Received: 27 October 2021 | Revised: 17 March 2022 | Accepted: 19 March 2022
DOI: 10.1111/acem.14489

SYSTEMATIC REVIEWS (WITH OR WITHOUT META-ANALYSES)

Mechanism of injury and special considerations as predictive of serious injury: A systematic review

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Funding information
Pacific Northwest Evidence-based Practice Center at Oregon Health & Science University (OHSU) was funded to perform a supplemental literature review by the American College of Surgeons (ACS) as part of a Cooperative Agreement (# 693JJ9195007) between ACS and the National Highway Traffic Safety Administration (NHTSA), Office of Emergency Medical Services (OEMS) funded in part by the Health Resources and Services Administration (HRSA), Maternal and Child Health Bureau (MCHB), Emergency Medical Services for Children Program (EMSC). The contents are those of the author(s) and do not

Abstract

Objectives: The Centers for Disease Control and Prevention's field triage guidelines (FTG) are routinely used by emergency medical services personnel for triaging injured patients. The most recent (2011) FTG contains physiologic, anatomic, mechanism, and special consideration steps. Our objective was to systematically review the criteria in the mechanism and special consideration steps that might be predictive of serious injury or need for a trauma center.

Methods: We conducted a systematic review of the predictive utility of mechanism and special consideration criteria for predicting serious injury. A research librarian searched in Ovid Medline, EMBASE, and the Cochrane databases for studies published between January 2011 and February 2021. Eligible studies were identified using a priori inclusion and exclusion criteria. Studies were excluded if they lacked an outcome for serious injury, such as measures of resource use, injury severity scores, mortality, or composite measures using a combination of outcomes. Given the heterogeneity in populations, measures, and outcomes, results were synthesized qualitatively focusing

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on positive likelihood ratios (LR+) whenever these could be calculated from presented data or adjusted odds ratios (aOR).

Results: We reviewed 2418 abstracts and 315 full-text publications and identified 42 relevant studies. The factors most predictive of serious injury across multiple studies were death in the same vehicle (LR+ 2.2–7.4), ejection (aOR 3.2–266.2), extrication (LR+ 1.1–6.6), lack of seat belt use (aOR 4.4–11.3), high speeds (aOR 2.0–2.9), concerning crash variables identified by vehicle telemetry systems (LR+ 4.7–22.2), falls from height (LR+ 2.4–5.9), and axial load or diving (aOR 2.5–17.6). Minor or inconsistent predictors of serious injury were vehicle intrusion (LR+ 0.8–7.2), cardiopulmonary or neurologic comorbidities (LR+ 0.8–3.1), older age (LR+ 0.6–6.8), or anticoagulant use (LR+ 1.1–1.8).

Conclusions: Select mechanism and special consideration criteria contribute positively to appropriate field triage of potentially injured patients.

KEYWORDS
age, emergency medical services, field triage, field triage guidelines, mechanism of injury, prehospital care, serious injury, special considerations, trauma

INTRODUCTION

The Centers for Disease Control and Prevention's *Guidelines for the Field Triage of Injured Patients* (FTG) is widely used by emergency medical services (EMS) in the United States to identify patients with serious injuries and guide decisions on proper transport destinations.[1] Ideally, the FTG would result in the transport of severely injured patients to the highest level trauma centers; less seriously injured patients to appropriate trauma centers, not necessarily the highest level; and patients with minor injuries to appropriate hospitals as per local protocols. The FTG were originally developed by the American College of Surgeons (ACS) in 1987 and have since undergone several evidence-based revisions, most recently in 2011.[1,2]

Despite improvements in the FTG, the 2011 FTG have limitations, with studies showing continued overtriage (patients without serious injuries transported to trauma centers when they could have been cared for elsewhere) and undertriage (seriously injured patients not transported to an appropriate trauma center).[3–8] The accuracy of the FTG in properly triaging injured patients is based on the predictive utility of the component steps of the FTG. Since 2011, there have been several studies evaluating the performance of components of the FTG, providing an opportunity to systematically review the literature published over the past decade to assess the FTG components most predictive of serious injury.

The current (2011) FTG have four steps to help determine trauma center need: Step 1 (physiologic), Step 2 (anatomic), Step 3 (mechanism of injury), and Step 4 (special considerations).[1] Examples of special considerations included in past FTG are criteria based on age, anticoagulant use, comorbidities, pregnancy, and provider judgment. Physiologic and anatomic parameters have more clear associations with potential for serious injury, with recent systematic reviews emphasizing the individual components most predictive of serious injury.[9,10] However, the predictive utility of the mechanism and special consideration criteria in the FTG remain unclear since the most recent FTG update in 2011. Our objective was to conduct a systematic literature review of the evidence of the utility of mechanism and special consideration criteria in predicting patients most at risk for serious injury during the decade since the 2011 FTG were published. This review was commissioned by the ACS 2021 National Expert Panel on Field Triage to inform the upcoming revision of the FTG.

METHODS

Study design

This systematic review followed the methods presented in the Agency for Healthcare Research and Quality (AHRQ) Methods Guide for Effectiveness and Comparative Effectiveness Reviews, with the exception that this study was not registered because it was performed at the direction of the ACS National Expert Panel on Field Triage.[11] The objective was to evaluate the mechanism of injury or special considerations for patients with known or suspected trauma that are predictive of serious injury requiring transport to trauma care when used in out-of-hospital assessment. Mechanism and special consideration criteria evaluated in the systematic review included but were not limited to those already listed in the 2011 FTG. These are outlined in detail in Table S1.

Literature search strategy

A research librarian conducted searches in Ovid MEDLINE, EMBASE, and Cochrane Databases (January 1, 2011, through February 28, 2021). Search strategies are provided in Table S2. We restricted search start dates to January 2011 because our objective was to identify and include only publications not included in previous reviews informing the 2011 guidelines. Reference lists of included articles, and selected excluded articles (e.g., systematic and narrative reviews) were reviewed to identify additional potentially relevant studies.

Study selection

Criteria used to triage abstracts and review full texts of research articles for inclusion and exclusion were preestablished, in accordance with the AHRQ Methods Guide,[11] and were developed based on the PICOTS framework (populations, interventions, comparators, outcomes, timing, and setting; see Table S1). A second team member independently reviewed all excluded abstracts to confirm exclusion. All abstracts deemed appropriate for inclusion by at least one reviewer triggered full-text retrieval. Each full-text article was then independently reviewed for eligibility by two team members. Disagreements about inclusion or exclusion were resolved by consensus. Research team authors did not review their own publications.

