World J Surg (2023) 47:1271–1281
https://doi.org/10.1007/s00268-023-06926-5

ORIGINAL SCIENTIFIC REPORT

The Effect of Angioembolization Versus Open Exploration for Moderate to Severe Blunt Liver Injuries on Mortality

Jared Gallaher[1] · Victoria Burton[1] · Andrew B. Schneider[1] · Trista Reid[1] · Lauren Raff[1] · Charlotte B. Smith[1] · Anthony Charles[1]

Accepted: 11 January 2023 / Published online: 27 January 2023

Abstract

Introduction Blunt liver injury is common and is associated with a high morbidity and mortality. More severe injuries often require either angioembolization or open operative repair, depending on patient factors and facility capacity. We sought to describe patient outcomes based on intervention type.

Methods We analyzed the National Trauma Data Bank (2017–2019) using ICD-10 codes to identify adult patients with blunt liver injury and their interventions. AIS (Abbreviated Injury Scale) scores were used to group patients based on liver injury severity (AIS 2–6). Logistic regression modeling was used to estimate the adjusted odds ratio of death based on intervention type, excluding patients with severe injury.

Results Of 2,848,592 trauma patients, 50,250 patients had a blunt liver injury. Among patients with AIS 3/4/5 injury, 1,140 had angioembolization, 1,529 had an open repair, and 188 had both angioembolization and open repair. In comparison with no intervention and adjusted for age, sex, shock index, ISS, and transfusion total (first four hours), angioembolization was associated with a significant decrease in the odds of mortality for patients with an AIS 4 (OR 0.68, 95% CI 0.47, 0.99) and AIS 5 injury (OR 0.39, 95% CI 0.24, 0.64). In patients with an AIS 5 injury, open repair had an increased odds of mortality at OR 1.99 (95% CI 1.47, 2.69).

Conclusion In an analysis of a national trauma database, patients with a moderate to severe injury (AIS 4 or 5), angioembolization was associated with a significant reduction in the adjusted odds of mortality compared to open repair and should be considered when clinically appropriate.

Introduction

The liver is one of the most injured intra-abdominal organs after blunt trauma and carries significant morbidity and mortality. In-hospital mortality after a liver injury is as high as 16% overall and approaches 65% -95% in higher grade injuries [1, 2]. Evidence also suggests that the incidence of blunt liver injuries is increasing, likely due to parallel increases in motor vehicle collisions (MVCs). [3] The high mortality associated with liver trauma is attributable to its robust blood supply and the risk of associated major vessel injury leading to massive hemorrhage. In addition, delayed complications, such as bile leak, are common, which places patients at risk of peritonitis or sepsis. [4] Blunt liver injuries also have a high incidence of concomitant multi-system trauma, complicating clinical management. [5–8] Consequently, trauma surgeons often face a complex decision on the appropriate intervention, especially in higher-grade injuries.

In the 1990s, the approach to blunt, traumatic liver injury shifted to selective non-operative management, in

✉ Jared Gallaher
jared_gallaher@med.unc.edu

1 Division of Trauma and Acute Care Surgery, Department of Surgery, University of North Carolina at Chapel Hill, 4006 Burnett Womack Building, Chapel Hill, NC 27599-7228, USA

contrast to routine operative exploration. [9] Both retrospective and prospective data from the era supported close monitoring in patients with stable hemodynamics, even with more severe liver injuries. [10–12] Concurrently, with the recognition that some liver injuries could be closely observed, angioembolization (AE) of liver hemorrhage became more widely available for patients with active arterial bleeding. [13] In comparison with operative exploration, AE offers the advantage of a less invasive procedure and the ability to manage bleeding from large and small vessels that may be difficult to control otherwise. [14]

Given the complexity and associated mortality of liver injury, there is an urgent need for clarity on what interventions surgeons should prioritize, particularly for moderate and severe liver injuries. Unfortunately, there is a dearth of national data on the comparative clinical outcomes of these differing procedural approaches, despite an increasing incidence of liver injury. Consequently, this study sought to quantify the differences in mortality based on the type of management utilized for moderate to severe liver injuries from a modern national patient sample of trauma patients.

Methods

We conducted a retrospective analysis of the National Trauma Data Bank (NTDB) from 2017 to 2019. The NTDB is a database that records trauma patients in the United States (US) and is administered by the American College of Surgeons. It tracks injury details, demographic information, diagnoses and procedures, and clinical outcome data. We included all trauma patients in the NTDB that were 16 years and older during the study period (2017–2019). We used variables available in the NTDB, including demographic details, injury mechanism, injury severity scores, a modified Charlson Comorbidity Index (CCI), coded diagnoses codes, performed procedures, blood transfusion data, and clinical outcomes. [15, 16]

The patient population was defined by having a liver injury as classified by the liver abbreviated injury scale (AIS) after a blunt mechanism. Only patients 16 years and older were included. Liver AIS scores range from 2 to 6 [1]. The NTDB records these scores for all trauma patients based on system injured. For analysis, patients were compared based on their liver AIS score (2–6).

Our primary exposure within the cohort of blunt liver injury patients was the type of procedural liver injury management used within 48 h of injury. Patients were categorized as: No intervention, angioembolization only, open repair only, angioembolization preceding open repair, and open repair preceding angioembolization. ICD-10 codes were used to categorize each patient. For angioembolization, we used the following procedural codes: 04L33DZ 04V33DZ 04L33ZZ 04L34ZZ 04L34DZ. We used the following codes for open liver repair: 0FQ00ZZ 0FQ10ZZ 0FQ20ZZ 0FB00ZZ 0FB10ZZ 0FB20ZZ 0F9000Z 0FT20ZZ 0F500ZZ 0FB00ZX 0FT00ZZ 0FT10ZZ 0F9100Z 0F900ZZ 0FB10ZX 0FB20ZX 0F520ZZ. Elapsed time after presentation recorded in the NTDB for procedures were used to determine chronicity for patients who underwent both types of procedures. The primary outcome was defined as crude, in-hospital death. The verification level for each trauma center was a composite of both American College of Surgeons (ACS) and state verification. Shock index (heart rate / systolic blood pressure) was used to compare vital signs among patients. Multi-system trauma was defined as patient having an AIS score for one more than organ system.

