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HEPATOBILIARY-PANCREAS

Liver trauma: hepatic vascular injury on computed tomography as a predictor of patient outcome

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Abstract

Objectives To evaluate hepatic vascular injury (HVI) on CT in blunt and penetrating trauma and assess its relationship to patient management and outcome.

Method and materials This retrospective study was IRB approved and HIPAA compliant. Informed consent was waived. Included were patients ≥ 16 years old who sustained blunt or penetrating trauma with liver laceration seen on a CT performed at our institution within 24 h of presentation over the course of 10 years and 6 months (August 2007–February 2018). During this interval, 171 patients met inclusion criteria (123 males, 48 females; mean age 34; age range 17–80 years old). Presence of HVI was evaluated and liver injury was graded in a blinded fashion by two radiologists using the 1994 and 2018 American Association for the Surgery of Trauma (AAST) liver injury scales. Hospital length of stay and treatment (angioembolization or operative) were recorded from the electronic medical record. Multivariate linear regressions were used to determine our variables' impact on the length of stay, and logistic regressions were used for categorical outcomes.

Results Of the included liver trauma patients, 25% had HVI. Patients with HVI had a 3.2-day longer length of hospital stay on average and had a 40.3-fold greater odds of getting angioembolization compared to those without. Patients with high-grade liver injury (AAST grades IV–V, 2018 criteria) had a 3.2-fold greater odds of failing non-operative management and a 14.3-fold greater odds of angioembolization compared to those without.

Conclusion HVI in liver trauma is common and is predictive of patient outcome and management.

Key Points

• *Hepatic vascular injury occurs commonly (25%) with liver trauma.*
• *Hepatic vascular injury is associated with increased length of hospital stay and angioembolization.*
• *High-grade liver injury is associated with failure of non-operative management and with angioembolization.*

Keywords Liver · Trauma · Abdominal injuries · Vascular system injuries · Multidetector computed tomography

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Abbreviations

HVI	Hepatic vascular injury
CVI	Contained vascular injury
NOM	Non-operative management
AAST	American Association for the Surgery of Trauma

Introduction

Liver injury is the leading cause of death in patients with abdominal trauma, and hemorrhage is the main cause of early liver injury–related death [1]. Indeed, there has been a recent shift toward recognizing the importance of hepatic vascular injury (HVI) in trauma patients. After using the same liver injury grading scale for 24 years [2], the American Association for the Surgery of Trauma (AAST) released updated liver injury grading criteria in 2018 which newly incorporates active contrast extravasation and contained vascular injury (CVI) into the grading system (Table 1) [3].

Table 1 The American Association for the Surgery of Trauma (AAST) grading scale for liver injury, with the 2018 changes outlined by red boxes. Kozar et al [3]

Liver Injury Scale (2018 revision)

AAST Grade	AIS Severity	Imaging Criteria (CT Findings)
I	2	Subcapsular hematoma <10% surface area
		Parenchymal laceration <1 cm depth
II	2	Subcapsular hematoma 10-50% surface area; intraparenchymal hematoma <10 cm in diameter
		Laceration 1-3 cm in depth and ≤10 cm length
III	3	Subcapsular hematoma >50% surface area; ruptured subcapsular or parenchymal hematoma
		Intrparenchymal laceration >10 cm
		Laceration >3 cm depth
		Any injury in the presence of a liver vascular injury or active bleeding contained within liver parenchyma
IV	4	Parenchymal disruption involving 25-75% of a hepatic lobe
		Active bleeding extending beyond the liver parenchyma into the peritoneum
V	5	Parenchymal disruption >75% of hepatic lobe
		Juxtahepatic venous injury to include retrohepatic vena cava and central major hepatic veins

The limited research that has been done on HVI generally lends support to the importance of HVI in patient management. A paper by Misselbeck et al [4] looks specifically at angioembolization therapy and finds that patients with active contrast extravasation on computed tomography (CT) are 20 times more likely to undergo angioembolization than those without. Other literature reports that active extravasation seen on CT could indicate the need for operative management [5–9], including a paper by Fang et al [9] where six (75%) of eight hepatic trauma patients with active extravasation failed non-operative management. However, there continues to be a paucity of information about the incidence of HVI and its relationship to patient outcome.

