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Severe Liver Trauma: Current Management

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Abstract

Background: Severe liver trauma requires rapid haemorrhage control while preserving viable liver and anticipating delayed vascular and biliary complications. Modern management is increasingly non-operative, but safe treatment depends on physiology, injury anatomy and institutional rescue capability.

Objective: To review current management of severe adult liver trauma with emphasis on physiology-based decision-making, liver-specific operative rescue, biliary complications and resource-sensitive pathways.

Findings: Anatomical grade identifies risk but should not determine treatment in isolation. Haemodynamically stable patients with high-grade blunt injury may undergo non-operative management when close monitoring, blood products, urgent surgery and interventional radiology are reliably available. Angioembolization is valuable for selected arterial bleeding but carries risks including hepatic

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necrosis, abscess and bile leak. Persistent instability, generalized peritonitis or another indication for laparotomy requires operative management. Damage-control priorities are compression, perihepatic packing and temporary inflow control. Bleeding that persists despite portal triad occlusion should raise concern for major hepatic venous or retrohepatic caval injury; unnecessary liver mobilisation can abolish tamponade, and complex vascular exposure should be reserved for situations in which physiology, expertise and resources permit definitive repair. Major resection is rarely appropriate during uncontrolled shock, whereas staged resectional debridement and, exceptionally, transplantation may be required. Post-traumatic bile leaks are managed stepwise with drainage, endoscopic decompression or stenting, percutaneous techniques and selected reconstruction. Resource availability is itself a treatment variable: high-grade non-operative management without reliable rescue is unsafe, and damage-control packing followed by transfer may be preferable to attempted definitive surgery in a non-specialist centre.

Conclusions and Relevance: Severe liver trauma is best managed through a physiology-first, liver-specific and capability-aware strategy. Outcomes depend on timely haemorrhage control, appropriate selection for non-operative management, expert-led operative rescue and early recognition of complications.

Keywords: Liver/injuries; Embolization, Therapeutic; Damage control resuscitation; Liver trauma; Non-operative management

Introduction

Severe liver trauma remains one of the most demanding problems in emergency surgery. The liver is large and highly vascular, with dual portal venous and hepatic arterial inflow, and lies adjacent to the diaphragm, retrohepatic inferior vena cava, duodenum, pancreas, colon and right kidney. Major hepatic injury can cause haemorrhagic shock and may coexist with significant thoracic, abdominal or vascular injury. The liver also has major roles in coagulation, metabolism, immune regulation, detoxification and bile production. Severe injury may therefore be followed by coagulopathy, bile leak, infected collections, hepatic necrosis and sepsis.

The liver has substantial regenerative capacity, and this supports a parenchymal-preserving philosophy whenever safe. However, regeneration should not be used to justify delayed haemorrhage control or unnecessary complex reconstruction during haemorrhagic shock. In the acute phase, the priority is damage control, haemostasis, tissue preservation and the management of concomitant injury.

Historically, operative haemorrhage control dominated liver trauma care. Pringle's 1908 paper, "Notes on the Arrest of Hepatic Hemorrhage Due to Trauma," remains a landmark paper and the Pringle manoeuvre is still relevant for inflow occlusion during damage control laparotomy.[1] Over the last four decades, however, the field has moved from mandatory laparotomy to selective non-operative management (NOM), computed tomography (CT) based triage, angioembolization, damage control resuscitation and staged operative care.[2-5] Recent reviews comprehensively describe contemporary assessment and general trauma management of liver injury.[6] The present review therefore focuses particularly on two areas that are less consistently integrated into general trauma algorithms: liver-specific technical rescue of major vascular, parenchymal and biliary injury, and adaptation of management to institutional capability when interventional radiology, specialist hepatopancreatobiliary surgery or critical-care resources are not continuously available. The practical framework is that physiology determines when intervention is required, hepatic anatomy determines what technical rescue is needed, and institutional capability determines where that rescue can safely be delivered. This review addresses severe liver trauma in adults.

Literature search

A focused literature search was undertaken using PubMed, OpenAlex and Google Scholar for publications from January 1990 to July 2026. Search concepts included liver or hepatic trauma, high-grade liver injury, non-operative management, angioembolization, damage-control surgery, hepatic packing, hepatic vascular injury, vena caval injury, bile leak, biliary injury, hepatic resection and transplantation. English-language adult human studies were considered. Priority was given to clinical guidelines, systematic reviews, multicentre and prospective studies, and landmark reports that materially influenced current management. Reference lists of key guidelines and reviews were also examined for relevant studies. Because this was a narrative review, study selection was purposive and no formal risk-of-bias assessment or quantitative synthesis was undertaken.

Classification and decision-making

Severe liver trauma in this review refers principally to American Association for the Surgery of Trauma (AAST) grade IV–V injury. Grade IV includes disruption of 25%–

75% of a hepatic lobe or active bleeding extending beyond the liver parenchyma, whereas grade V includes disruption of more than 75% of a lobe or juxtahepatic venous injury involving the retrohepatic vena cava or major hepatic veins.[7] The World Society of Emergency Surgery (WSES) integrates anatomy with physiology: haemodynamically stable AAST IV–V injuries are WSES grade III, whereas haemodynamic instability makes an injury WSES grade IV irrespective of anatomical grade.[8]

The key clinical point is that anatomical grade implies risk but does not dictate management in isolation. A grade IV or V injury identifies a patient at high risk of bleeding, complications and failure of NOM, but it does not automatically mandate laparotomy. Conversely, a lower-grade injury in an unstable patient with peritonitis, bowel injury or major associated trauma may require urgent operation. Modern decision-making should consider five linked questions:

1. Is the patient haemodynamically stable?
2. Is the patient responding to resuscitation?
3. Is there peritonitis or another indication for laparotomy?
4. Does CT show active arterial bleeding or a contained vascular lesion?
5. Can the institution provide close monitoring, transfusion, and interventional radiology?