We compared baseline characteristics and clinical outcomes of liver injury patients based on predefined liver AIS scores and then compared patients with a liver AIS score of 3, 4, or 5 based on the type of liver injury intervention. The least and most severe liver injuries were excluded from this analysis. [1] We used bivariate analysis to compare these groups, using chi-squared tests for categorical variables and a Fisher's exact test for binary variables. Continuous variables were compared with a one-way test of variance.

We explored the relationship between in-hospital mortality and the type of liver injury intervention performed using logistic regression modeling. We only analyzed patients with an AIS of 3, 4, or 5 as these patients were more likely to require intervention than patients with a less severe injury, while also excluding patients with the most severe injuries (AIS 6) that carry an exceptionally high mortality. In addition, patients with an AIS head injury severity score of 5 or 6 were excluded. Initially, a model was fit for an unadjusted analysis comparing intervention type with an outcome of in-hospital mortality. We then estimated the adjusted odds ratio of mortality. We initially fitted the model with variables identified in our bivariate analysis that had an association with mortality. We then removed these variables in a stepwise fashion if they had less than a 10% effect on the model point estimate. We subsequently used the same model to estimate the adjusted predicted probability of mortality. All estimates from the model are reported with 95% confidence intervals. This model was also used to graph the adjusted predictive probability of mortality, based on intervention type.

We performed all statistical analyses with Stata 17.1. (College Station, TX). The University of North Carolina Institutional Review Board approved this study (IRB # 20–3018).

Table 1 Characteristics of patients with blunt liver injury, stratified by their Liver Abbreviated Injury Scale (AIS) Score

	AIS 2 (*n* = 31,208)	AIS 3 (*n* = 10,155)	AIS 4 (*n* = 6,396)	AIS 5 (*n* = 2,524)	AIS 6 (*n* = 139)	*p* value
Sex: N (%)						
Male	19,067 (61.5)	5,991 (59.0)	3,589 (56.1)	1,422 (56.3)	89 (64.5)	<0.001
Female	11,955 (38.5)	4,163 (41.0)	2,806 (43.9)	1,102 (43.7)	49 (35.5)	
Age (years)						
Mean (SD)	41.6 (18.5)	38.1 (17.6)	36.3 (16.6)	35.5 (15.7)	37.1 (15.7)	<0.001
Race: N (%)						
African American	5,387 (17.8)	1,919 (19.3)	1,233 (19.9)	517 (21.2)	24 (18.6)	<0.001
Caucasian	20,836 (68.9)	6,543 (65.8)	4,039 (65.3)	1,572 (64.4)	79 (61.2)	
Asian	722 (2.4)	229 (2.3)	161 (2.6)	53 (2.2)	4 (3.1)	
American Indian	298 (1.0)	85 (0.9)	58 (0.9)	22 (0.9)	0 (0.0)	
Other	2,991 (9.9)	1,161 (11.7)	697 (11.3)	278 (11.4)	22 (17.1)	
Ethnicity: Latino						
Yes: N (%)	4,570 (15.4)	1,630 (16.7)	1,010 (16.7)	367 (15.3)	28 (22.8)	0.002
Charlson comorbidity score						
Median (IQR)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	<0.001
Transferred?						
Yes: N (%)	6,950 (22.4%)	2,384 (23.5%)	1,449 (22.7%)	468 (18.5%)	11 (7.9%)	<0.001
Injury mechanism: N (%)						
Fall	4,180 (13.7)	1,199 (12.0)	623 (9.9)	168 (6.8)	6 (4.4)	<0.001
MV Occupant	15,028 (49.3)	4,954 (49.6)	3,004 (47.9)	1,290 (52.1)	52 (38.5)	
Motorcyclist	2,730 (9.0)	961 (9.6)	623 (9.9)	270 (10.9)	24 (17.8)	
MV vs Pedestrian	2,876 (9.4)	813 (8.1)	648 (10.3)	275 (11.1)	22 (16.3)	
MV Other	1,875 (6.2)	649 (6.5)	433 (6.9)	147 (5.9)	12 (8.9)	
Cyclist	519 (1.7)	183 (1.8)	127 (2.0)	25 (1.0)	1 (0.7)	
Struck by Something	1,016 (3.3)	380 (3.8)	197 (3.1)	50 (2.0)	3 (2.2)	
Transport other	834 (2.7)	339 (3.4)	235 (3.7)	77 (3.1)	3 (2.2)	
Other	1,403 (4.6)	501 (5.0)	383 (6.1)	174 (7.0)	12 (8.9)	
Multi-system trauma?						
Yes: N (%)	29,265 (94.3)	9,556 (94.1)	6,036 (94.4)	2,431 (96.3)	127 (91.4)	<0.001
ISS						
Median (IQR)	17.0 (12.0–29.0)	22.0 (17.0–29.0)	29.0 (24.0–36.0)	38.0 (34.0–50.0)	75.0 (75.0–75.0)	<0.001
Revised trauma score (RTS)						
Median (IQR)	7.8 (6.9–7.8)	7.8 (7.1–7.8)	7.8 (6.0–7.8)	7.6 (4.1–7.8)	4.1 (1.2–6.9)	<0.001
Presenting vital signs: Mean (SD)						
Heart rate (BPM)	91.2 (30.9)	95.2 (27.0)	94.9 (32.2)	98.2 (35.9)	75.8 (57.3)	<0.001
Systolic blood pressure (mmHg)	119.6 (37.9)	120.8 (31.4)	113.2 (36.7)	104.7 (40.1)	68.3 (57.8)	<0.001
Temperature (Celsius)	36.4 (1.8)	36.5 (2.0)	36.4 (1.8)	36.2 (1.9)	34.6 (6.8)	<0.001
Respiratory rate (BPM)	19.3 (7.0)	19.9 (6.5)	19.9 (7.7)	20.2 (8.2)	17.1 (11.0)	< 0.001