We hypothesized that findings of HVI and high-grade liver injury on CT using the 2018 AAST criteria predict a worse clinical outcome and increased need for operative or interventional management as compared to lower grade injury or those without vascular injury. The purpose of this study was to evaluate the patterns of HVI on MDCT in blunt and penetrating trauma and to assess its relationship to patient management and outcome.

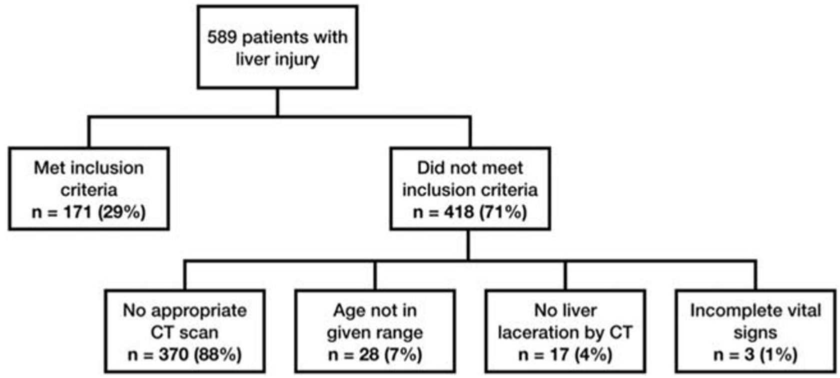
Materials and methods

This study was approved by the institutional review board and was conducted in compliance with the Health Insurance Portability and Accountability Act. The requirement for informed patient consent was waived.

Patient population

For this retrospective study, we used the trauma registry at our urban level I trauma center to identify adult (age ≥ 16 years) patients who sustained blunt or penetrating hepatic trauma between August 25, 2007, and February 25, 2018 (10 years and 6 months). During this period, 589 patients were identified. A total of 171 patients aged 17–80 years (mean age, 34 years; 123 male patients aged 16–80 [mean age, 33]; 48 female patients aged 18–72 [mean age, 37]) met inclusion criteria (liver laceration on trauma protocol CT with three phases of contrast through the liver performed at our institution within 24 h of presentation and before operative or IR-guided management, age ≥ 16, and documented heart rate and systolic blood pressure at presentation); thus, 418 were excluded (Fig. 1). Exclusion was as follows: age criteria ($n = 28$), no liver laceration on CT ($n = 17$), absence of relevant vital signs ($n = 3$), and absence of an appropriate CT study ($n = 370$). Those without an appropriate CT did not have imaging performed at our institution ($n = 223$), had a different imaging protocol ($n = 123$, of which 35 used our abdominal-

Fig. 1 Flow diagram of patient inclusion



only trauma protocol), only had post-treatment imaging ($n = 16$), were imaged too late ($n = 5$), or had no delayed phase images ($n = 3$).

CT technique

All CT examinations were performed with a 64-detector CT scanner (LightSpeed VCT; GE Medical Systems) with the following acquisition parameters: reconstruction thickness, 1.25 and 3.75 mm; noise index, 24; pitch, 1:0.984; and gantry rotation time, 0.5 s. All patients received a bolus of 100 mL of intravenous contrast (ioversol, 350 mg iodine/mL, Optiray, Mallinckrodt Pharmaceuticals, until January 2013, after which patients received iopamidol, 370 mg iodine/mL, Isovue, Bracco Diagnostics Inc.) at a rate of 4–5 mL/s with use of a power injector through an 18- or 20-gauge cannula in an antecubital vein. Per our institution's protocol, patients with penetrating trauma are given both oral and rectal contrast.

CT of the chest, from the thoracic inlet through the liver, was performed by using a 30-s delay (arterial phase) after intravenous contrast material injection. Subsequently, images of the abdomen and pelvis from the superior aspect of the diaphragm through the greater trochanters were acquired with a 70-s delay (portal venous phase). Five-minute delayed images through the abdomen and pelvis were routinely acquired given the presence of liver lacerations on the portal venous phase. Reformations in coronal and sagittal planes were routinely provided (2.5 mm thickness × 2.5 mm intervals).