Eligible study designs included comparative prospective and retrospective cohort studies, pre-post assessments, and cross-sectional studies. We excluded descriptive studies, commentaries, letters, and non-English articles. Because trauma and EMS systems differ significantly across countries outside of the United States, we focused on U.S. studies. However, we assessed the full text of relevant non-U.S. studies to determine whether their inclusion into the qualitative synthesis would change our conclusions. We excluded studies focused on physiologic or anatomic outcomes, such as cutoffs of vital signs by age, because these were previously evaluated in systematic reviews focusing on the physiologic components of the FTG.[9,10]

Data extraction and risk-of-bias assessment

After studies were selected for inclusion, data were abstracted including study design, year, setting, country, sample size, eligibility criteria, population, clinical and intervention characteristics, and relevant results. Data from included studies were abstracted into Microsoft Excel.

Predefined criteria were used to assess the risk of bias for individual studies (Table S3). Studies were evaluated using study design–specific criteria adapted from the Quality in Prognosis Studies (QUIPS) tool.[12] Two team members independently reviewed each study for risk of bias. Any disagreements were resolved by consensus. Team members who were involved in the conduct of a study were not involved in risk of bias assessment for that study.

The QUIPS tool includes domains on study participation, study attrition, prognostic factor measurement, outcomes measurement, study confounding, and statistical analysis and reporting. Studies were rated as "low risk of bias," "moderate risk of bias," or "high risk of bias." Studies rated as low risk of bias are considered to have minimal risk of bias, and their results are generally considered valid. Studies rated moderate risk of bias are susceptible to some bias, although not enough to invalidate the results. Studies rated high risk of bias have significant flaws indicating biases of various types that may invalidate the results. We did not exclude studies rated high risk of bias a priori, but such studies were considered less reliable than low or moderate risk of bias studies when synthesizing the evidence, particularly when discrepancies between studies were present.

Outcomes

Because the outcomes used varied significantly between studies, we focused on injury severity, mortality, or composite outcomes. Injury severity was defined most commonly in studies as a high (≥16) Injury Severity Score (ISS) but also included studies using a high Maximum Abbreviate Injury Scale scores, traumatic intracranial hemorrhage, or cervical spine injury. Mortality, though a clear outcome, varied in defined time cutoff used, ranging from 1 to 60 days after injury. Composite outcomes were included if they utilized measures of injury severity or mortality. Resource need was included as an outcome and commonly included emergent, nonorthopedic operations, intensive care admission, transfer to a higher level of care, or early discharge (inferred by studies as a lack of resource need).

Synthesis approach

We constructed evidence tables including study characteristics, results, and risk-of-bias ratings for all included studies and used these to develop summary tables that highlight the main findings. We did not conduct meta-analyses to generate pooled outcome estimates, because there were insufficient numbers of studies with the same outcomes, population, and risk factors. Rather, we performed qualitative synthesis of studies of similar risk factors that used the same or similar approaches to determine need for trauma center care.

Data analysis

Data were abstracted whenever possible from studies to calculate sensitivity, specificity, positive predictive value, negative predictive value, and likelihood ratios (LRs). The heterogeneity between studies precluded a meta-analysis. We were able to use LR if they were reported by the primary study or if these could be calculated from reported results. LRs indicate predictive utility without being dependent on the prevalence of the disease or condition in a given population. In general, a positive likelihood ratio (LR+) between 2 and 5 has a minor increase in posttest probability, whereas a LR+

between 5 and 10 has a moderate and >10 a large increase in posttest probability.[13,14] Similarly, a negative likelihood ratio (LR−) between 0.2 and 0.5 has a minor, 0.1–0.2 a moderate, and <0.1 a large decrease in posttest probability. LRs between 0.5 and 2 have small impact on the posttest probability and therefore less predictive utility. If LRs were not reported or could not be calculated, adjusted odds ratios (aORs) were reported although these were listed in the narrative text and included as a supplemental table. We focused on LR+ when examining and reporting results. However, we additionally examined LR− values to assure that we were not missing strong predictors of serious injury by focusing on LR+. We examined predicting factors with a LR− cutoff of less than 0.50 to determine whether it would change our predictive utility interpretations.

RESULTS

The literature search produced 2418 abstracts of potentially relevant publications. A total of 2103 abstracts were excluded after dual review, and 315 full-text publications underwent full-text review. Of 315 full-text publications, 42 studies were included. Of these, 20 evaluated the predictive utility of components of mechanism of injury criteria, 22 special considerations criteria, and 10 both. The literature flow diagram is shown in Figure 1. Details of the factors evaluated, and characteristics of included studies are included in Tables S4–S6 and aORs by factor and study are included in Table S7.

Mechanism of injury

Among the 30 studies on the predictive utility of mechanism of injury of the FTG, most were retrospective cohort studies of large registries, including the National Automotive Sampling System Crashworthiness Data System (10 studies), the U.S. National Trauma Data Bank (two studies), or state or multistate regional data sets (nine studies). The remaining studies analyzed data from a health system or smaller geographic region.

Motor vehicle collisions

There were 25 studies evaluating motor vehicle collision (MVC) characteristics predictive of serious injury and the LRs, if available, are listed in Table 1. Four studies of low to moderate risk of bias evaluated the predictive utility of death in the same vehicle, finding a mild to moderate increase in likelihood of serious injury (LR+ 2.2–7.4).[15–17] Five studies with low to moderate risk of bias examined ejection of an individual after an MVC, one evaluating ISS ≥ 16 but not excluding those meeting physiologic or anatomic criteria finding a LR+ of 1.0[18]; two evaluating composite outcomes of trauma center need in those not meeting physiologic or anatomic criteria, reporting LR+ of 3.0[15] and 3.2[16]; and two evaluated aOR (95% CI) for mortality (10.5 [10.2–10.9][19] and 34.0 [25.0–46.0][20]) and serious injury (13.7 [13.0–14.4][19] and 266.2 [70.0–999.0][20]). Four studies with low to moderate risk of bias evaluated the association between entrapment or need for extraction and serious injury, one