Results

During the period of 2017 through 2019, 2,848,592 patients aged $\geq$ 16 years were recorded in the NTDB. Among those patients, 50,250 had a liver injury from a blunt mechanism with a documented liver AIS score. Table 1 reports a comparison of all patients with blunt liver injury, stratified by AIS score. Notable differences between the groups included a much higher proportion of patients injured on a motorcycle in patients with a AIS 6 injury at

Table 2 Characteristics of patients with blunt liver injury, stratified by their Liver Abbreviated Injury Scale (AIS) Score

	AIS 2 (*n* = 31,208)	AIS 3 (*n* = 10,155)	AIS 4 (*n* = 6,396)	AIS 5 (*n* = 2,524)	AIS 6 (*n* = 139)	*p* value
Admission disposition: N(%)						
Floor or Stepdown Bed	9,405 (30.8)	2,253 (22.6)	670 (10.7)	141 (5.7)	1 (0.7)	<0.001
ICU Bed	12,367 (40.5)	5,273 (52.8)	3,461 (55.2)	1,117 (45.1)	11 (7.9)	
Operating room	5,924 (19.4)	1,901 (19.0)	1,551 (24.7)	959 (38.7)	78 (56.1)	
Home	211 (0.7)	30 (0.3)	21 (0.3)	7 (0.3)	0 (0.0)	
Died in ED	1,939 (6.3)	273 (2.7)	392 (6.3)	180 (7.3)	47 (33.8)	
Other	702 (2.3)	250 (2.5)	176 (2.8)	75 (3.0)	2 (1.4)	
Blood products given in first 4 hours after presentation: Mean (SD)						
Packed red blood Cells	1.2 (4.3)	1.4 (4.9)	2.1 (6.0)	4.5 (9.8)	7.8 (14.1)	<0.001
Plasma	0.7 (3.2)	0.9 (3.7)	1.4 (4.7)	3.0 (7.3)	4.3 (8.8)	<0.001
Platelets	0.2 (1.2)	0.2 (1.7)	0.4 (3.1)	0.7 (2.4)	0.9 (2.0)	<0.001
Had liver intervention?						
Yes: N (%)	1,563 (5.0)	878 (8.6)	1,220 (19.1)	759 (30.1)	37 (26.6)	<0.001
Liver intervention: N (%)						
Liver embolization only	240 (15.4)	299 (34.1)	571 (46.8)	270 (35.6)	9 (24.3)	<0.001
Open liver repair only	1,309 (83.7)	551 (62.8)	566 (46.4)	412 (54.3)	27 (73.0)	
Liver embolization preceding open repair	5 (0.3)	7 (0.8)	23 (1.9)	23 (3.0)	0 (0.0)	
Open repair preceding embolization	9 (0.6)	21 (2.4)	60 (4.9)	54 (7.1)	1 (2.7)	
Discharge disposition: N (%)						
Home	15,180 (53.9)	5,371 (55.9)	3,079 (53.0)	921 (40.7)	7 (7.8)	<0.001
Home (with services)	1,857 (6.6)	609 (6.3)	389 (6.7)	153 (6.8)	1 (1.1)	
SNF (Rehab)	2,266 (8.0)	662 (6.9)	338 (5.8)	133 (5.9)	0 (0.0)	
LTACH	3,896 (13.8)	1,425 (14.8)	849 (14.6)	309 (13.7)	3 (3.3)	
Died or Hospice	2,781 (9.9)	807 (8.4)	706 (12.2)	565 (25.0)	76 (84.4)	
Other	2,192 (7.8)	727 (7.6)	443 (7.6)	180 (8.0)	3 (3.3)	
Crude in-hospital mortality: N (%)						
Died	4,622 (14.9)	1,043 (10.3)	1,086 (17.0)	740 (29.3)	123 (88.5)	<0.001
Time to death						
Days: Median (IQR)	1.0 (1.0–3.0)	2.0 (1.0–5.0)	1.0 (1.0–3.0)	1.0 (1.0–2.0)	1.0 (1.0–1.0)	<0.001
Crude in-hospital mortality (Excluding severe head injury): N (%)						
Died	3,420 (11.7)	766 (7.9)	873 (14.5)	630 (26.6)	110 (87.3)	<0.001
Time to death						
Days: Median (IQR)	1.0 (1.0–3.0)	2.0 (1.0–5.0)	1.0 (1.0–3.0)	1.0 (1.0–2.0)	1.0 (1.0–1.0)	<0.001

17.8% compared to less than 11% in all other groups. Transfer status was similar between AIS 2–4 groups at around 23% but patients with AIS 5 or AIS 6 injuries were less likely to be transferred at 18.5% and 7.9%, respectively ($p > 0.001$). Over 90% of all patients had multi-system trauma, but median ISS scores were significantly higher as liver injury severity increased, although the liver AIS score contributes significantly to the total ISS score. Median Revised Trauma Scores (RTS) were between 7.6 and 7.8 for AIS 2–5 injuries but was significantly lower at 4.1 (IQR 1.2, 6.9, $p < 0.001$) for AIS 6 injuries. The most significant difference among vital signs was systolic blood pressure, which was much lower in the most severe liver injury group at 75.9 mmHg ($p < 0.001$) compared to all other groups with a mean above 105 mmHg.

The differences in interventions and clinical outcomes are demonstrated in Table 2. There were significant differences among the five levels of liver injury severity. An increasing proportion of patients went to the operating room from the emergency department as liver injury

Table 3 Characteristics and clinical outcomes of patients with blunt liver injury, stratified by trauma verification level

