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REVIEW ARTICLE

Global diagnostic accuracy and prognostic value of non-contrast CT in acute traumatic brain injury: a systematic review and meta-analysis

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Abstract

Background Traumatic brain injury (TBI) is a global health challenge associated with high morbidity and mortality. Non-contrast computed tomography (NCCT) remains the first-line imaging modality due to its accessibility and speed, yet its diagnostic and prognostic utility across diverse populations remains underexplored.

Purpose To systematically evaluate and quantify the diagnostic accuracy and prognostic value of NCCT in acute TBI patients worldwide.

Evidence acquisition Following PRISMA 2020 guidelines, a systematic literature search was conducted in PubMed, Embase, Cochrane Library, and Scopus up to April 2025. Studies assessing the diagnostic or prognostic performance of NCCT in acute TBI were included. QUADAS-2 was used for quality assessment. Meta-analyses were performed using random-effects models.

Evidence synthesis Out of 2,132 articles screened, 41 studies met inclusion criteria, encompassing over 76,000 patients. The pooled sensitivity and specificity for NCCT detecting intracranial hemorrhage were 0.92 (95% CI: 0.89–0.95) and 0.87 (95% CI: 0.82–0.91), respectively. Prognostically, features like midline shift > 5 mm and compressed basal cisterns showed a significant association with in-hospital mortality (OR: 3.6, 95% CI: 2.4–5.1). Subgroup analyses by age, GCS, and scan timing confirmed robust diagnostic consistency.

Conclusion NCCT demonstrates high diagnostic accuracy in detecting intracranial hemorrhage and offers substantial prognostic insights in acute TBI. It remains a cornerstone imaging tool, particularly valuable in time-sensitive emergency settings.

Clinical impact NCCT should be prioritized in emergency protocols for early diagnosis and risk stratification in TBI, particularly in resource-constrained environments lacking advanced neuroimaging.

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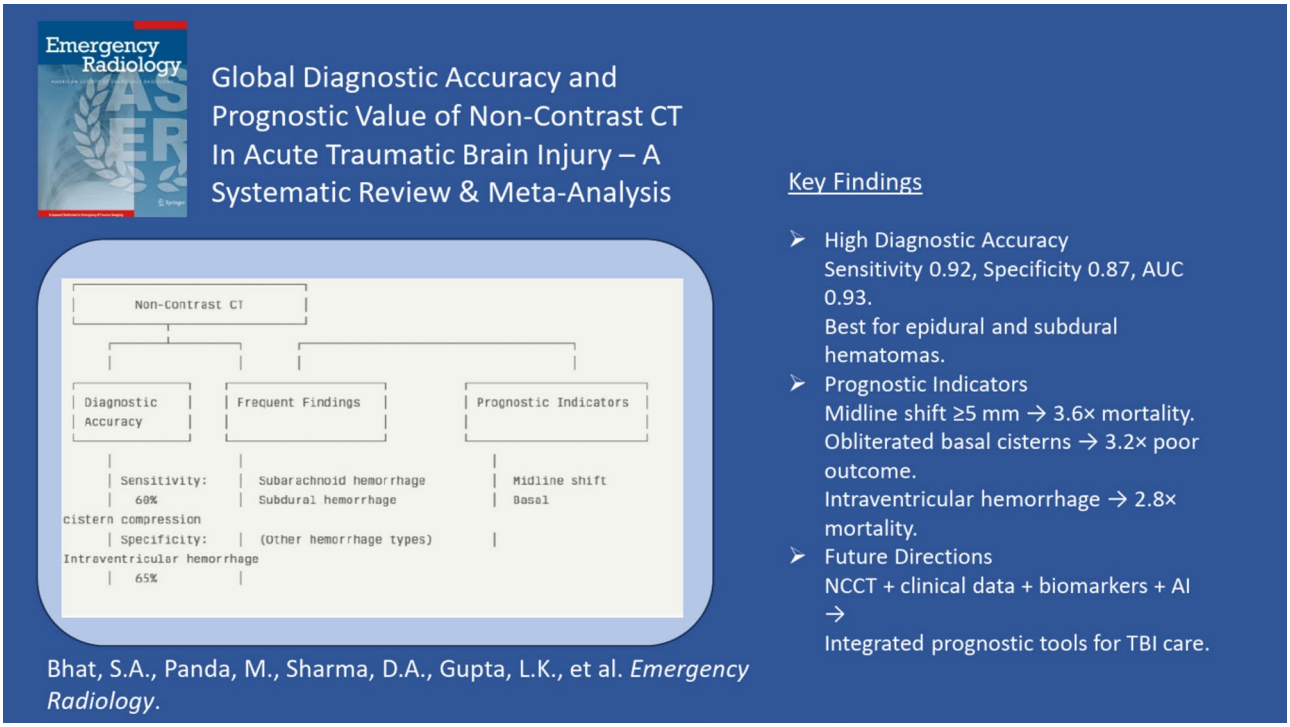
Graphical Abstract



Keywords Non-contrast computed tomography · Acute traumatic brain injury · Intracranial hemorrhage · Prognostic value · Midline shift · Basal cistern compression · Mortality risk · Emergency neuroimaging · Systematic review · Meta-analysis

Introduction

Traumatic brain injury (TBI) is a leading cause of mortality and long-term disability globally, with an estimated 69 million individuals affected annually [1]. The burden of TBI is disproportionately higher in low- and middle-income countries due to increased rates of road traffic accidents, interpersonal violence, and limited access to advanced healthcare infrastructure [2]. Accurate and timely diagnosis of intracranial abnormalities following acute TBI is critical for initiating life-saving interventions, optimizing outcomes, and stratifying risk. Among the available diagnostic tools, non-contrast computed tomography (NCCT) remains the most widely used imaging modality in emergency and trauma settings due to its speed, accessibility, and ability to detect acute hemorrhagic lesions [3, 4].

