



The Association of Mechanism of Injury with Predictable Injury Patterns: A Systematic Review

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ABSTRACT

INTRODUCTION: The mechanism of injury (MOI) is a cornerstone of trauma assessment, founded on the principle that the transfer of kinetic energy to the body produces specific and predictable patterns of tissue damage. An understanding of these patterns is critical for effective prehospital triage, rapid in-hospital diagnosis, and anticipatory patient management. This systematic review aims to synthesize the existing evidence linking specific blunt and penetrating trauma mechanisms to their resultant injury constellations across diverse patient populations.

METHODS: A systematic search of PubMed, Google Scholar, Semanthic Scholar, Springer was conducted for original research published between January 2000 and December 2024. Studies were included if they quantitatively evaluated the association between a defined MOI and specific injury patterns in human subjects. Data on study design, population, MOI, and outcomes

were extracted. The quality of included studies was assessed using the Cochrane Risk of Bias tool for non-randomized studies. A qualitative synthesis of the findings was performed, categorizing results by MOI and patient demographic.

RESULTS: A total of 18 studies met the inclusion criteria, encompassing a range of blunt and penetrating trauma mechanisms. Consistent and strong associations were identified. In blunt trauma, fall direction in the elderly was highly predictive of fracture location: sideways falls with hip fractures (Odds Ratio 3.68), forward falls with forearm/patella fractures, and backward falls with spinal fractures. High-energy falls from height were associated with a predictable pattern of axial loading injuries, including calcaneal, pelvic, and spinal fractures. Motor vehicle collisions (MVCs) demonstrated distinct patterns based on impact vector; side impacts were associated with a higher incidence of thoracic, pelvic, and proximal upper extremity injuries compared to frontal impacts. In pediatric MVCs, age-dependent patterns were observed, with severe head injuries predominating in young children (0-8 years) and abdominal injuries in adolescents (9-17 years). Penetrating trauma from gunshot wounds was associated with high mortality, particularly with cranial involvement (41% mortality), and a high degree of occult internal injury.

DISCUSSION: The evidence robustly supports the hypothesis that MOI is a powerful predictor of injury patterns, grounded in fundamental biomechanical principles. However, the predictive utility of MOI is significantly modulated by patient-specific factors, most notably age and physiological reserve. In geriatric patients, low-energy mechanisms frequently produce injury

patterns characteristic of high-energy trauma in younger adults. The clinical value of MOI lies not only in field triage but also as a cognitive tool to guide diagnostic strategy and maintain a high index of suspicion for occult injuries, particularly in patients who appear physiologically stable upon initial presentation.

CONCLUSION: A strong, evidence-based association exists between the mechanism of injury and predictable patterns of injury. This knowledge is essential for optimizing trauma care, from prehospital triage to definitive management. Future research should focus on developing more sophisticated predictive models that integrate MOI with patient-level factors such as frailty to enhance triage accuracy and improve patient outcomes.

KEYWORDS: Mechanism of Injury, Injury Pattern, Trauma, Triage, Biomechanics, Blunt Trauma, Penetrating Trauma

INTRODUCTION

Background: The Fundamental Link Between Energy, Mechanism, and Injury

Trauma is a disease of energy. The foundational principle of traumatology is that injury occurs when an external energy source imparts a load to the human body that exceeds the tissue's mechanical tolerance (Al-Thani et al., 2021). The characteristics of this energy transfer—its magnitude, direction, and rate of application—are dictated by the mechanism of injury (MOI). Consequently, the MOI is the single most important predisposing factor determining the nature, location, and severity of the resulting injuries (Al-Thani et al., 2021). The study of trauma biomechanics seeks to understand the complex interplay between the kinetics of a traumatic event and the subsequent pathophysiological response of the body (Donat et al., 2021).

Traumatic events are broadly categorized into blunt and penetrating mechanisms. Blunt trauma, which involves forces of acceleration, deceleration, compression, and shear, accounts for the majority of injuries and includes events such as falls, motor vehicle collisions (MVCs), and assaults (Toney-Butler and Varacallo, 2023). Penetrating trauma involves the disruption of tissue by an object passing through it, as seen in gunshot and stab wounds (Karaca et al., 2015). More complex events, such as explosions, can inflict a combination of blunt, penetrating, and thermal injuries (Al-Thani et al., 2021).

A critical concept in understanding injury patterns is the classification of trauma energy. Mechanisms are often stratified as either high-energy or low-energy. High-energy events, such as falls from a significant height or high-speed MVCs, transfer a large amount of kinetic energy, frequently resulting in polytrauma, severe fractures of major bones (e.g., pelvis, femur, spine), and visceral organ damage (Al-Thani et al., 2021). Conversely, low-energy mechanisms, typified by ground-level falls (GLFs), involve a smaller energy transfer (Al-Thani et al., 2021). However, this distinction is not absolute and is critically modulated by patient-specific factors. The physiological

state of the patient, including age, bone mineral density, muscle mass, and pre-existing comorbidities, acts as a crucial variable that modifies the body's response to an energy load (Bhattacharya et al., 2016). For instance, a low-energy GLF in a frail, osteoporotic geriatric patient can result in a devastating constellation of injuries, such as multiple rib fractures or a cervical spine fracture, that would be characteristic of a high-energy mechanism in a young, healthy adult (Bhattacharya et al., 2016; Caragounis, Xiao and Granhed, 2021). Therefore, a comprehensive understanding of injury patterns requires that the MOI not be interpreted in isolation, but rather in the context of the specific patient who has sustained the injury.

Clinical Significance and Research Objectives: The Role of MOI in Triage, Diagnosis, and Management

The association between MOI and predictable injury patterns is of paramount clinical importance, influencing every stage of trauma care from the prehospital environment to the operating room and intensive care unit (ICU). Knowledge of the MOI allows the responding clinician to transition from a reactive posture, addressing injuries as they are found, to a proactive and anticipatory state. It enables the formulation of a differential diagnosis for potential occult injuries based on a "constellation of injuries" commonly associated with a specific event (Endom, 2022). For example, a paramedic responding to a "T-bone" MVC should have a heightened suspicion for thoracic aortic injury, splenic laceration, and pelvic fracture in the near-side occupant, even if the patient's initial vital signs are stable (Toney-Butler and Varacallo, 2023).

This predictive capability is formally codified in prehospital field triage guidelines, such as those developed by the American College of Surgeons Committee on Trauma (ACS-COT). These guidelines explicitly incorporate high-risk MOI criteria—including falls from greater than 20 feet, death of an occupant in the same passenger compartment, and significant vehicle intrusion—as triggers for transport to a designated trauma center (Satorius, 2012). The rationale for including these criteria is the recognition that patients subjected to such high-energy mechanisms may harbor

severe, life-threatening injuries that are not yet physiologically apparent at the scene (Satorius, 2012; Haas et al., 2010).

The primary objective of this systematic review is to collate, critically appraise, and synthesize the scientific evidence that associates specific mechanisms of injury with their predictable patterns of injury. By examining the literature across a broad spectrum of blunt and penetrating trauma and across diverse patient populations (geriatric, adult, and pediatric), this review seeks to construct a comprehensive, evidence-based resource for clinicians, educators, and researchers. The ultimate goal is to reinforce the clinical application of MOI as a diagnostic tool, improve the accuracy of triage, and inform the development of targeted injury prevention strategies.