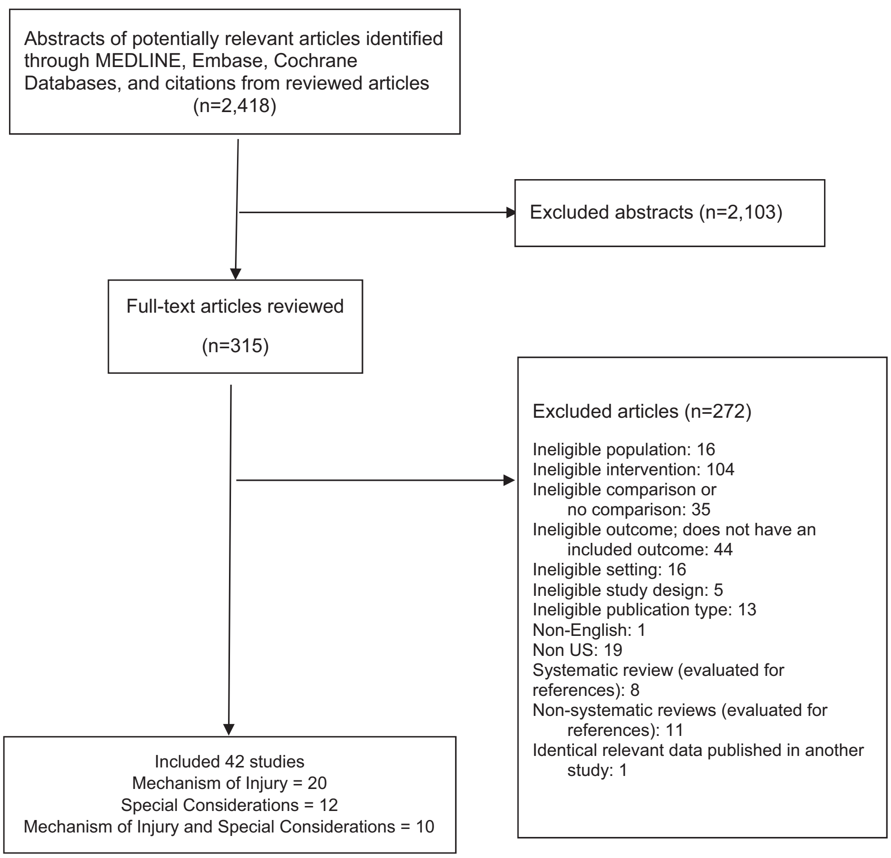

FIGURE 1 PRISMA literature flow. Excluded studies (examples) included those that had ineligible populations (nonhuman, nontrauma, cadaver studies, manikins), ineligible interventions (only physiologic or anatomic steps), ineligible comparison (descriptive study of all patients with a given factor), ineligible outcome (no outcome for serious injury), ineligible setting (in hospital), ineligible study design (case reports), or ineligible publication type (editorials) or were non-English studies, not conducted in the United States, reviews. or publications without primary data

TABLE 1 Predictive utility of motor vehicle collision characteristics for serious injury or death

Article	Factor	Outcome	LR+ (95% CI)	LR− (95% CI)	ROB	Note
Bosson, 2019[15]	Death in vehicle	Composite[a]	2.2 (1.8–2.9)	NR	Mod	A
Davidson, 2014[18]	Death in vehicle	ISS ≥ 16	2.22	0.87	Low	
Lerner, 2011[16]	Death in vehicle	Composite[b]	6.5 (2.7–16.7)	0.76	Mod	A
Lerner, 2020[17]	Death in vehicle	Composite[c]	7.42 (1.9–29.0)	0.91 (0.79–1.06)	Low	A, B
Bosson, 2019[15]	Ejection	Composite[a]	3.0 (2.4–3.6)	NR	Mod	A
Davidson, 2014[18]	Ejection	ISS ≥ 16	1.0	1.0	Low	
Lerner, 2011[16]	Ejection	Composite[b]	3.2 (1.3–8.2)	0.98	Mod	A
Davidson, 2014[18]	Entrapment	ISS≥16	1.07	0.98	Low	
Bosson, 2019[15]	Extrication	Composite[a]	2.2 (2.0–2.5)	NR	Mod	A
Lerner, 2011[16]	Extrication	Composite[b]	5.0 (3.2–8.0)	0.91	Mod	A
Lerner, 2020[17]	Extrication	Composite[c]	6.55 (1.7–25.4)	0.91 (0.79–1.06)	Low	A, B
Lerner, 2011[16]	Deformity > 20 in.	Composite[b]	2.3 (1.7–3.0)	0.85	Mod	A
Bosson, 2019[15]	Intrusion > 12 in., occupied	Composite[a]	0.9 (0.7–1.0)	NR	Mod	A
Bosson, 2019[15]	Intrusion > 18 in., unoccupied	Composite[a]	0.9 (0.7–1.0)	NR	Mod	A
Davidson, 2014[18]	Intrusion > 18 in., anywhere	ISS ≥ 16	0.77	1.12	Low	
Isenberg, 2011[24]	Intrusion	Composite[d]	7.24 (4.2–12.6)	0.45 (0.23–0.89)	Mod	
Lerner, 2011[16]	Intrusion > 12 in.	Composite[b]	3.7 (2.6–5.3)	0.88	Mod	A
Lerner, 2011[16]	Rollover	Composite[b]	1.0 (0.7–1.5)	1.00	Mod	A
Lerner, 2020[17]	Rollover	Composite[c]	0.78 (0.2–2.9)	1.03 (0.89–1.20)	Low	A, B
Davidson, 2014[18]	Roof crush 18 in.	ISS≥16	0.64	1.03	Low	A
Lerner, 2020[17]	Seat belt use	Composite[c]	0.7 (0.2–1.9)	1.09 (0.91–1.31)	Low	A, B
Lerner, 2011[16]	Speed > 40 mph	Composite[b]	1.8 (1.5–2.2)	0.75	Mod	A
Galanis, 2016[26]	Helmeted motorcyclist	Mortality	0.50 (0.3–0.8)	1.53 (1.29–1.81)	Mod	
Lerner, 2011[16]	Motorcycle > 20 mph	Composite[b]	1.1 (1.0–1.3)	0.72	Mod	A
Lerner, 2011[16]	Motorcycle rider separated	Composite[b]	1.0 (0.9–1.2)	0.89	Mod	A

Abbreviations: aOR, adjusted odds ratio; ISS, Injury Severity Score; LR+, positive likelihood ratio; Mod, moderate; NR, not reported; ROB, risk of bias.
Notes: (A) Patients meeting Step 1 or Step 2 criteria were excluded; (B) only including children ≤ 14 years. Composite measures included:
[a]Nonorthopedic surgery within 6 h, ISS ≥ 16, or surgical ICU admission.
[b]Nonorthopedic surgery within 24 h, ICU admission, or in-hospital mortality.
[c]Within 2 h of arrival receiving thoracostomy, within 4 h of arrival receiving emergent intubation, more than 1 unit of blood, or interventional radiology procedure, within 24 h of arrival requiring nonorthopedic surgery, a cesarean delivery, or a pericardiocentesis, within 48 h of admission requiring a thoracotomy or intracranial pressure monitoring, and in-hospital mortality or any admission for a spinal cord injury.
[d]Operative intervention of any type, spinal cord injury, intracranial hemorrhage, ICU admission, or in-hospital mortality.