	Level I (n = 29,333)	Level II (n = 16,687)	Level III + (n = 3,669)	p value
Multi-system trauma?				
Yes: N (%)	27,837 (94.9)	15,725 (94.2)	3,348 (91.3)	< 0.001
ISS				
Median (IQR)	22.0 (14.0–34.0)	21.0 (13.0–29.0)	17.0 (10.0–29.0)	< 0.001
Revised trauma score (RTS)				
Median (IQR)	7.8 (6.6–7.8)	7.8 (6.9–7.8)	7.8 (7.6–7.8)	< 0.001
Admission disposition: N(%)				
Floor or Stepdown bed	7,327 (25.5)	3,947 (24.0)	958 (26.2)	< 0.001
ICU bed	13,321 (46.3)	7,565 (46.0)	1,159 (31.7)	
Operating room	6,430 (22.3)	3,412 (20.8)	488 (13.4)	
Home	181 (0.6)	70 (0.4)	18 (0.5)	
Died in ED	1,462 (5.1)	1,077 (6.6)	264 (7.2)	
Other	67 (0.2)	368 (2.2)	765 (20.9)	
Had liver intervention?				
Yes: N(%)	2,818 (9.6)	1,452 (8.7)	163 (4.4)	< 0.001
Liver intervention: N(%)				
No intervention	26,515 (90.4)	15,235 (91.3)	3,506 (95.6)	< 0.001
Liver embolization only	873 (3.0)	467 (2.8)	45 (1.2)	
Open liver repair only	1,824 (6.2)	909 (5.4)	116 (3.2)	
Liver embolization preceding open repair	36 (0.1)	21 (0.1)	1 (0.0)	
Open repair preceding embolization	85 (0.3)	55 (0.3)	1 (0.0)	
Crude in-hospital mortality: N(%)				
Died	4,460 (15.2)	2,639 (15.8)	463 (12.6)	< 0.001

severity increased (19% in AIS 2 and 56.1% in AIS 6, $p < 0.001$). Transfusion with the first four hours was significantly higher for both packed red blood cells (pRBC) and plasma as liver injury severity increased. Only 5.0% (n = 1,563/31,208) of patients with AIS 2 and 8.6% (n = 878/10,155) of patients with AIS 3 liver injuries underwent an intervention for liver injury, compared to 19.1% (n = 1,979/8,992) of patients with an AIS 4 injury and 30.1% (n = 759/2,524) of patients with an AIS 5 injury. Among those who had an intervention, open repair was the most common in each group although was more often used among patients with lower grade injuries. Only a small number of patients in either cohort had both interventions. Mortality was very high among all cohorts but significantly increased as severity increased (11.7% in AIS 2, 29.3% in AIS 5, 88.5% in AIS 6, $p < 0.001$) with a median time to death of 1–2 days for all injury severities. When excluding patients with severe brain injury, mortality remained very high at 11.7% (n = 3,420/29,159) in AIS 2, 26.6% (n = 630/2,369) in AIS 5 and 87.3% (n = 110/126, $p < 0.001$) in AIS 6. For these patients, the median time to death was between 1 and 2 days for all patients.

Trauma center verification level

We also compared the variance in intervention based on trauma center verification level, as shown in Table 3. Most patients were treated at a Level I (59.0%, n = 29,333/49,696) or Level II (33.6%, n = 16,687/49,696) center in comparison with Level III or greater centers (7.4%, n = 3,669/49,696). Median ISS scores were higher at Level 1 and Level II trauma centers (22.0 at Level I, 21.0 at Level II, 17.0 at Level III, $p < 0.001$). More patients were admitted to the ICU (46.3, 46.0, 31.7%, $p < 0.001$), and more patients went to the operating room from the emergency department (23.3, 20.8, 13.4%, $p < 0.001$) at Level I and Level II centers, respectively. In addition, more patients had a liver intervention at these trauma centers with liver angioembolization significantly lower at Level III + hospitals (9.6, 8.7, 4.4%, $p < 0.001$). In-hospital mortality varied between the levels and was lowest at Level III + hospitals (15.2, 15.8, 12.6%, $p < 0.001$).

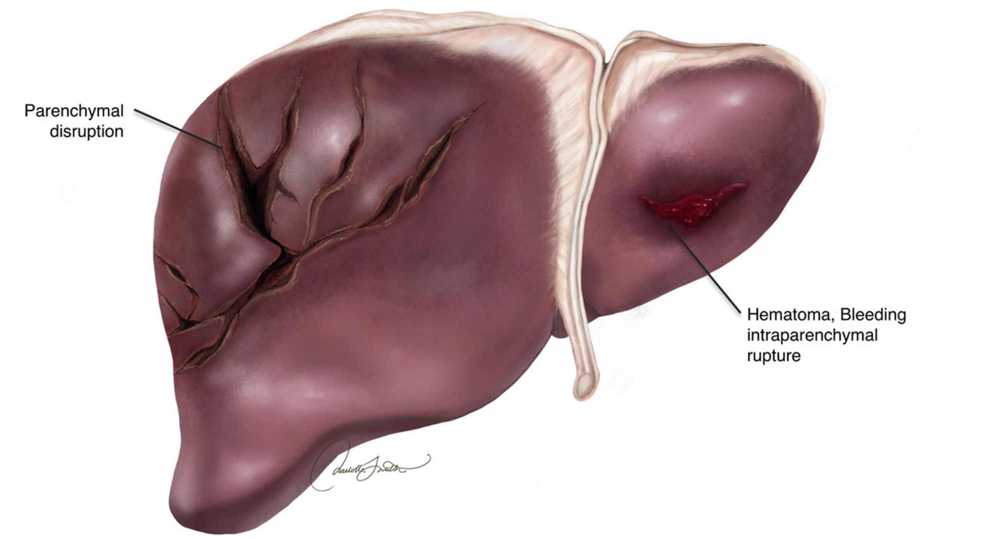

Fig. 1 Liver Injury: Abbreviated Injury Scale (AIS) 4 with parenchymal disruption involving 25-75% of a hepatic lobe