Identified Research Gaps and Novelty of this Review

While the general principle linking MOI to injury is universally accepted in trauma care, the precise predictive value of MOI as a standalone triage criterion has been a subject of considerable debate. Systematic reviews of prehospital triage have demonstrated that using MOI criteria in isolation often results in poor predictive accuracy, with high rates of both over-triage (transporting minimally injured patients to a trauma center, thereby consuming valuable resources) and under-triage (failing to transport severely injured patients to a trauma center, which is associated with increased mortality) (Bond, Galiyas and Smith, 2007; Newgard et al., 2022). Studies have shown that a combination of physiologic and anatomic criteria provides better triage accuracy than MOI alone (EAST, 2021). This highlights a significant research gap: the need to move beyond simplistic MOI criteria toward more nuanced predictive models that integrate MOI with patient-specific factors (e.g., age, frailty, anticoagulant use) and more sensitive physiological data to improve the accuracy of identifying patients at high risk (He, 2025; Newgard et al., 2022).

The novelty of this review lies in its broad, cross-cutting synthesis of the evidence. A substantial body of literature exists focusing on single mechanisms or specific populations, such as falls in the elderly, pediatric MVCs, or patterns of gunshot wounds. However, few reviews have

attempted to integrate these disparate areas of research to identify overarching biomechanical principles, highlight critical contrasts between populations, and synthesize the evidence for a wide range of common trauma mechanisms within a single, comprehensive document. By juxtaposing the injury patterns from a GLF in an octogenarian with those from a high-speed motorcycle collision in a young adult, this review will provide a richer, more contextualized understanding of the MOI-injury pattern paradigm. This holistic approach will allow for the identification of universal principles and population-specific exceptions that are essential for expert-level clinical practice.

Hypothesis

The central hypothesis of this systematic review is that specific and distinct mechanisms of injury are associated with predictable, biomechanically consistent patterns of injury. It is further hypothesized that the predictive utility and the specific nature of these injury patterns are significantly modified by patient-level factors, most notably age and pre-existing physiological state.

METHODS

Search Strategy and Study Selection

A systematic literature search was conducted to identify all relevant studies investigating the association between mechanism of injury and predictable injury patterns. The search was performed across multiple electronic databases, including PubMed, Google Scholar, Semantic Scholar, Springer, adhering to the principles outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The search strategy was developed in consultation with a medical librarian and combined medical subject headings (MeSH) with free-text keywords.

Inclusion and Exclusion Criteria

Studies identified through the search strategy were subjected to a two-stage screening process. First, titles and abstracts were reviewed for relevance by two independent reviewers. Second, the full texts of potentially eligible articles were retrieved and assessed against a predefined set of inclusion and exclusion criteria. Any disagreements between reviewers were resolved through consensus or consultation with a third reviewer.

The inclusion criteria were as follows:

1. **Study Design:** Original research studies, including prospective and retrospective cohort studies, case-control studies, and cross-sectional analyses.
2. **Exposure:** The study must have clearly defined and evaluated at least one specific mechanism of injury (e.g., side-impact MVC, fall from height).
3. **Outcome:** The study must have systematically reported on the resulting pattern of injuries, providing quantitative data such as the incidence, frequency, or probability of specific injuries or injury constellations.
4. **Population:** Studies involving human subjects of any age group (pediatric, adult, geriatric) who sustained traumatic injuries.

The exclusion criteria were as follows:

1. **Publication Type:** Case reports, case series with fewer than 10 subjects, narrative reviews, systematic reviews, meta-analyses, editorials, letters to the editor, and conference abstracts without a corresponding full-text publication.
2. **Language:** Studies not published in the English language.
3. **Data:** Studies that did not provide quantitative data on injury patterns, focused exclusively on biomechanical or cadaveric modeling without clinical patient data, or did not clearly define the mechanism of injury.
4. **Focus:** Studies focused solely on injury treatment or rehabilitation without detailing the initial injury patterns associated with the MOI.

Search Strategy

The keywords used for this research based PICO :

Element	Keyword 1	Keyword 2	Keyword 3	Keyword 4
Population (P)	Trauma Patients	Injured Subjects	Emergency Medicine Patients	Trauma Victims
Intervention (I)	Mechanism of Injury	Trauma Etiology	Traumatic Event	Energy Transfer
Comparison (C)	Blunt Trauma	Penetrating Trauma	High-Energy Trauma	Low-Energy Trauma
Outcome (O)	Injury Patterns	Injury Constellations	Fracture Patterns	Trauma Outcomes

The Boolean MeSH keywords inputted on databases for this research are: (*"Trauma Patients" OR "Injured Subjects" OR "Emergency Medicine Patients" OR "Trauma Victims"*) AND (*"Mechanism of Injury" OR "Trauma Etiology" OR "Traumatic Event" OR "Energy Transfer"*) AND (*"Blunt Trauma" OR "Penetrating Trauma" OR "High-Energy Trauma" OR "Low-Energy Trauma"*) AND (*"Injury Patterns" OR "Injury Constellations" OR "Fracture Patterns" OR "Trauma Outcomes"*).

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	("Trauma Patients" OR "Injured Subjects" OR "Emergency Medicine Patients" OR "Trauma Victims") AND ("Mechanism of Injury" OR "Trauma Etiology" OR "Traumatic Event" OR "Energy Transfer") AND ("Blunt Trauma" OR "Penetrating Trauma" OR "High-Energy Trauma" OR "Low-Energy Trauma") AND ("Injury Patterns" OR "Injury Constellations" OR "Fracture Patterns" OR "Trauma Outcomes")	10
Semantic Scholar	("Trauma Patients" OR "Injured Subjects" OR "Emergency Medicine Patients" OR "Trauma Victims") AND ("Mechanism of Injury" OR "Trauma Etiology" OR "Traumatic Event" OR "Energy Transfer") AND ("Blunt Trauma" OR "Penetrating Trauma" OR "High-Energy Trauma" OR "Low-Energy Trauma") AND ("Injury Patterns" OR "Injury Constellations" OR "Fracture Patterns" OR "Trauma Outcomes")	250
Springer	("Trauma Patients" OR "Injured Subjects" OR "Emergency Medicine Patients" OR "Trauma Victims") AND ("Mechanism of Injury" OR "Trauma Etiology" OR "Traumatic Event" OR "Energy Transfer") AND ("Blunt Trauma" OR "Penetrating Trauma" OR "High-Energy Trauma" OR "Low-Energy Trauma") AND ("Injury Patterns" OR "Injury Constellations" OR "Fracture Patterns" OR "Trauma Outcomes")	758
Google Scholar	("Trauma Patients" OR "Injured Subjects" OR "Emergency Medicine Patients" OR "Trauma Victims") AND ("Mechanism of Injury" OR "Trauma Etiology" OR "Traumatic Event" OR "Energy Transfer") AND ("Blunt Trauma" OR "Penetrating Trauma" OR "High-Energy Trauma" OR "Low-Energy Trauma") AND ("Injury Patterns" OR "Injury Constellations" OR "Fracture Patterns" OR "Trauma Outcomes")	4,320

