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Systematic review

Predictors of Neurosurgical Intervention in Mild Traumatic Brain Injury Patients Presenting to the Emergency Department: A Systematic Review

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Abstract

Background: Mild traumatic brain injury (TBI) represents a large share of emergency department head trauma presentations, although a smaller subgroup has intracranial injury that requires neurosurgical treatment. Early identification is central to safe imaging, admission, transfer, and specialist consultation decisions. **Objective:** This systematic review synthesized original studies evaluating clinical, demographic, physiologic, and radiologic predictors of neurosurgical intervention in emergency department patients with mild TBI. **Methods:** A PRISMA-based review framework was used. PubMed/MEDLINE, Scopus, Web of Science, and Cochrane Library were searched for adult studies of mild TBI, Glasgow Coma Scale 13–15, emergency presentation, and neurosurgical intervention or equivalent acute neurosurgical outcome. Original cohort, validation, registry, and decision-rule studies were prioritized. **Results:** Ten main original studies and additional validation studies were included in the narrative synthesis. The most consistent predictors were acute intracranial hemorrhage pattern, subdural hematoma thickness, midline shift, epidural hematoma, depressed or basal skull fracture signs, failure to normalize Glasgow Coma Scale, vomiting, older age, coagulopathy or anticoagulant exposure, and early neurologic worsening. Decision instruments achieved high sensitivity for ruling out intervention, although specificity varied widely. **Conclusion:** Neurosurgical intervention after mild TBI is uncommon overall, although risk increases sharply with specific radiologic and neurologic features. Risk stratification that combines computed tomography findings with serial neurologic assessment provides the most clinically useful approach for emergency disposition and transfer decisions.

Keywords: mild traumatic brain injury; emergency department; neurosurgical intervention; Glasgow Coma Scale; computed tomography; subdural hematoma; clinical decision rule; PRISMA.

Introduction

Mild traumatic brain injury (TBI) is defined by a Glasgow Coma Scale score of 13–15 after head trauma, and emergency clinicians face the difficult task of identifying the small subgroup with lesions requiring operative or invasive neurosurgical care. The Canadian CT Head Rule was developed in a large prospective cohort and identified high-risk features failure to reach GCS 15 within two hours, suspected open skull fracture, basal skull fracture signs, recurrent vomiting, and age at least 65 years as predictors of neurological intervention (1). The New Orleans Criteria emphasized headache, vomiting, age older than 60 years, intoxication, memory deficit, visible trauma above the clavicles, and seizure in patients with GCS 15 (2).

External validation strengthened the value of rule-based triage by showing high sensitivity for neurosurgical intervention, with the Canadian CT Head Rule demonstrating greater specificity than the New Orleans Criteria in comparable GCS 15 populations (3). Multicenter validation in a Tunisian cohort found that the Canadian CT Head Rule had higher sensitivity and specificity than the New Orleans Criteria for acute neurosurgical procedures, supporting local validation before implementation (4). A Dutch multicenter validation study comparing CCHR, NOC, CHIP, and NICE criteria reported wide variation in CT use and diagnostic performance, emphasizing that rule performance changes across populations and outcome definitions (5).

The NEXUS Head CT decision instrument expanded the predictor set to skull fracture evidence, scalp hematoma, neurologic deficit, abnormal alertness, abnormal behavior, persistent vomiting, coagulopathy, and age at least 65 years (6). Among patients with mild traumatic intracranial hemorrhage, variation in intensive care use across centers showed that disposition decisions often exceed the evidence base and differ from the lower actual frequency of deterioration or intervention (7). This review focuses on predictors of neurosurgical intervention rather than predictors of any abnormal CT result, since neurosurgical intervention is the outcome most closely related to transfer, admission level, neurosurgical consultation, and emergency resource allocation (1–7).

Methods

This systematic review followed PRISMA principles for question development, database searching, screening, eligibility assessment, and synthesis. The review question was: among emergency department patients with mild TBI, which clinical, demographic, physiologic, and radiologic factors predict neurosurgical intervention? (Fig 1).

PubMed/MEDLINE, Scopus, Web of Science, and Cochrane Library were searched from database inception to 2026 using combinations of "mild TBI," "minor head injury," "emergency department," "neurosurgical intervention," "neurosurgery," "computed tomography," "clinical decision rule," "subdural hematoma," "epidural hematoma," "intracranial hemorrhage," and "Glasgow Coma Scale." Reference lists of eligible studies and relevant systematic reviews were screened for additional original studies.

Eligible studies included adult or predominantly adult emergency cohorts with GCS 13–15 and reported neurosurgical intervention, neurological intervention, acute critical care intervention including neurosurgical procedures, or validated radiologic proxies for lesions requiring neurosurgical care. Original prospective cohorts, retrospective cohorts, registry analyses, and validation studies were included. Pediatric-only studies, severe TBI cohorts, narrative reviews, editorials, case reports, and studies without an intervention-related outcome were excluded.