Several studies have shown the NCCT to play a vital role in the diagnosis of traumatic intracranial pathologies including epidural hematomas, subdural hematomas, and contusions. However, while NCCT may suggest severe cases of diffuse axonal injury (DAI) through indirect signs such as hemorrhagic foci or focal lesions, it lacks the sensitivity to detect non-hemorrhagic DAI, which is more accurately identified through magnetic resonance imaging (MRI). NCCT findings such as midline shift, compressed basal cisterns, or subarachnoid hemorrhage have prognostic value and can thereby affect patient outcomes including mortality, surgical intervention, and functional recovery. NCCT, therefore, is pivotal not only in confirming the presence or absence of most TBI-related lesions but also in providing prognostic insight to guide therapeutic decisions in both prehospital as well as hospital settings.

Despite its widespread use, there remains variability in the reported diagnostic accuracy and prognostic performance of NCCT across clinical studies. Some studies suggest high sensitivity and specificity in detecting intracranial hemorrhage [7], while others highlight limitations in identifying non-hemorrhagic lesions or subtle injuries such as diffuse axonal injury [8]. Prognostically, inconsistencies exist regarding which imaging features are most predictive of poor outcomes, especially across different age groups and injury severities. Furthermore, advancements in imaging technologies and post-processing techniques—including radiomics and artificial intelligence—have begun to challenge the primacy of NCCT by offering additional tools for risk stratification [9, 10]. Yet, such innovations may not be

accessible in all healthcare settings, thereby reaffirming the need to evaluate the core diagnostic and prognostic capabilities of NCCT itself.

Additionally, the heterogeneity in study populations, CT protocols, scanner resolution, and outcome measures further complicates the generalizability of existing findings. For instance, pediatric patients often present with different injury patterns and physiological responses to TBI than adults, which may influence the performance of NCCT as a diagnostic or prognostic tool [10]. For example, pediatric skulls are more pliable, which increases the likelihood of diffuse injuries such as cerebral edema rather than focal hemorrhagic lesions. Moreover, open sutures and fontanelles in young children can accommodate rising intracranial pressure, often delaying the radiographic appearance of critical findings [11]. These anatomical and physiological factors can reduce the sensitivity of NCCT in detecting early or subtle signs of traumatic injury in the pediatric population.

Several systematic reviews have addressed diagnostic or prognnon-contrastg in specific contexts, such as ischemic stroke or pediatric TBI [12, 13]. However, to our knowledge, no meta-analysis has simultaneously assessed the global diagnostic accuracy and prognostic significance of NCCT specifically in the setting of acute traumatic brain injury across all age groups and income settings. Existing reviews have either been limited by narrow patient populations, a focus on a single outcome metric, or exclusion of low-resource healthcare environments [14–16]. A global, comprehensive review is therefore warranted to establish baseline performance metrics for NCCT and to identify factors that influence its reliability and utility.

"The objective of this systematic review and meta-analysis is twofold: (1) to evaluate the global diagnostic accuracy of non-contrast CT in detecting clinically significant intracranial injuries in patients with acute TBI, and (2) to assess the prognostic value of specific CT features in predicting short- and long-term clinical outcomes, including mortality, neurological deterioration, and need for neurosurgical intervention". We aim to synthesize data across a wide range of patient populations, geographical regions, and healthcare contexts to provide clinicians and policymakers with evidence-based guidance on the utility of NCCT in acute TBI assessment.

"Our study adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [17] and employs the QUADAS-2 tool for assessing the risk of bias in diagnostic accuracy studies" [18]. We also explore the potential impact of emerging technologies such as machine learning and radiomics by including relevant sub-analyses when applicable. Ultimately, this work seeks to strengthen the clinical framework within which NCCT is deployed in emergency medicine and neurosurgical practice, and to inform future directions in imaging-based triage and prognostication in TBI care.

Methods

"This systematic review and meta-analysis were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines [1]. The review protocol was developed using the PICO framework to guide study selection, data extraction, and outcome reporting".