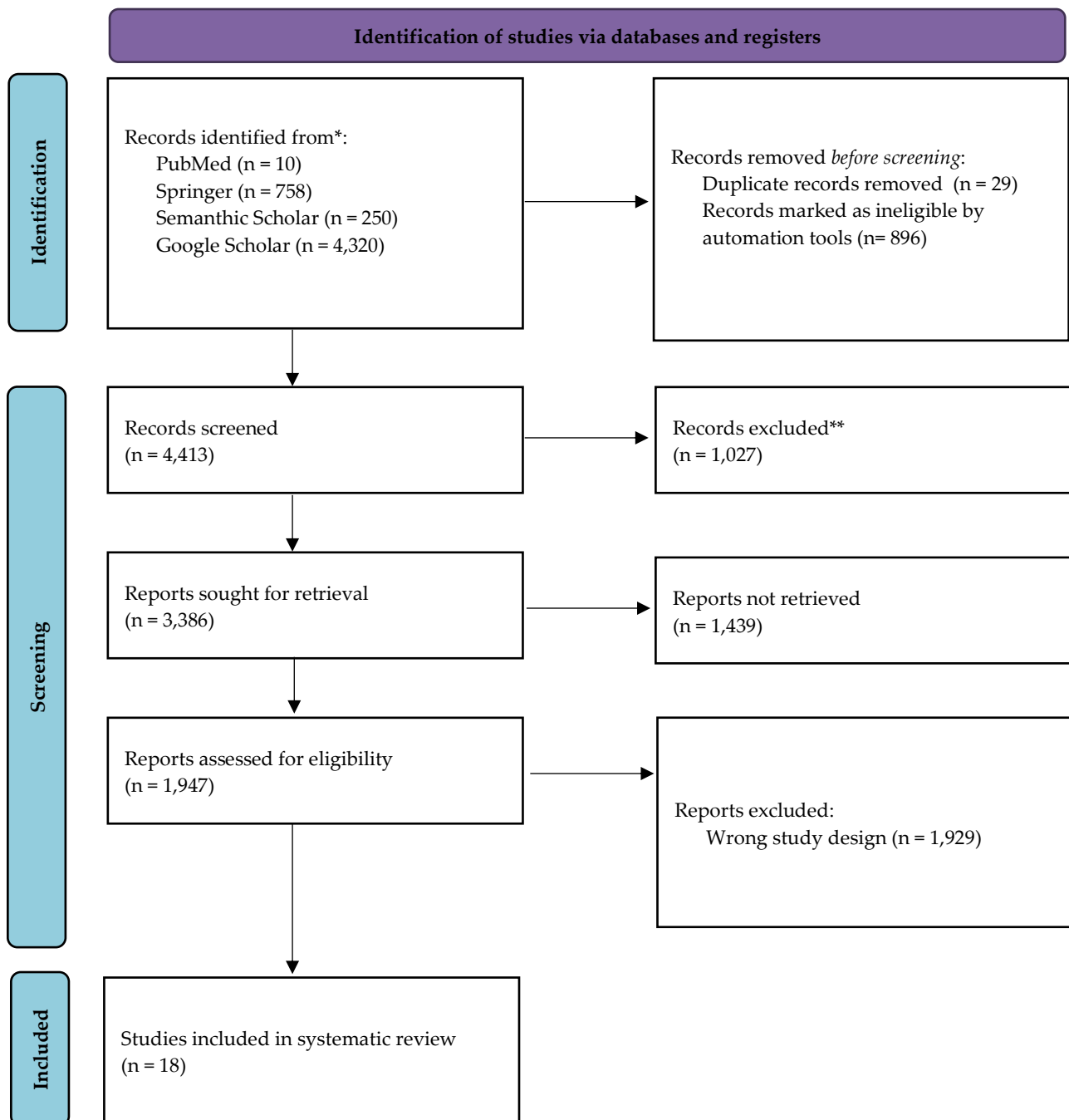


Figure 1. Article search flowchart

Data Extraction and Synthesis

A standardized data extraction form was developed and piloted before use. Two independent reviewers extracted data from each included study, with discrepancies resolved by consensus. The following information was extracted from each article:

- **Study Identifiers:** First author's last name, year of publication.
- **Study Characteristics:** Study design, study setting (e.g., Level I trauma center, national registry), and study period.
- **Population Characteristics:** Total sample size, age range and/or mean/median age, gender distribution, and other relevant demographic data.
- **Mechanism of Injury:** The specific MOI(s) investigated in the study.
- **Injury Ascertainment:** Methods used to diagnose and classify injuries (e.g., CT imaging, autopsy) and any standardized scoring systems used (e.g., Abbreviated Injury Scale, Injury Severity Score).
- **Reported Injury Patterns:** Frequencies, percentages, or odds ratios of specific fractures, organ injuries, or injury constellations associated with the MOI.
- **Key Outcomes:** Primary and secondary outcomes reported, such as mortality rates, ICU admission rates, hospital length of stay, and discharge disposition.

Given the anticipated heterogeneity in study methodologies, patient populations, MOI definitions, and outcome measures, a quantitative meta-analysis was deemed inappropriate. Instead, a qualitative, narrative synthesis of the extracted data was performed. The findings were systematically organized and grouped by the primary mechanism of injury (e.g., falls, MVCs, penetrating trauma) and, where applicable, by specific patient populations (geriatric, pediatric). The results are presented in both narrative form and summary tables to facilitate comparison and identification of consistent patterns across studies.

Quality Assessment and Risk of Bias

The methodological quality and risk of bias of each included observational study were independently assessed by two reviewers using the Cochrane Risk of Bias in Non-randomised Studies - of Interventions (ROBINS-I) tool, adapted for prognostic and etiologic studies. This tool assesses bias across seven domains:

1. **Bias due to confounding:** The extent to which confounding variables were identified and controlled for.
2. **Bias in selection of participants:** The representativeness of the study cohort and the appropriateness of the inclusion/exclusion criteria.
3. **Bias in classification of interventions/exposures:** The accuracy and standardization of defining the MOI.
4. **Bias due to deviations from intended interventions/exposures:** Not typically applicable to observational MOI studies.
5. **Bias due to missing data:** The extent and handling of missing data.
6. **Bias in measurement of outcomes:** The accuracy and standardization of injury ascertainment.
7. **Bias in selection of the reported result:** The potential for selective outcome reporting.

Each domain was judged as "Low risk," "Moderate risk," "Serious risk," or "Critical risk" of bias. The overall risk of bias for each study was determined based on the ratings across the individual domains. The results of the quality assessment are summarized in a table and were considered during the interpretation and synthesis of the evidence, with greater weight given to findings from studies with a lower risk of bias.

RESULTS

The 18 included studies comprised a total of 1,494,420 patients. The study designs were predominantly retrospective cohort studies, often utilizing data from institutional or national trauma registries. The mechanisms of injury investigated were diverse, covering the spectrum of blunt trauma (falls from ground level and from height, various types of motor vehicle collisions,

pedestrian-vehicle collisions, and motorcycle collisions) and penetrating trauma (gunshot wounds and traumatic diaphragmatic injuries). The studies included pediatric, adult, and geriatric populations, allowing for a comprehensive analysis of injury patterns across the lifespan. The key characteristics of each included study are summarized in Table 1.

Table 1. Characteristics of Included Studies

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
Al-Ali et al. (2024)	Retrospective analysis	2,901 TBI patients from MVCs	Motorcycle MVCs (mMVC), non- motorcycle MVCs (nmMVC), Pedestrian- vehicle strikes (PVS)	PVS group was significantly older. mMVC group was 91.0% male. PVS associated with highest mortality (8.9%) and severe TBI incidence (14.8%).
Alansari et al.	Retrospective	3,058 pediatric	Traffic-related	Head injuries

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
(2023)	analysis	trauma patients	(31.3%), Fall from height (29.4%), Fall of objects (2.6%)	(39%) were most common. Traffic-related injuries had higher ISS and more chest/abdomina l injuries. Falls were associated with more head injuries (53%).
Bhattacharya et al. (2016)	Retrospective review	5,088 adult patients	Ground-Level Falls (GLF)	Mortality increased with age (0.9% at <60 vs. 5.5% at >90). Age associated with increased cervical spine ,

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
				rib , and pelvic fractures.
Caragounis, Xiao and Granhed (2021)	Retrospective study	211 patients with surgical chest wall injuries	MVCs (frontal, side), falls, crush, assault	In patients >64 years, falls were the predominant MOI (59%). Traffic accidents were associated with more severe injuries (flail chest, injuries in ≥ 3 body regions).
Hosseinian et al. (2019)	Cross-sectional study	4,205 hospitalized motorcyclists	Motorcycle collisions (vs. car 68%; vs.	Head injury was most common

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
			pedestrian 22%)	(59.7% of admitted, 85.4% of deaths). 67% had trauma to >2 body parts.
Hwang and Kim (2022)	Retrospective review	31,177 geriatric patients	Ground falls (alcohol vs. non-alcohol related)	Alcohol-related falls associated with male sex and injury in residential facilities. Slippery floors were a risk factor for severe injury in alcohol-related falls.