Image analysis

Two abdominal fellowship-trained radiologists (C.L. and A.G.) retrospectively reviewed (blind) all images. The radiologists recorded the presence of HVI and categorized these as active extravasation or CVI. Injury to central major hepatic veins and juxta-hepatic veins was judged separately as juxta-hepatic injury [3] and was not counted as HVI, noting that juxta-hepatic venous injury was already accounted for in the 1994 grading criteria [2] and was not part of the recent inclusion of HVI within the liver parenchyma. Conspicuity of vascular injuries on arterial, portal venous, and delayed phase images were recorded. Active extravasation was defined as a focus of extravascular contrast in or adjacent to the liver that changed or expanded on portal venous and delayed phases (Figs. 2a, b and 3). CVI (arterial pseudoaneurysm or arteriovenous fistula) was defined as a focus of contrast similar in attenuation to the aorta which did not enlarge on delayed images [6] (Fig. 3). After AAST grading was assigned using the 1994 criteria, one radiologist (C.L.) assigned AAST grade (blind) using the updated 2018 criteria and all analyses were performed using the 2018 criteria. Liver injury was grouped into "low-grade" injury (AAST I-III) and "high-grade" injury (AAST IV-V) to preserve model stability during statistical analysis. There were 18 cases of inter-observer disagreement, which were adjudicated by the interpreting radiologists using consensus.

Clinical outcomes

Three medical students (J.C., A.M., J.G.) reviewed patient electronic medical records (blind). The specific data collected was as follows: mechanism of injury (categorized broadly as penetrating or blunt trauma, and more specifically as motor vehicle accident, pedestrian struck, fall, assault, and other), patient age, gender, vital signs at presentation, date of admission and discharge, treatment (primary angioembolization or operative), mortality, and whether the patient underwent an admission CT. The Abbreviated Injury Scale (AIS) assigned by the trauma service was used to record presence (AIS 1–5) or absence (AIS 0) of head injury. Given that many patients suffered polytrauma, operative and interventional treatments were recorded only if they involved repair of liver injury.

Statistical analysis

Multivariate linear regression was performed by Q.M. to determine crude and adjusted parameter estimates for length of stay. Logistic regression models were run and crude and adjusted odds ratios were calculated by Q.M. to estimate the association between categorical variables. The following were controlled for: age and vital signs (heart rate and systolic

