.
63. Wright JK, Kalns J, Wolf EA et al. Thermal Injury Resulting from Application of a Granular Mineral Hemostatic Agent. *J Trauma* 2004; **57**:224-230.
64. Wedmore I, McManus JG, Pusateri AE, Holcomb JB. A special report on the chitosan-based hemostatic dressing: experience in current combat operations. *J Trauma* 2006; **60**:655-8.
65. Reece TB, Maxey TS, Kron IL. A prospectus on tissue adhesives. *Am J Surg* 2001; **182**:40S-44S.
66. Heaton N. Advances and methods in liver surgery: haemostasis. *Euro J Gastroenterol & Hepatol* 2005; **17 Suppl 1**:S3-12.
67. Pusateri AE, McCarthy SJ, Gregory KW et al. Effect of a chitosan-based hemostatic dressing on blood loss and survival in a model of severe venous hemorrhage and hepatic injury in swine. *J Trauma* 2003; **54**:177-82.
68. Horio T, Ishihara M, Fujita M et al. Effect of photocrosslinkable chitosan hydrogel and its sponges to stop bleeding in a rat liver injury model. *Artif Organs* 2010; **34**:342-7.
69. Feinstein A, Varela J, Cohn S, Compton R, McKenney M. Fibrin glue eliminates the need for packing after complex liver injuries. *Yale J Biol and Med* 2001; **74**:315.
70. Monnin V, Sengel C, Thony F et al. Place of arterial embolization in severe blunt hepatic trauma: a multidisciplinary approach. *Cardiovasc and Interven Rad* 2008; **31**:875-882.
71. Gaarder C, Naess PA, Eken T et al. Liver injuries--improved results with a formal protocol including angiography. *Injury* 2007; **38**:1075-83.
72. Lin B-C, Wong Y-C, Lim K-E et al. Management of ongoing arterial haemorrhage after damage control laparotomy: optimal timing and efficacy of transarterial embolisation. *Injury* 2010; **41**:44-9.
73. Misselbeck TS, Teicher EJ, Cipolle MD et al. Hepatic angioembolization in trauma patients: indications and complications. *J Trauma* 2009; **67**:769-73.
74. Denton JR, Moore EE, Coldwell DM. Multimodality treatment for grade V hepatic injuries: perihepatic packing, arterial embolization, and venous stenting. *J Trauma* 1997; **42**:964.
75. Shahrudin M, Noori S. Biloma and biliary fistula associated with hepatorrhaphy for liver injury. *Hepato-Gastroenterol* 1997; **44**:519.
76. Merendino K, Dillard D, Cammock E. The concept of surgical biliary decompression in the management of liver trauma. *Surg, Gynae & Obs* 1963; **117**:285.
77. Lucas CE, Walt AJ. Analysis of randomized biliary drainage for liver trauma in 189 patients. *J Trauma* 1972; **12**:925.
78. Miyayama S, Matsui O, Taki K et al. Bile duct disruption after blunt hepatic trauma: treatment with percutaneous repair. *J Trauma* 2006; **60**:640-3.
79. Buckman RE, Miraliakbari R, Badellino MM. Juxtahepatic venous injuries: a critical review of reported management strategies. *J Trauma* 2000; **48**:978-84.
80. Waltuck T, Crow R, Humphrey L, Kauffman H. Avulsion injuries of the vena cava following blunt abdominal trauma. *Ann Surg* 1970; **171**:67.
81. Schrock T, Blaisdell FW, Mathewson C. Management of blunt trauma to the liver and hepatic veins. *Arch Surg* 1968; **96**:698-704.
82. Hartman A, Yunis J, Frei LW, Pinard BE. Profound hypothermic circulatory arrest for the management of a penetrating retrohepatic venous injury: case report. *J Trauma* 1991; **31**:1310-1.
83. Polanco P, Leon S, Pineda J et al. Hepatic resection in the management of complex injury to the liver. *J Trauma* 2008; **65**:1264-9; discussion 1269-70.
84. Angstadt J, Jarrell B, Moritz M et al. Surgical management of severe liver trauma: a role for liver transplantation. *J Trauma* 1989; **29**:606-8.
85. Tzakis AG. Role of Liver Transplantation in the management of Liver Trauma. *Ann Surg* 1997; **1345**:2848.
86. Leppäniemi A, Haapiainen R. Diagnostic laparoscopy in abdominal stab wounds: a prospective, randomized study. *J Trauma* 2003; **55**:636-45.

87. Elliott D, Rodriguez A, Moncure M et al. The accuracy of diagnostic laparoscopy in trauma patients: a prospective, controlled study. *Internat Surg* 2010; **83**:294.
88. Gorecki PJ, Cottam D, Angus LDG, Shaftan GW. Diagnostic and Therapeutic Laparoscopy for Trauma : A Technique of Safe and Systematic Exploration. *Surg Laparo, Endo & Perc Techn* 2002; **12**:195-198.
89. Kawahara NT, Alster C, Fujimura I, Poggetti RS, Birolini D. Standard examination system for laparoscopy in penetrating abdominal trauma. *J Trauma* 2009; **67**:589.
90. Israelit SH, Krausz MM. Laparoscopic management of a combat military injury during the Lebanon War in August 2006. *J Trauma* 2009; **67**:E108-10.
91. Croome KP, Yamashita MH. Laparoscopic vs open hepatic resection for benign and malignant tumors: An updated meta-analysis. *Arch Surg* 2010; **145**:1109-18.
92. Aldrete JS, Halpern NB, Ward S, Wright JO. Factors determining the mortality and morbidity in hepatic injuries. Analysis of 108 cases. *Ann Surg* 1979; **189**:466-74.
93. Knudson MM, Lim RC, Olcott EW. Morbidity and mortality following major penetrating liver injuries. *Arch Surg* 1994; **129**:256.
94. Scott CM, Grasberger RC, Heeran TF, Williams LF, Hirsch EF. Intraabdominal sepsis after hepatic trauma. *Am J Surg* 1988; **155**:284-8.