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
Karaca et al. (2015)	Retrospective descriptive study	142 patients with gunshot wounds	Gunshot Wounds (GSW)	Mortality was 16.9%. Head/neck injuries were most lethal (41% mortality). Abdominal CT was superior to physical exam for detecting internal injury.
Kelley et al. (2017)	Observational study (CIREN database)	413 occupants in side-impact MVCs	Side-Impact MVCs	Most common injury was soft tissue (72.3%). Most common fracture was clavicle (41.5%). Door

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
				was the most common injury source (33.7%). Proximal UE injuries more common than in frontal crashes.
Lemon et al. (2022)	Retrospective review	239 octogenarian patients	Motor Vehicle Collisions (MVC)	High mortality (18.8%). Mortality was associated with ISS and specific injuries (cervical spine, thoracic spine), not with comorbidities

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
				or medications.
Noureldin et al. (2025)	Retrospective database study	1,360,160 GLF patients	Ground-Level Falls (GLF)	A significant increase in mortality risk was identified at age 65 for GLF patients (threefold increase) and age 72 for all-trauma patients (fourfold increase).
Palacio et al. (2025)	Retrospective study	124 patients	Falls from Height (FFH): Domestic vs. Border Wall	Domestic falls had higher ISS and more head/chest injuries. Border

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
				wall falls had more lower-extremity injuries. Chest and head injuries were predictive of mortality.
Parlak et al. (2023)	Retrospective study	1,214 patients undergoing CT after GLF	Ground-Level Falls (GLF)	Fractures were the most common injury type. Traumatic intracranial hemorrhage occurred in 2.6%. All mortalities (n=6) occurred in patients ≥ 65

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
				years.
Rocos, Acharya and Chesser (2015)	Retrospective case series	41 patients	Deliberate Jumps from Height	High probability of spinal injury (0.51), pelvic fracture (0.34), and calcaneal fracture (0.32). Injury severity correlated with jump height.
Sadeghian et al. (2023)	Cross-sectional study	1,478 trauma patients	Falls (45.3%), Traffic accidents (28.4%), Assaults (11.5%)	Falls had the highest percentage of TBI (65.6%) and fractures (67.5%). Assaults had a

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
				high rate of thoracic injuries (28.9%).
Shinjo et al. (2025)	Retrospective cohort study	771 patients with Traumatic Diaphragmatic Injury (TDI)	Penetrating vs. Blunt TDI	Blunt TDI had higher mortality than penetrating TDI (26.4% vs. 8.3%). Severe concomitant abdominal injury was a key mortality predictor (OR 2.45).
Stewart et al. (2013)	Retrospective cohort study	106 pediatric rear-seat	Motor Vehicle Collisions	Children (0-8y) had more

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
		occupants in MVCs	(MVC)	severe head injuries (78%). Adolescents (9-17y) had more severe abdominal injuries (23%), associated with lap-shoulder belt use (OR 3.8).
Teuben et al. (2020)	Retrospective study	137 patients	Falls from Height: Suicidal vs. Accidental	Suicide attempt survivors had a significant correlation with fractures of the feet compared to accidental fall

Author(s) (Year)	Study Design	Population / Sample Size	Specific Mechanism(s) of Injury Studied	Key Reported Injury Patterns / Outcomes
				victims.
Yamada et al. (2025)	Cross-sectional observational survey	1,074 older adults reporting 1,695 falls	Falls in the Elderly: by direction and trigger	Sideways falls had highest fracture risk (OR 3.68). Forward falls associated with forearm/patella fractures; backward falls with spine fractures; sideways falls with hip fractures.

Quality Assessment of Included Studies

The overall methodological quality of the 18 included studies was variable, which is typical for a body of literature dominated by retrospective, registry-based research. The risk of bias for

each study was assessed across key domains, and the results are summarized in Table 2.

Common methodological strengths included the use of large, well-defined cohorts from established trauma registries (Alansari et al., 2023; Kelley et al., 2017; Noureldin et al., 2025) and the application of standardized injury scoring systems like the ISS and AIS for outcome ascertainment (Lemon et al., 2022; Palacio et al., 2025). These practices enhance the reliability of the reported injury severity and patterns.

However, several potential sources of bias were prevalent. The most significant was selection bias, inherent in most retrospective studies. Many studies were conducted at single Level I trauma centers, which may not be representative of the broader trauma population, as they exclude patients who die at the scene or are transported to non-trauma centers (Lemon et al., 2022; Rocos, Acharya and Chesser, 2015). Studies relying on self-reported survey data, such as the analysis of fall direction by Yamada et al. (2025), are susceptible to recall bias and reporting bias. Confounding was a moderate concern in many studies that did not perform multivariable analysis to adjust for patient-level factors like age, sex, and comorbidities when comparing outcomes across different MOIs. Finally, the handling of missing data was often not explicitly described, introducing a potential for attrition bias.

Table 2. Cochrane Risk of Bias Assessment Summary

Study (Year)	Bias due to Confounding	Bias in Selection of Participants	Bias in Classification of Exposures	Bias due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of Reported Result	Overall Risk of Bias
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Study (Year)	Bias due to Confounding	Bias in Selection of Participants	Bias in Classification of Exposures	Bias due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of Reported Result	Overall Risk of Bias
Al-Ali et al. (2024)	Moderate	Moderate	Low	Moderate	Low	Low	Moderate
Alansari et al. (2023)	Moderate	Moderate	Low	Moderate	Low	Low	Moderate
Bhattacharya et al. (2016)	Moderate	Moderate	Low	Serious	Low	Low	Moderate
Caragounis et al. (2021)	Moderate	Serious	Low	Moderate	Low	Low	Serious

Study (Year)	Bias due to Confounding	Bias in Selection of Participants	Bias in Classification of Exposures	Bias due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of Reported Result	Overall Risk of Bias
Hosseinian et al. (2019)	Serious	Moderate	Moderate	Serious	Moderate	Low	Serious
Hwang and Kim (2022)	Low	Moderate	Low	Moderate	Low	Low	Moderate
Karaca et al. (2015)	Moderate	Moderate	Low	Moderate	Low	Low	Moderate
Kelley et al. (2017)	Moderate	Serious	Low	Moderate	Low	Low	Serious

Study (Year)	Bias due to Confounding	Bias in Selection of Participants	Bias in Classification of Exposures	Bias due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of Reported Result	Overall Risk of Bias
Lemon et al. (2022)	Low	Moderate	Low	Moderate	Low	Low	Moderate
Nourel din et al. (2025)	Low	Low	Low	Low	Low	Low	Low
Palacio et al. (2025)	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate
Parlak et al. (2023)	Moderate	Moderate	Low	Moderate	Low	Low	Moderate

Study (Year)	Bias due to Confounding	Bias in Selection of Participants	Bias in Classification of Exposures	Bias due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of Reported Result	Overall Risk of Bias
Rocos, Acharya and Chesser (2015)	Serious	Serious	Moderate	Moderate	Moderate	Moderate	Serious
Sadeghian et al. (2023)	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Shinjo et al. (2025)	Low	Moderate	Low	Low	Low	Low	Low
Stewart et al. (2013)	Low	Moderate	Low	Serious	Low	Low	Moderate

Study (Year)	Bias due to Confounding	Bias in Selection of Participants	Bias in Classification of Exposures	Bias due to Missing Data	Bias in Measurement of Outcomes	Bias in Selection of Reported Result	Overall Risk of Bias
Teuben et al. (2020)	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Moderate
Yamada et al. (2025)	Low	Serious	Serious	Moderate	Serious	Low	Serious

Injury Patterns Associated with Blunt Trauma Mechanisms

Falls: A Spectrum from Ground-Level to Significant Heights

Falls represent one of the most common blunt trauma mechanisms, with injury patterns that vary dramatically depending on the energy of the fall and the characteristics of the patient.