reporting a LR+ of 1.1 for ISS ≥ 16[18] when not excluding those meeting physiologic or anatomic FTG criteria and three excluding those meeting physiologic or anatomic criteria, finding higher LR+ for composite outcomes indicative of trauma center need (range 2.2–6.6).[15–17]

Two studies with moderate risk of bias found that the odds of mortality[19] (aOR 2.93 [95% CI 2.81–3.06]) and serious injury (ISS ≥ 16[21]; unadjusted OR 2.50 [95% CI 1.50–4.18]) were higher when the vehicle was traveling over 55 mph. Studies using a lower speed threshold (40 mph) found an association with lower predictive value (LR+ 1.8).[16] Studies reported a much higher odds of mortality[19] (aOR 11.31 [95% CI 10.80–11.86]) and higher risk of most types of injuries[22,23] when seat belts were not used and lower odds of severe injury when seat belts were used.[21] Four studies with low to moderate risk of bias evaluated vehicle intrusion including roof crush using LRs with mixed results (LR+ 0.64–7.2). This broad range may be due to one study including orthopedic surgery at any time (LR+ 7.2)[24] in their composite outcome whereas the other studies excluded orthopedic surgeries (LR+ 0.64–3.7).[15,16,18] Vehicle rollover was assessed in two studies of low and moderate risk of bias reporting LR+ for composite outcome indicative of trauma center need (0.8–1.0).[16,17] One study, with a high risk of bias and not included with the aggregate results above, reported an aOR (95% CI) for a composite outcome of trauma center need for death in the same vehicle (3.40 [1.54–7.52]), ejection (3.17 [2.20–4.55]), extrication over 20 minutes

(3.98 [2.59–6.12]), intrusion over 12 inches (2.74 [2.08–3.61]), and speed > 40 mph (unadjusted OR 0.72 [0.60–0.88]).[25]

Motorcycle and moped MVC characteristics were evaluated in two studies with moderate risk of bias, with one reporting lower likelihood of mortality when wearing a helmet (LR+ 0.50),[26] whereas the other noted a speed over 20 mph or rider separation from the vehicle was not predictive of composite outcomes for trauma center need (LR+ 1.1 and 1.0, respectively).[16] A third study with high risk of bias evaluated unadjusted odds of serious injury for speed over 20 mph or rider separation from the vehicle, finding no significant associations.[25]

Five studies[27–31] evaluated crash factor algorithms to identify the specific factors from vehicle telemetry systems most useful in predicting serious injury. All studies used data from the National Automotive Sampling System Crashworthiness Data System. The General Motors telemetry model includes change in velocity, principal direction of force, multiple impacts, seat beat use, vehicle type and weight, and passenger age and sex. One variation in a study with high risk of bias included adding data on intrusion and the location of deformation.[31] One study[27] compared the General Motors model, which includes patient characteristics, to the Abbreviated University of Washington Nonrollover model, which is limited to crash variables that can be acquired from telemetric data. Overall, the algorithms performed well (LR+ 4.7–22.2). Another model, the Occupant Transportation Decision Algorithm (OTDA), resulted in improved under- and overtriage rates.[30] However, the OTDA model's performance varied by type of crash (e.g., side or front impact) and these analyses used a different approach to determine need for trauma care that integrated severity with time sensitivity (urgency in need to treat a specific injury) and predictability (likelihood for an occult injury).[30] One study with high risk of bias focused on the threshold to deploy EMS automatically from telemetry data, finding a risk of serious injury cutoff of 10% for automatic dispatch was required to improve care quality but at a high cost of inappropriate dispatch.[32] These differences made it difficult to compare across algorithms, and the studies included were retrospective and no studies evaluated the performance of vehicle telemetry in real time.

Pedestrians and bicyclists struck by motor vehicles

Five studies with low to moderate risk of bias assessed pedestrian or bicyclists struck by a vehicle as a mechanism of injury and those with available LRs are reported in Table 2. Two studies did not exclude those already meeting physiologic or anatomic FTG criteria, one finding older adults (≥65 years) struck at any speed had poor predictive utility for mortality (LR+ 0.9),[33] while another found in all ages being struck by a vehicle had higher associations with ISS ≥ 16 (LR+ 2.8).[34] Three studies excluded those meeting Step 1 and 2 criteria and evaluated composite outcomes indicative of trauma center need. These found that low-speed collisions (<20 mph) were less predictive of serious injury than high-speed (>20 mph) collisions in adults (LR+ 0.4 and 1.5, respectively)[15] and children[17] (LR+ for >20 mph of 2.3). Being run over appeared more predictive of trauma center need than being thrown by a vehicle for children (LR+ 2.7 and 1.1, respectively).[17] One study with high risk of bias not included above reported aOR for trauma center need for a pedestrian run over or thrown (1.54 [95% CI 1.19–1.99]).[25]

Non–motor vehicle mechanisms of injury

Several studies evaluated non–MVC-related mechanisms of injury including falls, firearm injury or violent assaults, and diving or axial load injuries with those with available LRs reported in Table 3. Falls were assessed as a mechanism of injury in nine studies, and findings

TABLE 2 Predictive utility of pedestrians or bicyclists struck by vehicles for serious injury or death

Article	Factor	Outcome	LR+ (95% CI)	LR− (95% CI)	ROB	Note
Dams-O'Connor, 2013[33]	Ped/bicycle vs. auto	Mortality	0.90 (0.75–1.09)	1.00 (1.00–1.00)	Low	A
Newgard, 2013[34]	vs. auto	ISS ≥ 16	2.83 (2.51–3.19)	0.97 (0.96–0.98)	Low	
Bosson, 2019[15]	vs. auto < 20 mph	Composite[a]	0.4 (0.4–0.6)	NR	Mod	B
Lerner, 2011[16]	vs. auto > 5 mph	Composite[b]	1.2 (1.0–1.5)	0.55	Mod	B
Bosson, 2019[15]	vs. auto > 20 mph	Composite[a]	1.5 (1.3–1.7)	NR	Mod	B
Lerner, 2020[17]	vs. auto > 20 mph	Composite[c]	2.32 (1.52–3.55)	0.43 (0.17–1.11)	Low	B, C
Lerner, 2020[17]	vs. auto, thrown	Composite[c]	1.12 (0.52–2.42)	0.93 (0.56–1.55)	Low	B, C
Lerner, 2020[17]	vs. auto, run over	Composite[c]	2.7 (1.02–7.18)	0.79 (0.52–1.18)	Low	B, C
Lerner, 2011[16]	vs. auto, thrown or run over	Composite[b]	1.2 (0.9–1.6)	0.76	Mod	B