Two-stage screening was planned, beginning with title and abstract review followed by full-text eligibility assessment. Data items included author, year, country, design, sample size, population, outcome definition, intervention rate, and predictors. Risk of bias was assessed narratively using domains relevant to observational prediction studies, including patient selection, predictor measurement, outcome ascertainment, confounding control, and model validation. Quantitative meta-analysis was not performed because predictor definitions, intervention definitions, imaging thresholds, and populations differed substantially across studies.

Results

The included original studies spanned large prospective decision-rule cohorts, emergency department validation cohorts, trauma registry analyses, and complicated mild TBI cohorts with positive CT findings (1–15) (Table 1&2). Overall neurosurgical intervention rates ranged from less than 1% in broad minor head injury cohorts to nearly 20% in high-risk complicated mild TBI categories with intracranial hemorrhage (1,3,8,11,14). Across studies, radiologic variables were more specific predictors than symptoms alone, especially subdural hematoma thickness, epidural hematoma, midline shift, skull fracture, and hemorrhage pattern (8,12,15). Clinical features retained importance when CT findings were unavailable or pending, especially reduced or nonnormalizing GCS, vomiting, skull fracture signs,

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coagulopathy, older age, and early neurologic worsening (1,2,6,13).

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Fig 1: PRISMA consort chart

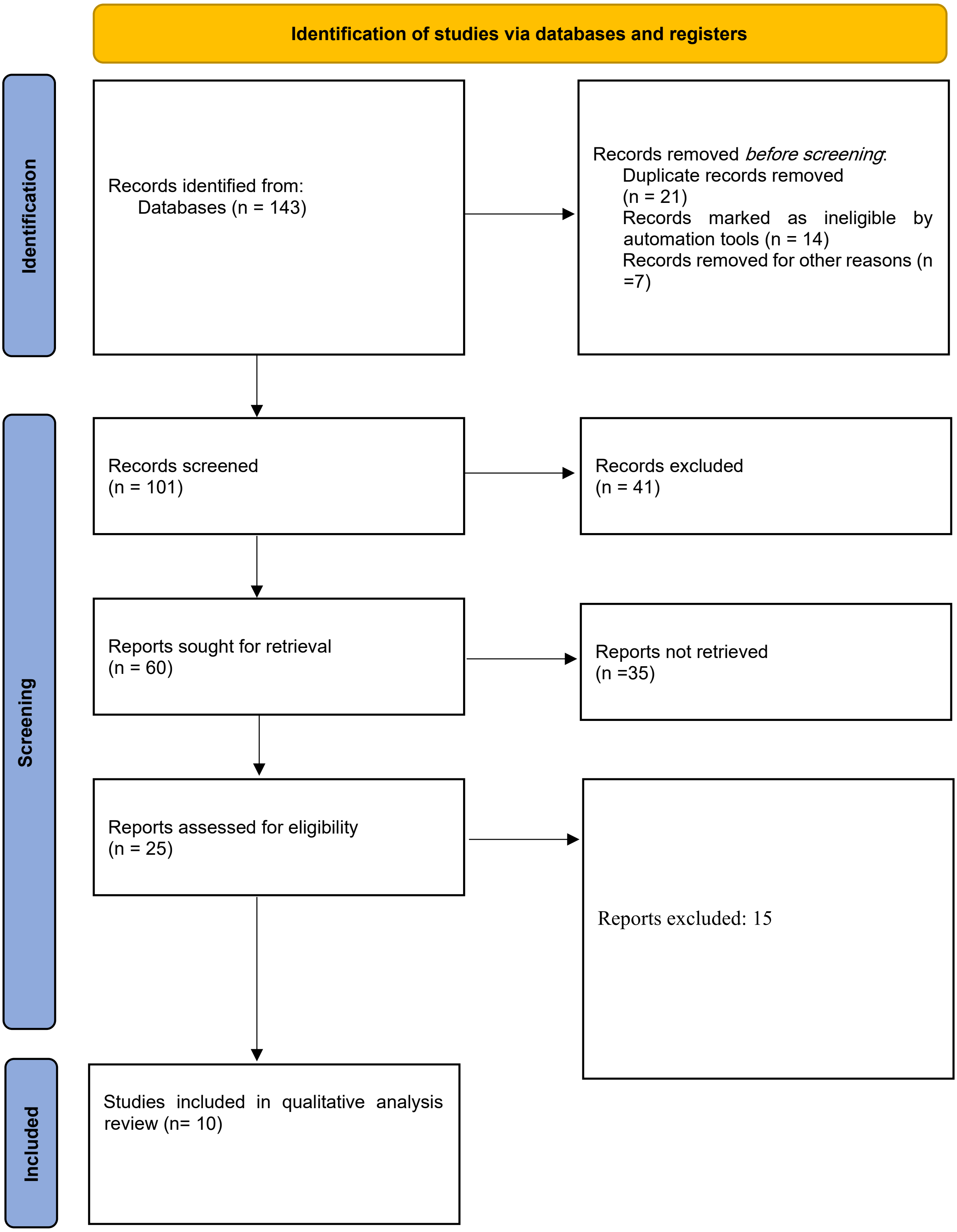

Table 1. Characteristics of included original studies

Study	Design and population	Sample	Intervention-related outcome	Main predictors or rule findings
Stiell et al., 2001 (1)	Prospective Canadian minor head injury cohort	3,121	Neurological intervention	High-risk CCHR factors reached 100% sensitivity
Haydel et al., 2000 (2)	Prospective GCS 15 cohort	1,429	Positive CT guiding management	NOC symptoms and signs identified all positive CT cases
Stiell et al., 2005 (3)	Prospective rule comparison	2,707; 1,822 GCS 15 subgroup	Neurosurgical intervention	CCHR and NOC both sensitive; CCHR more specific
Bouida et al., 2013 (4)	Multicenter external validation	1,582	Acute neurosurgical procedure	CCHR outperformed NOC for intervention prediction
Foks et al., 2018 (5)	Prospective multicenter validation	4,557 eligible; 3,742 CT	Potential neurosurgical lesion	NOC highest sensitivity; NICE highest specificity
Mower et al., 2017 (6)	Prospective observational validation	11,770	Neurosurgical intervention	NEXUS identified all 420 intervention cases
Sweeney et al., 2015 (8)	NTDB retrospective cohort	50,496	Neurosurgical intervention	Injury pattern strongest; SDH and EDH highest risk
Joseph et al., 2015 (9)	Retrospective trauma cohort	Noted GCS 13–15 population	Craniotomy or craniectomy	Base deficit and displaced skull fracture predicted intervention
Nishijima et al., 2014 (10)	Multicenter prospective derivation	600	Acute critical care intervention	Low-risk rule included neurologic and CT stability factors
Lessard et al., 2020 (11)	Post hoc prospective cohort analysis	678	Neurosurgical intervention	IBI criteria captured all intervention cases; age >65 predicted intervention