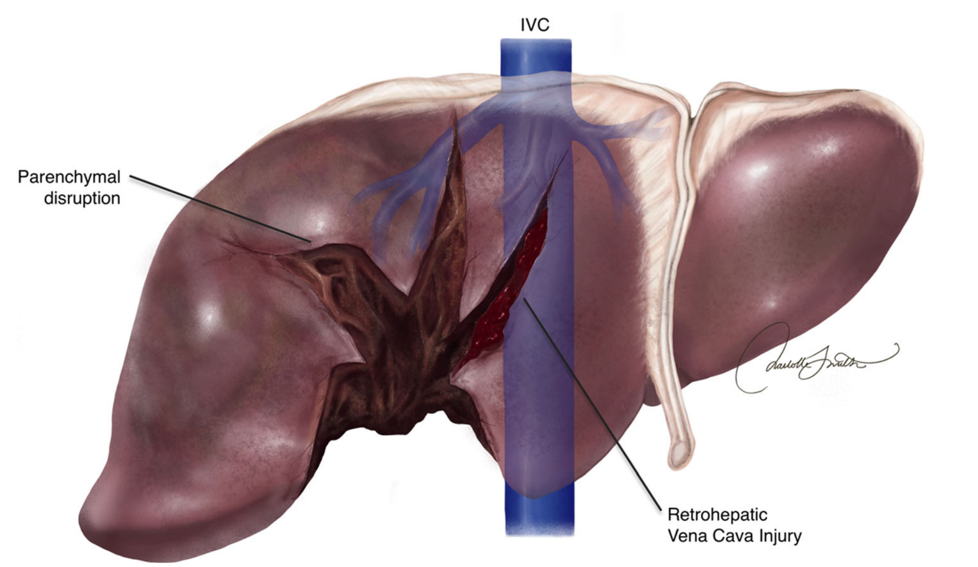

Fig. 2 Liver Injury: Abbreviated Injury Scale (AIS) 5 with parenchymal disruption > 75% of a hepatic lobe and/or juxtahepatic venous injury

Patients with AIS 3/4/5 Liver injury

We then compared patients with AIS 3, 4, or 5 liver injury by intervention type. A visual representation of AIS 4 and AIS 5 liver injuries is shown in Figs. 1 and 2. Notably, sex, age, race, and ethnicity were relatively similar between the groups (Table 4). Multi-system trauma was present in at least 94% of patients in every group (p = 0.08). Median ISS scores were lower in the no intervention (26.0, IQR 19.0–34.0) and angiography only (29.0, IQR 21.0–38.0) groups compared to those who had open repair (35.0, IQR 27.0–43.0, p < 0.001). Median RTS was also higher in the no intervention (7.8, IQR 6.9–7.8) and angioembolization only (7.8, IQR 6.9–7.8) groups compared to open repair (6.4, IQR 4.1–7.8, p < 0.001). Patients who underwent no intervention or AE were more likely to be transferred at 23.8% and 21.1%, respectively, compared to only 12.4% among those who had open exploration and 9.0% (p < 0.001) for those who had both procedures. Blood transfusion totals within the first hours were significantly lower in patients with no intervention or AE only compared to open repair for both pRBCs and plasma. Patients who underwent no intervention received a mean of 1.3 units (SD 4.6) of pRBCs compared to 2.2 units (SD 5.5) in the AE only group and 8.6 (SD 12.3, $p < 0.001$) in the open group. Crude, in-hospital mortality was significantly higher among those with no intervention (19.3%, n = 1,342/ 6,943), open only repair (37.2%, n = 364/978), both

Table 4 Comparison of patients with a AIS 3/4/5 Liver Injury stratified by liver intervention. AE = angioembolization

	No intervention (n = 16,218)	AE only (n = 1,140)	Open only (n = 1,529)	Both AE and open (n = 188)	p value
Sex: N (%)					
Male	9,225 (56.9)	680 (59.6)	971 (63.5)	126 (67.0)	< 0.001
Female	6,992 (43.1)	460 (40.4)	557 (36.5)	62 (33.0)	
Age (years)					
Mean (SD)	36.8 (17.0)	40.4 (18.6)	38.0 (16.9)	36.3 (14.8)	< 0.001
Race					
African American	3,131 (19.8)	209 (18.8)	291 (19.6)	38 (21.3)	0.05
Caucasian	10,338 (65.5)	743 (66.9)	967 (65.2)	106 (59.6)	
Asian	373 (2.4)	37 (3.3)	29 (2.0)	4 (2.2)	
American Indian	152 (1.0)	5 (0.5)	6 (0.4)	2 (1.1)	
Other	1,801 (11.4)	117 (10.5)	190 (12.8)	28 (15.7)	
Ethnicity: Latino					
Yes: N (%)	2,527 (16.3)	176 (16.1)	262 (18.0)	42 (23.3)	0.032
Multi-system trauma?					
Yes: N (%)	15,287 (94.3)	1,077 (94.5)	1,478 (96.7)	181 (96.3)	0.08
ISS					
Median (IQR)	26.0 (19.0–34.0)	29.0 (21.0–38.0)	35.0 (27.0–43.0)	36.0 (29.0–44.0)	< 0.001
Revised trauma score (RTS)					
Median (IQR)	7.8 (6.9–7.8)	7.8 (6.9–7.8)	6.4 (4.1–7.8)	6.6 (4.1–7.8)	< 0.001
Trauma verification level: N (%)					
Level I	9,604 (60.0)	719 (63.3)	959 (63.0)	114 (61.6)	< 0.001
Level II	5,288 (33.0)	379 (33.4)	505 (33.2)	69 (37.3)	
Level III +	1,127 (7.0)	38 (3.3)	59 (3.9)	2 (1.1)	
Transferred?					
Yes: N (%)	3,855 (23.8)	240 (21.1)	189 (12.4)	17 (9.0)	< 0.001
Blood products given in first 4 hours after presentation:					
Mean (SD)					
Packed red blood Cells	1.3 (4.6)	2.2 (5.5)	8.6 (12.3)	9.8 (12.9)	< 0.001
Plasma	0.8 (3.4)	1.4 (4.3)	6.2 (9.8)	7.6 (10.8)	< 0.001
Platelets	0.2 (2.2)	0.4 (2.1)	1.5 (4.1)	1.4 (1.9)	< 0.001
Crude					
In-hospital mortality: N (%)					
Died	2,202 (13.6)	112 (9.8)	510 (33.4)	51 (27.1)	< 0.001
Time to death					
Days: Median (IQR)	1.0 (1.0–3.0)	5.0 (2.0–10.0)	2.0 (1.0–4.0)	4.0 (2.0–10.0)	< 0.001

interventions (28.1%, n = 45/160), compared to those who had angioembolization (9.8%, n = 82/841, $p < 0.001$).