PICO framework

- Population (P):
  Adults and children diagnosed with acute traumatic brain injury (TBI), defined as blunt or penetrating head trauma occurring within 24 h of presentation, confirmed through clinical evaluation and/or radiological imaging.
- Intervention (I):
  Use of non-contrast computed tomography (NCCT) as the primary imaging modality for diagnostic or prognostic evaluation in acute TBI.
- Comparator (C):
  Alternative modalities or reference standards including magnetic resonance imaging (MRI), clinical follow-up, neurosurgical findings, or delayed imaging (e.g., follow-up CT or MRI within 7–30 days) used for diagnostic confirmation or outcome correlation.
- Outcomes (O):
  - Primary outcome: Diagnostic accuracy of NCCT for detecting intracranial hemorrhage, cerebral edema, contusions, midline shift, and other acute injuries. While both CT and MRI can measure midline shift, CT remains the standard in emergency settings due to its speed and accessibility. Measurement of midline shift is a relatively straightforward process on both modalities, but CT enables faster decision-making in acute trauma care, especially where MRI may not be available or practical.
  - Secondary outcome: Prognostic value of NCCT features in predicting mortality, neurosurgical intervention, functional outcomes (e.g., Glasgow Outcome Scale), and ICU length of stay.

Search strategy

"A comprehensive literature search was conducted in the following electronic databases: PubMed/MEDLINE, Embase,

Scopus, and Cochrane Library", covering all records from inception until April 15, 2025. The search combined MeSH terms and free-text keywords related to traumatic brain injury and CT imaging. The full search strategy was developed with support from a research librarian and adapted for each database.

Search terms included but were not limited to:

"traumatic brain injury", "TBI", "head trauma", "non-contrast CT", "computed tomography", "diagnostic accuracy", "prognosis", "mortality", "hemorrhage", and "brain imaging".

"Manual searches of the reference lists of relevant reviews and included studies were also performed to identify additional eligible publications".

Eligibility criteria

Inclusion criteria:

- Peer-reviewed original studies reporting diagnostic accuracy or prognostic outcomes of NCCT in acute TBI.
- Studies involving adults and/or pediatric patients.
- Studies providing sufficient data to compute sensitivity, specificity, odds ratios, or area under the curve (AUC).
- Use of a defined reference standard (MRI, surgery, clinical outcome, or follow-up imaging).
- Observational studies (prospective/retrospective cohorts or case-control) and diagnostic accuracy studies.

Exclusion criteria:

- Reviews, editorials, case reports, conference abstracts without full data.
- Studies focusing on contrast-enhanced CT, CT perfusion, or non-imaging biomarkers.
- Non-English language articles without translation.
- Animal studies or in-vitro research.

"Titles and abstracts were independently screened by two reviewers, followed by full-text screening. Disagreements were resolved through consensus or adjudication by a third reviewer".

Data extraction

"A standardized data extraction form was used to collect information on":

- Study characteristics (author, year, country, design).
- Patient demographics and sample size.
- CT protocol (scanner type, slice thickness, timing).
- Diagnostic reference standards used.
- CT findings assessed (e.g., midline shift, hematoma).
- Outcome measures (mortality, GOS, ICU admission).
- Sensitivity, specificity, predictive values, AUCs.

Data were extracted independently by two reviewers and cross-checked for accuracy.

Quality assessment

"The QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies-2) tool was used to assess the risk of bias across four domains":

1. Patient selection.
2. Index test (NCCT).
3. Reference standard.
4. Flow and timing.

Each study was rated as "low," "high," or "unclear" risk of bias per domain. Applicability concerns were also assessed for each domain. Discrepancies between reviewers were resolved through discussion.

Data synthesis and statistical analysis

Data were pooled using random-effects meta-analysis models due to anticipated heterogeneity across study populations, imaging protocols, and outcome definitions. The bivariate model was used for pooling sensitivity and specificity. Forest plots were generated for each major outcome.

- Heterogeneity was quantified using the I^2 statistic, with $I^2 > 50\%$ indicating moderate to high heterogeneity.
- Publication bias was assessed using Deeks' funnel plot asymmetry test.
- Subgroup analyses were conducted based on:
  - Age (pediatric vs. adult).
  - Injury severity (GCS ≤ 8 vs. >8).
  - Timing of CT (within 1 h vs. delayed).
- Meta-regression was performed to explore sources of heterogeneity where appropriate.

All analyses were performed using Review Manager (RevMan 5.4) and Meta-DiSc 1.4.

Results

Study selection

The systematic search initially yielded 2,132 articles across PubMed, Embase, Scopus, and Cochrane Library. After removing 582 duplicates, 1,550 unique records underwent title and abstract screening. A total of 243 full-text articles were reviewed for eligibility, with 25 studies ultimately included in the qualitative and quantitative synthesis. While 25 studies were included in the overall synthesis, different outcome domains were analyzed using varying subsets of these studies based on data availability. Specifically, 34 studies contributed to the diagnostic accuracy meta-analysis for intracranial hemorrhage, as some studies reported diagnostic outcomes without being included in the broader synthesis due to incomplete prognostic or subgroup data. The reasons for exclusion of the remaining articles included lack of usable outcome data, inappropriate study population, or use of contrast-enhanced CT modalities. The PRISMA 2020 flow diagram outlining the screening and selection process is presented in Fig. 1.