Abbreviations: aOR, adjusted odds ratio; ISS, Injury Severity Score; LR+, positive likelihood ratio; Mod, moderate; NR, not reported; ROB, risk of bias.
Notes: (A) Only age ≥ 65 years; (B) patients meeting Step 1 or Step 2 criteria were excluded; (C) only age ≤ 14 years. Composite measures included:
[a]Nonorthopedic surgery within 6 h, ISS ≥ 16, or surgical ICU admission.
[b]Nonorthopedic surgery within 24 h, ICU admission, or in-hospital mortality.
[c]Within 2 h of arrival receiving thoracostomy, within 4 h of arrival receiving emergent intubation, more than 1 unit of blood, or interventional radiology procedure, within 24 h of arrival requiring nonorthopedic surgery, a cesarean delivery, or a pericardiocentesis, within 48 h of admission requiring a thoracotomy or intracranial pressure monitoring, and in-hospital mortality or any admission for a spinal cord injury.

varied by patient age.[15–17,25,33,35–38] In studies in an older age population (≥70 years-old), head injuries were more common from falls regardless of height, whereas in pediatrics, falls over 10 ft were associated with higher odds for serious injury. For studies of adults of any age, falls over 15 ft were less predictive of trauma center need (LR+ 2.4)[15] than falls over 20 ft (LR+ 5.2)[16] when evaluating only patients not meeting Step 1 or 2 FTG criteria. In one study with high risk of bias, mechanisms in children younger than 14 were assessed, with higher likelihood of mortality from firearm injury (LR+ 2.4) or assault of any kind (LR+ 4.1) regardless of the anatomic location of the injury.[39] Diving (relative risk 13.7, aOR 9.2),[40] clotheslining (relative risk 3.3),[40] and injuries causing an axial load (relative risk 3.2[40] and 5.0,[41] aOR 2.5[40]) were much more likely to result in cervical spine injury in children under 18 years old.

Overall utility of the mechanism of injury step

In five studies, including one with high risk of bias,[25] the added predictive utility of the mechanism of injury FTG step in patients who specifically met none of the FTG physiologic or anatomic criteria was evaluated. In these studies, meeting any current FTG mechanism-of-injury criteria was predictive of injury severity (LR+ 11.1)[18] but weakly predictive of composite outcomes (LR+ 1.7)[16] with no studies evaluating mortality alone. In the pediatric population, nearly one-quarter of children did not have a mechanism of injury included in the current mechanism criteria, and of those with an applicable mechanism, the LR+ for meeting any FTG mechanism criteria was higher than that of adults (LR+ 3.7).[17] The two studies evaluating adults that used the 2011 FTG[15,18] reported better results than studies that used mechanism of injury criteria from earlier versions.[16,25]

Special considerations

There were 22 studies evaluating special considerations including patient characteristics and EMS judgment as predictive factors in the prehospital setting for serious injury.

Anticoagulant use

Five studies of low and moderate risk of bias evaluated the predictive utility of anticoagulant use for serious injury, intracranial hemorrhage, or a composite outcome indicative of trauma center need, with LRs, if available, reported in Table 4. Two studies, excluding patients meeting any physiologic or anatomic FTG criteria, found that any anticoagulation use was minimally predictive of a composite outcome indicative of trauma center need (LR+ 1.6[15] for adult patients and 1.9[42] for patients ≥55 years) or for intracranial hemorrhage in patients ≥55 years (LR+ 1.8).[42] The predictive utility was lower in studies evaluating older adults without excluding those meeting other FTG criteria (LR+ 1.1 for ISS ≥ 16 and age ≥ 65 years[4]; LR+ 1.1 for intracranial hemorrhage and age ≥ 55 years[43]). A single study evaluating specific types of anticoagulation and outcomes of intracranial hemorrhage or a composite including neurosurgery or in-hospital death found no clear associations by anticoagulation type.[43] In this study, the composite outcome had lower predictive utility for trauma center need likely as patients with intracranial hemorrhage that did not result in mortality or surgical intervention would have not been included in the composite outcome for trauma enter need.[43] One study reported the aOR for intracranial hemorrhage in older adults (age ≥ 55 years) using any anticoagulation, finding an insignificant association (aOR 1.61 [95% CI 0.94–2.75]).[44]

TABLE 3 Predictive utility of non–motor vehicle mechanisms of injury for serious injury or death

Article	Factor	Outcome	LR+ (95% CI)	LR– (95% CI)	ROB	Note
Buehner, 2017[39]	Any assault	Mortality	4.11 (2.61–6.49)	0.96 (0.93–0.98)	High	A
Buehner, 2017[39]	Firearm	Mortality	2.40 (1.45–3.98)	0.97 (0.95–1.00)	High	A
Dams-O'Connor, 2013[33]	Assault	Mortality	0.67 (0.56–0.79)	1.01 (1.00–1.01)	Low	B
Newgard, 2013[34]	Fall	ISS ≥ 16	1.88 (1.81–1.94)	0.79 (0.77–0.81)	Low	
Staudenmayer, 2013[36]	Fall	Mortality	1.21 (1.12–1.30)	0.79 (0.70–0.89)	Mod	C
Lerner, 2020[17]	Fall > 10 ft	Composite[a]	5.9 (2.8–12.6)	0.60 (0.33–1.08)	Low	D, E
Bosson, 2019[15]	Fall > 15 ft	Composite[b]	2.4 (2.1–2.6)	NR	Mod	E
Lerner, 2011[16]	Fall > 20 ft	Composite[c]	5.2 (2.4–11.3)	0.97	Mod	E

Abbreviations: ISS, Injury Severity Score; LR+, positive likelihood ratio; Mod, moderate; NR, not reported; ROB, risk of bias. Notes: (A) Only age < 14 years; (B) only age ≥ 65 years; (C) only age ≥ 55 years; (D) only age ≤ 14 years; (E) patients meeting Step 1 or Step 2 criteria were excluded. Composite measures included:

[a]Within 2 h of arrival receiving thoracostomy, within 4 h of arrival receiving emergent intubation, more than 1 unit of blood, or interventional radiology procedure, within 24 h of arrival requiring non-orthopedic surgery, a cesarean delivery, or a pericardiocentesis, within 48 h of admission requiring a thoracotomy or intracranial pressure monitoring, and in-hospital mortality or any admission for a spinal cord injury.

