Archives of Academic Emergency Medicine. 2026; 14(1): e13

OPEN ACCESS

REVIEW ARTICLE

Diagnostic Accuracy of Ultrasonography for Identification of Skull Fracture in Children: A Systematic Review and Meta-analysis

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Received: January 2026; Accepted: February 2026; Published online: 24 April 2026

Abstract: **Introduction:** There is no consensus on the diagnostic performance of ultrasonography for identifying skull fractures in children, and the accuracy of this imaging modality in this age group has been questioned. This study performed a pooled analysis to explore the diagnostic performance characteristics of ultrasonography in this regard. **Methods:** Three databases, Web of Science, Medline, and Scopus, were systematically searched from their inception through August 2025. Data extraction of diagnostic parameters was performed by two independent authors. Pooled estimates of the diagnostic parameters were calculated using Meta-Disc software and the MIDAS package of Stata. **Results:** The estimated sensitivity of ultrasonography for detecting skull fracture in children was 0.89 (95% confidence interval (CI): 0.86–0.92), and the specificity was 0.97 (95% CI: 0.96–0.98). The estimated positive likelihood ratio (PLR) was 23.21 (95% CI: 14.84–36.32), while the negative likelihood ratio (NLR) was 0.13 (95% CI: 0.09–0.20). The diagnostic odds ratio (DOR) was 208.89 (95% CI: 112.68–387.27), and the estimated overall diagnostic accuracy of ultrasonography was 0.96. **Conclusion:** Ultrasonography demonstrated high diagnostic accuracy for identifying skull fractures in children, with evidence indicating stronger performance for confirmation than for exclusion. However, the high risk of bias in patient selection across the studies limits the generalizability of the evidence, and the results should therefore be interpreted with appropriate caution.

Keywords: Meta-analysis; Pediatrics; Skull fractures; Systematic review; Tomography, X-Ray Computed; Ultrasonography

Cite this article as: Soltani Motlagh R, Zare Lahijan L, Farrokhi M, et al. Diagnostic Accuracy of Ultrasonography for Identification of Skull Fracture in Children: A Systematic Review and Meta-analysis. Arch Acad Emerg Med. 2026; 14(1): e13. https://doi.org/10.22037/aaem.v14i1.2951.

1. Introduction

Head trauma is known as one of the most prevalent causes of infant admissions to emergency departments, which commonly recover with minor symptoms and no major negative outcomes (1, 2). Skull fracture (SF) and intracranial hemorrhage (ICH), as two main types of traumatic brain injury (TBI), have been reported in 3–10 percent of infantile cases with minor blunt trauma to the head (1). Early diagnosis and management of skull fracture as a main cause of death and morbidity in children is essential. TBI with annual incidence of 15 per 100,000 to 450 per 10,000 is considered as one of the most important cause of pediatric mortality and disability (3, 4).

The imaging modality of choice for diagnosing skull fractures

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in emergency departments is computed tomography (CT), which is an X-ray–based technique (5). However, diagnosing skull fractures in children is associated with increased exposure to ionizing radiation, a known risk factor for malignancy, as well as higher costs and the need for sedation (6). To reduce exposure to ionizing radiation, many emergency medicine specialists follow clinical guidelines or use imaging techniques without ionizing radiation, such as magnetic resonance imaging (MRI) and ultrasonography (1). Among MRI and ultrasonography, ultrasonography is suggested due to its widespread availability, operational simplicity, and rapid application in emergency settings (7).

Ultrasonography can serve as an auxiliary evaluation method to CT scanning in emergency departments, offering non-ionizing radiation, rapid and reproducible assessment, and promising results for the diagnosis of intracranial injuries when performed by skilled practitioners (8). While previous studies have attempted to reduce the rate of CT scanning in pediatric head injuries by identifying traumatic brain injury (TBI) through ultrasonography, this diagnostic approach is not currently recommended in international guidelines (9). Consequently, there is no consensus on the diagnostic performance of ultrasonography for identifying skull fractures in children, and the accuracy of this imaging modality in this age group has been questioned.

Therefore, in this secondary study, we performed pooled analyses to explore the estimates of the screening performance characteristics of ultrasonography for the detection of skull fractures in children.

2. Methods

2.1. Search strategy

To identify published English-language articles on the diagnostic accuracy of ultrasonography for identification of skull fractures, we performed a systematic search of three databases, including Web of Science, Medline, and Scopus, from their inception to August 2025. We used both keywords and MeSH terms related to "ultrasonography," "skull fracture," "children," and "accuracy" to perform an advanced search in PubMed. Combinations of keywords and synonymous terms were also used to conduct advanced searches in Web of Science and Scopus. Details of the search strings, including the combinations of terms using OR and AND operators for each database, are summarized in Appendix 1. We also searched Google Scholar as part of a gray literature search to ensure the inclusion of all eligible publications on the diagnostic performance of ultrasonography for identifying skull fractures.