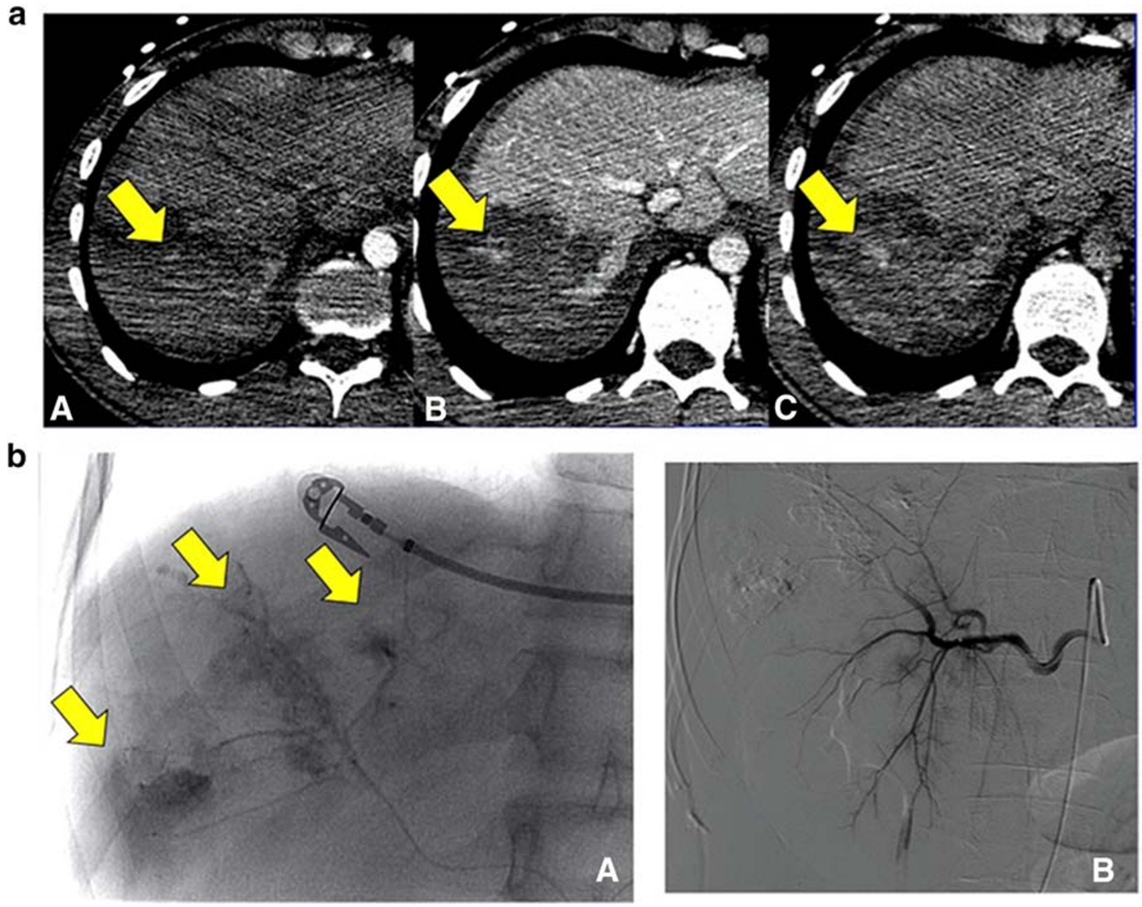


Fig. 2 **a** Contrast-enhanced axial CT images of a 25-year-old male who was crushed by a falling truck demonstrate a grade V liver laceration containing a focus of extravascular contrast (arrow) on arterial phase (A) that enlarges on portal venous (B) and delayed phase (C) imaging, consistent with active arterial hemorrhage. **b** Right hepatic artery angiographic image (A) of the same patient shows three areas of active extravasation (arrows) in the right lobe. Post-embolization angiogram (B) shows resolution of active extravasation

