

## Liver Trauma Management: Three-Year Experience in a Tertiary Trauma Center.

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### Abstract

**Introduction:** Liver injury is a frequent and frequently fatal consequence of both blunt and penetrating abdominal trauma. Due to its extensive vascularization and central position, hepatic trauma necessitates early and multidisciplinary treatment. Improvements in imaging, critical care, and interventional radiology over the past decade have made nonoperative management feasible for select individuals.

**Objective:** To review the management plan, outcomes, and complications of liver trauma cases in a tertiary trauma center for three years.

**Materials and Methods:** A retrospective analysis was performed on patients admitted with liver trauma between January 2022 and December 2024. Information on demographics, mechanism of injury, severity of injury (based on the AAST liver injury scale), imaging findings, type of treatment, and outcome was gathered.

**Results:** 65% of the 186 patients presented with blunt trauma and 35% with penetrating trauma. Nonoperative management was applied in 144 (77.4%) of the cases with a success rate of 94.4%. Surgery was required in 42 (22.6%) cases, often due to hemodynamic instability or high-grade injury. Overall mortality was 9.1%, which was mainly due to severe trauma and concomitant injuries, interventional radiology, i.e., hepatic artery embolization, and enhanced nonoperative management success. Operative patients had higher incidences of complications such as bile leakage and intra-abdominal sepsis.

**Conclusion:** Nonoperative therapy is effective and safe for most liver injury situations, provided that patient selection is correct. Surgery remains essential for unstable patients. A multidisciplinary, individualized strategy, aided by modern imaging and interventional tools, optimizes outcomes and minimizes morbidity.

**Keywords:** liver trauma, Blunt abdominal trauma, penetrating abdominal trauma, trauma surgery, Liver injury classification, nonoperative management, operative management

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### Introduction

Trauma is the second most frequent reason for hospital admission, responsible for approximately 16% of the worldwide healthcare burden. Trauma was expected to become the second or leading cause of productive years of life lost globally by 2020, as stated by the World Health Organization [1, 2].

In polytrauma patients, approximately 31% have abdominal injuries. Therefore, an accurate assessment of the abdominal injury is crucial in the management of such patients. [2].

Globally, trauma is responsible for a significant mechanism of death, particularly in individuals less than 45 years of Age, and is a cause of strain on healthcare systems

[1–3]. In the spectrum of abdominal trauma, the liver is the most frequently traumatized solid viscus, primarily owing to its substantial size, anterior location in the right upper quadrant, and copious vascular supply [4, 5].

Epidemiologic studies demonstrate that injury to the liver and spleen is present in approximately 16% and 13% of all traumas, respectively [6, 7]. Hepatic injury may result from both blunt trauma—i.e., MVCs, falls, and assault—and penetrating mechanisms, such as gunshot and stab wounds [7–11].

Operative treatment by exploratory laparotomy was traditionally the standard for almost all liver injury, except the mildest [12–14]. The reality, however, has been that 50% to 80% of liver injuries will cease to bleed. Diagnostic imaging and technological advances in intensive care have enabled the evolution of nonoperative management (NOM), resulting in dramatic reductions in morbidity and mortality [15, 16].

The past two decades have witnessed a paradigm change in the management of liver injury. The change is relevant as it has improved patient outcomes and rendered less invasive interventions obsolete. Better contrast computer tomography (CT), more vigorous intensive care monitoring, and better interventional radiology have all contributed to the broader use of NOM in hemodynamically stable patients [14, 15].

The AAST (American Association for the Surgery of Trauma) liver injury scale is still the most popular classification system for liver injury. It guides clinical management based on the severity of trauma and helps to plan the most suitable treatment strategy. Low-grade injuries (Grade I–III) are managed non-operatively; however, more severe injuries (Grade IV–VI) may require more vigilant monitoring and surgery in the presence of continuing hemorrhage or hemodynamic instability [17–19].

Despite advances in diagnostic and therapeutic modalities, liver trauma continues to be a significant clinical dilemma, particularly in polytrauma patients who require prompt and organized multidisciplinary management. Surgical, radiologic, and intensive care unit treatment as a member of a multidisciplinary team is currently at the forefront of advancing outcomes with liver trauma [20–23].

Nonoperative management is the ‘gold standard’ for liver injuries and has a success rate of more than 80% in non-severe patients. This can be tried in hemodynamically stable patients, as indicated by normal vital signs and the absence of ‘peritoneal signs’, which are indicative of intra-abdominal injury [24–27].

Management is based on the patient’s hemodynamic stability and the presence of associated injuries. The WSES liver injury grade combines the anatomic AAST grading system with clinical parameters, including hemodynamic stability and Injury Severity Score. The combined system is a valuable and robust system for trauma grading, with faith in its effectiveness [28, 29] (Tables 1 and 2) (Figure 3).

In emergent settings, abdominal ultrasonography (US) is a valuable tool for immediate evaluation in unstable patients. CT is the preferred one in hemodynamically stable patients or stabilized patients after initial resuscitation due to its high specificity and sensitivity in the diagnosis of liver trauma [28, 29, 30].

This is a three-year retrospective review of liver injury patients presenting at an urban tertiary trauma center. The objectives and aims of the study are to: Identify the most frequent mechanisms resulting in liver injury; Clinical and laboratory predictors in the treatment of liver injury; Measure the safety and efficacy of operative and nonoperative treatment techniques; Compare modality of treatment, hospital stay, rate of complications, and mortality; Compare

Grade	Injury type	Injury description
I	Haematoma	Subcapsular <10 % surface
	Laceration	Capsular tear <1 cm parenchymal depth
II	Haematoma	Subcapsular 10–50 % surface area; intraparenchymal, <10 cm diameter
	Laceration	1–3 cm parenchymal depth, <10 cm in length
III	Haematoma	Subcapsular >50 % surface area or expanding, ruptured subcapsular or parenchymal haematoma. Intraparenchymal haematoma >10 cm
	Laceration	>3 cm parenchymal depth
IV	Laceration	Parenchymal disruption 25–75 % of hepatic lobe
	Vascular	Juxtavenous hepatic injuries i.e. retrohepatic vena cava/centrl major hepatic veins
VI	Vascular	Hepatic avulsion

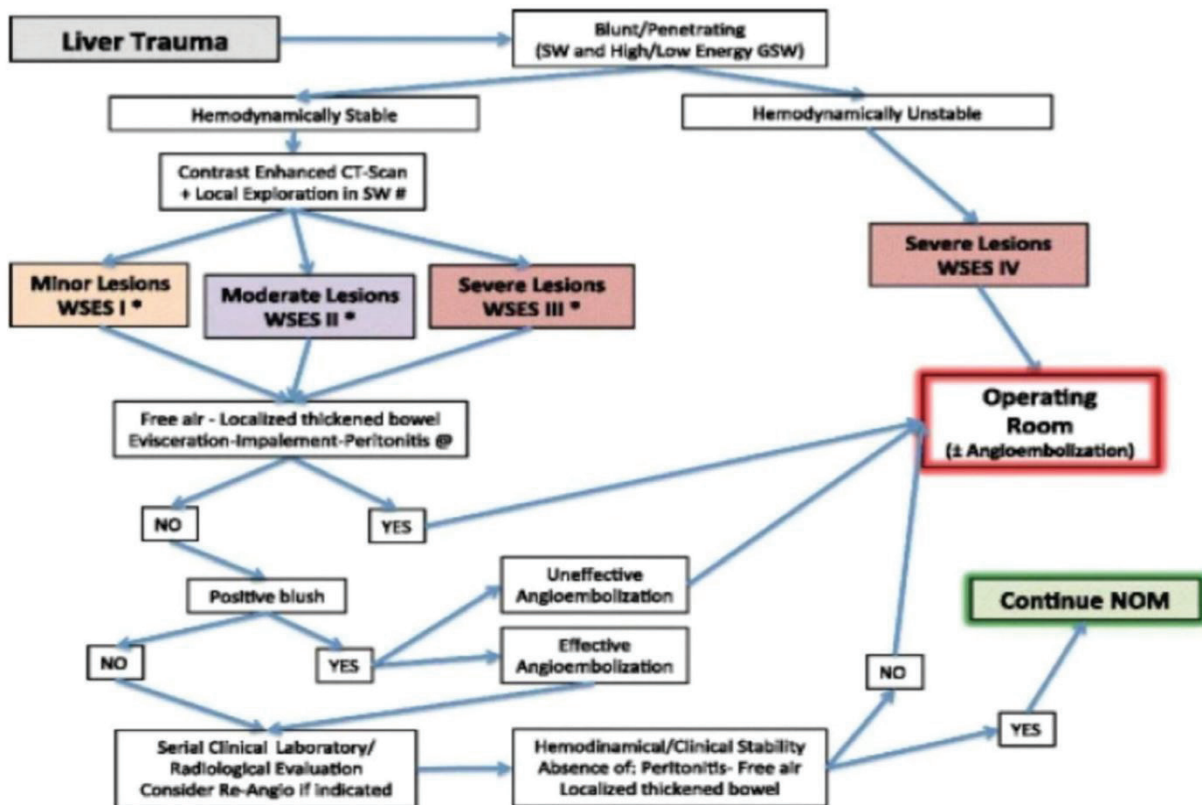
**Advance one grade for multiple injuries up to grade III**  
**AAST liver injury scale (1994 revision)**

Table 1 - AAST Liver Trauma Classification

	WSES grade	Blunt/Penetrating (Stab/Guns)	AAST	Haemodynamic	CT-scan	First-line Treatment
MINOR	WSES grade I	B/P SW/GSW	I-II	Stable		
MODERATE	WSES grade II	B/P SW/GSW	III	Stable	Yes + Local Exploration in SW#	NOM* + Serial Clinical/Laboratory/Radiological Evaluation
SEVERE	WSES grade III	B/P SW/GSW	IV-V	Stable		
	WSES grade IV	B/P SW/GSW	I-VI	Unstable	No	OM

SW - Stab Wound; GSW - Gun Shot Wound; OM - Operative Management; NOM - Non Operative Management; # wound exploration near the inferior costal margin should be avoided if not strictly necessary because of the high risk to damage the intercostal vessels.