Using logistic regression, we modeled the odds ratio of in-hospital death for patients with AIS 3/4/5 liver injury based on what type of intervention they received, stratified by the severity of liver injury (Table 5). For patients with AIS 3 injuries, only open repair had a statistically significant difference compared to no intervention with an odds ratio of 3.97 (95% CI 3.17, 4.96). For patients with an AIS 4 injury, AE only had a OR of 0.54 (95% CI 0.39, 0.74) while open repair only had a OR of 2.02 (95% CI 1.69, 2.59). In patients with an AIS 5 injury the unadjusted OR for AE only was 0.34 (95% CI 0.23, 0.52) while it was 2.77 (95% CI 2.20. 3.48) for open only repair. We also created an adjusted model that included age, sex, shock index, ISS, and total blood transfusions in the first four hours. Notably, trauma center verification level, transfer status, and Charlson Comorbidity Index (CCI), did not significantly contribute to the model and were excluded. For patients with AIS 3 injuries, only open repair had a statistically

Table 5 Odds ratio of in-hospital death for patients with a liver injury AIS 3, 4, or 5, stratified by liver intervention. Second model adjusted for age, sex, shock index, Injury Severity Score (ISS), and total four-hour transfusion requirement

Intervention	Unadjusted OR of In-hospital death (95% CI)		
	AIS 3	AIS 4	AIS 5
No intervention	1.00	1.00	1.00
Embolization only	1.26 (0.83, 1.91)	0.54 (0.39, 0.74)	0.34 (0.23, 0.52)
Open repair only	3.97 (3.17, 4.96)	2.09 (1.69, 2.59)	2.77 (2.20, 3.48)
Both	2.52 (0.86, 7.35)	2.02 (1.20, 3.42)	1.11 (0.65, 1.89)
	Adjusted OR of In-hospital Death (95% CI)		
	AIS 3	AIS 4	AIS 5
No intervention	1.00	1.00	1.00
Embolization only	1.26 (0.77, 2.07)	0.68 (0.47, 0.99)	0.39 (0.24, 0.64)
Open repair only	1.46 (1.07, 1.99)	1.24 (0.91, 1.68)	1.99 (1.47, 2.69)
Both	0.46 (0.09, 2.33)	0.94 (0.45, 1.93)	0.78 (0.40, 1.49)

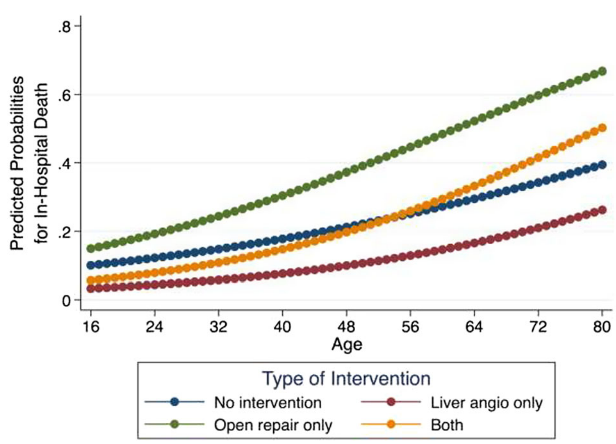

Fig. 3 Adjusted predicted probability of dying after blunt liver injury, based on the type of liver intervention, plotted against increasing age for patients with Abbreviated Injury Scale (AIS) 5 liver injury. Model adjusted for sex, shock index, Injury Severity Score (ISS), and total four-hour transfusion requirement

significant difference with no intervention with an adjusted OR of 1.46 (95% CI 1.07, 1.99). In patients with an AIS 4 injury, the adjusted odds ratio of death for AE only was 0.68 (95% CI 0.47, 0.99) while both open repair and the use of both interventions were not statistically significant. Lastly, in AIS 5 injuries, AE only had an adjusted OR of 0.39 (95% CI 0.24, 0.64) while open repair only had an adjusted OR of 1.99 (95% CI 1.47, 2.69). Using our adjusted logistic regression model, we also calculated the adjusted predicted probability of dying, based on the type of liver intervention, for patients with AIS 5 injuries, plotted against increasing age. (Fig. 3).

Discussion

In this US National Trauma Databank analysis, liver injury was a significant source of mortality in blunt trauma patients. Among this population, angioembolization of moderate to severe liver injury was associated with a 30% or greater decrease in the adjusted odds of mortality compared to no intervention. In contrast, open exploration was associated with increased mortality, doubling the odds of death in patients with an AIS 5 injury. A small number of patients underwent both procedures and had similar odds of death to those who experienced no intervention.

Over the last thirty years, there has been an increasing shift to non-operative management from open exploration, in hemodynamically stable patients. Although many early studies did not include angioembolization patients, published data from the 1990s supported a non-operative approach to most liver injuries. [9–11, 17] Unfortunately, while more recent data have incorporated AE into a "non-operative" algorithm, there is minimal data on the relative outcomes between patients who undergo AE compared to open exploration or observation only. A 2015 study from Australia examined patient outcomes after liver injury over fifteen years (1999–2013). They found a significant decrease in mortality after instituting an AE protocol for liver patients. The adjusted mortality decreased from 18.8% at the beginning of the study to 3.6% at the end (p = 0.001). [18] A similar study from the Netherlands in 2011 showed a small but comparable benefit for higher grade liver injuries. [19] A 2007 study from Norway showed that an angiography protocol decreased laparotomy rates, but most patients were not embolized, and patient outcomes were not different during the study period. [20] An older study US single-institution study more directly measured the effect of AE on mortality after severe liver injury. The authors found that AE conferred an adjusted odds ratio of mortality of 0.51 (95% CI, 0.27, 0.98) compared to patients who did not undergo AE [21]. While these studies are limited with retrospective designs and small patient cohorts, they provide evidence for the benefit for AE, especially in more severe liver injuries.