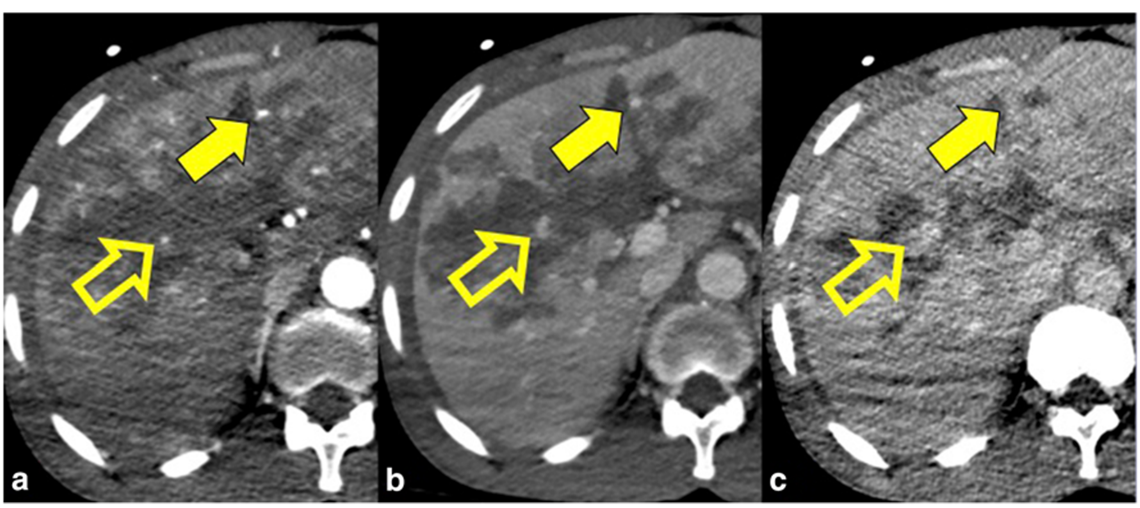


Fig. 3 Contrast-enhanced axial CT images of a 24-year-old male after a motor vehicle accident. Images show a grade IV liver laceration with an internal focus of contrast (solid arrow) on arterial phase imaging (**a**) which follows arterial blood pool attenuation and which does not enlarge on portal venous (**b**) and delayed (**c**) images, consistent with contained vascular injury. There is also a focus of extravascular contrast (open arrow) on arterial phase (**a**) that enlarges on portal venous (**b**) and delayed phase (**c**) imaging, consistent with active arterial hemorrhage. This patient was treated with non-operative management and did not undergo any interventions

blood pressure), mechanism of injury (blunt or penetrating), and presence or absence of head injury with variables summarized in Table S1. A p value of < 0.05 was considered statistically significant.

Results

Patient population

Of the 171 included patients, 111 suffered blunt trauma, and 60 suffered penetrating trauma. Trauma was further subdivided into assault ($n = 69$), motor vehicle collision ($n = 65$), pedestrian struck ($n = 20$), fall ($n = 15$), and other ($n = 2$)—one was crushed under a falling truck and the second did not recall but had no penetrating wounds. Additionally, 54 patients had a concomitant head injury. The median length of hospital stay was 6 days (range 0–46 days), median heart rate was 90 beats per minute (range 44–166), and median systolic blood pressure was 133 mmHg (range 18–218). Key descriptive characteristics are summarized in Table 2.

Vascular injury

Vascular injuries were found in 42 (25%) of the 171 included patients. While a majority (65%) of the included patients suffered from blunt trauma, most HVI was seen in patients with penetrating trauma. Twenty-two (37%) of the 60 penetrating trauma patients had HVI, while only 20 (18%) of the 111 blunt trauma patients had HVI.

Patients with HVI had on average 3.2-day longer length of hospital stay than those without HVI (11.9 days versus 8.7 days, $p < 0.05$ for the difference) (Table 3). Patients with HVI also had greater odds of primary angioembolization (Table 4) compared to those without (odds ratio 40.3; 95% CI = 4.8–340.1, $p = 0.001$): 17 (40%) of the 42 HVI patients underwent angiography and 11 (26%) underwent angioembolization. Ten (30%) of the 33 AE cases and one (8%) of 12 CVI cases underwent angioembolization. Statistically significant relationships are summarized in Table S2.

Our study did not find a significant relationship between vascular injury and operative management, after performing multivariate analysis (Table 5). Univariate analysis did attribute a greater odds of undergoing operative management in vascular injury patients (odds ratio 2.3; 95% CI = 1.0–5.3, $p < 0.05$), but this was nulled after controlling for the confounding variables of age, mechanism of injury, associated head injury, and vital signs.

We saw an increased prevalence of vascular injury in patients with high-grade liver injury. Thirty-two (44%) of 73 high-grade liver injury patients had HVI, as compared to only 10 (10%) of 98 low-grade injury patients. Thirty-two (76%) of the 42 vascular injury patients had "high-grade" liver injury.

Table 2 Key descriptive characteristics

	All patients $N = 171$
	Median (IQR)
Age (years)	29.3 (23.0–42.7)
Heart rate (beats per minute)	90 (79–106)
Systolic blood pressure (mmHg)	133 (115–146)
Length of stay (days)	6 (3–12)
	n (column percent)
Gender	
Male	123 (71.9%)
Female	48 (28.1%)
Mechanism of injury	
Blunt	111 (64.9%)
Penetrating	60 (35.1%)
Head injury	
AIS 0	117 (68.4%)
AIS 1–5	54 (31.6%)
AAST grade (1994)	
Low	100 (58.5%)
High	71 (41.5%)
AAST grade (2018)	
Low	98 (57.3%)
High	73 (42.7%)
Vascular injury	
No	129 (75.4%)
Yes	42 (24.6%)
Contained vascular injury	
No	159 (93.0%)
Yes	12 (7.0%)
Active extravasation	
No	138 (80.7%)
Yes	33 (19.3%)
Operative treatment	
No	140 (81.9%)
Yes	31 (18.1%)
Angioembolization	
No	160 (93.6%)
Yes	11 (6.4%)