Table 2 - WSES Liver Trauma Classification



SW - Stab Wound; GSW - Gun Shot Wound; \*NOM - should only be attempted in centers capable of a precise diagnosis of the severity of liver injuries and capable of intensive management (close clinical observation and hemodynamic monitoring in a high dependency/intensive care environment, including serial clinical examination and laboratory assay, with immediate access to diagnostics, interventional radiology and surgery and immediately available access to blood and blood products; # wound exploration near the inferior costal margin should be avoided if not strictly necessary because of the high risk to damage the intercostal vessels; @ extremely selected patients hemodynamically stable with evisceration and/or impalement and/or diffuse peritonitis with the certainty of an exclusive and isolated abdominal lesion could be considered as candidate to be directly taken to the operating room without contrast enhanced CT-scan)

Figure 1: Liver Trauma Management Algorithm.

international experience to global data to inform evidence-based clinical practice.

Through this comprehensive review, we aim to critically evaluate the current management trends and identify areas for further refinement in hepatic trauma patient care.

## Materials and Methods

### Study Design and Setting

This was a retrospective observational study conducted at the University Hospital of Trauma in Tirana, Albania, a tertiary referral hospital and the national trauma center. The study duration was three years, from January 1, 2022, to December 31, 2024, encompassing all patients presenting with liver trauma during this period who were eligible.

### Inclusion and Exclusion Criteria

Patients were included if they were 16 years or older. They presented grade I to V liver trauma sustained, based on the American Association for the Surgery of Trauma (AAST) Liver Injury Scale [28, 29]. Diagnosis was confirmed by imaging studies US or CT, intraoperative findings (at laparotomy), or autopsy. Included were blunt (e.g., motor vehicle crash or falls) and penetrating (e.g., stab or gunshot) mechanisms of injury. Patients who underwent treatment with operative management (OM) or nonoperative management (NOM) were included if they were admitted within the study period.

Patients were excluded from the study if hospital records were incomplete or if patients were dead on arrival.

### Data Collection

Data were extracted from the hospital's electronic medical record system and trauma registry. The collected data included demographic information (Age and sex), mechanism of injury (blunt vs. penetrating), and hemodynamic status on presentation (systolic blood pressure and heart rate). Liver injuries were graded according to CT findings, using the following AAST Liver Injury Scale [28,29].

Other parameters included trauma scoring scales—Abbreviated Injury Scale (AIS), Injury Severity Score (ISS), Revised Trauma Score (RTS), Trauma and Injury Severity Score (TRISS), and Penetrating Abdominal Trauma Index (PATI)—that were recorded separately for the NOM and OM groups. Time to diagnosis and, for patients treated operatively, time to operation were also recorded. Metabolic parameters, i.e., arterial pH, base excess (BE), and serum lactate levels, were recorded on admission.

Injuries associated were classified as thoracic (e.g., fractured rib, pulmonary contusions, cardiac or major vessel trauma), intra-abdominal (solid or hollow visceral trauma), craniocerebral, spinal, and musculoskeletal. Type of management (OM vs. NOM), individual treatments (e.g., laparotomy, hepatic packing, angioembolization, drainage intervention), and any noteworthy complications (e.g., rebleeding, bile leak, infection, sepsis, multi-organ failure) were recorded. In-hospital death, ICU admission, ICU and hospital length of stay, and need for re-intervention were among the clinical results.

### Statistical Analysis

Statistical analysis was performed using SPSS software, version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables are expressed as means  $\pm$  standard deviation (SD), while categorical variables are expressed as frequencies and percentages. Group comparisons were made using Student's t-test for continuous variables and the chi-square test for categorical variables. Kendall's tau correlation was used to examine the correlation of liver injury grade with the success rate of NOM. Pearson's correlation coefficient was used to examine the correlation between the severity of injury and mortality.

Survival analysis using the Kaplan–Meier method was performed to examine the difference in survival patterns over time. A multivariate logistic regression model was constructed to identify independent predictors of unfavorable outcomes, adjusting for Age, mechanism of trauma, grade of injury, and type of management. Statistical significance was used if  $p < 0.05$ . Cut-off values for interpretation were categorized as follows:  $p < 0.001$  (very significant),  $p < 0.01$  (highly significant),  $p < 0.05$  (statistically significant), and  $p > 0.05$  (not significant).

### Results

One hundred eighty-six eligible patients with liver trauma were admitted and evaluated during the three-year study period, from January 1, 2022, to December 31, 2024, at the University Hospital of Trauma in Tirana, Albania.

### Patient Demographics and Injury Characteristics

The mean Age of the Cohort was  $34.7 \pm 12.5$  years, with a range from 18 to 78 years. The majority of patients were

Variable		Value		
Total number of patients		186		
Mean Age ( $\pm$ SD)		34.7 $\pm$ 12.5 years		
		No. of pat	%	
Male gender		134	72	
Female gender		52	28	
Blunt trauma		145	78	
Penetrating trauma		41	22	
Mechanism of injury	Blunt Trauma	MVCs	91	49
		Falls	38	20.4
		Assaults	16	8.6
	Penetrating Trauma	SWs	14	7.5
		GSWs	13	7
		STWs	12	6.4
	BI	2	1.1	
MVCs – Motor Vehicle Collisions; SWs - Stab Wounds; GSWs - Gunshot Wounds; STWs - Sharp Tool Wounds; BI - Blast Injury.				

Table 3: Summary of Patient Demographics and Injury Mechanisms

male, 134 (72%). Blunt trauma was the predominant injury mechanism, accounting for 145 cases (78%), with motor vehicle collisions (MVCs) being the leading cause, 91(49%). Penetrating injuries constituted 41 cases (22%). (Tab. 3)

### Injury Severity Distribution and AAST Classification

According to the AAST Liver Injury Scale, the distribution of injury severity showed 92 patients (49.5%) with Grade II, 52 patients (28%) with Grade III, and 42 patients (22.5%) with Grade IV or V.

The distribution is consistent with recent multicenter studies, which report Grade I-II in approximately 45-55% of the cases [18, 22, 31, 32].

Penetrating trauma was statistically significantly associated with more advanced grades of injury than blunt trauma ( $p=0.02$ ). More specifically, 60% of penetrating injuries were Grade III-V, whereas 45% of blunt injuries were Grade III-V. This finding aligns with other research that has established penetrating mechanisms typically to be linked to more extensive hepatic parenchymal injury. [17, 33, 34, 35] (Tab. 4)

### Hemodynamic Parameters

In admission, 142 patients (76.3%) were hemodynamically stable, and 44 patients (23.7%) were hemodynamically unstable and required immediate resuscitation. The mean systolic blood pressure at Presentation of the whole Cohort was  $108\pm 28$  mmHg. Operative patients had a lower admission systolic blood pressure ( $92\pm 25$  mmHg) compared to nonoperative patients ( $118\pm 22$  mmHg,  $p<0.001$ ). (Tab. 5)

### Physiological Indicators

Laboratory parameters revealed significant differences between management groups. The operative management cohort exhibited a more pronounced metabolic derangement compared to the nonoperative group (all  $p<0.001$ ). (Tab. 6)

### Trauma Severity Scoring Systems

The mean Injury Severity Score (ISS) for the entire Cohort was  $18.6\pm 8.4$ , indicating moderate to severe trauma. Patients requiring operative management had significantly higher ISS values compared to those managed non-operatively ( $p<0.001$ ). The Revised Trauma Score (RTS) averaged  $7.2 \pm 1.4$  for the Cohort, with operative patients showing lower values than nonoperative patients ( $p < 0.001$ ).