[b]Nonorthopedic surgery within 6 h, ISS ≥ 16, or surgical ICU admission.

[c]Nonorthopedic surgery within 24 h, ICU admission, or in-hospital mortality.

Patient comorbidities

Five studies with low to moderate risk of bias evaluated comorbidities including alcohol use and their association with serious injury or mortality from traumatic injuries, with studies with available LRs reported in Table 5. These studies found congestive heart failure (LR+ 3.1),[45] prior cerebrovascular accident at any age (LR+ 2.5) or age ≥ 60 years (LR+ 3.0),[45] chronic kidney disease and a fall mechanism with age ≥ 65 years (aOR 2.5 [95% CI 1.85–3.33]),[46] a cardiac history and older age (age ≥ 55 years aOR 1.66 [95% CI 1.28–2.15] and age ≥ 70 years aOR 1.77 [95% CI 1.31–2.39]),[47] and alcohol use (aOR 3.10 [95% CI 2.94–3.26])[19] were significantly associated with mortality. The presence of any comorbidity[4] or two or more comorbidities[47] regardless of specific comorbidity type was not strongly predictive of serious injury (LR+ 1.1)[4] or significant adjusted odds for mortality.[47] There were no studies specifically on child or elder abuse, interpersonal violence, or pregnancy as predictors of injury severity.

Patient age

The association between older age and serious injury or mortality was assessed in 10 studies. Six of these studies reported LRs, with older age cutoffs more frequently having higher LR+ for serious injury or mortality (Figure 2).[33,36,37,45,48,49] One of these studies evaluated unadjusted odds and two studies evaluated the aOR for mortality by age, finding higher odds (95% CI) of mortality as age increased from ≥44 years (OR 2.72 [1.07–6.92] vs. age < 44 years)[50] to ≥60 years (aOR 4.53 [4.03–5.09] vs. age < 60 years),[45] 65–79 years (aOR 4.55 [4.25–4.87] vs. age 15–39 years),[19] or for ≥80 years (aOR 11.06 [10.17–12.04] vs. age 15–39 years).[19] One study found that

TABLE 4 Predictive utility of anticoagulant use for severe injury

Article	Factor	Outcome	LR+ (95% CI)	LR− (95% CI)	ROB	Note
Bosson, 2019[15]	Any anticoagulant	Composite[a]	1.6 (1.3–1.8)	NR	Mod	A
Newgard, 2019[4]	Any anticoagulant	ISS ≥ 16	1.11	0.31	Low	B
Nishijima, 2017[42]	Any anticoagulant	Composite[b]	1.94 (1.37–2.73)	0.62 (0.41–0.95)	Low	A, C
Nishijima, 2017[42]	Any anticoagulant	ICH	1.78 (1.44–2.18)	0.70 (0.58–0.85)	Low	A, C
Nishijima, 2018[43]	Any anticoagulant	Composite[b]	0.72 (0.36–1.42)	1.17 (0.91–1.52)	Low	C
Nishijima, 2018[43]	Any anticoagulant	ICH	1.12 (0.89–1.41)	0.93 (0.79–1.09)	Low	C
Nishijima, 2018[43]	DOAC	Composite[b]	0	1.04 (1.03–1.05)	Low	C
Nishijima, 2018[43]	DOAC	ICH	0.73 (0.23–2.33)	1.01 (0.98–1.04)	Low	C
Nishijima, 2018[43]	Aspirin only	Composite[b]	0.05 (0.01–0.32)	1.23 (1.19–1.28)	Low	C
Nishijima, 2018[43]	Aspirin only	ICH	1.29 (0.89–1.87)	0.94 (0.85–1.04)	Low	C
Nishijima, 2018[43]	Other antiplatelet only	Composite[b]	0.39 (0.10–1.60)	1.03 (1.00–1.06)	Low	C
Nishijima, 2018[43]	Other antiplatelet only	ICH	0.82 (0.30–2.24)	1.01 (0.97–1.05)	Low	C
Nishijima, 2018[43]	Warfarin only	Composite[b]	0.21 (0.06–0.86)	1.07 (1.04–1.10)	Low	C
Nishijima, 2018[43]	Warfarin only	ICH	0.92 (0.46–1.86)	1.01 (0.95–1.06)	Low	C

Abbreviations: DOAC, direct oral anticoagulant; ICH, intracranial hemorrhage; ISS, Injury Severity Score; LR+, positive likelihood ratio; LR−, negative likelihood ratio; Mod, moderate; NR, not reported; ROB, risk of bias. Notes: (A) Patients meeting Step 1 or Step 2 criteria were excluded; (B) only age ≥ 65 years; (C) only age ≥ 55 years. Composite measures included:

[a]Nonorthopedic surgery within 6 h, ISS ≥ 16, or surgical ICU admission.

[b]Neurosurgery or death due to trauma during hospitalization.

TABLE 5 Predictive utility of patient comorbidities for serious injury

Article	Factor	Outcome	LR+ (95% CI)	LR− (95% CI)	ROB	Note
Benjamin, 2018[45]	CVA history	24-h mortality	2.47 (2.01–3.04)	0.97 (0.96–0.98)	Low	
Benjamin, 2018[45]	CVA history + age	24-h mortality	2.95 (2.62–3.33)	0.91 (0.89–0.93)	Low	A
Benjamin, 2018[45]	CHF history	24-h mortality	3.13 (2.71–3.61)	0.93 (0.92–0.95)	Low	
Benjamin, 2018[45]	HTN on medications	24-h mortality	0.84 (0.78–0.90)	1.05 (1.03–1.07)	Low	
Benjamin, 2018[45]	Obesity	24-h mortality	0.81 (0.60–1.10)	1.01 (1.00–1.01)	Low	
Benjamin, 2018[45]	Respiratory disease	24-h mortality	1.39 (1.19–1.62)	0.98 (0.96–0.99)	Low	
Newgard, 2019[4]	>2 comorbidities	ISS ≥ 16	1.10	0.51	Low	B

Abbreviations: CHF, congestive heart failure; CVA, cerebrovascular accident; HTN, hypertension; ISS, Injury Severity Score; LR+, positive likelihood ratio; LR−, negative likelihood ratio; ROB, risk of bias. Notes: (A) Only age ≥ 60 years; (B) only age ≥ 55 years.