N, number of patients; *IQR*, interquartile range; *AIS*, Abbreviated Injury Scale; *AAST*, American Association for the Surgery of Trauma

Active extravasation was more common than CVI. Thirty-three (79%) of 42 HVI patients had active extravasation, while 12 (29%) had CVI. Three (7%) of the HVI patients had both active extravasation and CVI. Given the low number of CVI patients, we were unable to find any statistically significant relationships between CVI and treatment or patient outcome, and we grouped CVI and active extravasation under HVI for statistical analysis.

Table 3 Univariate and multivariate regression model for hospital length of stay

	Crude				Adjusted model		
	N	Mean	Estimate (SE)	*p*	Mean	Estimate (SE)	*p*
AAST grade							
Low	98	8.0	Ref		8.57	Ref	
High	73	10.37	2.37 (1.36)	0.083	10.96	2.39 (1.36)	0.081
Vascular injury							
No	129	8.32	Ref		8.73	Ref	
Yes	42	11.14	2.83 (1.56)	0.072	11.91	3.19 (1.59)	0.046

Adjusted model includes age, heart rate, systolic blood pressure, mechanism of injury, and head injury

SE, standard error; *Ref*, referent

We evaluated the conspicuity of CVI on arterial, portal venous, and delayed phase imaging to see whether arterial phase imaging in hepatic trauma improves detection of CVI, as has been found in splenic trauma [10]. Our study found no cases where CVI was only seen on arterial phase imaging. Of the 12 cases of CVI, 8 (67%) were seen on all phases, with the remaining four (33%) seen only on portal venous phase imaging. Of the 33 cases of active extravasation, 29 (89%) were seen on all phases, two (6%) were seen on both portal venous and delayed phase imaging, and two (6%) were only seen on delayed phase imaging.

Of the 18 cases of inter-observer disagreement, 16 involved HVI and three involved AAST grade, including one which involved both HVI and injury grade. Of the disputed HVI cases, 10 questioned the presence or absence of HVI and six questioned type of HVI. Ultimately, nine of the 16 disputed HVI cases were included as HVI patients in the study.

Injury grade

Using the 2018 grading criteria, 98 patients (57% of total) suffered a low-grade liver injury (AAST I–III) while 73 (43%) suffered a high-grade injury (AAST IV–V): 12 had a grade I injury; 40 had a grade II injury; 46 had a grade III injury; 44 had a grade IV injury; and 29 had a grade V injury. Patients with high-grade injury had a greater odds (odds ratio 3.2; 95% CI = 1.3–8.0, $p = 0.011$) of failing non-operative management (NOM) (Table 5) and a greater odds (odds ratio 14.3; 95% CI = 1.8–115.4, $p = 0.013$) of getting angioembolization (Table 4) compared to those with a low-grade injury.

When comparing the 2018 AAST criteria to the 1994 criteria, grade of injury can only stay the same or increase, not decrease, because the 2018 AAST grading criteria upgrades liver injury based on vascular injury. Of the 42 patients with vascular injury, six patients (14%) had an increase in grade of injury when applying the newer AAST criteria—with the grade increasing by two points for one patient and by one point each for the remaining five patients. Of the six patients whose grade changed, two upgraded from low-grade injury to high-grade injury while the other four remained in the same group (low/high) in both grading systems. Three of the six whose grade changed were managed operatively, but only one of the two whose grade increased from low grade to high grade was managed operatively.

Mortality

While mortality data was collected, only eight patients died, of which one had HVI and three had a high-grade liver injury.