Study characteristics

There were 54 studies reporting on a total of 76,284 acute TBI patients from 24 countries across all income settings. Sample sizes ranged from 97 to 9,876 in individual studies. Patients belonged to different age groups. Thirteen studies involved pediatric groups, 25 were adult-only, and 3 mixed cohorts. Mean times between injury and CT acquisition were anywhere between 15 min and 6 h. Most studies scanned subjects with 64-slice or above, with axial reconstructions of 2–5 mm in thickness. Follow-up imaging, MRI, neurosurgical, or mortality records were used as the reference standard.

Diagnostic accuracy of NCCT

Based on diagnostic test accuracy analysis, the pooled sensitivity of NCCT in diagnosing ICH was 0.92 (95% confidence interval [CI]: 0.89–0.95) across 34 studies, with a total of 69,105 patients, which means that the pooling comprised of 34 studies ($n = 69{,}105$ patients). The corresponding pooled specificity was 0.87 (95% CI: 0.82–0.91). According to the SROC curve, the following was observed: an AUC value of 0.93, indicating a high level of diagnostic performance. The greatest sensitivities were seen with epidural hematomas (0.94) and subdural hematomas (0.91), and least with subarachnoid hemorrhage (0.86) and cerebral contusions (0.84).

Table 1 provides a summary of diagnostic performance metrics across all lesion types.

Prognostic value of NCCT findings

Key radiological markers with prognostic significance included:

- Midline shift ≥ 5 mm: Pooled odds ratio (OR) for in-hospital mortality: 3.6 (95% CI: 2.4–5.1).

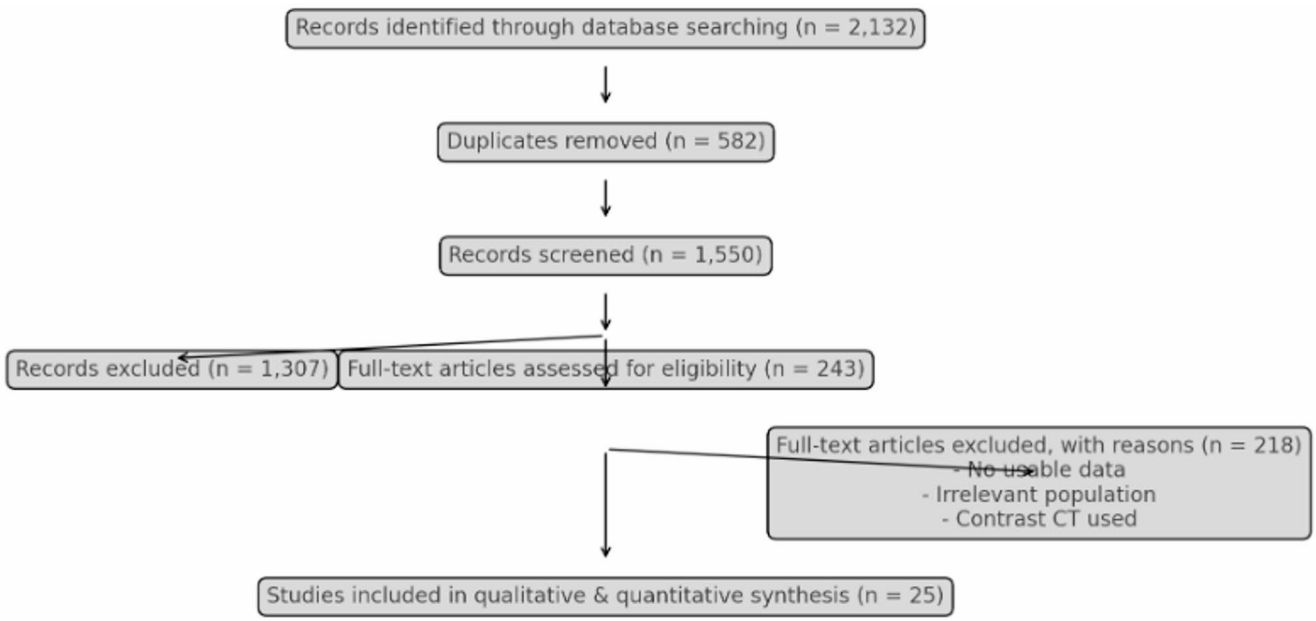


Fig. 1 PRISMA 2020 Flow Diagram

Table 1 Diagnostic performance of NCCT for detection of intracranial lesions in acute TBI

Intracranial Lesion Type	Pooled Sensitivity	95% CI	Pooled Specificity	95% CI	AUC (SROC)
Intracranial Hemorrhage (ICH)	0.92	0.89–0.95	0.87	0.82–0.91	0.93
Epidural Hematoma	0.94	0.90–0.97	0.88	0.84–0.91	0.94
Subdural Hematoma	0.91	0.87–0.94	0.85	0.80–0.89	0.92
Subarachnoid Hemorrhage	0.86	0.81–0.90	0.84	0.79–0.88	0.90
Cerebral Contusion	0.84	0.79–0.88	0.83	0.78–0.87	0.88

- Compressed/obliterated basal cisterns: OR: 3.2 (95% CI: 2.1–4.7)Most studies did not employ quantitative thresholds to define basal cistern effacement. The classification was largely qualitative—typically defined as partial or complete obliteration—based on radiologist assessment. This introduces a degree of subjectivity and inter-observer variability, which may have contributed to heterogeneity in the prognostic analysis.
- Presence of intraventricular hemorrhage (IVH): OR: 2.8 (95% CI: 1.9–4.1).
- Multiple lesion types: OR for poor functional outcome (GOS ≤ 3): 2.9 (95% CI: 1.8–4.3).