NOM is appropriate only when serial reassessment, blood products, interventional radiology and urgent operative rescue are reliably available. Associated injuries are central. Major traumatic brain or spinal injury, thoracic or abdominal trauma, major vascular injury, pelvic or orthopaedic trauma and other injuries requiring urgent intervention may determine treatment priorities more than the liver grade itself. The decision should be based on the whole injury pattern, not the liver injury grade alone. Recent pathway-level evidence further supports physiology-based decision-making. In a protocolized cohort of 350 patients, NOM was initiated in 86.9% and delayed laparotomy was required in 4.9%, most commonly for haemodynamic deterioration, ongoing or delayed haemorrhage, or failed haemostatic control after interventional radiology. Shock index, Injury Severity Score and lactate independently predicted mortality, whereas anatomical grade alone had limited discriminatory value.[9] This approach is consistent with contemporary guideline frameworks that prioritize physiology, associated injuries and rescue capability over anatomical grade alone.[8,10] The principal clinical and institutional decision modifiers are summarized in Table 1.

Initial assessment and resuscitation

Initial assessment follows Advanced Trauma Life Support xABCDE priorities, with immediate control of exsanguinating haemorrhage, airway and breathing assessment, circulatory resuscitation, neurological assessment and exposure with prevention of hypothermia.[5] Extended focused assessment with sonography in trauma (E-FAST) can identify intraperitoneal fluid rapidly, but it does not grade liver injury or reliably exclude hollow viscus injury. A negative

Table 1. Decision modifiers in severe liver trauma

Domain	Key findings	Management implication
Physiology	Stable, transient responder, non-responder, shock, lactate trend, transfusion need	Physiology overrides grade
Anatomy	AAST grade IV–V, devascularization, juxtahepatic venous injury	Identifies risk and need for senior planning
CT vascular findings	Contrast blush, active extravasation, pseudoaneurysm, arteriovenous fistula	Consider angiography/embolization if stable or stabilized
Peritonitis	Abdominal tenderness, guarding, free air, suspected bowel injury	Usually operative exploration
Associated injuries	Hollow viscus, pancreas/duodenum, spleen, kidney, pelvis, thorax, brain, major vessels	May determine pathway more than liver injury
Resources	Blood bank, ICU, operating room, interventional radiology, HPB support, transfer network	Determines safety of NOM and timing of transfer

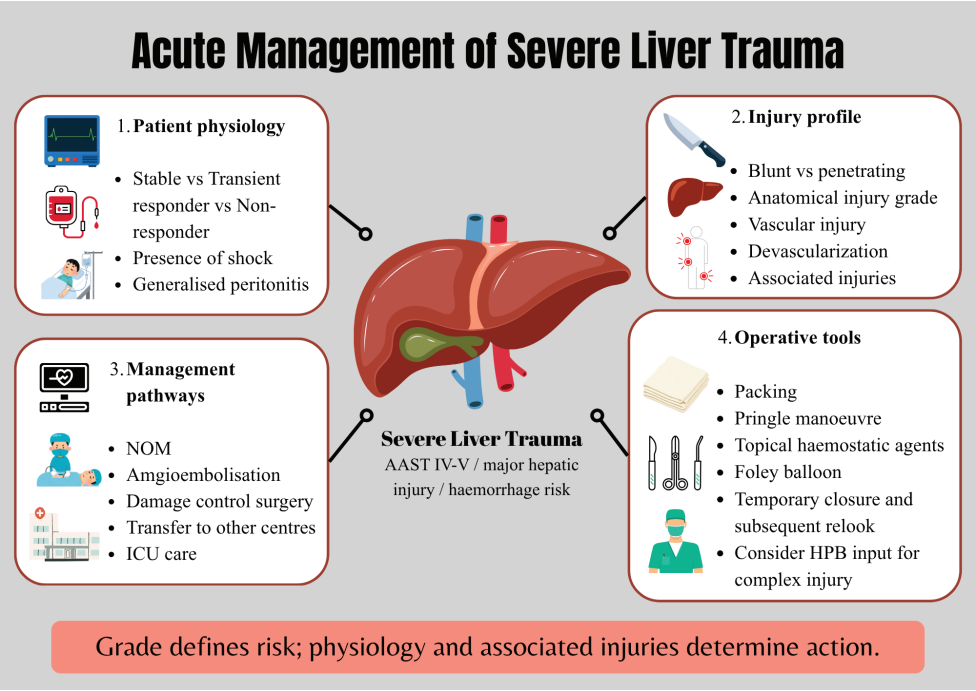
AAST: American Association for the Surgery of Trauma; CT: computed tomography; HPB: hepatopancreatobiliary; ICU: intensive care unit; NOM: non-operative management.