Even as more data emerge showing that angioembolization may provide a mortality benefit to patients, the ideal patient population for this intervention remains elusive. The 2012 EAST (Eastern Association for the Surgery of Trauma) Guidelines recommend using AE in two patient populations: Hemodynamically stable patients with active extravasation and patients who are transient responders to resuscitation. [22] While the use of AE in stable patients with evident arterial extravasation is not controversial; our findings suggest that patients with moderate to severe injury may benefit from AE regardless of whether extravasation is noted on imaging. Because CT imaging is not perfect at identifying arterial injury, with an estimated sensitivity of 75% in abdominal trauma, surgeons use clinical judgment to decide whether to proceed with AE, especially in the setting of more severe liver injuries. [23] While we are not able to differentiate patients based on whether they had a blush on CT scan, we found that AE had a significant mortality benefit compared to non-operative management in patients with more severe injuries, even when adjusting for physiological factors and the severity of trauma. Consequently, when the surgeon determines that the patient may require intervention in more severe injuries, they should consider AE before open exploration. While unstable patients have traditionally undergone open exploration first, some tertiary centers may perform AE before open exploration with appropriate anesthesia support.

A 2020 clinical review also highlighted the potential to use AE as a planned adjunct to operative intervention or as a salvage maneuver when open liver packing fails, with limited data supporting this approach. [24] A 2018 study of the NTDB identified 205 patients over a seven-year period that underwent both operative exploration and post-operative AE [25]. After propensity analysis, they found lower mortality for patients who underwent both procedures compared to only open exploration. A similar 2020 analysis of the American College of Surgeons Trauma Quality Improvement Program database propensity-matched patients who underwent laparotomy compared to patients who had both laparotomy and angioembolization. [26] They found that patients who underwent both procedures had improved twenty-four-hour mortality but that both procedures did not improve overall in-hospital mortality. Lastly, a 2015 USA multicenter retrospective review showed that post-operative CT imaging after open liver exploration helped identify ongoing bleeding and the need for post-operative AE. They showed that routinely ordering a post-operative CT imaging had a mortality benefit (OR 0.16, 95% CI 0.10, 0.23). [27] In our adjusted analysis, patients who had both procedures had a lower odds of mortality than open intervention alone, but were still higher compared to patients with only observation in AIS 4 injuries. The benefit over no exploration also disappeared at age 55, although the differences were small between these two groups. Liver injuries that require both procedures are more likely to be complex and may carry a higher mortality at baseline compared to injuries that are adequately managed by AE alone. However, it is difficult to make any conclusions based on a small number of patients. Overall, the limited data available suggest that this practice of using both interventions may improve patient outcomes compared to open exploration alone, but surgeons must use clinical judgement in utilizing AE before or after open exploration.

Unfortunately, angioembolization carries its pitfalls and complications despite at least 93% efficacy. [14, 28] Significant venous injuries will not be successfully managed with arterial embolization. They may present as ongoing bleeding after seemingly successful AE [29]. Major complications after AE include hepatic necrosis, hepatic infection, and bile leak following necrosis. Published data suggest the rate of these complications is relatively high, ranging from 30–60%, with liver necrosis as the most common. [30–34] Fortunately, despite these reported high rates, there has not been an association with mortality in these studies, with the most recent multicenter study showing no deaths at 30 days for patients who underwent AE. [33] The high morbidity associated with AE and higher-grade liver injuries should undoubtedly factor into decision-making. Still, it must be weighed against the potential higher mortality and morbidity associated with ongoing bleeding.

While there appears to be a benefit for AE in certain patients, there may be significant variability in available expertise between trauma centers. Recent data from a 2018 study of a statewide trauma registry in the USA found that AE was being utilized at lower rates at Level II trauma centers compared to Level I centers and showed an associated increase in crude mortality at centers using AE at lower rates. [35] In contrast, our study showed that on a national level, the use of procedural interventions, including AE were relatively similar between Level I and Level II trauma centers with comparable crude mortality, while the lower use of AE was much more notable at Level III + centers. In addition, the trauma center level was not associated with mortality in our adjusted model. Further research is needed to delineate differences in practice patterns nationally, emphasizing appropriate triage criteria to ensure patients with more severe liver injuries have access to AE if required.

Our findings are limited by dependency on a large national database reliant on accurate coding and data collection. Using a database like the NTDB to compare these cohorts is inherently challenging as all potential confounders cannot be accounted for, limiting interpretation of the results. This is particularly true in the trauma patient population which is very complex both in injury pattern and management strategy. We have attempted to mitigate these challenges by including any available variables in the NDTB that can be used to stratify mortality risk but our conclusions must be interpreted within the limitations of this study design. In addition, the benefits of using the NTDB during the 2017–2019 years are that data are based on ICD-10 codes, which includes more granular diagnostic and procedural coding. Nonetheless, despite these database improvements, it is impossible to distinguish which patients had an intra-abdominal injury that required exploration, such as a bowel injury. We attempted to mitigate this potential confounder by adjusting for multi-system trauma in our model but acknowledge the very high rate of multi-system trauma in blunt liver injury makes this more difficult. Lastly, the NDTB may exclude clinical data, including procedures, for some transferred patients if they did not initially present to a facility that participates in NTDB. We have included transfer status in the bivariate analysis and reported that it did not contribute to our logistic regression model for mortality.

Conclusion

Mortality after blunt liver injury remains high in the USA despite improvements in management strategies over the last thirty years. In an analysis of a national trauma database, patients with moderate or severe injury (AIS 4/5), angioembolization was associated with a significant reduction in the adjusted odds of mortality compared to open repair. Angioembolization may be an appropriate first intervention when clinically appropriate.

Funding Financial support was provided by the Department of Surgery at the University of North Carolina.

Declarations

Conflict of interest The authors have no conflict of interest to disclose. The authors have no financial relationships to disclose.