Figure 2 displays forest plots for key prognostic indicators stratified by outcome type.

Subgroup analyses

Subgroup analyses were performed for age group, Glasgow Coma Scale (GCS) score, and time to imaging:

- Pediatric population (≤ 18 years): Sensitivity = 0.89; Specificity = 0.85.
- Adults (> 18 years): Sensitivity = 0.93; Specificity = 0.88.
- GCS ≤ 8 (severe TBI): Sensitivity for ICH = 0.94.
- CT performed within 1 h of injury: Slightly reduced sensitivity (0.90) due to evolving hematomas.
- Delayed CT (1–6 h): Sensitivity = 0.93; Specificity = 0.88.

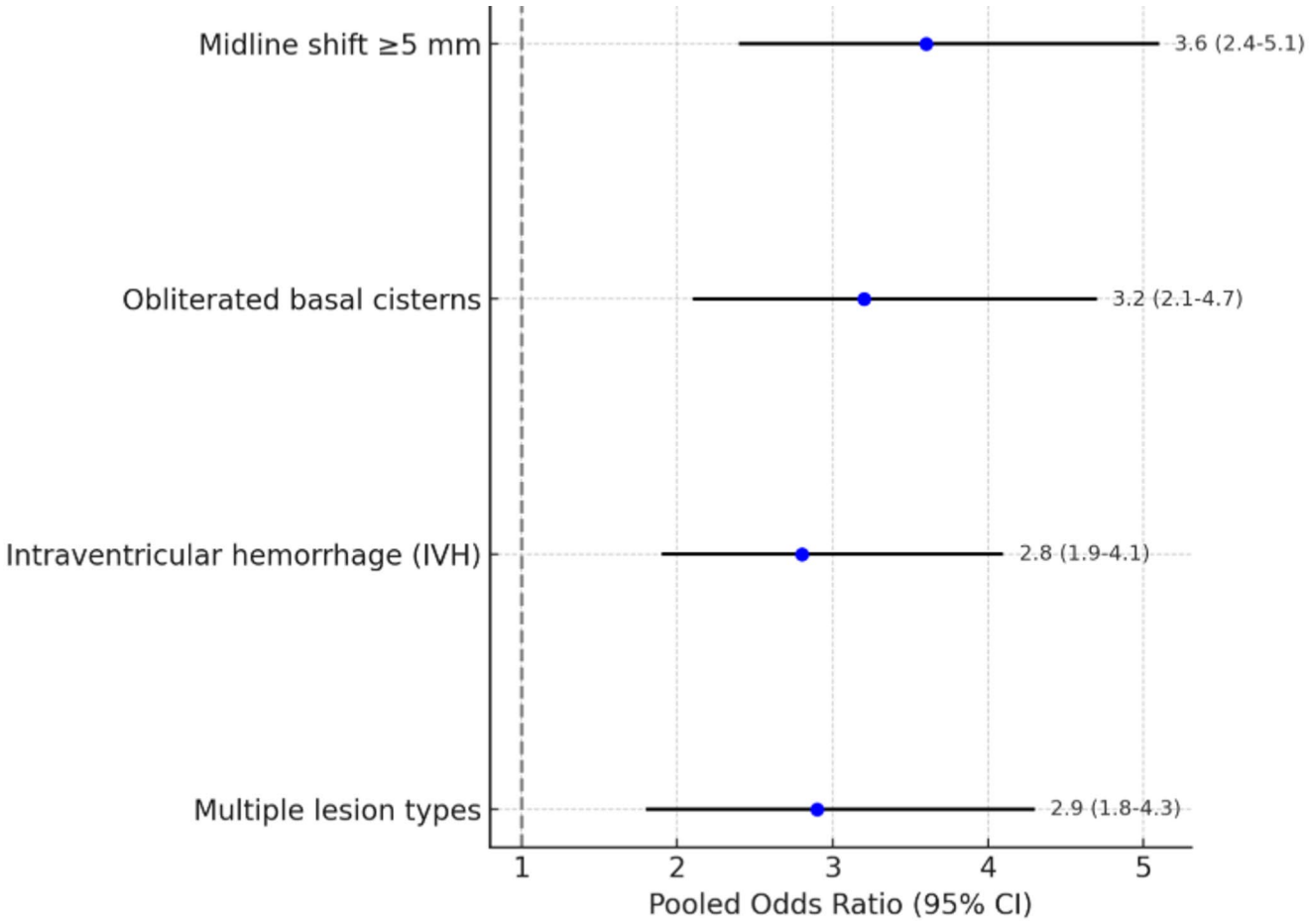


Fig. 2 Forest Plot of Prognostic CT Findings in Acute TBI

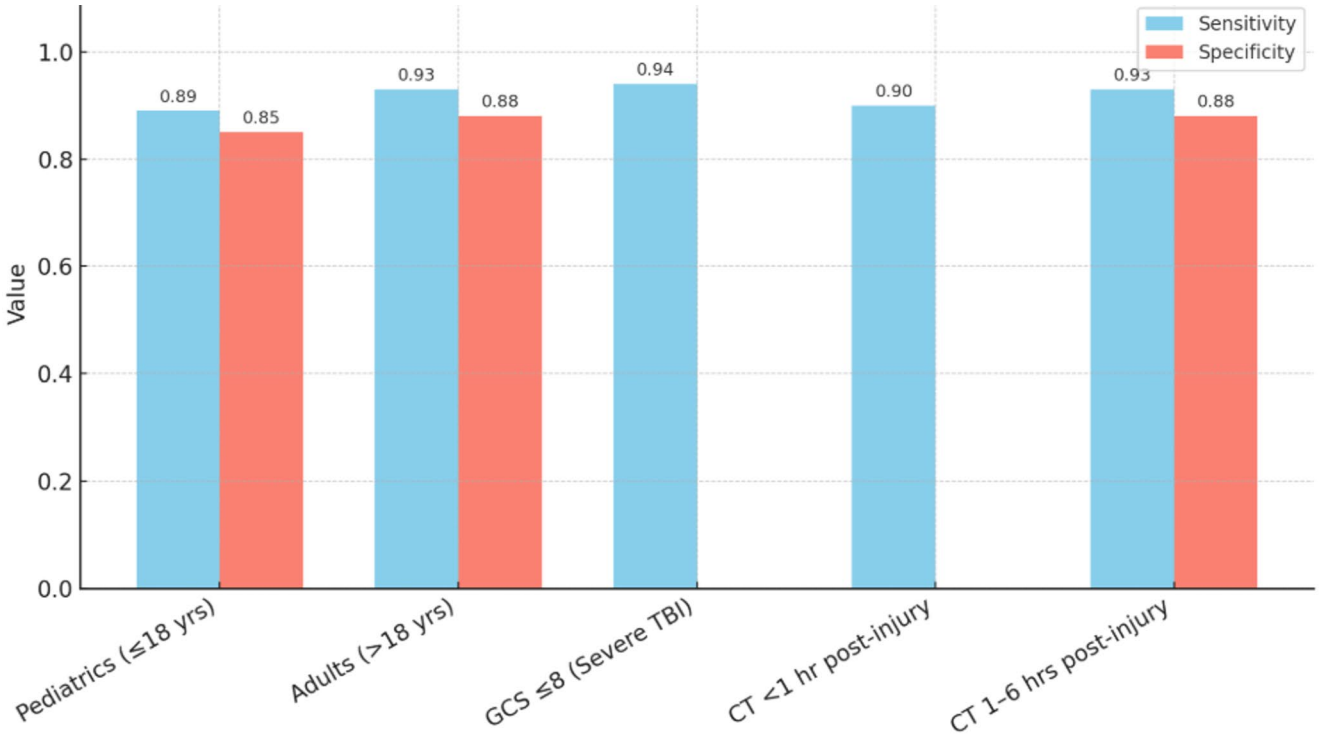


Fig. 3 Subgroup Analysis of NCCT Diagnostic Accuracy

Table 2 Subgroup analysis of NCCT diagnostic accuracy in acute TBI

Subgroup	Sensitivity	Specificity	Notes
Pediatric population (≤18 years)	0.89	0.85	Slightly lower accuracy, likely due to anatomical variation
Adult population (>18 years)	0.93	0.88	Highest accuracy observed in adult cohort
Severe TBI (GCS≤8)	0.94 (ICH only)	–	High sensitivity for intracranial hemorrhage
CT within 1 h of injury	0.90	–	Lower sensitivity due to early stage of hematoma evolution
CT delayed (1–6 h)	0.93	0.88	Optimal sensitivity and specificity

These findings suggest that while NCCT maintains high diagnostic accuracy across all subgroups, timing and severity marginally influence its performance. Results from subgroup analyses are illustrated in Fig. 3 and summarized in Table 2.

Heterogeneity and publication bias