E-FAST examination does not exclude significant hepatic injury and should not override concerning physiology, mechanism or subsequent clinical deterioration.[8,10] Contrast-enhanced CT is the investigation of choice in haemodynamically stable patients or those who have responded to resuscitation.[8,10]

The practical decision is whether the patient can safely proceed to CT, angioembolization or observation. Stable patients should undergo contrast-enhanced CT to define the grade of liver injury, presence of vascular injury, presence and extent of haemoperitoneum and associated injuries. Transient responders require individualized assessment; CT is appropriate only after sufficient physiological stabilization and where immediate operative or endovascular rescue remains available. If CT and interventional radiology are immediately available, a hybrid pathway may be appropriate. Persistent non-responders and patients with generalized peritonitis should proceed to operative management.[8,10]

Resuscitation and haemorrhage control should proceed as a single pathway. Massive-transfusion activation, active warming, calcium replacement and correction of trauma-associated coagulopathy should accompany definitive haemostasis. Tranexamic acid should be administered as early as possible to patients who are bleeding or at risk of significant bleeding and within three hours of injury; treatment should not await viscoelastic results. Where available, thromboelastography or rotational thromboelastometry can subsequently guide goal-directed haemostatic therapy.[11] Whole blood may be incorporated into major-haemorrhage protocols according to local transfusion capability, although the 2026 SWiFT randomized trial did not demonstrate superiority of prehospital whole blood over standard component care for death or massive transfusion.[12] Resuscitative endovascular balloon occlusion of the aorta has been proposed as a temporary bridge in selected exsanguinating torso haemorrhage but is not a liver-specific treatment. The UK-REBOA randomized trial showed no survival benefit and possible harm; REBOA should therefore not delay laparotomy, packing or other definitive haemorrhage control.[13] The principal acute assessment and treatment domains are illustrated in Figure 1.

Figure 1. Acute management of severe liver trauma.



The acute management of severe liver trauma is guided by four interrelated domains: patient physiology, injury profile, available management pathways and operative rescue tools. Anatomical grade identifies injury severity and complication risk but does not independently determine treatment. Haemodynamic response, peritonitis, associated injuries, computed tomography findings and institutional capability determine selection among non-operative management, angioembolization, damage control surgery, definitive surgery or transfer. Operative options include perihepatic packing, temporary inflow occlusion with the Pringle manoeuvre, balloon tamponade of selected deep bleeding tracts, temporary abdominal closure and planned relook surgery.

Abbreviations: AAST, American Association for the Surgery of Trauma; CT, computed tomography; HPB, hepatopancreatobiliary; ICU, intensive care unit; NOM, non-operative management.

Non-operative management of severe liver trauma

NOM is now the preferred approach for haemodynamically stable blunt liver trauma in appropriately selected patients.[8,10,14] Landmark prospective and multicentre studies established that many adult blunt hepatic injuries can be managed without laparotomy when patients are stable and can be closely monitored. In Croce's prospective study, non-operatively managed patients required fewer transfusions than matched operative controls (1.9 vs 4.0 units) and had fewer abdominal complications (3% vs 11%).[2] Pachter's 13-centre study reported that 98.5% of 404 selected patients avoided laparotomy, although grade IV–V injuries accounted for two-thirds of those requiring operation.[3] Malhotra and colleagues described the paradigm shift from operative to NOM in stable blunt hepatic injury.[4] Van der Wilden subsequently reported 91.3% successful NOM among selected grade IV–V blunt injuries.[15]

This approach extends to carefully selected high-grade injuries. In a UK multicentre cohort of 190 grade IV–V injuries, 64% were initially managed non-operatively and only 7% subsequently required surgery. Liver-specific complications occurred in 18%, predominantly bile leak/biloma (20 patients) and abscess/infection (7 patients).[16] Higher Injury Severity Score, lower admission systolic pressure, grade V injury and penetrating mechanism predicted operative treatment. Across the studies, successful NOM is primarily associated with stable or responding physiology, absence of another indication for laparotomy and reliable rescue capability; failure becomes more likely with physiological deterioration, ongoing bleeding, grade V injury and greater overall injury burden.[8,14-16]

NOM is an active process which involves close monitoring and serial clinical examination. It requires a monitored setting, repeated clinical examination, serial haemoglobin and lactate assessment, access to blood products, immediate operative capability and a low threshold for repeat imaging or intervention when the clinical course changes. Intensive care or high-dependency monitoring is recommended for many high-grade injuries, especially when there is large-volume haemoperitoneum, ongoing transfusion requirement, vascular injury, associated injuries or marginal physiology. The role of surveillance imaging remains unsettled. Repeat imaging aims principally to identify treatable vascular and biliary complications. The pooled risk of hepatic pseudoaneurysm rises to 4.6% after grade IV and 10.6% after grade V injury.[17] Although older guidelines favour clinically triggered reimaging, recent prospective multicentre evidence found that scheduled imaging identified complications in 20.6% of grade IV and 34.1% of grade V injuries, with most detected within 36–72 hours.[18] Braschi and colleagues subsequently reported liver-specific complications in 23.1% and reintervention in 19.2% among patients with grade IV–V injury in a two-centre cohort of 229 blunt liver injuries.[19] Together, these findings support consideration of scheduled surveillance imaging after high-grade injury when detection would alter management, although the optimal timing, modality and patient selection remain uncertain. Venous thromboembolism prevention remains important during NOM. Mechanical prophylaxis is appropriate when not contraindicated, and low-molecular-weight heparin should be introduced once haemostatic stability is established.[8]

During NOM, escalation is prompted by haemodynamic deterioration, ongoing transfusion requirement or unexplained haemoglobin fall, rising lactate, new or increasing abdominal pain or peritonism, fever or sepsis, jaundice, or bilious drain output.[8,14] A point of caution is that success in high-volume trauma centres should not be generalized to all hospitals. NOM is safest when deterioration can be recognized and rescued quickly. Smaller centres with limited capacity for close monitoring and rescue should have a low threshold for transferring to a trauma centre. Practical circumstances in which NOM should not be initiated or should be discontinued are summarized in Table 2.