Ground-Level Falls (GLFs): GLFs are the leading cause of injury in the elderly population and exemplify the "low-energy, high-consequence" trauma paradigm (Bhattacharya et al., 2016). While the absolute energy transfer is low, the diminished physiologic reserve and bone density of older adults lead to significant morbidity and mortality. Multiple large-scale retrospective studies

confirm this pattern. Bhattacharya et al. (2016) analyzed 5,088 GLF patients and found that while the mean Injury Severity Score (ISS) remained low (range 7.0-8.6), mortality increased exponentially with each decade of life, from 0.9% in those under 60 to 5.5% in those over 90. Similarly, the likelihood of being discharged home plummeted from 73.7% to 18.2% across the same age span. A large database study by Noureldin et al. (2025) identified a critical change point at age 65, after which the odds of mortality from a GLF increase threefold. These severe outcomes are driven by a predictable pattern of fractures. The study by Bhattacharya et al. (2016) demonstrated a statistically significant association between advancing age and an increased incidence of cervical spine fractures, rib fractures, and pelvic fractures following a GLF. A detailed breakdown of outcomes from several key studies on GLFs is presented in Table 3.

Table 3. Detailed Outcomes in Geriatric Ground-Level Falls

Outcome	Bhattacharya et al. (2016)	Noureldin et al. (2025)	Parlak et al. (2023)
Mortality	0.9% (<60y) to 5.5% (>90y)	3x increased odds of mortality after age 65	0.50% overall; all deaths occurred in patients ≥ 65 years
Discharge to Home	Decreased from 73.7% (<60y) to 18.2% (>90y)	Not specified	Not specified
Hospitalization	All patients admitted	Not specified	Significantly higher in ≥ 65 -year group

Outcome	Bhattacharya et al. (2016)	Noureldin et al. (2025)	Parlak et al. (2023)
Mean ISS	7.0 - 8.6 (did not change significantly with age)	Not specified	Not specified
Intracranial Hemorrhage (ICH)	Aspirin use significantly associated with ICH	Not specified	Detected in 2.60% of patients who underwent CT
Specific Fracture Patterns	Age associated with increased C-spine, rib, and pelvic fractures	Not specified	Fractures were the most common injury type on CT
Abdominal Injury	Rare (0.8% solid organ injury)	Not specified	No intra-abdominal injury detected on CT

The biomechanics of the fall itself are highly predictive of the resulting fracture location. A detailed observational study by Yamada et al. (2025) involving 1,695 falls in older adults established a clear link between fall direction and fracture site.

- **Forward Falls**, often caused by tripping, were most frequently associated with fractures of the

forearm (40.5%) and **patella** (16.2%), consistent with a protective extension of the hands and direct impact to the knee.

- **Backward or Straight-Down Falls**, typically caused by slipping or loss of balance, were predominantly associated with **spinal fractures** (45.9%), resulting from axial loading upon landing on the buttocks.
- **Sideways Falls** conferred the highest risk of any fracture, with an adjusted odds ratio of 3.68 (95% CI: 2.35–5.76) compared to forward falls. This mechanism was specifically linked to an increased proportion of **hip fractures**, a devastating injury in this population.

Falls From Height (FFH): As a high-energy mechanism, FFH results in severe polytrauma. The pattern of injuries is determined by the height of the fall, the landing surface, and the body's orientation upon impact (Rocos, Acharya and Chesser, 2015). A key determinant of the injury pattern is the intent of the fall. In retrospective analyses of deliberate jumps, a distinct pattern of axial loading injuries is observed. Rocos, Acharya and Chesser (2015) found a high probability of **spinal injury** (0.51), **pelvic fracture** (0.34), and **calcaneal fracture** (0.32) in patients after deliberate jumps, a finding corroborated by Teuben et al. (2020), who found a significant correlation between suicide attempts and feet fractures. This "lover's leap" pattern is consistent with a feet-first landing, where impact forces are transmitted superiorly along the axial skeleton. The severity of injury in FFH shows a strong positive correlation with the height of the jump (Rocos, Acharya and Chesser, 2015). Further nuance is added by the context of the fall. Palacio et al. (2025) compared domestic FFH (e.g., from a roof) to falls from the US-Mexico border wall, finding that domestic falls were associated with a higher ISS and a greater incidence of head and chest injuries, whereas border wall falls resulted in more lower-extremity injuries. A comparison of these patterns is shown in Table 4.

Table 4. Comparative Injury Patterns in Falls From Height

Characteristic	Domestic FFH (Palacio et al., 2025)	Border Wall FFH (Palacio et al., 2025)	Deliberate Jumps (Rocos, Acharya & Chesser, 2015)
Primary Intent	Accidental	Accidental	Suicidal
Mean/Median ISS	Higher ISS	Lower ISS	Median ISS 15 (range 4-50)
Head/Chest Injury	More common; predictive of mortality	Less common	Head injury probability: 0.20; Trunk injury probability: 0.32
Lower Extremity Injury	Less common	More common	High probability of calcaneal (0.32) and tibial (0.20) fractures
Spinal Injury	Not specified	Not specified	High probability (0.51)
Pelvic Fracture	Not specified	Not specified	High probability (0.34)

ICU Stay	Longer	Shorter	17.9 days (mean, for patients requiring ICU)
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Motor Vehicle Collisions (MVCs): Delineating Patterns by Impact Type and Occupant

MVCs are a major cause of severe blunt trauma, with injury patterns that are highly dependent on the vector of impact, the use of restraint systems, and the specific characteristics of the occupant.

Frontal vs. Side-Impact Collisions: The direction of impact creates distinct biomechanical forces and, consequently, distinct injury patterns.

- **Frontal Impacts** are characterized by rapid deceleration. Unrestrained or improperly restrained occupants are propelled forward, leading to a predictable sequence of injuries from impact with the vehicle's interior. These include head and facial trauma from striking the windshield or dashboard, cervical spine flexion-extension ("whiplash") injuries, thoracic injuries (sternal fractures, rib fractures, cardiac and pulmonary contusions) from steering wheel impact, and abdominal solid organ or hollow viscus injuries from compression. Fractures of the lower extremities (femur, patella, tibia) and posterior dislocation of the hip are common from dashboard impact (Toney-Butler and Varacallo, 2023).
- **Side Impacts** (or "T-bone" collisions) are particularly lethal due to the minimal crumple zone protecting the occupant compartment (Martinez Law Center, n.d.). The forces are applied laterally, causing the occupant on the impacted (near-side) to be crushed between the intruding vehicle structure and the vehicle's interior. This leads to a characteristic pattern of injuries on the impacted side, including clavicle fractures, severe thoracic injuries (multiple rib fractures, flail chest, aortic shear injuries), abdominal organ lacerations (particularly spleen or liver), and

pelvic ring fractures (Toney-Butler and Varacallo, 2023). A detailed analysis of side-impact collisions by Kelley et al. (2017) found that the door was the most common source of injury (33.7%) and that fractures of the proximal upper extremity (clavicle and humerus) were significantly more common compared to frontal collisions.