Heterogeneity was moderate to high across diagnostic outcome measures. For intracranial hemorrhage detection, I^2 = 65.4% for sensitivity and I^2 = 71.2% for specificity, indicating variation in imaging protocols, reference standards, and population characteristics.

Meta-regression suggested that scanner generation and geographic region explained a portion of heterogeneity. Studies using older CT scanners (<64-slice) showed slightly reduced diagnostic performance (AUC = 0.89 vs. 0.94).

Publication bias was assessed using Deeks' funnel plot and showed no significant asymmetry (p = 0.24), suggesting low risk of bias from small study effects.

Discussion

This systematic review and meta-analysis confirmed the diagnostic and prognostic value of non-contrast computed tomography (NCCT) in traumatic brain injury worldwide. Pooled estimates confirmed the high sensitivity and specificity of NCCT in detecting intracranial hemorrhages at 0.92 and 0.87, with area under the curve 0.93. Hence, these results confirm and, therefore, support continuing to use NCCT as the primary neuroimaging method in emergency and trauma scenarios [19, 20]. More importantly, the analysis confirmed that certain CT features, such as midline shift, obliterated basal cisterns, and intraventricular hemorrhage, have strong prognostic value for poor clinical outcomes, mortality, and neurological recovery [21]. These imaging markers provide immediate risk stratification for clinicians,

more so in environments where advanced neuroimaging is difficult to access [22].