Angioembolization and hybrid care

Angioembolization is a major adjunct in severe liver

Table 2. When NOM should not be initiated or continued

Situation	Key triggers
Immediate operation	Persistent instability/non-response; generalized peritonitis; associated injury requiring laparotomy
Local NOM unsafe	Inadequate monitoring, blood products, emergency surgery, or timely rescue/transfer
Failure of NOM	New instability; rising transfusion need or unexplained haemoglobin fall; worsening lactate/peritonism; significant delayed bleeding, vascular, biliary or septic complication

Note: High injury grade alone is not a contraindication to NOM in a stable patient with adequate monitoring and rescue capability.

trauma. Its main role is control of arterial bleeding in patients who are stable or stabilized enough to reach the angiography suite. Common indications include contrast blush, active arterial extravasation, pseudoaneurysm, arteriovenous fistula, delayed haemorrhage, haemobilia and persistent arterial bleeding after operative packing. Ciraulo and colleagues helped establish selective hepatic arterial embolization as an extension of resuscitation in grade IV and V blunt hepatic injury.[20]

Contrast extravasation should not be equated automatically with mandatory embolization. In a 23-centre study of 128 stable patients with blunt liver injury and CT contrast extravasation, observation-first and angioembolization-first strategies had similar adjusted risks of liver-related complications and similar mortality.[21] The embolization group had more severe anatomical injuries, and the study was not randomized; therefore, the findings support selective rather than reflex embolization but do not establish the superiority of observation.

A national registry analysis of 18,445 severe liver injuries found that the use of angioembolization increased between 2017 and 2022, while overall in-hospital mortality remained 18.7%.[22] Integrated operative and endovascular pathways were associated with lower adjusted mortality than laparotomy alone, but registry data are limited in their ability to determine optimal treatment sequence or remove selection and survivor bias.

Angioembolization can support both non-operative and operative pathways. In stable patients with CT blush, it may prevent the failure of NOM. In unstable patients who undergo damage control laparotomy and packing, postoperative angiography may control persistent arterial bleeding that is difficult to control surgically. Hybrid operating rooms may reduce transfer delays, but their availability varies between centres.

Angioembolization should not be portrayed as risk-free. Mohr and colleagues described the combination of low mortality but high morbidity after hepatic embolization.[23] Later work highlighted hepatic necrosis as an important complication, especially after extensive embolization in high-grade injuries.[24] A systematic review likewise identified hepatic necrosis, abscess formation and bile leak or biloma as important morbidities after hepatic angioembolization.[25] These complications may require radiological drainage, endoscopic treatment or delayed surgery. Super-selective embolization, avoidance of unnecessary non-selective occlusion and close post-procedure surveillance are therefore important. When technically feasible, segmental rather than main hepatic arterial embolization is preferred to limit ischaemic burden; temporary embolic agents such as Gelfoam may also be used according to bleeding pattern and interventional-radiology strategy.[26]

Operative management and damage control surgery

Operative management remains essential for unstable non-responders, patients with generalized peritonitis and patients with associated injuries requiring laparotomy. The modern shift toward non-operative care should not create a false impression that operative skill is obsolete. Asensio and colleagues emphasized that trauma surgeons still need to operate for complex grade IV–V hepatic injuries, although angioembolization may help.[27]

The initial operation should follow damage-control principles: rapid haemorrhage and contamination control, avoidance of prolonged definitive reconstruction, and transfer to intensive care for correction of hypothermia, acidosis and coagulopathy. Complex resections and definitive reconstructions should generally be avoided during index surgery. If resection or debridement is needed for the devascularized liver, this is usually safer if performed as a staged procedure by experienced trauma or hepatopancreatobiliary surgeons.

The Pringle manoeuvre remains useful because it is both therapeutic and diagnostic. Temporary occlusion of the hepatoduodenal ligament reduces hepatic arterial and portal venous inflow. A marked reduction in bleeding suggests a source from hepatic arterial or portal venous branches. If major bleeding persists, hepatic venous, retrohepatic caval or back-bleeding sources should be considered.

Major hepatic venous and retrohepatic caval injury

Persistent major haemorrhage despite effective portal triad occlusion should prompt consideration of a juxtahepatic hepatic venous or retrohepatic caval source, although aberrant arterial inflow should also be excluded. Unnecessary mobilisation of the injured liver may release posterior tamponade and convert partially controlled venous bleeding into exsanguinating haemorrhage. Manual compression and correctly directed perihepatic packing should therefore remain the initial strategy when they control bleeding.[8]

When packing achieves haemostasis in a patient with severely deranged physiology, the appropriate operation may be to stop. Correction of hypothermia, acidosis and coagulopathy takes priority over difficult vascular exposure. Persistent uncontrolled venous haemorrhage requires escalation according to anatomy, physiology and expertise.