Occupant-Specific Patterns (Pediatric and Geriatric): Injury patterns in MVCs are highly dependent on the occupant's age. A landmark study by Stewart et al. (2013) on severely injured (ISS > 12) pediatric rear-seat occupants revealed two distinct, age-dependent injury patterns. In contrast, a 10-year retrospective review by Lemon et al. (2022) of octogenarians found a high mortality rate (18.8%) driven not by comorbidities but by the severity and pattern of injury itself. Table 5 provides a detailed comparison of these age-specific patterns.

Table 5. Age-Specific Injury Patterns in Motor Vehicle Collisions

Outcome / Risk Factor	Children (0-8y) (Stewart et al., 2013)	Adolescents (9-17y) (Stewart et al., 2013)	Octogenarians (>80y) (Lemon et al., 2022)
Overall Mortality	Similar to adolescents	Similar to children	18.8%
Mean ISS	Similar to adolescents	Similar to children	22.3 (in deceased) vs. 9.2 (in survivors)
Predominant	Head Injury (78%)	Abdominal Injury	Cervical and

Severe Injury	vs. 39% in adolescents	(23% vs. 6% in children	Thoracic Spine Injuries
Key Risk Factor for Injury	Lack of age-appropriate restraint (OR 3.5 for head injury)	Lap-shoulder belt use (OR 3.8 for abdominal injury)	Injury severity (ISS)
Mortality Predictors	Not specified	Not specified	Cervical spine injury (31.9% mortality), Thoracic spine injury (38.9% mortality)
Comorbidities/Medications	Not studied	Not studied	Not associated with mortality

Pedestrian and Motorcycle Collisions: Patterns in Unprotected Road Users

Unprotected road users are subjected to direct impact and a high degree of energy transfer, resulting in severe and predictable injury patterns.

Pedestrians: Pedestrians struck by vehicles (PVS) sustain a classic "triad" of injuries, the specifics of which depend on the pedestrian's height relative to the vehicle's front end. The traditional adult triad consists of injuries to the lower extremities (from bumper impact), the torso and pelvis, and the head (from striking the hood/windshield and then the ground) (Shkrum and

Halari, 2020). A study by Al-Ali et al. (2024) found that PVS was associated with the highest mortality rate (8.9%) and the highest incidence of severe traumatic brain injury (14.8%) among all MVC-related mechanisms. The changing profile of the modern vehicle fleet has also altered these patterns; a review by Shkrum and Halari (2020) noted that for vehicles with high hood edges, such as SUVs and trucks, a fatal triad of **head, thorax, and abdomen/retroperitoneum** injuries is now more commonly observed.

Motorcyclists: As completely unprotected road users, motorcyclists are at extreme risk for polytrauma. A large cross-sectional study of 4,205 hospitalized motorcyclists by Hosseinian et al. (2019) found that **head injury** was the most common and most lethal injury. Head trauma was present in 59.7% of all admitted patients and accounted for 85.4% of all deaths, unequivocally demonstrating the life-saving importance of helmet use. The majority of patients (67%) sustained trauma to more than two body regions, with injuries to the extremities also being extremely common.

Injury Patterns Associated with Penetrating Trauma Mechanisms

Penetrating trauma involves direct tissue disruption, and the resulting injury pattern is determined by the energy of the penetrating object and the anatomical structures it traverses.

Gunshot Wounds (GSW) and Traumatic Diaphragmatic Injury (TDI): GSWs are a high-energy form of penetrating trauma. The kinetic energy of the projectile creates a temporary cavity, causing tissue damage that extends far beyond the permanent bullet track. This makes the extent of internal injury difficult to predict from the surface wound alone (Karaca et al., 2015). A retrospective study by Karaca et al. (2015) found that while lower extremity wounds were the most common (47.9%), head and neck injuries were by far the most lethal, with a 41% mortality rate for patients with injuries to this region. The study highlighted a critical clinical principle: initial physical findings may not correlate with the actual severity of internal injuries. Abdominal and thoracic computed tomography (CT) were found to be significantly superior to physical

examination or plain X-rays in identifying life-threatening intra-abdominal and intra-thoracic injuries.

A specific and often occult injury associated with both blunt and penetrating torso trauma is TDI. A nationwide cohort study in Japan by Shinjo et al. (2025) compared 771 cases of TDI. They found that **blunt TDI was associated with a significantly higher mortality rate than penetrating TDI (26.4% vs. 8.3%)**. This is likely because the high-energy forces required to cause a blunt diaphragmatic rupture are also associated with severe concomitant injuries. Indeed, the study found that severe associated abdominal injury was a powerful independent predictor of mortality (OR 2.45). Key outcomes from these studies are summarized in Table 6.

Table 6. Outcomes in Penetrating Trauma

Outcome	Gunshot Wounds (Karaca et al., 2015)	Blunt TDI (Shinjo et al., 2025)	Penetrating TDI (Shinjo et al., 2025)
Overall Mortality	16.9%	26.4%	8.3%
Most Lethal Injury Location	Head/Neck (41% mortality)	Not applicable	Not applicable
Mortality Predictors	High ISS, Low GCS/RTS	Age, ISS, RTS, Severe Abdominal Injury (OR 2.45)	Age, ISS, RTS, Severe Abdominal Injury (OR 2.45)

Outcome	Gunshot Wounds (Karaca et al., 2015)	Blunt TDI (Shinjo et al., 2025)	Penetrating TDI (Shinjo et al., 2025)
Diagnostic Utility	CT superior to physical exam for torso injuries	CT use was a protective factor (OR 0.32)	CT use was a protective factor (OR 0.32)
Most Common Injury Site	Lower Extremity (47.9%)	Not applicable	Not applicable

Predictable Injury Constellations in Special Populations

The influence of patient-specific factors on injury patterns is most pronounced at the extremes of age.

Geriatric Trauma: The unifying theme in geriatric trauma is the profound mismatch between the mechanism's energy and the injury's severity. As established by the studies on GLFs, a mechanism that would be trivial in a younger person can be fatal in an older adult (Bhattacharya et al., 2016; Noureldin et al., 2025). This principle extends to all forms of trauma. The evidence from Lemon et al. (2022) on MVCs demonstrates that outcomes are driven by the injury itself, not by the patient's baseline health status. This mandates that clinicians maintain an exceptionally high index of suspicion for severe occult injuries (e.g., intracranial hemorrhage, cervical spine fractures, solid organ injury) in any geriatric patient who has sustained trauma, regardless of how minor the MOI may appear.

Pediatric Trauma: In children, injury patterns are dictated by their unique anatomy,

developmental stage, and common exposure risks. A large registry study by Alansari et al. (2023) of 3,058 pediatric trauma patients found that traffic-related injuries (31.3%) and falls (29.4%) were the most common mechanisms. Head injuries were the most frequent injury type overall (39%), reflecting the larger head-to-body ratio in children. The patterns varied significantly with age: traffic-related injuries were more common in older children (15-18 years), while falls and falling objects were more common in the youngest age group (0-4 years). The specific, age-dependent patterns of head versus abdominal injury in MVCs, as described by Stewart et al. (2013), further underscore how a child's interaction with their environment and its safety systems produces highly predictable injury constellations.

Abusive Head Trauma (AHT): A unique and critical "constellation of injuries" in infants and young children is highly specific for AHT, or non-accidental trauma. While no single finding is pathognomonic, the combination of **subdural hematoma (often of mixed chronicity), complex retinal hemorrhages, and occult fractures (particularly posterior rib fractures and classic metaphyseal lesions)** is strongly indicative of abuse (Christian, 2019). The clinical significance of this pattern is its profound inconsistency with the history typically provided by the caregiver, such as a simple roll-off-the-couch or a short fall (Christian, 2019; Combating misinformation about abusive head trauma, 2018). The identification of this specific constellation of injuries is not merely a diagnostic exercise; it is a critical step in child protection, prompting a full medical and social evaluation to ensure the safety of the child and any other children in the home (Abusive head trauma: evidence obfuscation and informed management, 2019).