References

1. Tinkoff G, Esposito TJ, Reed J et al (2008) American association for the surgery of trauma organ injury scale I: spleen, liver, and kidney, validation based on the National Trauma Data Bank. J Am Coll Surg 207:646–655
2. Scollay JM, Beard D, Smith R et al (2005) Eleven years of liver trauma: the Scottish experience. World J Surg 29:744–749
3. David Richardson J, Franklin GA, Lukan JK et al (2000) Evolution in the management of hepatic trauma: a 25-year perspective. Ann Surg 232:324–330
4. Parks R, Chrysos E, Diamond T (1999) Management of liver trauma. Br J Surg 86:1121–1135
5. Matthes G, Stengel D, Seifert J et al (2003) Blunt liver injuries in polytrauma: results from a cohort study with the regular use of whole-body helical computed tomography. World J Surg 27:1124–1130
6. Matthes G, Stengel D, Bauwens K et al (2006) Predictive factors of liver injury in blunt multiple trauma. Langenbecks Arch Surg 391:350–354
7. Chien L-C, Lo S-S, Yeh S-Y (2013) Incidence of liver trauma and relative risk factors for mortality: a population-based study. J Chin Med Assoc 76:576–582
8. Chmatal P, Kupka P, Fuksa Z et al (2008) Liver trauma usually means management of multiple injuries: analysis of 78 patients. Int Surg 93:72–77
9. Malhotra AK, Fabian TC, Croce MA et al (2000) Blunt hepatic injury: a paradigm shift from operative to nonoperative management in the 1990s. Ann Surg 231:804–813
10. Croce MA, Fabian TC, Menke PG et al (1995) Nonoperative management of blunt hepatic trauma is the treatment of choice for hemodynamically stable patients. Results of a prospective trial. Ann Surg 221:744–753 (**discussion 753–745**)
11. Pachter HL, Knudson MM, Esrig B et al (1996) Status of nonoperative management of blunt hepatic injuries in 1995: a multicenter experience with 404 patients. J Trauma 40:31–38
12. Goan YG, Huang MS, Lin JM (1998) Nonoperative management for extensive hepatic and splenic injuries with significant hemoperitoneum in adults. J Trauma 45:360–364 (**discussion 365**)
13. Cadili A, Gates J (2021) The role of angioembolization in hepatic trauma. Am Surg 87:1793–1801
14. Green CS, Bulger EM, Kwan SW (2016) Outcomes and complications of angioembolization for hepatic trauma: a systematic review of the literature. J Trauma Acute Care Surg 80:529–537
15. Charlson M, Szatrowski TP, Peterson J et al (1994) Validation of a combined comorbidity index. J Clin Epidemiol 47:1245–1251
16. Samuel AM, Grant RA, Bohl DD et al (2015) Delayed surgery after acute traumatic central cord syndrome is associated with reduced mortality. Spine (Phila Pa 1976) 40:349–356
17. Carrillo EH, Platz A, Miller FB et al (1998) Non-operative management of blunt hepatic trauma. Br J Surg 85:461–468
18. Suen K, Skandarajah AR, Knowles B et al (2016) Changes in the management of liver trauma leading to reduced mortality: 15-year experience in a major trauma centre. ANZ J Surg 86:894–899
19. Saltzherr TP, van der Vlies CH, van Lienden KP et al (2011) Improved outcomes in the non-operative management of liver injuries. HPB 13:350–355
20. Gaarder C, Naess PA, Eken T et al (2007) Liver injuries–improved results with a formal protocol including angiography. Injury 38:1075–1083
21. Asensio JA, Roldán G, Petrone P et al (2003) Operative management and outcomes in 103 AAST-OIS grades IV and V complex hepatic injuries: trauma surgeons still need to operate,

but angioembolization helps. J Trauma Acute Care Surg 54:647–654
22. Stassen NA, Bhullar I, Cheng JD et al (2012) Nonoperative management of blunt hepatic injury: an Eastern Association for the Surgery of Trauma practice management guideline. J Trauma Acute Care Surg 73:S288–S293
23. Ahmed N, Kassavin D, Kuo Y-H et al (2013) Sensitivity and specificity of CT scan and angiogram for ongoing internal bleeding following torso trauma. Emerg Med J 30:e14–e14
24. Cadili A, Gates J (2021) The role of angioembolization in hepatic trauma. Am Surg 87(11):1793–1801
25. Matsumoto S, Cantrell E, Jung K et al (2018) Influence of postoperative hepatic angiography on mortality after laparotomy in Grade IV/V hepatic injuries. J Trauma Acute Care Surg 85:290–297
26. Matsushima K, Hogen R, Piccinini A et al (2020) Adjunctive use of hepatic angioembolization following hemorrhage control laparotomy. J Trauma Acute Care Surg 88:636–643
27. Kutcher ME, Weis JJ, Siada SS et al (2015) The role of computed tomographic scan in ongoing triage of operative hepatic trauma: a western trauma association multicenter retrospective study. J Trauma Acute Care Surg 79:951–956
28. van der Wilden GM, Velmahos GC, Emhoff T et al (2012) Successful nonoperative management of the most severe blunt liver injuries: a multicenter study of the research consortium of New England centers for trauma. Arch Surg 147:423–428
29. Duane TM, Como JJ, Bochicchio GV et al (2004) Reevaluating the management and outcomes of severe blunt liver injury. J Trauma Acute Care Surg 57:494–500
30. Misselbeck TS, Teicher EJ, Cipolle MD et al (2009) Hepatic angioembolization in trauma patients: indications and complications. J Trauma 67:769–773
31. Mohr AM, Lavery RF, Barone A et al (2003) Angiographic embolization for liver injuries: low mortality, high morbidity. J Trauma 55:1077–1081 (**discussion 1081-1072**)
32. Dabbs DN, Stein DM, Scalea TM (2009) Major hepatic necrosis: a common complication after angioembolization for treatment of high-grade liver injuries. J Trauma 66:621–627 (**discussion 627-629**)
33. Samuels JM, Urban S, Peltz E et al (2020) A modern, multicenter evaluation of hepatic angioembolization–complications and readmissions persist. Am J Surg 219:117–122
34. Samuels JM, Carmichael H, Kovar A et al (2020) Reevaluation of hepatic angioembolization for trauma in stable patients: weighing the risk. J Am Coll Surg 231(123–131):e123
35. Tignanelli CJ, Joseph B, Jakubus JL et al (2018) Variability in management of blunt liver trauma and contribution of level of American College of Surgeons Committee on Trauma verification status on mortality. J Trauma Acute Care Surg 84:273–279