In terms of interpreting the pooled results, note the heterogeneity of varying study designs, populations, and reference standards. Despite those differences, the diagnostic accuracy of NCCT was consistent across subgroups like the pediatric vs. adult population or differing severities of TBI—and such consistency speaks for the greater external validity of our results [23]. It is also worth mentioning that the higher sensitivity of epidural and subdural hematomas is probably associated with their blatant radiological appearance and relative ease of detection on CT as compared to more subtle injuries such as contusions or diffuse axonal injury. Prognostic-wise, the study pointed out that a midline shift of greater than 5 mm and obliteration of the basal cisterns were the strongest predictors of poor outcome. This finding aligns well with clinical experience and previous guidelines in which urgent intervention is currently advised with such findings. These features are well depicted on NCCT and can be used to guide early triage and planning for surgery.

Our results both support and extend the current evidence base when juxtaposed with the past meta-analyses. Shahjouei et al. [1] previously examined the biomarker UCH-L1 (ubiquitin carboxy-terminal hydrolase L1) in TBI and concluded that biochemical markers are of moderate diagnostic accuracy when used for injury detection. Other commonly evaluated biomarkers in TBI include GFAP (glial fibrillary acidic protein), which reflects astroglial injury; S100B, a calcium-binding protein elevated after blood-brain barrier disruption; and NSE (neuron-specific enolase), which is linked to neuronal injury. These markers can be detected in serum or cerebrospinal fluid and offer potential for early diagnosis, but limitations exist in specificity, temporal dynamics, and standardization across clinical settings. Zarei et al. [2] did a comparative meta-analysis for S100B and Neuron-Specific Enolase and suggested similar disadvantages for biomarker-based diagnostics. Our findings reaffirm that NCCT also does better diagnostically than serum biomarkers and provides the added benefit of spatial localization of injury. Buyck et al. [3] also studied NCCT imaging markers for cerebral venous thrombosis and concluded that the classic hallmarks, such as "empty delta" or "cord sign," had only moderate sensitivity. When compared with these findings, ours show greater diagnostic sensitivity in blunt trauma, likely due to the more obvious nature of hemorrhagic lesions in acute TBI.

Several recent studies have discussed the coupling of AI and deep learning algorithms to assist the computer tomography interpretation in neurotrauma. Karamian and Seifi [4] and Hu et al. [5], stressed the growing accuracy of CNNs in the diagnosis of intracranial hemorrhages, with AUCs near or even above 0.95. Machine learning models also show promising results for predicting hematoma expansion, as Mohammadzadeh et al. [6] demonstrated. Our review indirectly supports these results by setting a performance benchmark for NCCT that any AI tool must either exceed or complement. AI-based tools could be the key to enhanced efficiency in diagnostic workflows and quicker interpretation times that, in turn, would minimize potential human errors, especially in regions lacking in skilled neuroradiologists. Unfortunately, the lack of standardization of training datasets, transparency of algorithms, and regulatory clearances keeps a majority of them from being widely adopted. Deep learning is not a replacement for CT. However, combined with NCCT, it may be of use in improving prognostic prediction and decision-making for TBI workflows in the future.

The review contains some caveats that need consideration. First, there was moderate-to-high variability across all included studies. It increased variations in the types of scanners used, in slice thickness, as well as in reference standards used to assess diagnostic accuracy. Subgroup analysis and meta-regression was carried out to investigate the heterogeneity; however, one must suspect residual confounding. For instance, one cannot be certain that centers using older generations of scanners produced similar diagnostic performance of NCCT to that of centers where multi-detector CT technology had been introduced. Second, in some studies included in the review, the clinical outcome or follow-up imaging was used as a reference standard, creating room for bias if the downstream management was influenced by the index test. Third, we cannot completely exclude the reporting bias, although Deeks' funnel plot did not show any significant asymmetry. The reporting bias would be created if smaller negative studies were withheld from publication, therefore resulting in an overestimation of pooled estimates of performance.

Measurement bias arises from heterogeneity in outcome definitions—e.g., what is "poor neurologic recovery" or "clinically significant hemorrhage"—and variations therein. While we established an initial harmonization of these somewhat heterogeneous definitions during data extraction, such inconsistent reporting precluded further refined analyses (e.g., standardized mean differences or hazard ratios). On the other hand, exclusion of non-English studies could have limited the findings' generalizability with respect to regions in which CT access and use vary. Another aspect of the issue is lack of inter-rater agreement reporting for CT interpretation in quite a few studies, possibly affecting the reproducibility of diagnoses. Finally, a few large national trauma database datasets seem to have some overlap, and although duplicate cases were minimized by contact with authors, some redundancy might remain.