Table 4 Univariate and multivariate logistic regression model for odds of getting angioembolization

	Crude				Adjusted model	
	N	Events (%)	OR (95% CI)	*p*	OR (95% CI)	*p*
AAST grade						
Low	98	1 (1.02)	Ref		Ref	
High	73	10 (13.7)	15.40 (1.92–123.24)	0.010	14.25 (1.76–115.37)	0.013
Vascular injury						
No	129	1 (0.78)	Ref		Ref	
Yes	42	10 (23.8)	40.00 (4.94–323.97)	0.001	40.34 (4.79–340.09)	0.001

Adjusted model includes age, heart rate, systolic blood pressure, mechanism of injury, and head injury

OR, odds ratio; *CI*, confidence interval; *Ref*, referent

Table 5 Univariate and multivariate logistic regression model for odds of getting operative management

	Crude				Adjusted model	
	N	Events (%)	OR (95% CI)	*p*	OR (95% CI)	*p*
AAST grade						
Low	98	11 (11.2)	Ref		Ref	
High	73	20 (27.4)	2.99 (1.33–6.72)	0.008	3.24 (1.31–8.02)	0.011
Vascular injury						
No	129	19 (14.7)	Ref		Ref	
Yes	42	12 (28.6)	2.32 (1.01–5.30)	0.047	1.51 (0.60–3.76)	0.380

Adjusted model includes age, heart rate, systolic blood pressure, mechanism of injury, and head injury

OR, odds ratio; *CI*, confidence interval; *Ref*, referent

Five had a concomitant head injury. No significant association was found between HVI and death, or AAST grade and death.

Discussion

In this study, HVI was prevalent among liver trauma patients (25%) and was associated with longer length of hospital stay. Vascular injury was also associated with increased angioembolization, which supports prior research [4]. Not surprisingly, there was a higher incidence of vascular injury in patients with high-grade liver injury (44%) and in those with penetrating trauma (37%). Of those with vascular injury, 14% saw an increase in specific AAST grade when applying the 2018 grading system, and 5% moved from low-grade to high-grade injury.

Interestingly, we were unable to find a significant relationship between HVI and operative management, which contrasts with a study by Fang et al [8] that reported intraperitoneal contrast extravasation as the most specific sign on CT in predicting the need for surgery in blunt liver trauma. The findings of that study are reflected in the most recent AAST criteria, which assign a minimum grade of IV to patients with active intraperitoneal contrast extravasation. The cause of this discrepancy is unclear, but possible contributing factors could be that we did not look at intraperitoneal hemorrhage separately from active hemorrhage, that we included penetrating trauma patients whereas Fang et al only evaluated blunt trauma patients, or that Fang et al did not control for the same confounding variables. Our study also found that high-grade liver injury is associated with failure of NOM, even controlling for blood pressure, whereas several previous studies did not find a convincing association [8, 11, 12]. Our finding of a positive relationship between high-grade liver injury and angioembolization supports prior research [4, 12–14].

One limitation of this study is its reliance on CT for evaluation of vascular injury. At our institution, patients with hepatic trauma do not routinely undergo angiography, so vascular injury is not often confirmed with angiography. Poletti et al [15] demonstrated that in blunt trauma patients, CT was 65% sensitive and 85% specific for the detection of arterial vascular injury compared to hepatic angiography. The goal of our study, however, is to correlate CT findings, not angiographic findings, with patient management and clinical outcome, especially given that angiography is more invasive and labor-intensive than CT [6]. Another limitation is our study's retrospective design and our inability to control how imaging findings themselves influenced a decision for angioembolization. While the decision for operative management relies primarily on hemodynamic instability in the setting of blunt trauma, the decision for angioembolization has less defined criteria and is often multifactorial, with CT findings of high-grade injury and HVI often influencing the decision [4, 14–16]. This variability makes our angioembolization-related findings less broadly applicable. Another limitation is the small number of patients with HVI (42), which limits our sample size. Additionally, we only included patients with our standard trauma protocol and excluded patients who had imaging only of the abdomen and pelvis, given the lack of arterial phase imaging in this tailored protocol at our institution. This decision was made knowing that in patients with liver injury, there is often concern for concomitant intrathoracic injury given the liver's location adjacent to the diaphragm. Indeed, only 8% of the excluded patients had a trauma protocol of only the abdomen and pelvis. Additionally, many of our patients suffered polytrauma, and while we were unable to control for all concomitant injuries, we did control for head injury, injury mechanism, and vital signs to limit confounders.