Options include direct venorrhaphy after adequate vascular control, repair with selective or total hepatic vascular isolation, and selected lobar resection.[8] Complete hepatic vascular exclusion may be poorly tolerated in profound shock. Veno-venous bypass and atriocaval shunting have been described but are technically demanding rescue strategies with historically high mortality and should not be regarded as routine next steps after packing.[8]

Useful operative manoeuvres include manual compression, anatomical packing, temporary inflow occlusion, selective vessel ligation, topical haemostatic adjuncts and temporary abdominal closure. Balloon tamponade has been described for selected deep transfixing or non-compressible hepatic tracts when direct compression and packing are insufficient, but it is an uncommon rescue technique rather than a routine component of liver-trauma surgery.[8,29]

Perihepatic packing remains one of the most important damage control techniques. Packs should reconstitute normal liver anatomy while avoiding unnecessary caval compression or abdominal compartment syndrome (ACS). Persistent arterial bleeding after packing should prompt postoperative or intraoperative angiography when available. Pack removal should be planned after correction of major physiological derangement rather than performed reflexively. In a damage-control pathway, relook laparotomy and pack removal are undertaken after adequate intensive-care resuscitation, generally within approximately 24–72 hours; removal before the first 24 hours may increase rebleeding risk.[30] Packs should be removed sequentially in an operating room with immediate access to blood products and haemostatic rescue. Temporary abdominal closure allows correction of physiology, planned relook surgery and staged repair of liver injury. Recent bicentre observational data suggest that open-abdomen management with negative-pressure therapy is feasible in selected patients with major liver trauma.[31]

Hepatic arterial and portal venous injury

Major inflow vascular injury should be approached according to the vessel involved. An identifiable proper hepatic arterial injury should be repaired when feasible. If repair is not possible during damage-control surgery, selective right or left hepatic arterial ligation is preferable to unnecessary proximal arterial sacrifice. If the right or common hepatic artery must be ligated, cholecystectomy should be considered because of the risk of gallbladder ischaemia; hepatic necrosis, abscess and biloma are also recognized consequences of major arterial devascularization.[8] Main portal venous injury should preferentially undergo primary repair. Main portal vein ligation is an extreme salvage manoeuvre because hepatic necrosis and severe mesenteric venous congestion may follow, particularly when hepatic arterial inflow is compromised. For lobar or segmental portal venous injuries, packing or resection of unsalvageable parenchyma may be preferable to ligation.[8]

Resection and transplantation

The role of hepatic resection should distinguish limited resectional debridement from formal anatomical hepatectomy. Clearly devitalized or freely disrupted parenchyma may occasionally require limited resectional debridement, but major anatomical resection should rarely be undertaken as the initial haemostatic manoeuvre during uncontrolled shock. Once haemorrhage is controlled and physiology restored, staged segmental or lobar resection may be appropriate for irreversible devascularization, necrosis, uncontrolled sepsis or anatomically unsalvageable liver.[8] Liver transplantation lies at the extreme end of this pathway. It is exceptionally uncommon but may be considered after otherwise unsalvageable hepatic destruction, extensive irreversible necrosis or post-traumatic hepatic failure when conventional reconstruction is not feasible. Only 72 liver transplants for trauma were identified in the United Network for Organ Sharing database between 1987 and 2022, underscoring the rarity and highly selected nature of this strategy.[28] Early discussion with a transplant centre is appropriate when such a trajectory becomes plausible.

Hepatopancreatobiliary input is valuable when there is juxtahepatic venous injury, major devascularization, complex bile duct injury, delayed necrosis, difficult biliary fistula or consideration of staged debridement/resection. However, the first operation in an unstable patient should remain damage-control focused. Specialist input is most valuable after initial damage control, when organ-preserving reconstruction or staged definitive management is considered. A cohort from a centre using a structured trauma–liver surgery partnership provides supportive observational evidence for early hepatobiliary involvement in complex high-grade injury. In a centre with an established active partnership between trauma and liver surgeons, operative 30-day mortality for grade IV–V injury was 23.4% and liver-attributable operative mortality was 15.7%.[32] These observational outcomes cannot isolate the effect of specialist collaboration, but the model supports early HPB involvement when complex haemostasis, major devascularization or staged hepatic reconstruction is anticipated. Selected management options,

operative manoeuvres and their limitations are summarized in Table 3.

Penetrating liver trauma

Penetrating liver trauma requires particular attention to wound trajectory and associated hollow-viscus, diaphragmatic and vascular injuries. Haemodynamically unstable patients and those with peritonitis require laparotomy. Stable patients with low-energy penetrating injury may be considered for selective NOM in experienced centres if CT defines the tract, there is no generalized peritonitis and monitoring is reliable. Gunshot wounds, transabdominal trajectories, thoracoabdominal wounds and uncertainty about bowel injury lower the threshold for operative or laparoscopic evaluation. The principles of operative management are similar: control haemorrhage, avoid prolonged complex surgery during shock, manage contamination and plan staged rescue.[30] Angioembolization may still be useful when the dominant problem is arterial bleeding and the patient is stable enough for angiography. Recent national data suggest a selective role for angioembolization in penetrating liver trauma. After propensity matching, mortality did not differ significantly between angioembolization and surgery, 2.0% versus 4.8%, although angioembolization was associated with longer hospital, intensive-care and ventilation durations.[33] These findings support integration of endovascular treatment in stable or stabilized patients with a dominant arterial bleeding source, but not its substitution for laparotomy in uncontrolled shock, peritonitis or suspected hollow-viscus injury.