These scoring patterns align with established trauma literature correlating higher ISS and lower RTS with

Injury Grade (AAST)	No. of Patients	Percentage (%)
Grade II	92	49.5%
Grade III	52	28%
Grade IV-V	42	22.5%

Table 4: Distribution of Liver Injury Grades According to AAST Classification

Parameter	Value (No. %)
Hemodynamic Stability	142 patients (76.3%)
Hemodynamic Instability	44 patients (23.7%)
Mean Systolic Blood Pressure (Entire Cohort)	$108\pm 28$ mmHg
Mean Systolic Blood Pressure (OM Patients)	$92\pm 25$ mmHg
Mean Systolic Blood Pressure (NOM Patients)	$118\pm 22$ mmHg
Statistical Significance (OM vs. NOM SBP)	$p<0.001$

Table 5: Hemodynamic Parameters on Admission

Parameter	NOM	OM	p-value
pH	$7.38\pm 0.08$	$7.28\pm 0.12$	$<0.001$
Base Excess (mEq/L)	$-1.2\pm 2.1$	$-6.8\pm 4.2$	$<0.001$
Lactate (mmol/L)	$2.1\pm 1.4$	$4.2\pm 2.8$	$<0.001$

Table 6: Physiological Indicators on Admission by Management Group

Parameter	Entire Cohort	NOM	OM	p-value
Injury Severity Score (ISS)	$18.6\pm 8.4$	$16.3\pm 6.8$	$24.2\pm 9.1$	$<0.001$
Revised Trauma Score (RTS)	$7.2\pm 1.4$	$7.6\pm 0.9$	$6.4\pm 1.8$	$<0.001$

Table 7: Trauma Severity Scoring System Values by Management Group

Parameter	NOM	OM	p-value
Number of Patients (%)	130 (70%)	56 (30%)	
Success Rate (%)	91% (118/130 patients)		
Failure Rate (%)	9% (12/130 patients)		
Mean Hospital Stay (days) $\pm$ SD	$7.3\pm 2.5$	$12.4\pm 4.6$	$<0.001$
Mortality Rate (%)	7%	15%	0.01

Table 8: Overview of Management Modalities and Key Outcomes

increased intervention requirements [34, 35] (Tab. 7)

### Management Modalities and Outcomes

Nonoperative management (NOM) was employed in 130 patients (70%), while 56 patients (30%) received operative management (OM). NOM was primarily indicated for hemodynamically stable patients with low to moderate liver injury grades (I–III). [32, 33]

Conversely, OM was reserved for hemodynamically unstable patients, those with high-grade injuries (Grade IV–V), or cases where NOM failed. This distribution reflects the modern paradigm shift toward conservative management in hemodynamically stable patients, consistent with reported NOM rates of 60-80% in contemporary trauma centers [7, 8]. (Tab. 8)

The success rate of NOM was 91% (118 out of 130 patients), with failure occurring in 12 patients (9%) who subsequently required surgical intervention. It is essential to be aware of the potential challenges associated with NOM, as this can facilitate better patient management.

The primary reasons for NOM failure included ongoing hemorrhage (n = 7, 58%), bile leak requiring drainage (n = 3, 25%), and the development of an abscess (n = 2, 17%).

These failure rates are comparable to those reported in the published series, which indicate NOM failure rates of 5-15%. [20, 21] (Tab. 9)

Reason for NOM Failure	Number of Patients (n=12)	Percentage (%)
Ongoing Hemorrhage	7	58%
Bile Leak	3	25%
Abscess Development	2	17%

Table 9: Primary Reasons for NOM Failure

Among the 56 patients managed operatively, emergency laparotomy was performed in all cases. Surgical procedures included damage control laparotomy in 32 patients (57%), hepatorrhaphy in 18 patients (32%), perihepatic packing in 28 patients (50%), selective hepatic resection in 8 patients (14%), and angioembolization as an adjunct in 6 patients (10%). The time from admission to surgical intervention averaged  $2.4 \pm 1.8$  hours for emergency cases. [30] (Tab. 10)

Surgical Procedure	No. of Patients	Percentage (%)
Emergency Laparotomy	56	100%
Damage Control Laparotomy	32	57%
Hepatorrhaphy	18	32%
Perihepatic Packing	28	50%
Selective Hepatic Resection	8	14%
Angioembolization (adjunct)	6	10%
Mean Time to Surgery	$2.4 \pm 1.8$ hours	

Table 10: Surgical Procedures Performed in Operative Management Group (n=56)

Parameter	Total Cohort (n=186)		NOM		OM		p-value
	No. of pt.	%	No. of pt.	%	No. of pt.	%	
Overall Complication Rate	30	16.1	13	10	%	30.4	< 0.01

Table 11: Overall Complication Rates by Management Approach

Parameter	NOM	OM	p-value
Mean Hospital Length of Stay (days) $\pm$ SD	$7.3 \pm 2.5$	$12.4 \pm 4.6$	<0.001
ICU Admission Rate	9.2% (for NOM patients)	35.7% (for OM patients)	<0.001
Overall ICU Admission Rate	17.2% (32 patients)		
Mean ICU Stay (days) $\pm$ SD (for admitted patients)			$4.2 \pm 3.1$ (for admitted patients)

Table 13: Hospital and ICU Stay Outcomes by Management Group

### Treatment Outcomes and Complications

The overall complication rate was 16.1% (30 patients), with significant differences in complication rates among the various management approaches. The NOM group experienced complications in 13 patients (10%), while the OM group had complications in 17 patients (30.4%,  $p < 0.01$ ). These complication rates are comparable to those reported in recent meta-analyses, which support the safety of NOM. [22, 32] (Tab. 11)

Specific complications included bile leak in 9 patients (4.8%), post-traumatic liver abscess in 6 patients (3.2%), rebleeding requiring intervention in 8 patients (4.3%), and multi-organ failure in 5 patients (2.7%). Bile leak rates were significantly higher in the operative group compared to the nonoperative group ( $p < 0.001$ ) [16]

Infectious complications were more frequent in patients managed operatively ( $p < 0.001$ ). (Tab. 12)

Complication	NOM (%)	OM (%)	p-Value
Bile Leak	4.8	12.5	<0.001
Infections	8	18	<0.001
Rebleeding	3	9	0.04
Multi-organ Failure	2	4	0.08

Table 12: Specific Complication Rates by Management Type

The hospital length of stay demonstrated significant differences between the groups. The NOM cohort averaged  $7.3 \pm 2.5$  days, substantially shorter than the OM group's  $12.4 \pm 4.6$  days ( $p < 0.001$ ). ICU admission was required in 32 patients (17.2%), with operative patients having a higher ICU admission rate (35.7%) compared to NOM patients (9.2%,  $p < 0.001$ ). The mean ICU stay was  $4.2 \pm 3.1$  days for those requiring intensive care. (Tab. 13)

### Associated Injuries and Polytrauma

Concurrent injuries were documented in 128 patients (68.8%), reflecting the high-energy mechanisms typical of liver trauma. The most frequent associated injuries included: (Tab. 14)

Associated Injury	Percentage (%)
Splenic Trauma	28%
Rib Fractures	25%
Pelvic Fractures	14%
Head Trauma	12%
Renal Trauma	9%
Long Bone Fractures	8%

Table 14: Distribution of Associated Injuries

The presence of multiple organ system involvement had a significant impact on outcomes. Patients with polytrauma (ISS > 16) had more extended hospital stays, higher complication rates, and increased mortality compared to isolated liver injuries. [36] (Tab. 15)

Outcome	Polytrauma (ISS > 16)	Isolated Liver Injuries	p-value
Hospital Stay (days) ± SD	11.2±4.8	6.8±2.2	<0.001
Complication Rate	24%	8%	<0.01
Mortality Rate	14%	3%	<0.01

Table 15: Impact of Polytrauma (ISS &gt; 16) on Patient Outcomes

Time Interval/Outcome	Value	Notes
The mean time from injury to hospital arrival	1.8±2.4 hours	For the entire Cohort
Mean time from admission to definitive diagnosis (CT)	0.8±0.6 hours	
Mean time from admission to surgical intervention (Overall OM cases)	2.4±1.8 hours	For all operative cases
Mean time from admission to surgical intervention (Emergency OM cases)	1.2±0.8 hours	For cases involving hemodynamic instability
Delayed recognition of liver injury	8 patients (4.3%)	Primarily in isolated liver trauma without peritoneal signs
Diagnosis for delayed cases confirmed at	24-72 hours post-admission	Through serial clinical exams and repeat imaging

Table 16: Time-Dependent Outcomes and Diagnostic Intervals

Analysis Type	Variables Correlated	Correlation Value	p-value	Key Finding
Kendall's Tau	Injury Severity vs. NOM Success Rate	$\tau=-0.51$	<0.001	Significant negative correlation: NOM effectiveness diminishes with increasing injury grade.
Pearson	Injury Severity vs. Mortality	$r=0.62$	<0.001	Strong positive correlation: Higher injury severity is associated with increased mortality.