In summary, HVI occurs commonly with liver trauma, particularly in patients with high-grade liver injury and in those with penetrating trauma. There has been a recent shift in recognizing the clinical importance of vascular injury. Indeed, we find that HVI is associated with increased morbidity and angioembolization. We also found that high-grade injury using the updated AAST grading system is associated with failure of NOM and with angioembolization. Of those with vascular injury, 5% saw an increase from low-grade to high-grade injury when applying the new grading criteria. The question remains to what extent HVI should be reflected in injury grading, and whether the updated grading criteria do enough to account for HVI.

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Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Dr. Christina LeBedis.

Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors has significant statistical expertise.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- observational
- performed at one institution

References

1. Doklestić K, Stefanović B, Gregorić P et al (2015) Surgical management of AAST grades III-V hepatic trauma by damage control surgery with perihepatic packing and definitive hepatic repair–single centre experience. World J Emerg Surg 10(1). https://doi.org/10.1186/s13017-015-0031-8
2. Moore EE, Cogbill TH, Jurkovich GJ, Shackford SR, Malangoni MA, Champion HR (1995) Organ injury scaling. J Trauma Injury Infect Crit Care 38(3):323–324
3. Kozar RA, Crandall M, Shanmuganathan K et al (2018) Organ injury scaling: spleen and liver (1994 revision). J Trauma 38(3): 323–324
4. Misselbeck TS, Teicher EJ, Cipolle MD et al (2009) Hepatic angioembolization in trauma patients: indications and complications. J Trauma 67(4):769–773
5. Huber-Wagner S, Lefering R, Qvick L-M et al (2009) Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet 373(9673):1455–1461
6. Baghdanian AH, Armetta AS, Baghdanian AA, Lebedis CA, Anderson SW, Soto JA (2016) CT of major vascular injury in blunt abdominopelvic trauma. Radiographics 36(3):872–890
7. Moore EE, Moore FA (2010) American Association for the Surgery of Trauma organ injury scaling: 50th anniversary review article of the Journal of Trauma. J Trauma 69(6):1600–1601
8. Fang J-F, Wong Y-C, Lin B-C, Hsu Y-P, Chen M-F (2006) The CT risk factors for the need of operative treatment in initially hemodynamically stable patients after blunt hepatic trauma. J Trauma. 61(3):547–554
9. Fang J-F, Chen R-J, Wong Y-C et al (1998) Pooling of contrast material on computed tomography mandates aggressive management of blunt hepatic injury. Am J Surg 176(4):315–319
10. Uyeda JW, Lebedis CA, Penn DR, Soto JA, Anderson SW (2014) Active hemorrhage and vascular injuries in splenic trauma: utility of the arterial phase in multidetector CT. Radiology. 270(1):99–106
11. Becker CD, Gal I, Baer HU, Vock P (1996) Blunt hepatic trauma in adults: correlation of CT injury grading with outcome. Radiology. 201(1):215–220
12. Kumar R, Kumar A, Baliyan V et al (2015) Correlating MDCT liver injury grade and clinical outcome in patients without significant extra-hepatic injury. Indian J Surg 78(4):275–280
13. Letoublon C, Morra I, Chen Y, Monnin V, Voirin D, Arvieux C (2011) Hepatic arterial embolization in the management of blunt hepatic trauma: indications and complications. J Trauma 70(5): 1032–1037
14. Green CS, Bulger EM, Kwan SW (2016) Outcomes and complications of angioembolization for hepatic trauma. J Trauma Acute Care Surg 80(3):529–537
15. Poletti PA, Mirvis SE, Shanmuganathan K, Killeen KL, Coldwell D (2000) CT criteria for management of blunt liver trauma: correlation with angiographic and surgical findings. Radiology. 216(2): 418–427
16. Yoon W, Jeong YY, Kim JK et al (2005) CT in blunt liver trauma. Radiographics 25(1):87–104