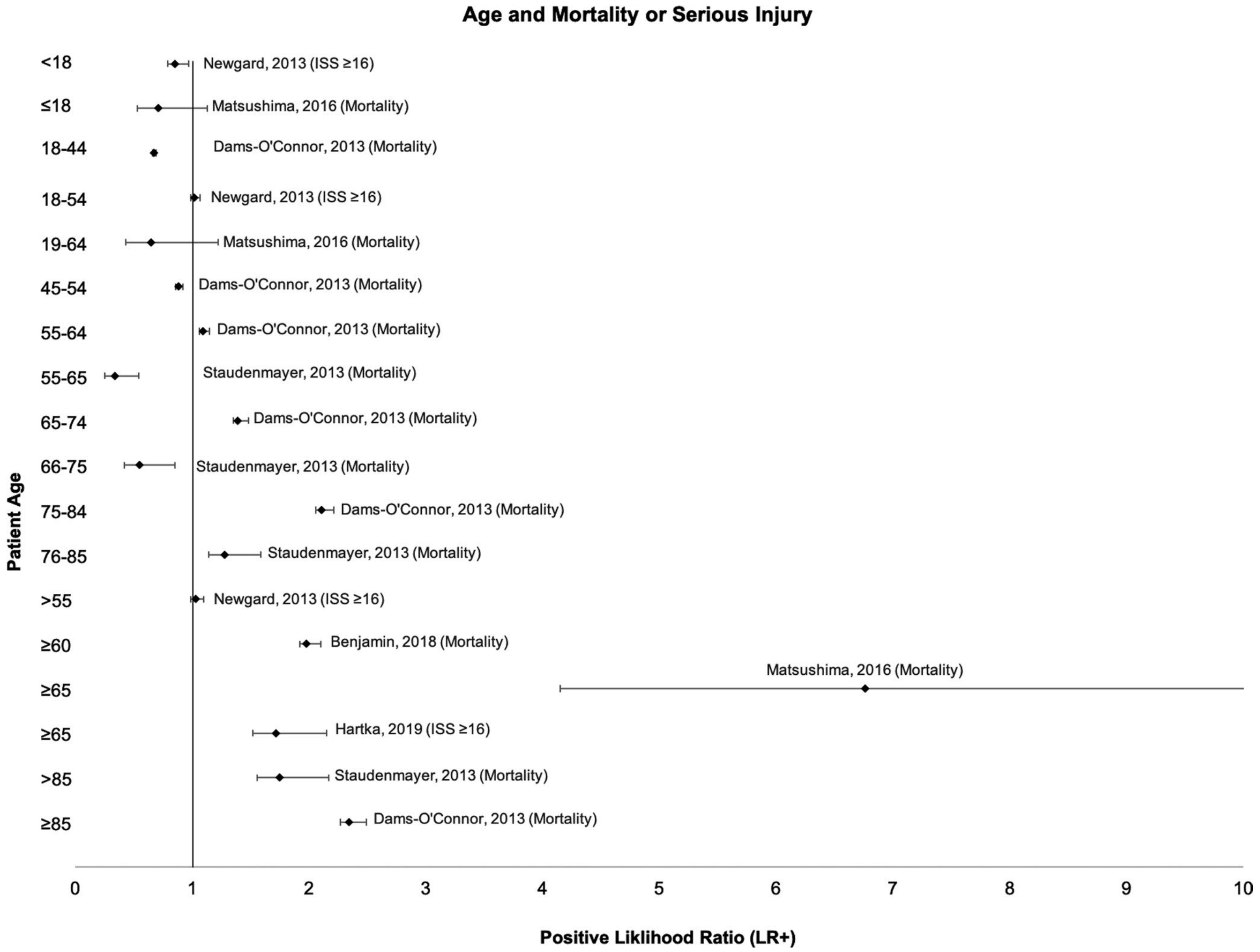

FIGURE 2 Graphical representation of the LR+ for serious injury and mortality by age cutoff. Included studies were those reporting the positive LR for serious injury or mortality by patient age[33,36,37,45,48,49]

patients who are older (>65 years) were more likely to be undertriaged despite having high-risk features for injury, but this study did not assess impacts of this undertriage on patient injury severity.[51] A final study evaluated the odds for mortality comparing adults ≥ 70 years to adults < 70 years, finding higher unadjusted odds of in-hospital mortality in older adults after being a pedestrian hit by a car or a fall with traumatic brain injury.[35]

EMS provider judgment

Six studies with low to moderate risk of bias evaluated the predictive utility of EMS provider judgment. One study found EMS judgment to be minimally associated with serious injury, defined as ISS ≥ 16, for all patients (aOR 1.23 [95% CI 1.03–1.47]), with stronger associations for older (≥55 years) adults (aOR 1.50 [95% CI 1.15 to 1.96]).[52] In this same study, use of EMS provider judgment in patients not meeting anatomic or physiologic FTG criteria resulted in worse predictive utility (LR+ 0.62 [95% CI 0.57–0.67]) than when used in combination with all FTG steps (LR+ 0.97 [95% CI 0.93–1.01].[52] This is similar to another study that also excluded patients meeting any physiologic, anatomic, or mechanism of injury steps in the FTG, finding poor predictive utility of EMS judgment (LR+ 0.5 [95% CI 0.4–0.5]) in this population.[15] Another study found EMS providers judgment of risk of traumatic intracranial hemorrhage positively correlated with the actual incidence of intracranial hemorrhage, with EMS provider judgment having greater sensitivity than Steps 1–3 of the FTG (77.6% vs. 26.3%) but lower specificity (41.5% vs. 88.3%).[44] Similarly, sensitivity was greater in another retrospective study of paramedic judgment and its association with serious injury.[53] One additional study found associations with higher overtriage and lower undertriage when an advanced life support EMS crew was used to transport rather than a basic life support crew.[54] One additional study found that EMS judgment had an inverse association with resource need and may result in overtriage.[55]

Non-U.S. Studies

There were 18 non-U.S. studies meeting eligibility criteria that evaluated the predictive utility of components of mechanism (eight studies), special considerations (three studies), and both (seven studies). These studies were consistent with the findings reported above from U.S. studies and would not change the overall conclusions of our results. Descriptive information for these studies is included in Table S8.

DISCUSSION

We performed a systematic review of the literature on the utility of mechanism and special consideration criteria for predicting serious injury in the prehospital triage of trauma patients since the publication of the 2011 FTG. Death in the same vehicle, ejection, high-speed > 55 mph collision (if known with accuracy on scene), entrapment requiring extrication, falls from height, high-risk features of vehicle telemetry alert systems, diving or axial load injuries (especially in children), and certain comorbidities were most predictive of resource need, serious injury, or mortality.