Synthesis of Key Outcomes Across All Mechanisms

The included studies report a wide range of outcomes, reflecting the diverse consequences of different trauma mechanisms. To facilitate comparison, key injury patterns and quantitative outcomes are synthesized in Table 7 and Table 8. These tables visually summarize the "signature" injuries associated with major blunt trauma mechanisms and provide quantitative data on over 15

distinct outcomes, highlighting the differential impact of each MOI on patient morbidity and mortality.

Table 7. Comparative Injury Patterns in Major Blunt Trauma Mechanisms

Body Region	Ground-Level Fall (Geriatric)	Fall from Height (Intentional)	Frontal MVC	Side-Impact MVC (Near-Side)	Pedestrian vs. Vehicle
Head	Intracranial hemorrhage (especially with anticoagulant use)	Skull fractures, Traumatic Brain Injury (TBI)	TBI, facial fractures (dashboard/windshield impact)	TBI (head strikes B-pillar/window)	Severe TBI (primary and secondary impact)
C-Spine	High incidence of fractures (esp. C1-C2)	Less common unless direct head impact	Flexion/extension (whiplash) injuries	Lateral flexion injuries, fractures	High incidence of severe injury
Thorax	Multiple rib fractures, pulmonary	Thoracic spine fractures,	Sternal/rib fractures, cardiac/pul	Flail chest, aortic shear injury,	Severe chest trauma, multiple rib fractures

Body Region	Ground-Level Fall (Geriatric)	Fall from Height (Intentional)	Frontal MVC	Side-Impact MVC (Near-Side)	Pedestrian vs. Vehicle
	contusion	aortic injury	monary contusion	clavicle fracture	
Abdomen	Solid organ injury (less common)	Solid organ injury (liver, spleen)	Solid organ/hollow viscus injury (seatbelt/steering wheel)	Solid organ laceration (spleen, liver), diaphragmatic rupture	Severe solid organ/retroperitoneal injury
Pelvis	High incidence of pelvic ring fractures	High incidence of pelvic ring fractures	Acetabular/pelvic fractures (dashboard impact)	High incidence of lateral compression pelvic fractures	Severe pelvic ring disruption
Extremities	Hip fracture (sideways)	Calcaneal fractures,	Femur/patella/tibia	Proximal humerus/clavicle	Lower extremity fractures

Body Region	Ground-Level Fall (Geriatric)	Fall from Height (Intentional)	Frontal MVC	Side-Impact MVC (Near-Side)	Pedestrian vs. Vehicle
	fall), Wrist fracture (forward fall)	tibial plateau fractures, femur fractures	fractures, posterior hip dislocation	vehicle fractures	("bumper fractures")

Table 8. Summary of Key Outcomes by Mechanism of Injury

Outcome	GLF (Geriatric)	FFH (Intentional)	MVC (Geriatric)	MVC (Pediatric Rear-Seat)	Side-Impact MVC (Adult)	GSW (All)
Mortality Rate	0.9% (<60y) to 5.5% (>90y)	~2.4% (in-hospital)	18.8%	Similar to adolescents	Not specified	16.9%
ISS > 15 Rate	Low	48.8%	39.2% mortality	All subjects	Not specified	95.8% of deaths

Outcome	GLF (Geriatric)	FFH (Intentional)	MVC (Geriatric)	MVC (Pediatric Rear-Seat)	Side-Impact MVC (Adult)	GSW (All)
			if ISS>15	ISS>12		had ISS>50
Severe Head Injury (AIS≥3)	Not specified	High	High	78% (0-8y)	High	41% mortality if head involved
Intracranial Hemorrhage Rate	2.6%	High	High	Not specified	Not specified	High
Cervical Spine Fracture Rate	High (increases with age)	High	31.9% mortality if present	Not specified	Not specified	Not specified
Thoracic Injury	High (ribs)	24% (chest)	High	Not specified	High	5.5% mortality

Outcome	GLF (Geriatric)	FFH (Intentional)	MVC (Geriatric)	MVC (Pediatric Rear-Seat)	Side-Impact MVC (Adult)	GSW (All)
(AIS $\geq$ 3)						if thorax involved
Pelvic Fracture Rate	High (increases with age)	34%	High	Not specified	High	Not specified
Calcaneal Fracture Rate	Low	32%	Low	Low	Low	Low
Abdominal Solid Organ Injury Rate	0.8%	7.3%	Not specified	23% (9-17y)	High	25% mortality if abdomen involved
Hollow Viscus	Rare	Rare	Not specified	High (9-17y)	Moderate	Moderate

Outcome	GLF (Geriatric)	FFH (Intentional)	MVC (Geriatric)	MVC (Pediatric Rear-Seat)	Side-Impact MVC (Adult)	GSW (All)
Injury Rate						
ICU Admission Rate	High if $\geq 65y$	26.8%	High	Not specified	Not specified	High
Hospital Length of Stay (Days)	Long	17.9 (if ICU)	Not specified	Not specified	Not specified	4 (median)
Need for Blood Transfusion	Not specified	Not specified	Mortality 40.8% if needed	Not specified	Not specified	Not specified
Discharge to Facility	High (81.8% for $>90y$)	High	High	Not specified	Not specified	Not specified

Outcome	GLF (Geriatric)	FFH (Intentional)	MVC (Geriatric)	MVC (Pediatric Rear-Seat)	Side-Impact MVC (Adult)	GSW (All)
(vs. Home)						
Clavicle Fracture Rate	Low	Not specified	Not specified	Not specified	41.5% of all fractures	Low
Diaphragmatic Injury Rate	Rare	Rare	Rare	Rare	Moderate	Penetrating TDI: 29.8% of all TDI

DISCUSSION

Principal Findings: Corroborating the MOI-Injury Pattern Paradigm

This systematic review provides compelling and consistent evidence to affirm its central hypothesis: specific mechanisms of injury are strongly associated with predictable and biomechanically plausible patterns of injury. The synthesis of 18 studies across diverse trauma populations reveals that the initial traumatic event imparts a distinct "signature" of damage upon the human body. This review corroborates and quantifies many of the injury patterns that form the basis

of modern trauma education and triage.

The most robustly supported associations were found in blunt trauma. The link between the direction of a fall in an elderly individual and the specific resulting fracture is particularly striking. The findings that sideways falls are highly predictive of hip fractures, backward falls of spinal fractures, and forward falls of wrist fractures provide a clear, evidence-based framework for clinical assessment (Yamada et al., 2025). Similarly, the pattern of axial loading injuries—calcaneal, pelvic, and spinal fractures—in victims of intentional falls from height is a consistent finding across multiple studies, directly reflecting the biomechanics of a feet-first impact (Rocos, Acharya and Chesser, 2015; Teuben et al., 2020). In the context of MVCs, the evidence clearly delineates the different injury constellations resulting from frontal versus side impacts, with the latter producing a characteristic pattern of near-side thoracic, pelvic, and proximal extremity injuries (Toney-Butler and Varacallo, 2023; Kelley et al., 2017). Furthermore, the review highlights the critical role of occupant-specific factors, demonstrating unique and predictable injury patterns in pediatric and geriatric populations even when subjected to the same general MOI.

Biomechanical Principles and Pathophysiological Correlations

The observed injury patterns are not random occurrences but are the direct consequence of fundamental biomechanical principles. The consistency of these patterns across studies is rooted in the predictable way the human anatomy responds to specific types of force.