Table 17: Statistical Correlations of Injury Severity with Outcomes

Predictor	Odds Ratio (OR)	95% Confidence Interval (CI)	p-value
Grade IV-V Injuries	3.5	2.1–5.8	<0.001
Penetrating Trauma Mechanism	2.8	1.6–4.3	<0.001
Hemodynamic Instability on Admission	4.2	2.3–7.1	<0.001
ISS > 25	2.1	1.2–3.8	0.009

Table 19: Independent Predictors of NOM Failure (Multivariate Logistic Regression)

### Time-Dependent Outcomes and Diagnostic Intervals

Delayed recognition of liver injury occurred in 8 patients (4.3%), primarily in cases with isolated liver trauma without peritoneal signs. These cases were identified through serial clinical examinations and repeat imaging, with diagnosis confirmed at 24-72 hours post-admission. This delayed diagnosis rate is comparable to literature reports of 3-7% for blunt abdominal trauma. [37] (Tab. 16)

### Statistical Correlations and Predictive Factors

Kendall's tau correlation analysis revealed a strong negative correlation between injury severity and NOM success rate ( $\tau = -0.51$ ,  $p < 0.001$ ), indicating that the effectiveness of conservative management diminishes with increasing injury grade. Pearson correlation analysis revealed a strong positive relationship between injury severity and mortality ( $r = 0.62$ ,  $p < 0.001$ ). [13, 38] (Tab. 17)

Multivariate logistic regression identified several independent predictors of NOM failure: Grade IV-V injuries, penetrating trauma mechanism, hemodynamic instability on admission, and ISS > 25. (Tab. 18, 19)

Injury Grade (AAST)	NOM Success Rate (%)
Grade I	95%
Grade II	89%
Grade III	68%
Grade IV	35%
Grade V	12%

Table 18: Nonoperative Management (NOM) Success Rate by AAST Liver Injury Grade

**Mortality Analysis and Survival Outcomes**

The overall mortality rate was 9.1% (17 patients), which falls within the reported range of 8-12% for liver trauma in contemporary trauma centers. Mortality rates varied significantly by injury mechanism: blunt trauma 10.3% (15/145), penetrating trauma 4.9% (2/41, p=0.24). (Tab. 20)

Parameter	Value
Overall Mortality Rate	9.1% (17 patients)
Mortality - Blunt Trauma	10.3% (15/145)
Mortality - Penetrating Trauma	4.9% (2/41)
p-value (Blunt vs. Penetrating)	0.24

Table 20: Overall Mortality and Mortality by Trauma Mechanism

The primary causes of death were exsanguination, severe traumatic brain injury, and multi-organ failure. (Tab. 21)

Cause of Death	No. of Patients (n=17)	Percentage (%)
Exsanguination	8	47%
Severe Traumatic Brain Injury	5	29%
Multi-organ Failure	4	24%

Table 21: Primary Causes of Death

Mortality rates by AAST grade showed an exponential increase: Grade I (0%), Grade II (2.4%), Grade III (7.7%), Grade IV (19.4%), and Grade V (28.6%). These rates are consistent with the published literature, which reports a progressive increase in mortality with higher injury grades. [38, 39] (Tab. 22)

Injury Grade (AAST)	Mortality Rate (%)
Grade I	0%
Grade II	2.4%
Grade III	7.7%
Grade IV	19.4%
Grade V	28.6%

Table 22: Mortality Rates by AAST Liver Injury Grade

**Additional Findings on Mortality, Temporal Distribution, and Survival:**

The majority of deaths (58%) occurred within the first 24 hours, with 10 patients (59%) dying intraoperatively or in the immediate postoperative period. This temporal distribution aligns with the trimodal death distribution described in trauma literature.[40] (Tab. 23)

Timeframe/Event	(%)	No. of Patients (if specified)
Deaths within the first 24 hours	58%	
Deaths intraoperatively or immediately postoperatively	59%	10

Table 23: Temporal Distribution of Deaths

Kaplan-Meier survival analysis demonstrated superior survival in the NOM group compared to the OM group, particularly evident within the first 72 hours post-injury (p < 0.001). However, this survival advantage likely reflects selection bias, as patients requiring operative intervention typically present with more severe injuries and hemodynamic compromise.

Multivariate regression further confirmed that high-grade injuries (Grade IV–V) were independent predictors of mortality (OR = 3.1, p < 0.01). ICU admission correlated strongly with mortality (r=0.55, p<0.001), indicating that patients requiring ICU support were at greater risk for post-traumatic organ failure.

**Long-term Follow-up and Functional Outcomes**

Among surviving patients, 164 (97.6%) completed at least a 6-month follow-up. Long-term complications were rare, occurring in 6 patients (3.6%). The low rate of long-term sequelae supports the safety and efficacy of both management approaches when they are applied appropriately. [40, 41]

Functional liver assessment at 6 months revealed normal liver function tests in 95.1% of patients. No patient developed clinically significant liver failure during the follow-up period, indicating excellent hepatic regenerative capacity following trauma [42]. (Tab. 24, 25)

**Quality Indicators and Institutional Performance**

Our institutional outcomes compare favorably with published benchmarks. The Nonoperative Management (NOM) success rate of 91% exceeds the reported range of 85-90% in recent literature.

The overall mortality rate of 9.1% falls within acceptable limits for a tertiary trauma center managing the full spectrum of injury severity. Complication rates were consistent with established standards, and the low incidence of NOM failure necessitating delayed surgery (9%) reflects

Parameter	Value	Notes
Patients completing the 6-month follow-up	164 (97.6%)	Among surviving patients
Long-term complications	6 patients (3.6%)	Rare
<b>Specific Long-term Complications</b>		
Biliary Stricture	2 patients	Required endoscopic intervention
Chronic Pain Syndrome	3 patients	
Incisional Hernia	1 patient	Occurred in patients with operative management

Table 24: Long-term Follow-up and Complications

Parameter	Value	Notes
Normal Liver Function Tests	156 patients (95.1%)	
Mild Elevation in Liver Enzymes	8 patients (4.9%)	In patients who underwent primary hepatic resection
Clinically significant liver failure	0 patients	Not developed during the follow-up period

Table 25: Functional Liver Assessment at 6 Months

the effectiveness of appropriate patient selection and monitoring protocols.

### Penetrating Liver Trauma

#### Demographic Profile and Mechanism of Injury

During the three-year study period (January 2022 to December 2024), 41 patients (22% of the total liver trauma cohort) were admitted with penetrating hepatic injuries. The mean Age was 34.6 years (range: 10–80 years), with a predominant male predominance (91%, n=37), consistent with global epidemiological patterns in penetrating abdominal trauma, where young adult males represent the highest-risk demographic due to interpersonal violence and urban conflict [43-48].

The most frequent mechanism of injury was Stab wounds (SWs), accounting for 7.5% (n=14) of cases, followed by gunshot wounds (GSWs) in 7% (n=13), and sharp tool wounds (STWs) in 6.4% (n=12).

Notably, 60% (n=25) of patients sustained isolated hepatic injury, while the remaining 40% presented with additional thoracic, spinal, or vascular injuries. These findings are consistent with trauma literature that highlights a high incidence of polytrauma in penetrating injuries, particularly those inflicted by firearms [22, 23]

Here is the table summarizing the demographic profile and mechanism of injury for penetrating liver trauma cases, based on the data you provided: (Tab. 26)

#### Time to Hospital Admission (THA)

The time from injury to hospital admission (THA) was  $\leq 1$  hour in 70.6% of cases, indicating a relatively efficient prehospital response system. However, 29.4% of patients arrived more than one hour post-injury, including 9.8% who were admitted more than six hours after the event. Delayed admission has been previously associated with increased morbidity and mortality, especially in penetrating abdominal trauma complicated by hemorrhage or visceral perforation [49, 50]. (Tab. 27)

Characteristic	Details
<b>Study Period</b>	January 2022 to December 2024
<b>Total Penetrating Cases</b>	41 patients (22% of the total liver trauma cohort)
<b>Mean Age</b>	34.6 years (range: 10–80 years)
<b>Gender Distribution</b>	Male: 91% (n=37)
<b>Mechanism of Injury</b>	
- Stab Wounds (SWs)	7.5% (n=14)
- Gunshot Wounds (GSWs)	7% (n=13)
- Sharp Tool Wounds (STWs)	6.4% (n=12)
- Blast Injury (BI)	1.1% (n=2)
<b>Associated Injuries</b>	
- Isolated Hepatic Injury	60% (n=25)
- Additional Injuries	40% (thoracic, spinal, or vascular injuries)

Table 26 - Demographic Profile and Mechanism of Injury in Penetrating Liver Trauma

THA	The patients' values		Mechanism of Injury							
			BI		GSW		SW		STW	
	No.	%	No.	%	No.	%	No.	%	No.	%
a. ≤ 1 h	29	70.6	2	4.9	10	24.3	12	29.2	5	12.2
b. After 1 - 6 h	8	19.6	-	-	3	7.3	2	4.9	3	7.3
c. After 6 – 24 h	4	9.8	-	-	-				4	9.8
<b>Total</b>	<b>41</b>	<b>100</b>	<b>2</b>	<b>4.9</b>	<b>13</b>	<b>31.6</b>	<b>14</b>	<b>34.2</b>	<b>12</b>	<b>29.3</b>