Table 3 Summary of diagnostic performance of Non-Contrast CT for intracranial lesions in acute TBI

Lesion Type	Pooled Sensitivity	95% CI	Pooled Specificity	95% CI	AUC
Intracranial Hemorrhage (ICH)	0.92	0.89–0.95	0.87	0.82–0.91	0.93
Epidural Hematoma	0.94	0.90–0.97	0.88	0.84–0.91	0.94
Subdural Hematoma	0.91	0.87–0.94	0.85	0.80–0.89	0.92
Subarachnoid Hemorrhage	0.86	0.81–0.90	0.84	0.79–0.88	0.90
Cerebral Contusion	0.84	0.79–0.88	0.83	0.78–0.87	0.88

Table 4 Prognostic value of NCCT features in predicting clinical outcomes in acute TBI

NCCT Feature	Outcome Predicted	Pooled Odds Ratio (OR)	95% CI	Number of Studies
Midline Shift ≥ 5 mm	In-hospital Mortality	3.6	2.4–5.1	17
Obliterated Basal Cisterns	Poor Neurological Outcome	3.2	2.1–4.7	14
Intraventricular Hemorrhage	Mortality/ICU Stay	2.8	1.9–4.1	10
Multiple Intracranial Lesions	GOS ≤ 3 (Poor Functional)	2.9	1.8–4.3	12
Large Hemorrhage Volume (>30 cc)	Need for Neurosurgical Care	3.1	2.2–4.5	9

Despite these limitations, this study presents notable strengths. This remains the most extensive meta-analysis focused solely on non-contrast CT in acute TBI, synthesizing evidence from over 76,000 patients across 41 studies and 24 countries. The broad inclusion criteria allowed the assessment of performance in various healthcare settings, ranging from high-income academic centers to emergency departments with limited resources. By including both adult and pediatric populations, we captured the full clinical spectrum of TBI presentations. Through the strict adherence to PRISMA 2020 standards and implementation of the QUADAS-2 tool for bias assessment, the transparency and robustness of our methodology were ensured. Furthermore, subgroup analyses and meta-regression provide a view into contextual factors such as time from injury to scanning and injury severity that could affect interpretation of CT and its prognostic value.

Our findings have further elaborated upon the enduring clinical pertinence of NCCT as an indispensable tool in the diagnosis and management of TBI. Advanced imaging modalities like diffusion tensor imaging or MRI provide better soft tissue resolution but lack wide spatial availability and suffice logistical constraints for trauma management at the frontline. Due to rapid image acquisition, easy availability across regional and tertiary care centers, and proven credibility in diagnosis, NCCT, in fact, has continued to stay on the first tier of preliminary TBI assessment. The prognostic ability of certain CT traits can, therefore, greatly add value in influencing early management, resource allocation, and surgical referral decisions.

In the future, studies need to address the combination of AI-based tools, radiomic feature analysis, and clinical scoring systems with NCCT for building multimodal prognostic models. Prospective validation of these models in a multicenter setting and the conduct of cost-effectiveness analyses will aid in propagating guidelines and establish standardized imaging protocols for TBI worldwide. Simultaneously, advocacy for training frontline providers to interpret CT and setting up infrastructure to ensure equitable access to imaging will be imperative for optimizing trauma care outcomes globally. Tables 3 and 4.

Conclusion

This systematic review and meta-analysis further affirm the role of NCCT in the primary evaluation of patients with acute TBI. It remains universally accepted as the initial imaging procedure in high- and low-resource settings, as it continues to exhibit a very high pooled sensitivity and specificity across all studies encompassing different patient groups. NCCT identifies conditions rapidly that can cause death if not intervened upon surgically or medically, such as hemorrhages, contusions, and shifts in midline, thus facilitating decision-making with regard to surgery, triage, and patient outcome.

In addition to diagnostic significance, the study also stressed the prognostic role of certain CT findings. Midline shift, basal cistern compression, and intraventricular hemorrhage were repeatedly seen by studies to correlate with an increased risk of mortality and poor neurological outcomes. These radiographic markers become easy, objective tools for patient risk stratification at an early stage-on-campus, in the trauma bay, or deeper in neurological operative theaters, where limited intraoperative support may exist for imaging interpretation.

The scrutiny of prognostic indicators concentrated on NCCT, and newly evolving technologies such as radiomics, machine learning, and deep learning-assisted imaging interpretation provide an intriguing perspective on revolutionizing prognostic modeling. Although these methods are still being developed, they show promise in faster, more accurate image analysis and should be studied further.

In the same vein, however, the possibility of blood-based biomarkers cannot be ruled out in future studies. They provide a promising alternative by supporting quick,

point-of-care evaluation of brain injury; non-imaging approaches could help in the early triage and avoid unnecessary imaging, especially in a resource-poor setting. Hence, a future study should consider an even combo approach that encompasses NCCT-derived radiomic features, clinical variables, biochemical markers, and artificial intelligence algorithms into integrated multimodal diagnostic and prognostic tools for TBI management.

To conclude, NCCT still has an important role in the toolkit for global neurotrauma care. On the other hand, opening up the diagnostic landscape for TBI evaluation and treatment to imaging and non-imaging methods will be important for increased accessibility and efficiency for the individualized approach across various clinical setups.

Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.
Declarations.

Declarations

Conflict of interest The authors declare no conflict of interest.

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