Several features currently listed as mechanism or special consideration criteria in the 2011 FTG did not consistently have high predictive utility for serious injury, mortality, or resource need, including vehicle intrusion (LR+ range 0.8 to 3.7 in studies excluding orthopedic injuries) or pedestrians hit by a vehicle and thrown (LR+ range 1.1 to 1.2), run over (LR+ range 1.2 to 2.7), or struck with speed > 20 mph (LR+ range 1.5 to 2.3). EMS provider judgment also frequently resulted in overtriage. However, use of provider judgment resulted in improved rates of undertriage, suggesting that judgment may identify patients likely to have serious injuries missed by other FTG criteria but at the cost of overtriage. It is also likely that EMS provider judgment varies widely with EMS system and by individual EMS providers, and thus applying studies on the predictive utility of this measure to an individual system is difficult.

Future FTG revisions may consider adding certain factors not currently in the 2011 FTG but associated with serious injury, such as high speeds > 55 mph (if speed is known accurately), entrapment requiring extrication, diving or axial load injuries, or certain comorbidities. For comorbidities, although there were associations between cardiac comorbidities[47] or comorbidities that may impair neurologic function such as alcohol use[19] or stroke,[45] these were assessed in all-comers, and the added value of these special considerations in a patient in whom no anatomic, physiologic, or mechanism of injury triage criteria are met is unknown. Thus, it is difficult to say whether inclusion of these to the FTG would improve rates of undertriage or simply add additional instances of overtriage. Notably for anticoagulant use, currently in the FTG as a special consideration, when assessed in addition to physiologic, anatomic, and mechanism (Steps 1–3) criteria it performed similarly to its predictive utility for intracranial hemorrhage in only patients not meeting any Step 1–3 criteria (LR+ 1.81 vs. 1.78, respectively).[42]

The challenge of the FTG remains fitting a uniform algorithm to vastly different patient populations including infants, toddlers, children, adults, and the elderly. Furthermore, each individual patient has unique comorbidities and risk factors, such as preexisting cardiac disease, alcohol intoxication, or anticoagulant use. As a result, it is not surprising that the literature reviewed suggests different risks of serious injury based on age[19,45,48,49] and indicated interactions between age and mechanism[16,17,33,35,36] as they relate to risk of serious injury. For example, pediatric patients (≤15 years old) not meeting physiologic or anatomic criteria had a comparable likelihood of trauma center need for lower impact falls (>10 ft, LR+ 5.9)[17] to adults (≥18 years old) not meeting physiologic and anatomic criteria, who had a comparable likelihood of trauma center need (LR+ 5.2) for falls from a greater height (>20 ft).[16] Similarly, older adults generally had higher likelihood for serious injury or mortality, regardless of mechanism, compared to nonelderly adults (Figure 2). Unfortunately, published studies differed significantly in the cutoff used for age for pediatrics (12–18 years) and elderly (50–80 years), making any synthesis or definitive conclusions from these studies difficult. Future research should focus whenever possible on using standardized cutoffs to facilitate comparison of results.

We did not a priori remove publications that assessed predictive utility without excluding patients already meeting physiologic or anatomic criteria, although this may be the best way to assess the added value of mechanism of injury, patient characteristics, or EMS provider judgment criteria to the FTG. Using this restriction would eliminate the studies reporting the lowest LR+ for death in the same vehicle, ejection, need for extrication, and falls from height, thus only strengthening their reported predictive utility for serious injury. This is not the case for intrusion or pedestrians struck by vehicles, where the studies reporting the highest LR+ in each would be excluded in this more restrictive approach as they did not limit their analysis to patients not meeting physiologic or anatomic criteria. These methodologic differences were likely less impactful on studies using aORs, such as those showing that high speeds (>55 mph), diving or axial load injuries, or certain comorbidities were associated with serious injury. Future studies should aim to evaluate not only the utility of individual criteria in isolation but also their added value in detecting seriously injured patients who do not meet any other FTG criteria.

LIMITATIONS

Although the risk of bias was low or moderate for most studies, there were several methodologic limitations making synthesis of data difficult, and thus the major limitation of our systematic review was the inability to quantitively present a meta-analysis due to the heterogeneity of studies. More specifically, studies varied widely in their definitions of predictive measures, including varied definitions of age cutoffs, vehicle intrusion cutoffs, and vehicle speed, among other parameters. Similarly, some studies evaluated mechanism and special considerations in all patients while others restricted the analysis to only those not meeting any anatomic or physiologic criteria, which may bias the results. Furthermore, outcomes varied significantly with different definitions of serious injury, resource utilization, or even the time course for mortality (ranging from 1- to 60-day mortality). Thus, comparing outcomes between studies is limited, in particular comparing composite outcomes to noncomposite outcomes.

As with prior systematic reviews on this topic, studies included in our review were mostly retrospective studies of large trauma registries, thus missing a subset of injured patients not transported to trauma centers or entered into the trauma system. Several of the studies used the same large databases and the degree of overlap of their patient populations reduces the independent nature of each study. We also excluded studies published before the 2011 FTG. While this restriction likely captured data most relevant to current EMS practices and trauma resources, it did not include important data on mechanism or special considerations published before 2011 that informed the 2011 FTG. Finally, this review did not specifically explore the additive role of mechanism or special considerations in patients already meeting physiologic or anatomic criteria. Specifically, while a subset of studies evaluated mechanism or special considerations in only those not meeting physiologic or anatomic criteria, several studies did not exclude those meeting physiologic or anatomic criteria. These differences may be one explanation for a portion of the variability in results between studies.

CONCLUSION

In the field triage of injured patients by emergency medical services, select mechanism of injury characteristics and special considerations are useful components of appropriate field triage. Specifically, death in the same vehicle, ejection, prolonged extrication, lack of seat belt use, high speeds, concerning crash variable from vehicle telemetry, falls from height, and axial load injuries were predictive of serious injury. The evidence was limited by heterogeneity among studies with varied definitions of predictive measures and patient outcomes. Future studies should use standardized definitions of mechanism of injury characteristics, standard cutoffs for patient age, and standard definitions of serious injury and mortality to facilitate comparisons, data synthesis, and an evaluation of the additive or independent value of each factor.

ACKNOWLEDGMENTS

The authors acknowledge the following individuals for their contributions to this project Tracy Dana, MLS, Leah Williams, BS, and Elaine Graham, MLS.

CONFLICT OF INTEREST

All authors report no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Lupton JR, Davis-O'Reilly C, Jungbauer RM, et al. Mechanism of injury and special considerations as predictive of serious injury: A systematic review. *Acad Emerg Med*. 2022;00:1-12. doi: 10.1111/acem.14489