Complications and delayed rescue

The second phase of severe liver trauma includes delayed haemorrhage, vascular complications, biliary complications, infection and tissue necrosis. High-grade injury carries a substantial risk of liver-related complications.[34] Greater injury severity, transfusion requirement, devascularization and associated abdominal injury are associated with increased hepatic morbidity.[35] Delayed haemorrhage or pseudoaneurysm is usually treated by angioembolization. Abscess is commonly managed with image-guided drainage and antibiotics, whereas hepatic necrosis requires individualized treatment ranging from drainage and antimicrobial therapy to staged debridement or resection.[35]

Post-traumatic bile leakage ranges from small peripheral leaks that may resolve with drainage to central duct disruption, disconnected ducts and extrahepatic bile duct injury. Symptomatic bilomas should undergo image-guided drainage, which also helps quantify ongoing bile output.[36] In a 10-centre study of 2,225 patients with AAST grade III or higher liver injury, bile leak occurred in 5%, typically around hospital day 6; 30% were managed with drainage alone, while higher-output leaks more often required ERCP, percutaneous transhepatic drainage or surgery.[37] Persistent

Table 3. Current management options and operative tools

Situation or tool	Role	Key caution
Non-operative management	Stable blunt injury without peritonitis or other laparotomy indication	Requires monitoring and rescue capacity
Angioembolization	Arterial blush, pseudoaneurysm, delayed haemorrhage, persistent arterial bleeding after packing	Risk of necrosis, abscess, bile leak and rebleeding
Manual compression	Immediate temporary control during laparotomy	Provides rapid temporary haemorrhage control while packing, vascular control or definitive rescue is prepared
Perihepatic packing	Damage control for major bleeding	Avoid overpacking and monitor for ACS
Pringle manoeuvre	Temporary inflow control; helps distinguish inflow from venous/caval bleeding	Persistent bleeding suggests non-inflow source
Foley balloon tamponade	Deep bleeding tract or cavity not controlled by surface packing	Bridge technique requiring reassessment
Temporary abdominal closure	Allows correction of physiology and planned relook	Requires active closure strategy and ICU care
HPB referral	Complex bile duct injury, devascularization, necrosis, staged resection/debridement	Should not delay initial life-saving damage control

HPB: hepatopancreatobiliary; ICU: intensive care unit; ACS: Abdominal compartment syndrome

or high-output leakage should prompt biliary decompression. ERCP with transpapillary stenting, with selective sphincterotomy, is appropriate when ductal continuity is preserved. An output of approximately 300–400 mL/day has been proposed as a pragmatic threshold for considering ERCP, although this is not absolute.[37] Nasobiliary drainage can provide temporary decompression and repeat cholangiographic assessment, while percutaneous transhepatic drainage is useful when endoscopic access is not possible or for selected proximal/disconnected ducts. Extrahepatic bile duct injury is rare and may present late; a systematic review of 66 blunt-trauma injuries reported a mean diagnosis at 11 days in stable patients initially managed non-operatively.[38] Persistent jaundice, recurrent bilious collections or bile peritonitis should raise concern for a major bile leak or duct injury and prompt further biliary evaluation.[39] Bilothorax, including biliopleural fistula, is uncommon and generally requires pleural drainage with control of the biliary source.[40] Major duct disruption, uncontrolled sepsis or failure of endoscopic/percutaneous treatment warrants early HPB involvement and consideration of definitive reconstruction after physiological stabilization.

ACS should be anticipated after massive transfusion, visceral oedema, extensive packing, ongoing shock or temporary abdominal closure. ACS should be suspected when increasing abdominal distension or tension is accompanied by new organ dysfunction. Bladder-pressure measurement can confirm the diagnosis when clinically suspected; routine pressure monitoring is unnecessary in patients without relevant risk or clinical features. ACS is defined by sustained intra-abdominal pressure above 20 mmHg with new organ dysfunction and requires urgent recognition because progressive organ failure may be fatal.[41]

Longer-term outcomes after severe trauma include physical function, return to work, psychological health and quality of life. Future liver-trauma studies should therefore complement mortality and procedural outcomes with functional recovery and validated patient-reported outcomes.[42]

Outcome reporting in liver trauma is also becoming more standardized. A 2026 modified Delphi study involving 20 experts identified 12 core outcomes across operative decision-making, success of non-operative management, hepatic complications and healthcare utilization, with strong inter-rater agreement.[43] Future studies should report these core clinical outcomes consistently, while functional recovery, quality of life and patient-reported outcomes should be developed as complementary longer-term endpoints. Landmark evidence shaping current liver-trauma management is summarized in Table 4. The multidisciplinary rescue, recovery and systems-of-care pathway is illustrated in Figure 2.