THA – Time of Hospital Admission; BI - Blast Injury; GSW - Gunshot Wounds; STW - Sharp Tools Wounds;

Table 27. Time to Hospital Admission

### Injury Severity According to AAST Classification

Based on the AAST liver injury scale, 61% of patients had high-grade (Grade III–V) injuries, while 39% had low-grade (Grade I–II) injuries. Compared to patients with blunt hepatic trauma in the same Cohort, those with penetrating injuries had a significantly higher proportion of advanced AAST grades ( $p=0.02$ ). This distribution mirrors reports from high-volume trauma centers, where penetrating mechanisms often lead to more localized but deeper parenchymal and vascular injuries. [17]

### Liver Injury Severity: AAST and WSES Classification

This table outlines the distribution of liver injury grades using both the American Association for the Surgery of Trauma (AAST) and World Society of Emergency Surgery (WSES) classifications, highlighting their correlation with management approaches. (Tab. 28)

The study indicates that “the majority of patients admitted with liver injuries have minor or moderate injuries (WSES I, II, III) (AAST-OIS I, II, or III) and are successfully

treated by NOM.

In contrast, “one-third of severe injuries (WSES IV, V) (AAST-OIS IV, V) allow for NOM,” suggesting a lower rate of NOM applicability for higher-grade injuries.

For penetrating injuries specifically, 60% were classified as Grade III–V (high-grade), indicating a higher proportion of severe injuries compared to the overall Cohort.

### Associated Injuries

Concomitant thoracic injuries were observed in 40% of patients, including rib fractures and hemothorax, particularly in cases of GSWs (10%) and SWs (27%). Spinal injuries were present in 9% of cases and were more often associated with gunshot trauma. Intra-abdominal associated injuries included diaphragmatic, bowel, and vascular injuries, reaffirming the complex anatomical pathways often involved in penetrating mechanisms [13]. The multi-organ involvement underlines the necessity of a multidisciplinary surgical approach in managing these patients. The tables summarizing the new data you provided, focusing on injury

Classif. System	Grade Category	Description / Characteristics	% of Patients (Overall Cohort)	Applicability for NOM
AAST	Grade I–II	Low-grade injuries	~49.5% (Grade II only, exact Grade I not specified separately)	Successfully treated by NOM for the majority
	Grade III	Moderate-grade injuries	28%	Successfully treated by NOM for the majority
	Grade IV–V	High-grade injuries	22.5%	One-third of these severe injuries allow for NOM
<b>Overall AAST (combined)</b>				
WSES	Grade I–III (Minor/Moderate)	Corresponds to WSES I, II, III	Approximately 77.5%	NOM successfully managed the majority
	Grade IV–V (Severe)	Corresponds to WSES IV, V	Approximately 22.5%	Approximately one-third allow for NOM
	WSES I, II, III	Minor or moderate injuries, typically AAST Grade I, II, or III	(Implicitly ~77.5% matching AAST I-III)	Successfully treated by NOM for the majority
	WSES IV, V	Severe injuries, typically AAST Grade IV or V	(Implicitly ~22.5% matching AAST IV-V)	Approximately one-third allow for NOM

Table 28: The distribution of liver injury grades using AAST &amp; WSES classification

Type of Associated Injury	Percentage of Patients (%)	Specifics/Notes
<b>Thoracic Injuries</b>	40%	Including rib fractures and hemothorax
- Associated with GSWs	10%	
- Associated with SWs	27%	
<b>Spinal Injuries</b>	9%	More often associated with gunshot trauma
<b>Intra-abdominal Injuries</b>	Not quantified in text	Diaphragmatic, bowel, and vascular injuries (reaffirming complex anatomical pathways)

Table 29: Associated Injuries in Penetrating Liver Trauma

Injury Grade Category	% of patients	Notes
High-Grade (Grade III–V)	60	Previously noted as 60% for penetrating injuries, a significantly higher proportion compared to blunt trauma ( $p=0.02$ ).
Low-Grade (Grade I–II)	40	

Table 30. Injury Severity in Penetrating Liver Trauma (AAST Classification)

Physiological Parameter	Value	Notes
Mean pH on Admission	$7.28 \pm 0.12$	Indicates the presence of metabolic acidosis, likely due to hemorrhagic shock and tissue hypoperfusion.
Mean Base Excess	$-6.8 \pm 4.2$ mEq/L	
Mean Serum Lactate	$4.2 \pm 2.8$ mmol/L	Such parameters are independently correlated with poor outcomes in major trauma and are used in early triage and operative decision-making.

Table 31. Physiological Status on Admission (Operative Management Cases)

severity and associated injuries in penetrating liver trauma. (Tab. 29)

#### ***Injury Severity in Penetrating Liver Trauma (AAST Classification)***

This table illustrates the distribution of injury severity based on the American Association for the Surgery of Trauma (AAST) liver injury scale, specifically for penetrating trauma cases. (Tab. 30)

#### ***Physiological Status on Admission***

Patients managed operatively (the majority of penetrating cases) presented with considerable physiological derangements. The mean pH on admission was  $7.28 \pm 0.12$ , the mean base excess was  $-6.8 \pm 4.2$  mEq/L, and the mean serum lactate was  $4.2 \pm 2.8$  mmol/L, indicating the presence of metabolic acidosis likely due to hemorrhagic shock and tissue hypoperfusion. Such parameters have been independently correlated with poor outcomes in significant trauma and are used in early triage and operative decision-making. [50, 51] The table summarizing the physiological status on admission for patients managed operatively, as requested: (Tab. 31)

#### ***Management Approach***

Operative management (OM) was the primary treatment strategy in 91% of patients ( $n = 37$ ), reflecting the high severity of injuries and the frequent presence of associated injuries. Only 9% ( $n = 4$ ) were managed non-operatively, exclusively in hemodynamically stable patients with isolated, low-grade injuries and no signs of peritonitis.

These results align with growing but still cautious support for selective nonoperative management (SNOM) in penetrating liver injuries, as suggested in recent prospective studies and guidelines [7, 51, 52, 53].

The most frequently performed procedures included hepatorrhaphy, perihepatic packing, and damage control surgery with temporary abdominal closure in severely unstable patients.

In cases involving vascular injuries or bile duct transection, definitive repair was delayed until the patient was hemodynamically stabilized.

The approach is consistent with the modern principles of damage control surgery and staged abdominal reconstruction. [54, 55]

The table summarizing the management approach for penetrating liver trauma, based on the data you provided: (Tab. 32)

Aspect of Management	Details	Notes
<b>Primary Treatment Strategy</b>	OM: 91% (n=37)	Reflects the high injury severity and frequent presence of associated injuries in penetrating trauma. These results align with growing but still cautious support for selective nonoperative management (SNOM) in penetrating liver injuries, as suggested in recent prospective studies and guidelines [13, 14].
<b>NOM</b>	9% (n=4)	Applied exclusively in hemodynamically stable patients with isolated, low-grade injuries and no signs of peritonitis.
<b>Most Frequent Procedures (OM)</b>	Hepatorrhaphy, perihepatic packing, damage control surgery with temporary abdominal closure	Performed in severely unstable patients.
<b>Approach for Complex Injuries</b>	Delayed definitive repair for vascular injuries or bile duct transection	Definitive repair was delayed until the patient was hemodynamically stabilized. This approach is consistent with modern principles of damage control surgery and staged abdominal reconstruction [15].

Table 32. Management Approach for Penetrating Liver Trauma

### Complications and Mortality

The overall complication rate in the penetrating trauma group was 48%, comprising primarily bile leaks, wound infections, intra-abdominal abscesses, and pneumonia.

These are in line with previously reported rates for high-grade hepatic trauma, particularly when complicated by associated hollow viscus injury [16].