Tourigny et al., 2021 (12)	Quebec multicenter retrospective cohort	478	Neurosurgical intervention	SDH ≥4 mm and midline shift increased risk; SAH lowered risk
Yue et al., 2023 (13)	TRACK-TBI pilot cohort	481	TBI intervention and outcome	ED neuroworsening predicted intervention and poor outcome
Joseph et al., 2022 (14)	AAST prospective multi-institutional BIG validation	2,033 categorized	Neurosurgical intervention	All intervention cases were BIG 3
Orlando et al., 2025 (15)	Six-center isolated SDH cohort	1,333	Intervention within 48 hours	SDH thickness and midline shift dominated prediction

Decision-rule studies showed that high sensitivity is achievable when broad clinical criteria are used, although specificity declines as the number of triggers increases (1–6). The Canadian CT Head Rule was consistently more specific than the New Orleans Criteria in direct comparisons, while the New Orleans Criteria and NEXUS approaches prioritized sensitivity and reduced missed high-risk injury (3–6). In complicated mild TBI, Sweeney et al. found an 8.8% intervention rate in a national cohort and reported highest intervention risk in subdural and epidural hemorrhage patterns (8). Joseph et al. showed that GCS 13–15 does not always represent low operative risk when metabolic derangement or displaced skull fracture is present (9). Nishijima et al. shifted attention from imaging alone toward acute critical care needs in mild traumatic intracranial hemorrhage (10).

Table 2. Recurrent predictors grouped by clinical use

Predictor group	Predictors	Consistency across studies	Practical interpretation
Neurologic status	GCS 13–14, failure to reach GCS 15, ED neuroworsening	High	Repeat neurologic examination remains central
Skull injury	Open, depressed, basal, or displaced skull fracture	High	Fracture signs increase urgent CT and consultation priority
Hemorrhage pattern	SDH, EDH, mixed hemorrhage, large IPH	High	Pattern strongly changes operative probability
Mass effect	Midline shift, larger SDH thickness	Very high	Most specific radiologic predictors
Age and drugs	Older age, anticoagulation, coagulopathy	Moderate to high	Raises imaging and observation threshold
Symptoms	Vomiting, severe headache, seizure, amnesia	Moderate	Useful before CT, less specific after CT
Low-risk lesions	Isolated small SAH, tiny contusion without shift	Moderate	Lower intervention frequency in stable patients

Lessard et al. validated Important Brain Injury criteria among patients with abnormal CT and found 100% sensitivity for neurosurgical intervention, although specificity was low and many IBI-positive patients did not require intervention (11). Tourigny et al. identified subdural hemorrhage of at least 4 mm and midline shift as independent predictors, while isolated subarachnoid hemorrhage carried lower risk (12). Yue et al. highlighted ED neuroworsening as a dynamic predictor, linking early neurologic decline to intervention and unfavorable outcome (13). The AAST BIG study showed that all neurosurgical interventions occurred in BIG 3 patients, while BIG 1 and BIG 2 groups avoided intervention in that cohort (14). Orlando et al. demonstrated that maximum

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subdural hematoma thickness and midline shift produced strong discrimination for early intervention in isolated subdural hematoma, with radiologic variables outperforming demographic and clinical variables (15).