Resource-sensitive pathway

Severe liver trauma is best managed as a system rather than a single technical problem, with trauma and HPB surgery, interventional radiology, critical care, transfusion medicine and endoscopy contributing at different stages. Safe non-operative management of grade IV–V injury is resource dependent and requires serial reassessment, blood products, emergency operative rescue and access to further haemostatic intervention.[8,10] Observation without

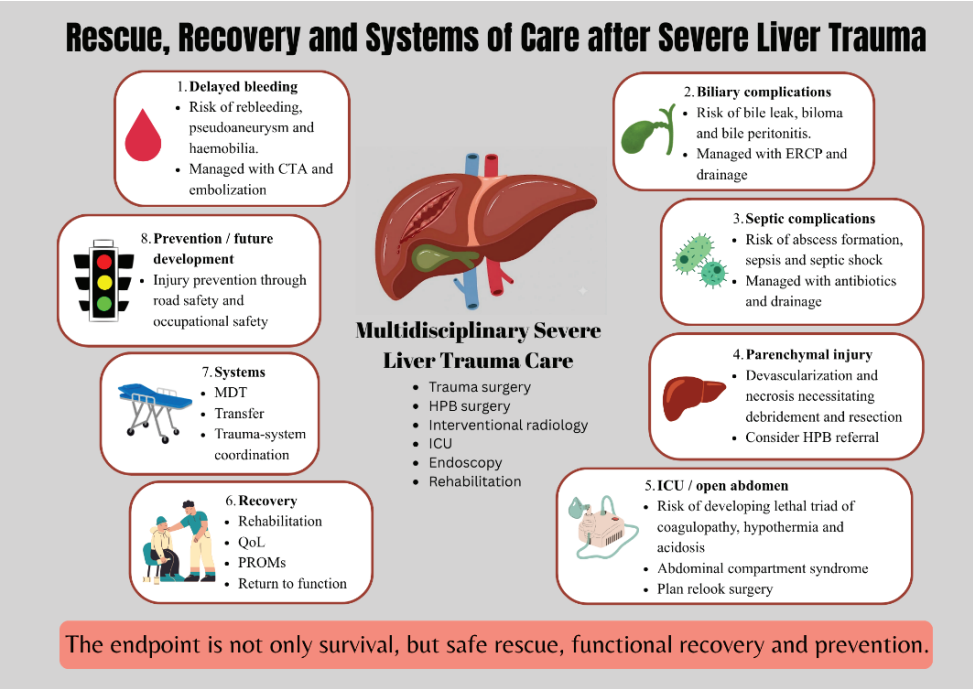
Table 4. Landmark and contemporary evidence in severe liver trauma

Study	Design and population	Key findings	Clinical contribution
Pringle[1], 1908	Historical operative description	Temporary occlusion of the hepatoduodenal ligament was described to arrest traumatic hepatic haemorrhage.	Established temporary hepatic inflow control; the manoeuvre remains both therapeutic and diagnostically useful during trauma laparotomy.
Pachter et al.[3], 1996	Multicentre study of 404 adults managed non-operatively at 13 level I trauma centres	Demonstrated that selected haemodynamically stable blunt liver injuries could be managed without mandatory laparotomy.	Landmark multicentre validation of non-operative management, provided close monitoring and operative rescue are available.
Asensio et al.[27], 2003	Operative series of 103 AAST grade IV–V injuries	Mean Injury Severity Score was 33, mean estimated blood loss was 9414 mL and overall survival was 43%; 80 injuries were penetrating.	Illustrates the extreme physiological burden of injuries requiring operation and the continuing importance of damage control surgery.
van der Wilden et al.[15], 2012	Multicentre cohort of 393 adults with grade IV–V blunt liver injury	NOM was attempted in 262 of 393 patients (66.7%) and succeeded in 91.3%.	Established the feasibility of non-operative management for selected high-grade blunt injuries.

WSES[8], 2020	International evidence-based guideline	Recommended integration of anatomical grade, haemodynamic status and associated injuries; supported non-operative management of stable high-grade injuries in appropriately resourced centres.	Provides the principal multidisciplinary framework for modern management.
Nguyen et al.[21], 2024	WTA multicentre study of 128 stable patients with blunt liver injury and CT contrast extravasation	Observation-first and angioembolization-first strategies had similar mortality, 5.3% versus 5.7%. After adjustment, an embolization-first strategy was not independently associated with more liver-related complications.	Suggests that CT contrast extravasation alone should not mandate reflex angioembolization in every stable patient.
Ramos-Jimenez et al.[32], 2025	Single-centre cohort of 179 grade IV–V injuries managed through trauma surgery–liver surgery collaboration	Among operatively managed patients, 30-day mortality was 23.4% and liver-attributable mortality was 15.7%; 19.4% of planned non-operative management failed.	Supports early liver-surgery involvement for complex haemorrhage, devascularization, venous injury and staged definitive treatment.
Schaid et al.[22], 2025	TQIP study of 18,445 severe liver injuries, 2017–2022	Observation was used in 47.0%, laparotomy alone in 42.7%, laparotomy followed by embolization in 5.1% and embolization alone in 4.5%. Overall mortality remained 18.7% despite increasing embolization use.	Shows that severe liver injury mortality remains substantial and supports integrated operative–endovascular pathways rather than reliance on a single modality.
Brooks et al.[16], 2026	UK multicentre study of 190 grade IV–V injuries	Initial non-operative management was used in 64%; only 7% subsequently required surgery. Overall mortality was 7% and liver-specific complications occurred in 18%.	Provides contemporary multicentre support for high-grade non-operative management while emphasizing continued complication surveillance.
Cirillo et al.[9], 2026	Protocolized single-centre cohort of 350 blunt and penetrating injuries	Non-operative management was initiated in 86.9%, with conversion to laparotomy in 4.9%. Shock index, Injury Severity Score and lactate predicted mortality, whereas AAST grade alone had limited discrimination.	Reinforces physiology-first decision-making and the limited value of anatomical grade as an isolated treatment trigger.
Braschi et al.[19], 2026	Two-centre study of 229 blunt liver injuries	Grade IV–V injuries had liver-specific complications in 23.1% and required reintervention in 19.2%, compared with 2.0% and 2.6%, respectively, for grade II–III injuries.	Reopens the question of scheduled surveillance imaging after high-grade injury, although optimal timing and patient selection remain uncertain.
Cain et al.[43], 2026	Modified Delphi consensus involving 20 trauma surgery experts	The expert panel generated 102 initial suggestions, which were consolidated into 41 unique outcomes; 12 outcomes reached final consensus across four domains. Inter-rater agreement was strong (ICC 0.89).	Provides a standardized outcome set for future liver-trauma studies and facilitates comparison across centres and management strategies.
Schellenberg et al.[37], 2022	Retrospective 10-centre study of 2,225 patients with AAST grade ≥III liver injury	Bile leak occurred in 108 patients (5%); 30% were managed with external drainage alone, while patients requiring ERCP, PTBD or surgery had significantly higher bilious drain output	Defines the burden of post-traumatic bile leak and supports a step-up approach in which external drainage may suffice for selected patients, with persistent or higher-output leaks prompting biliary intervention