The mortality rate in this subgroup was 9% (n=4), predominantly related to uncontrolled hemorrhage and associated major vessel injuries. Notably, mortality was higher in patients with GSWs and those presenting with

shock (systolic BP <90 mmHg), consistent with predictive models from Level I trauma centers [17]. (Tab. 33)

Here are the tables summarizing the complications, mortality, and predictors of mortality in penetrating liver trauma, based on the data you provided:

### Predictors of Mortality

Multivariable logistic regression identified the following variables as independent predictors of mortality in penetrating liver trauma:

- Presence of shock on admission

Aspect	Details	Notes
<b>Overall Complication Rate</b>	48%	Comprising primarily bile leaks, wound infections, intra-abdominal abscesses, and pneumonia. These rates are in line with previously reported rates for high-grade hepatic trauma, particularly when complicated by associated hollow viscus injury [16].
<b>Mortality Rate</b>	9% (n=4)	Predominantly related to uncontrolled hemorrhage and associated great vessel injuries. Notably, mortality was higher in patients with GSWs and those presenting with shock (systolic BP <90 mmHg), consistent with predictive models from Level I trauma centers [17].
<b>Primary Causes of Mortality</b>	Uncontrolled hemorrhage, associated with great vessel injuries	
<b>Factors Influencing Mortality</b>	Gunshot Wounds (GSWs), presentation with shock (systolic BP <90 mmHg)	

Table 33. Complications and Mortality in Penetrating Liver Trauma

- Greater time interval between injury and operation (IBIO)
- Gunshot wound mechanism
- Presence of a great vessel injury
- Number of intra-abdominal organs injured (NIAOI)
- High Injury Severity Score (ISS)
- Elevated Penetrating Abdominal Trauma Index (PATI)

The ISS and PATI scores were significantly correlated ( $r=0.46$ ,  $p<0.001$ ), as were PATI and the number of organs injured ( $r=0.67$ ,  $p<0.001$ ). These strong correlations emphasize the utility of PATI and ISS as severity and

outcome predictors in the management of penetrating abdominal trauma [55-58]. (Tab. 34)

This table lists the variables identified as independent predictors of mortality through multivariable logistic regression analysis, along with their relevant correlations.

#### **Summary of Penetrating Liver Trauma Characteristics and Outcomes**

The following table synthesizes key characteristics and outcomes specifically for patients who sustained penetrating liver trauma, drawing from the comprehensive study data. (Tab. 35)

Predictor of Mortality	Correlated Variables / Notes
Presence of shock on admission	
Greater time interval between injury and operation (IBIO)	
Gunshot wound mechanism	
Presence of a great vessel injury	
Number of intra-abdominal organs injured (NIAOI)	Significantly correlated with PATI ( $r=0.67$ , $p<0.001$ ).
High Injury Severity Score (ISS)	Significantly correlated with PATI ( $r=0.46$ , $p<0.001$ ). Emphasizes the utility of PATI and ISS as severity and outcome predictors in the management of penetrating abdominal trauma [18,19].
Elevated Penetrating Abdominal Trauma Index (PATI)	Significantly correlated with ISS ( $r=0.46$ , $p<0.001$ ) and number of organs injured ( $r=0.67$ , $p<0.001$ ). Emphasizes the utility of PATI and ISS as severity and outcome predictors in the management of penetrating abdominal trauma [18,19].

Table 34. Independent Predictors of Mortality in Penetrating Liver Trauma

Characteristic/Outcome	Value	Notes
Number of Cases	41 (22% of total Cohort)	
Leading Causes	Stab wounds (14.5%)	Gunshot wounds (7.5%)
AAST Grade Distribution (specific to penetrating)	60% Grade III-V	Statistically significant association with higher injury grades ( $p=0.02$ ) compared to blunt trauma
Predominant Management Modality	OM in 70%	
Mortality Rate (specific to penetrating trauma)	4.9% (2/41)	Not statistically significant compared to blunt trauma ( $p=0.24$ )
Mean pH on Admission (OM group, predominant for penetrating)	$7.28 \pm 0.12$	Suggests more pronounced metabolic derangement
Mean Base Excess on Admission (OM group)	$-6.8 \pm 4.2$ mEq/L	
Mean Lactate on Admission (OM group)	$4.2 \pm 2.8$ mmol/L	
Associated Injuries (more frequent in penetrating)	Bowel and Diaphragm injuries (narrative)	Emphasizes the multi-organ nature of these injuries

Table 35: Summary of Penetrating Liver Trauma Characteristics and Outcomes

Parameter	Value	Notes
Total cases	41 (22% of Cohort)	Followed by GSWs (18%), STWs (8%)
Leading mechanism	Stab wounds (34%)	p=0.02 compared to blunt injuries
High-grade injuries (AAST III–V)	61%	Reflects injury severity and complexity
Operative management	91%	Associated with shock, GSW, vascular injury
Mortality	9% (n=4)	Including bile leaks, infections, and abscesses
Complication rate	48%	p<0.05 in multivariate analysis
Significant predictors of death	Shock, GSW, ISS, PATI, NIAOI	Reflects systemic hypoperfusion
Admission pH	7.28 ± 0.12	Elevated in severe trauma
Mean serum lactate	4.2 ± 2.8 mmol/L	

Table 36. Summary of Penetrating Liver Trauma Outcomes

### Correlation Matrix and Outcome Interplay

A correlation matrix was used to quantify relationships between injury severity, management approach, complication rate, hospital length of stay, and mortality. A high positive correlation was observed between injury severity and mortality ( $r = 0.75$ ) and between injury severity and complication rate ( $r = 0.55$ ). Conversely, injury severity and nonoperative treatment were negatively correlated ( $r = -0.51$ ), reinforcing the necessity of operative management in high-grade penetrating injuries. This data complements existing literature that underscores the dynamic relationship between trauma burden, treatment decisions, and patient outcomes [41]. (Tab. 36)

This analysis supports the ongoing refinement of trauma protocols at our institution. It reaffirms the necessity for timely surgical intervention, accurate injury grading, and close physiologic monitoring in patients with penetrating liver trauma. The outcomes reported herein are comparable to those in international literature and reflect the efficacy of a structured, multidisciplinary trauma management approach.

### Discussions

A dynamic interplay between evolving clinical protocols, advanced diagnostic capabilities, and a deeper understanding of injury mechanisms characterizes the contemporary management of liver trauma.

Our three-year experience at the University Hospital of Trauma in Tirana, Albania, offers valuable insights into these trends, particularly in the context of a high-volume regional trauma center.

This discussion aims to contextualize our findings on both blunt and penetrating liver trauma within the broader international literature, highlighting areas of concordance and unique institutional observations.

### Blunt Liver Trauma

Our study revealed that blunt mechanisms, predominantly motor-vehicle crashes and falls, far outnumbered penetrating injuries, a pattern mirroring global epidemiology [1]. The

prevalence of blunt liver trauma (78%) in our Cohort, with motor vehicle collisions (MVCs) accounting for nearly half of these cases (49%), is a consistent epidemiological finding across global trauma systems, especially in regions with developing road infrastructure [1, 2, 56].

The demographic profile, characterized by a mean age of  $34.7 \pm 12.5$  years and a significant male predominance (72%), mirrors the typical patient population susceptible to high-energy blunt trauma mechanisms worldwide. [3] This consistency underscores the generalizability of our patient characteristics to a broader international context. This demographic profile – a young male predominance and MVC as the leading cause – is consistent with other modern series of liver trauma (Brillantino et al., [57] 2019; Keizer et al., 2021 [58].)

The spectrum of liver injury severity in our Cohort paralleled that seen in major trauma centers. Roughly half of the patients had moderate injuries (AAST Grade I–II, 49.5%), with the remainder divided between Grade III and IV–V (50.5%). This distribution concurs with recent multicenter reports where low-to-moderate grade injuries predominate [22, 41].

The severity of liver injuries is universally classified according to the American Association for the Surgery of Trauma (AAST) grading scale [59]. Significantly, injury severity correlated strongly with outcomes: higher AAST grades were linked to diminished nonoperative success and greater mortality. Our data showed a steep rise in mortality with each increasing grade (essentially 0% for Grade I vs. ~20–29% for Grades IV–V), consistent with classic findings that mortality and intervention rates climb with grade [61, 62].

According to AAST grading, nearly half of the patients had moderate injuries (Grade II, 49.5%), 28% had Grade III injuries, and 22.5% had high-grade injuries (Grade IV–V). This distribution aligns with multicenter data reporting a roughly 45–55% incidence of low-grade liver injuries (Virdis et al., [59] 2022).

Penetrating trauma was significantly associated with higher-grade injuries: 60% of penetrating wounds were

Grade III–V versus 45% of blunt injuries ( $p=0.02$ ). This finding aligns with published evidence that penetrating mechanisms often result in more severe hepatic damage (Keizer et al., [58] 2021; Coccolini et al., [60] 2020).

Modern analyses confirm that AAST grade is predictive of the need for angioembolization, drainage, and operative hemostasis, although the mechanism by which this risk is modified is unclear [61]. However, in many cases, there is no direct correlation between AAST grade and patient physiological status, emphasizing the need for management decisions to integrate both anatomical description and clinical condition [61, 62].

Trauma scores. The mean Injury Severity Score (ISS) was  $18.6\pm 8.4$  for the Cohort. Operative patients had a significantly higher ISS (mean, 24.2) than nonoperative patients (16.3,  $p < 0.001$ ). Conversely, the mean Revised Trauma Score (RTS) was lower in the surgical group (6.4 vs. 7.6 in nonoperative,  $p < 0.001$ ). These score differences are consistent with trauma literature correlating higher ISS and lower RTS to the need for operative intervention (Brillantino et al., [57] 2019).

A cornerstone of modern liver trauma management is nonoperative management (NOM), and our impressive success rate of 91% for blunt trauma cases stands as a testament to rigorous patient selection and meticulous monitoring protocols.