Discussion

This review shows that neurosurgical intervention in mild TBI is uncommon in broad emergency cohorts and concentrated in patients with specific CT patterns or neurologic deterioration (1–15). Clinical decision rules remain valuable at the pre-CT stage because they identify patients needing urgent imaging, while post-CT disposition depends more on hemorrhage morphology and neurologic course (1–7,10–15). This distinction explains why symptom-heavy rules show high sensitivity and low specificity, whereas radiology-based models offer stronger discrimination after intracranial injury is confirmed (3–6,11–15).

The most consistent radiologic predictors were subdural hematoma, epidural hematoma, increasing hematoma thickness, midline shift, and displaced skull fracture (8,9,12,15). These findings align with the biological plausibility that mass effect, focal compression, and surgically accessible extra-axial blood increase operative likelihood (8,12,15). In contrast, isolated traumatic subarachnoid hemorrhage appeared lower risk when neurologic examination remained stable and no mass effect existed (8,12).

Clinical predictors still matter because ED decisions often precede imaging interpretation and transfer calls in hospitals without neurosurgical coverage (1,2,6,13). GCS 13–14, delayed normalization to GCS 15, repeated vomiting, signs of skull fracture, coagulopathy, anticoagulant exposure, and age at least 65 years repeatedly appeared in rules and cohort analyses (1,2,6,7,11,13). Early neurologic worsening deserves special attention because it transforms a static risk estimate into an active warning sign during observation (13).

The findings support a two-step emergency approach: first, use sensitive clinical criteria to select patients for CT; second, use CT pattern and serial examination to decide transfer, admission level, neurosurgical consultation, and repeat imaging (1–7,10–15). The ACEP clinical policy favors the Canadian CT Head Rule for decision support in adult minor head injury and recognizes NEXUS Head CT and New Orleans Criteria as alternatives with lower specificity (17). Systematic review evidence also confirms that the Canadian CT Head Rule is the most studied adult decision rule and that outcome definitions influence estimates of diagnostic accuracy (16).

Risk stratification for complicated mild TBI is increasingly moving from universal neurosurgical consultation toward structured low-risk pathways (10,12,14,15,18). The BIG validation data and BIG meta-analysis support the role of tiered categories for reducing unnecessary repeat CT and neurosurgical consultation while preserving sensitivity for intervention (14,18). Strong caution remains necessary in external settings because transfer thresholds, neurosurgical availability, anticoagulant prevalence, scanner access, and observation capacity differ across hospitals (4,5,7,15,17).

This review has limitations related to heterogeneity in inclusion criteria, CT availability, neurosurgical intervention definitions, and study design (3–7,11–15). Several studies used broad proxies such as potential neurosurgical lesion or acute critical care intervention rather than operative intervention alone (5,10). Many cohorts focused on patients who already underwent CT or had abnormal CT, which inflates intervention prevalence compared with all ED mild TBI presentations (5,8,10–15).

Conclusion

Neurosurgical intervention after mild TBI is infrequent overall, although risk rises sharply with subdural hematoma, epidural hematoma, midline shift, larger hemorrhage thickness, skull fracture, lower or worsening GCS, coagulopathy, and older age. Clinical decision rules are most useful for early imaging selection, while CT morphology and serial neurologic assessment provide stronger guidance for neurosurgical consultation, observation, transfer, and admission decisions.

List of Abbreviations

AAST: American Association for the Surgery of Trauma
BIG: Brain Injury Guidelines
CCHR: Canadian CT Head Rule
CHIP: CT in Head Injury Patients rule
CI: Confidence interval
CT: Computed tomography
ED: Emergency department
EDH: Epidural hematoma
GCS: Glasgow Coma Scale
IBI: Important Brain Injury
ICH: Intracranial hemorrhage
ICU: Intensive care unit
mTBI: Mild TBI
NEXUS: National Emergency X-Radiography Utilization Study
NICE: National Institute for Health and Care Excellence
NOC: New Orleans Criteria
NSI: Neurosurgical intervention
NTDB: National Trauma Data Bank
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SAH: Subarachnoid hemorrhage
SDH: Subdural hematoma
TBI: TBI

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