Abbreviations: AAST, American Association for the Surgery of Trauma; CT, computed tomography; TQIP, Trauma Quality Improvement Program; WSES, World Society of Emergency Surgery; WTA, Western Trauma Association; ERCP, Endoscopic retrograde cholangiopancreatography; PTBD, Percutaneous transhepatic biliary drainage.

Figure 2. Rescue, recovery and systems of care after severe liver trauma.



Management extends beyond initial haemorrhage control and includes surveillance and rescue for delayed bleeding, pseudoaneurysm, haemobilia, biliary complications, abscess, sepsis, hepatic devascularization or necrosis, and complications related to critical illness or the open abdomen. Treatment may require repeat imaging, angioembolization, percutaneous drainage, endoscopic therapy, antibiotics, reoperation, staged hepatic debridement or resection, and hepatopancreatobiliary referral. Multidisciplinary care incorporates trauma surgery, hepatopancreatobiliary surgery, interventional radiology, intensive care, endoscopy and rehabilitation. Longer-term priorities include functional recovery, quality of life, patient-reported outcomes, trauma-system coordination, and injury prevention.

Abbreviations: ACS, abdominal compartment syndrome; CTA, computed tomography angiography; ERCP, endoscopic retrograde cholangiopancreatography; HPB, hepatopancreatobiliary; ICU, intensive care unit; MDT, multidisciplinary team; PROMs, patient-reported outcome measures; QoL, quality of life.

reliable rescue capability should not be regarded as equivalent to non-operative management in a mature trauma system.

Stable or adequately stabilized patients whose needs exceed local capability should be discussed early with a definitive trauma or HPB centre. Arterial injury requiring embolization, extensive devascularization, suspected juxtahepatic venous injury or complex biliary, vascular or hepatic complications should lower the threshold for transfer; outcomes from specialist centres should be interpreted in the context of the systems that enabled them.[16,32] Persistent non-responders require local haemorrhage control before transfer. Where interventional radiology is unavailable and the liver is the dominant bleeding source, manual compression and perihepatic packing may be the primary damage-control operation.[8] Once haemorrhage is controlled, temporary abdominal closure, continued resuscitation and transfer may be safer than unnecessary liver mobilisation, caval exposure or formal hepatectomy. A practical pack–resuscitate–transfer pathway should communicate the injury pattern, physiological trajectory, transfusion, packs placed, portal triad occlusion, vascular ligation, suspected caval injury and abdominal closure. Local management of grade IV–V injury requires monitored care, blood-product support, contrast-enhanced CT, immediate operative capability and critical care, with interventional radiology, advanced endoscopy, vascular and HPB expertise available locally or through a defined transfer network. Regional systems should support clear referral criteria, shared imaging and direct surgeon-to-surgeon communication.

Conclusion

Current management of severe liver trauma is physiology-first, multidisciplinary and staged. Anatomical grade identifies risk, but haemodynamic response, peritonitis, associated injuries, CT findings and rescue capacity determine treatment. Stable patients with high-grade blunt

liver injury can often be managed non-operatively when monitoring, blood products, urgent surgery and angioembolization are available. Unstable patients still require operative skill, damage control surgery and timely escalation. The best outcomes depend not on choosing operation or observation as an ideology, but on selecting the right intervention at the right time and rescuing complications before they become irreversible.

Author contributions

Dai Ailin: Literature review; clinical interpretation; tables and figures; critical revision and final approval of the manuscript.

Rebekah Young: Literature review; clinical interpretation; critical revision of the manuscript; and final approval of the manuscript.

Vishal G. Shelat: Conceptualization; literature review; interpretation of evidence; development of the clinical framework, tables and figures; writing of the original draft; critical revision and final approval of the manuscript.

All authors meet the International Committee of Medical Journal Editors criteria for authorship, have reviewed and approved the final manuscript, and accept responsibility for the integrity of the work.

Declarations

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Consent

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