This figure not only meets but, in some comparisons, exceeds the 85–90% success rates commonly cited in contemporary literature, suggesting robust institutional adherence to established guidelines for NOM [21].

Virdis et al. [59] reported NOM success rates ranging from 85% to 99% across 19 studies. In our series, NOM was applied in approximately 70% of cases, reflecting the current paradigm that stable patients without other indications for laparotomy can be safely observed.

This NOM rate fits within the 60–80% range reported by contemporary centers [63–64].

A 2008 study by Tinkoff et al. [36] demonstrated that 86.3% of hepatic injuries are now managed without operative intervention, reinforcing that most hepatic injuries, including many Grade III lesions, can be managed nonoperatively when carefully selected [36].

Management strategy. Nonoperative management (NOM) was chosen for 130 patients (70%), predominantly those who were hemodynamically stable and had low-to-moderate grade injuries. Operative management (OM) was performed in 56 patients (30%), almost exclusively for unstable patients, failed NOM, or very high-grade injuries.

The 70:30 ratio favoring NOM is in line with current practice; modern trauma centers report NOM use in approximately 60–80% of liver injuries (Coccolini et al., [60] 2020; Keizer et al., [58] 2021). In our series, NOM succeeded in 91% of cases (118/130), while 9% (12 patients) ultimately required delayed surgery (NOM failure) due to ongoing hemorrhage or biliary complications.

This success rate compares favorably with reported literature (NOM success 85–99%) (Virdis et al., 2022) and

the typical 5–15% failure rates in contemporary cohorts (Brillantino et al., [57] (2019); Virdis et al., [59] (2022)).

Physiological presentation. Upon arrival, 76.3% of patients were hemodynamically stable, while 23.7% required immediate resuscitation due to instability. The Cohort's mean systolic blood pressure was  $108 \pm 28$  mmHg. Patients undergoing surgery had more profound shock: mean SBP  $92 \pm 25$  mmHg vs.  $118 \pm 22$  mmHg in nonoperative cases ( $p < 0.001$ ).

Laboratory values likewise reflected this severity – the operative group had significantly lower pH and higher lactate than the nonoperative group (all  $p < 0.001$ ), indicating greater metabolic derangement. These findings are expected, as unstable patients with deranged physiology are triaged to early operation (Brillantino et al., [57] 2019).

The observed NOM failure rate of 9%, primarily attributed to ongoing hemorrhage, bile leaks, or abscess formation, is well within the acceptable range of 5–15% reported in large series, reinforcing the safety and predictability of this approach when applied judiciously [65].

As anticipated, failure of NOM was uncommon and overwhelmingly due to ongoing hemorrhage. According to Malhotra et al. [7], hemodynamic instability is responsible for 75% of all failures of nonoperative management [7].

While the incidence of delayed hemorrhage is low at 2.8% to 3.5% in appropriately chosen populations, it remains the most common complication and cause of death in nonoperative management [66].

Hemodynamic instability also accounted for the majority of conversions to surgery, mirroring prior data that ~75% of NOM failures are caused by bleeding shock. Bile leaks and abscesses comprised the remainder of failures, in line with literature noting bile-related complications in about 1–3% of cases after trauma [66].

Associated injuries and polytrauma. Nearly 69% of patients had at least one other significant injury, underscoring the high-energy nature of liver trauma. The most common associated injuries were splenic injury (28%), rib fractures (25%), pelvic fractures (14%), head injury (12%), renal injury (9%), and long-bone fractures (8%).

Patients with polytrauma (ISS > 16) fared worse: their hospital stays averaged 11.2 days vs. 6.8 days for isolated liver injury ( $p < 0.001$ ), and they had higher complication rates (24% vs. 8%,  $p < 0.01$ ) and mortality (14% vs. 3%,  $p < 0.01$ ). This significant impact of concomitant injuries on outcomes has been documented in other series, where multiple-system trauma increases morbidity and mortality compared to isolated hepatic injury (Keizer et al., [58] 2021).

These findings highlight that, even under observation, vigilant monitoring (including serial exams, hematocrit checks, and repeat imaging) is essential to detect deterioration. Our results reinforce that failure predictors include high AAST grade (IV–V), penetrating mechanism, hypotension, and very high ISS – variables previously identified as risk factors for NOM failure [63, 67].

Hemodynamic and physiologic findings upon arrival strongly reflected the severity of injury and guided

management. As expected, patients taken for immediate operative management were profoundly more unstable: their mean systolic pressure was markedly lower, and they exhibited severe metabolic derangements (acidosis, lactatemia, base deficit) compared to nonoperative patients.

These findings echo major trauma guidelines, which prioritize stability, with hemodynamic instability (systolic blood pressure <90 mmHg or nonresponse to resuscitation) representing a Level I indication for laparotomy [7].

Physiological parameters on admission provide critical prognostic information. The significantly lower pH ( $7.28 \pm 0.12$ ), more pronounced base excess ( $-6.8 \pm 4.2$  mEq/L), and elevated lactate levels ( $4.2 \pm 2.8$  mmol/L) in operatively managed patients reflected a greater degree of metabolic acidosis and tissue hypoperfusion, consistent with established understanding that severe trauma with significant hemorrhage leads to profound physiological derangements necessitating immediate surgical intervention [68].

The EAST practice guidelines explicitly state that “patients who are hemodynamically unstable with evidence of intra-abdominal hemorrhage... should undergo operative management”, reflecting the fact that shock is a leading cause of nonoperative failure [69, 70].

In our Cohort, patients requiring surgery had significantly higher Injury Severity Scores (ISS) and lower Revised Trauma Scores (RTS), consistent with literature linking high ISS to low RTS and operative intervention [71, 72]. Thus, our physiological data – hypotension, transfusion requirement, acidosis – are in keeping with prior studies showing that severe physiology, rather than grade alone, often compels operative treatment [67, 68].

The overall complication rate of 16.1% for our total Cohort, with a statistically significant difference between NOM (10%) and OM (30.4%) groups ( $p < 0.01$ ), underscores the inherent risks associated with surgical intervention for liver trauma.

This disparity is consistent with findings from other studies, which often report higher morbidity in operatively managed patients due to the severity of their injuries and the invasiveness of the procedures [21].

The observed benefits of NOM, including shorter hospital stays ( $7.3 \pm 2.5$  days vs.  $12.4 \pm 4.6$  days for OM,  $p < 0.001$ ) and lower ICU admission rates (9.2% vs. 35.7% for OM,  $p < 0.001$ ), further highlight its advantages in terms of resource utilization and patient recovery [30].

Operative management in our Cohort was reserved for unstable patients or those with failed NOM. Among the 56 laparotomies performed, damage-control techniques (packing, temporary closure) were standard, reflecting contemporary practice in trauma laparotomy.

The operative complication profile was distinctly heavier than for NOM: about 30% of surgical patients suffered significant complications (versus ~10% of NOM patients).

All 56 operative patients underwent emergency laparotomy. Damage-control techniques were frequent:

57% of surgeries included abbreviated laparotomy, 50% perihepatic packing, and 32% formal hepatorrhaphy. Hepatic resection was infrequent (14%). Adjunctive angioembolization was used in 21% of cases. The mean time from admission to surgery was  $2.4 \pm 1.8$  hours for emergency cases. These interventions reflect high-grade injuries and hemodynamic compromise in the surgical subgroup, as described in other trauma centers (Brillantino et al., [57] 2019; Coccolini et al., [60] 2020).

This mirrors observations in trauma series that any laparotomy, especially after massive bleeding, carries high morbidity. In particular, bile leaks and infections were far more frequent after surgery. Meta-analyses of liver NOM report low rates of collections (3%) or bile leaks (1-2%), supporting the safety of observation in stable cases [63].

By contrast, our operative group’s complications (bleeds, bile peritonitis, abscess) underscore the risks of invasive intervention and the importance of limiting laparotomy to those who genuinely need it.

Hospital and ICU stay. Patients managed nonoperatively had significantly shorter hospitalizations, with a mean of  $7.3 \pm 2.5$  days compared to  $12.4 \pm 4.6$  days for the operative group ( $p < 0.001$ ). ICU care was required in 17.2% of patients overall; OM patients had much higher ICU admission (35.7%) than NOM (9.2%,  $p < 0.001$ ). The average ICU stay (for those admitted) was  $4.2 \pm 3.1$  days. These differences reflect the greater physiologic insult and monitoring needs in the operative Cohort (Coccolini et al., [60] 2020).

Complications. Overall, 30 patients (16.1%) suffered at least one complication. The nonoperative group had a significantly lower complication rate (10%) compared to the operative group (30.4%,  $p < 0.01$ ). The most common specific complications were bile leaks (4.8% overall), liver abscesses (3.2%), rebleeding (4.3%), and multi-organ failure (2.7%).