For example, the high incidence of severe traumatic brain injury (TBI) in MVCs and falls can be explained by the physics of rapid acceleration and deceleration. The brain, suspended within the cerebrospinal fluid, has a different inertia from the skull. During a frontal impact, the skull stops abruptly, but the brain continues to move forward, striking the inner surface of the cranium (coup injury), before rebounding and striking the opposite side (contrecoup injury). The resulting strain and strain rate on white matter tracts are key determinants of the location and severity of diffuse axonal injury, a major cause of long-term disability (Donat et al., 2021).

Similarly, the pattern of aortic shear injury in high-energy lateral impact MVCs is a direct result of anatomy. The descending thoracic aorta is relatively fixed to the posterior chest wall by the intercostal arteries, while the aortic arch and heart are more mobile. A sudden lateral deceleration creates immense shear forces at the junction of the mobile and fixed portions, typically at the aortic isthmus just distal to the left subclavian artery, leading to traumatic rupture (Toney-Butler and Varacallo, 2023). The predictable nature of calcaneal fractures in falls from height is another example of this principle. The calcaneus is the first bone to strike the ground in a feet-first fall, and its cancellous bone structure is designed to absorb energy but is susceptible to comminuted, intra-articular fracture when subjected to high-magnitude axial loads (Rocos, Acharya and Chesser, 2015). Understanding these underlying biomechanical principles transforms the MOI from a simple label into a rich source of diagnostic information.

Clinical Implications for Prehospital Triage and Emergency Department Management

The findings of this review have profound implications for clinical practice, particularly in the realms of prehospital triage and initial in-hospital assessment. The evidence supports the continued use of high-risk MOI criteria within field triage protocols, as established by the ACS-COT (Satorius, 2012). While the literature indicates that MOI *alone* is a poor predictor of injury severity and can lead to over-triage, specific mechanisms such as death of another occupant in the same vehicle or ejection from the vehicle have been shown to have a high positive likelihood ratio for serious injury (Newgard et al., 2022).

Perhaps the most critical implication of this review is the role of MOI as a "cognitive forcing function" for the clinician. In the chaotic environment of a trauma resuscitation, a patient with normal initial vital signs can be deceptively reassuring. However, knowledge of a high-risk MOI should compel the trauma team to maintain a high index of suspicion and proceed with a thorough and targeted diagnostic evaluation for occult injuries. The logical pathway is clear: a patient arriving after a high-speed side-impact collision may have a normal blood pressure, but the

biomechanics of the event dictate a significant risk of aortic, splenic, or pelvic injury. This knowledge should prompt the clinician to pursue advanced imaging, such as a pan-scan CT, to rule out these life-threatening conditions, thereby preventing premature diagnostic closure based on transiently stable physiology. The MOI, therefore, is not just a criterion for determining hospital destination; it is an essential tool for shaping the entire diagnostic and management strategy from the moment the patient arrives. This is particularly true for GSWs, where the external wound gives little indication of the internal destruction, making early, aggressive cross-sectional imaging mandatory (Karaca et al., 2015).

This review also highlights the need to refine triage tools by incorporating MOI with other critical patient data. The development of scoring systems like the MGAP (Mechanism, GCS, Age, Pressure) score, which formally integrates MOI with physiologic and demographic data, represents a move in this direction (Sertic et al., 2022). The evidence strongly suggests that the most accurate triage will be achieved not by relying on a single criterion, but by combining physiologic data, anatomic findings, MOI, and patient-specific factors like age and frailty (EAST, 2021).

Discrepancies and Nuances Across Populations (Geriatric vs. Pediatric)

A central finding of this review is that the clinical interpretation of MOI is not "one size fits all." The same mechanism produces vastly different outcomes and injury patterns at the extremes of age.

In the geriatric population, the concept of "high-energy" trauma must be redefined. As demonstrated by multiple studies, low-energy GLFs produce fracture patterns (cervical spine, pelvis, multiple ribs) and mortality rates that are characteristic of severe, high-energy trauma in younger cohorts (Bhattacharya et al., 2016; Caragounis, Xiao and Granhed, 2021). This discrepancy is due to age-related changes, including osteoporosis, sarcopenia, and diminished cardiovascular reserve, which collectively reduce the body's ability to withstand and respond to traumatic stress. The clinical implication is that any trauma in an elderly patient should be considered potentially

severe until proven otherwise, and triage tools must be adjusted to have a lower threshold for activation and transport to a trauma center for this population (He, 2025).

In the pediatric population, injury patterns are shaped by their unique anatomy and developmental stage. The disproportionately large and heavy head of an infant or young child, combined with weak neck muscles, makes them exceptionally vulnerable to head and cervical spine injuries from acceleration-deceleration forces (Stewart et al., 2013). As children grow, their center of gravity lowers, their bones ossify, and their injury patterns begin to resemble those of adults. However, their interaction with safety systems designed for adults can create unique injuries, such as the abdominal hollow viscus injuries seen in adolescents wearing lap-shoulder belts (Stewart et al., 2013). These population-specific nuances underscore the necessity of using age-appropriate triage criteria and maintaining a differential diagnosis that is tailored to the developmental stage of the child.

CONCLUSION AND RECOMMENDATIONS

Summary of Evidence

This systematic review confirms that the mechanism of injury is a fundamental and powerful predictor of injury patterns. The transfer of kinetic energy during a traumatic event is governed by the laws of physics, resulting in biomechanically consistent and predictable damage to the human body. A thorough understanding of the forces inherent to a specific MOI—be it the axial load of a fall from height, the lateral compression of a side-impact collision, or the deceleration of a frontal MVC—allows clinicians to anticipate a probable constellation of injuries with a high degree of confidence. However, this review also unequivocally demonstrates that this predictive power is critically modulated by patient-specific factors. Age and underlying physiological state can dramatically alter the clinical expression of a given energy transfer, with the geriatric population being particularly susceptible to severe injury from seemingly minor mechanisms.

Recommendations for Clinical Practice and Future Research

Based on the synthesis of the available evidence, the following recommendations are proposed:

For Clinical Practice:

1. **Integrate MOI into Clinical Reasoning:** Clinicians in both the prehospital and hospital settings should actively use detailed MOI information not just for triage, but as a primary tool to guide their secondary survey, diagnostic workup, and clinical suspicion.
2. **Maintain a High Index of Suspicion:** A high-risk MOI should prompt a thorough search for predictable occult injuries, even in patients who appear physiologically stable on initial presentation.
3. **Apply Age-Specific Interpretations:** The interpretation of MOI must be tailored to the patient's age. In geriatric patients, low-energy mechanisms should be treated with the same level of concern as high-energy mechanisms in younger adults. In pediatric patients, injury patterns should be considered in the context of their developmental stage and the type of safety restraints in use.
4. **Promote Education:** Continuous education for all trauma care providers on the biomechanics of common injury mechanisms and their associated injury patterns is essential to optimize patient assessment and management.

For Future Research:

1. **Develop and Validate Advanced Triage Models:** There is a pressing need for prospective, multi-center studies to develop, validate, and implement more sophisticated trauma triage models. These models should move beyond simple criteria and integrate MOI with dynamic physiological data, point-of-care laboratory values, and validated assessments of patient frailty.
2. **Investigate Biomechanics in Vulnerable Populations:** Further biomechanical research is needed to better understand injury tolerance thresholds in geriatric and pediatric populations. This knowledge is crucial for designing more effective injury prevention strategies, such as

improved vehicle safety systems, personal protective equipment (e.g., hip protectors for the elderly), and safer home and public environments.

3. **Standardize Outcome Reporting:** Future trauma research should strive for greater standardization in the reporting of outcomes. The adoption of consensus-based definitions for "major trauma" and a core set of reported outcomes would reduce heterogeneity and facilitate future meta-analyses, thereby strengthening the evidence base.

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