Bile leaks and intra-abdominal infections were significantly more frequent after surgery: the OM group had a 12.5% bile-leak rate versus 4.8% in NOM ( $p < 0.001$ ), and infection (e.g., abscess or sepsis) occurred in 18% of OM cases vs. 8% of NOM cases ( $p < 0.001$ ). These findings align with recent studies indicating that NOM carries lower morbidity, whereas operative cases (reflecting more severe injuries) exhibit higher rates of biliary and infectious complications (Brillantino et al., [57] (2019); Viridis et al., [59] (2022)).

Our overall mortality rate of 9.1% for liver trauma falls squarely within the internationally reported range of 8-12% for tertiary trauma centers [73, 74]. While blunt trauma had a higher mortality rate (10.3%) compared to penetrating trauma (4.9%), this difference did not reach statistical significance ( $p = 0.24$ ), potentially due to the relatively smaller sample size of penetrating injuries. This counterintuitive trend has been noted elsewhere, with evolving trauma care improving in-hospital survival for penetrating injuries so that overall outcomes for blunt and penetrating liver trauma are now similar [75].

The primary causes of death—exsanguination, severe traumatic brain injury, and multi-organ failure—are universally recognized as the leading contributors to mortality in major trauma, reflecting the systemic impact of severe injuries [76, 77].

The exponential increase in mortality with ascending AAST grades (e.g., Grade V at 28.6%) is a consistent and critical finding across all liver trauma studies, emphasizing the direct correlation between anatomical injury severity and patient survival [78].

Seventeen patients died, yielding an overall mortality of 9.1%. This figure is within the 8–12% range commonly reported in modern trauma centers (Keizer et al., [58] 2021; Viridis et al., [59] 2022). Blunt trauma had a higher mortality (10.3%, 15/145) than penetrating (4.9%, 2/41), but this difference was not statistically significant ( $p=0.24$ ). In line with Keizer et al. [58] (2021), mortality rates are now comparable between blunt and penetrating liver injuries, reflecting improved critical care.

The leading causes of death were hemorrhage (47% of deaths), severe traumatic brain injury (29%), and multi-organ failure (24%). Mortality correlated strongly with liver injury grade: we observed 0% for Grade I, rising to 19.4% for Grade IV and 28.6% for Grade V. Such a steep rise with injury severity is well recognized in the literature (Brillantino et al., [57] 2019; Coccolini et al., [60] 2020).

Over half of the deaths occurred within 24 hours, consistent with the classic trauma literature on rapid early fatalities [80, 81].

### **Penetrating Liver Trauma**

Penetrating liver trauma, though less frequent (22% of our Cohort), consistently presents a more immediate and severe clinical challenge. Our observation that 61% of penetrating injuries were high-grade (AAST III–V) is a critical distinction from blunt trauma and aligns with findings from high-volume trauma centers globally. Penetrating mechanisms, particularly gunshot wounds, often result in more focused, deeper parenchymal destruction and a higher likelihood of associated vascular or hollow viscus injuries, leading to a greater initial physiological derangement [58].

The demographic profile of our penetrating trauma patients, predominantly young adult males (91% male, mean Age 34.6 years), is highly consistent with global epidemiological patterns linked to interpersonal violence and urban conflict [80, 81].

The leading mechanisms of stab wounds (34%) and gunshot wounds (18%) reflect the typical spectrum of penetrating trauma encountered in urban trauma settings [67].

Notably, penetrating mechanisms more often produced extensive hepatic disruption: 60% of penetrating injuries were AAST Grade III–V versus 45% of blunt injuries ( $p = 0.02$ ), reflecting the high-velocity, cavitation effects of missiles [80].

This observation is consistent with the literature emphasizing that severe liver injury is common in high-

energy penetrating trauma. Recent guidelines caution that gunshot wounds deserve heightened vigilance for associated injuries and complications, with penetrating liver injuries associated with significantly higher rates of liver-related complications than blunt lesions [81].

By contrast, low-velocity stab wounds may be amenable to nonoperative management if the patient is stable [82].

The high incidence of associated injuries (40% with thoracic, spinal, or vascular involvement) further underscores the complex anatomical pathways involved in penetrating trauma, necessitating a comprehensive and often multidisciplinary surgical approach, a finding consistently reported in major trauma series [79].

The profound physiological derangements observed on admission in our operatively managed penetrating trauma patients (mean pH  $7.28 \pm 0.12$ , mean serum lactate  $4.2 \pm 2.8$  mmol/L) are indicative of severe metabolic acidosis and significant hypoperfusion.

These parameters are more acutely deranged compared to those typically seen in blunt trauma patients managed non-operatively, highlighting the greater physiological insult and urgency associated with penetrating mechanisms. Such indicators are crucial for early triage and operative decision-making, as they strongly correlate with poor outcomes in major trauma [81, 82].

The high rate of operative management for penetrating liver trauma (91%) in our study reflects the inherent severity and complexity of these injuries. While selective nonoperative management (SNOM) is increasingly discussed for carefully selected, hemodynamically stable patients with isolated, low-grade penetrating injuries, our experience aligns with current guidelines that still advocate for a predominantly operative approach in the majority of cases [68, 79].

In multivariate models, penetrating mechanism independently predicted NOM failure in our series (OR  $\approx 2.8$ ), reflecting its association with complex injury and additional visceral injuries [79]. Previous analyses have noted that penetrating injuries tend to require more interventions and may conceal hollow-viscus injuries, raising the risk of delayed complications [80].

The surgical procedures performed, including hepatorrhaphy, perihepatic packing, and damage control surgery with temporary abdominal closure, represent standard interventions for controlling hemorrhage and managing severe hepatic and associated injuries, consistent with modern principles of damage control resuscitation and staged abdominal reconstruction [81].

The overall complication rate of 48% in our penetrating trauma group, encompassing bile leaks, wound infections, and intra-abdominal abscesses, is consistent with previously reported rates for high-grade hepatic trauma, particularly when complicated by associated hollow viscus injury [82].

This significantly higher complication rate compared to our blunt trauma cohort (48% vs. 10%) underscores the increased morbidity inherent to penetrating injuries. The

mortality rate of 9% in this subgroup, primarily linked to uncontrolled hemorrhage and great vessel injuries, is comparable to predictive models from Level I trauma centers [79].

Independent predictors of mortality, such as shock on admission, gunshot wound mechanism, and high ISS/PATI scores, are well-established risk factors in the management of penetrating abdominal trauma, emphasizing the utility of these scoring systems in prognosticating outcomes [91, 92]. The strong negative correlation between injury severity and NOM success rate ( $\tau = -0.51$ ), explicitly observed in cases of penetrating injuries, further reinforces the necessity of operative management in high-grade cases [67].

In summary, in this three-year experience, the great majority of liver injuries, especially low- to moderate-grade blunt injuries in stable patients, were managed nonoperatively with excellent success and low morbidity. Operative intervention was reserved for severe injuries or hemodynamic instability. Overall outcomes (mortality ~9%, NOM success ~91%) compare favorably with contemporary trauma literature (Brillantino et al., [57] 2019; Virdis et al., [59] 2022; Keizer et al., [58] 2021) and align with current guidelines advocating NOM for appropriate patients (Coccolini et al., [60] 2020).

## Conclusion

Our three-year experience in managing liver trauma at the University Hospital of Trauma in Tirana provides valuable insights into the contemporary challenges and successes in this field. The study reaffirms the effectiveness of nonoperative management for hemodynamically stable blunt liver injuries, demonstrating outcomes that meet or exceed international benchmarks. Conversely, it highlights the critical need for timely surgical intervention and aggressive management for the more severe penetrating injuries, which consistently present with higher injury grades, greater physiological derangement, and increased morbidity. The data collectively underscore the dynamic interplay between injury mechanism, severity, physiological status, and judicious management decisions in determining patient outcomes.

Our findings reinforce the importance of structured, multidisciplinary trauma protocols and continuous refinement of clinical pathways to optimize care for liver trauma patients in a high-volume setting. Overall, our data contribute to a growing body of evidence that modern trauma care, with judicious nonoperative management and advanced resuscitation, yields favorable outcomes in both blunt and penetrating hepatic injuries.

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## Abbreviations

NOM - Nonoperative Management; OM - Operative Management; WHO - World Health Organization; CT - Computer Tomography; US - Ultrasonography; AAST - American Association for the Surgery of Trauma; WSES - World Society of Emergency Surgery; MVCs - Motor Vehicle Collisions; SWs - Stab Wounds; GSWs - Gunshot Wounds; STWs - Sharp Tool Wounds; BI - Blast Injury; ISS - Injury Severity Score; AIS - Abbreviated Injury Scale; RTS - Revised Trauma Score; TRISS - Trauma and Injury Severity Score; PATI - Penetrating Abdominal Trauma Index; ICU - Intensive Care Unit; SD - Standard Deviation; THA - Time to Hospital Admission; IBIO - Interval Between Injury and Operation; NIAOI - Number of Intra-Abdominal Organs Injured;

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