2.2. Eligibility criteria and study selection

Studies evaluating the performance of ultrasonography to accurately identify and exclude skull fractures were assessed based on the following inclusion criteria: reporting false negatives (FN), false positives (FP), true negatives (TN), and true positives (TP), or providing sufficient information from which these values could be extracted; involving pediatric patients; and being published in the English language. Articles were excluded if they were case reports, case series with fewer than 10 participants, editorials, review articles, preprints, conference papers, or if they lacked adequate data to construct a 2×2 contingency table. Duplicate publications were removed using EndNote software (Version 20). All articles were initially screened by title and abstract. Publications deemed relevant then underwent full-text review based on the predefined criteria for selecting eligible publications. The screening of titles and abstracts, along with the full-text evaluation, was carried out independently by two authors. Any discrepancies were resolved by a third author.

2.3. Data extraction and quality assessment

The baseline variables of the studies were extracted, including the first author's name, year of publication, country of origin, sample size, patient age, and the prevalence of skull fracture. Diagnostic data such as sensitivity, specificity, FN, FP, TN, TP, and the reference (gold) standard used in each study were also collected.

Quality assessment was performed using the Quality Assessment Tool for Diagnostic Accuracy Studies 2 (QUADAS-2). This tool evaluates studies across two main areas: risk of bias and applicability concerns, using a total of seven criteria.

2.4. Statistical analysis

Pooled estimates of the screening performance characteristics of ultrasonography in detection of skull fracture in children (Sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR), area under the receiver operating characteristic (ROC) curve, and total accuracy) were calculated using Meta-Disc software and the MIDAS package in Stata (Version 17). Deeks' test funnel plot was used for publication bias assessment. The I^2 statistic and the Q test were used to quantify heterogeneity, and meta-regression analyses were conducted to explore its potential determinants. Residual-based goodness-of-fit testing, assessment of bivariate normality, and influence and outlier detection analyses were performed using the MIDAS package. The clinical applicability of ultrasonography for diagnosing skull fractures was examined using a Fagan plot. The exclusion and confirmation value of ultrasonography was illustrated using the likelihood ratio scattergram.

3. Results

3.1. Study selection

Through a systematic search of relevant databases to identify original publications evaluating the diagnostic performance of ultrasonography for detecting skull fractures, we initially retrieved 3,556 publications. After deduplication using EndNote software, 2,821 unique records remained. Screening of titles and abstracts reduced this number to 89 publications eligible for full-text assessment. Following the full-text review, 13 articles met eligibility criteria and were incorporated into both the qualitative and quantitative meta-analyses (Figure 1). The United States was the primary setting for most of the included studies. All studies, except for two, used CT scanning as the gold standard. Additional characteristics of the included studies are summarized in Table 1.

3.2. Quality assessment and publication bias

Quality assessment revealed that most had a substantial risk of bias in the patient selection domain, predominantly attributable to inappropriate exclusion criteria and reliance on convenience sampling rather than random or consecutive enrollment. Several studies also demonstrated a high risk of bias in the flow and timing domain, mainly because not all enrolled patients were analyzed or because different reference standards were applied across participants (Table 2). Deeks' funnel plot, along with Deeks' test, demonstrated no evidence of significant publication bias ($p = 0.69$) (Figure 2).

3.3. Meta-analysis

Figure 3 shows the pooled estimated sensitivity (A), specificity (B), positive likelihood ratio (LR) (C), negative LR (D); diagnostic odds ratio (DOR) (E); and accuracy (F); as well as area under the summary ROC (SROC) curve (G) of ultrasonography in detection of skull fracture in children.
A sensitivity of 0.89 (95% CI: 0.86–0.92) and a specificity of 0.97 (95% CI: 0.96–0.98) were estimated through the pooled analyses. The estimated PLR was 23.21 (95% CI: 14.84–36.32), while the NLR was 0.13 (95% CI: 0.09–0.20). The pooled analysis calculated a diagnostic odds ratio (DOR) of 208.89, and the summary ROC curve indicated an area under the curve of 0.97. The estimated overall diagnostic accuracy of ultrasonography was 0.96 (95% CI: 0.93-.097).
A paired forest plot comparing empirical Bayes estimates with the primary sensitivity and specificity values is presented in Figure 4, showing close agreement across most studies. Figure 5 provides the graphical model check. The goodness-of-fit and bivariate normality plots (panels a and b) indicate that the residuals follow the expected theoretical distributions, supporting an adequate model fit and the plausibility of the bivariate normality assumption. The influence analysis (panel c) identifies several studies with higher Cook's distance values, suggesting some influence on the pooled estimates, but not at a level that would compromise model stability. The outlier assessment (panel d) shows that most studies fall within acceptable residual limits, with only one study appearing as a potential outlier. Overall, these diagnostics reinforce the reliability and robustness of the fitted model.
The Fagan nomogram (Figure 4) demonstrates that a positive ultrasonography result increases the pre-test probability of skull fracture in children from 29% to 93%, whereas a negative result lowers it to 4%, underscoring the test's clinical value. The likelihood ratio scattergram (Figure 6) indicates that ultrasonography is primarily suitable for confirming skull fractures rather than excluding them. Finally, the probability-modifying plot (Figure 6) shows that a positive ultrasonography result shifts the curve toward the (0, 1) region, further supporting its appropriateness for confirming skull fractures.

3.4. Heterogeneity assessment and meta-regression

Significant between-study heterogeneity was present for sensitivity, specificity, and NLR ($I^2 > 50\%$ and $p < 0.05$). In contrast, heterogeneity for the PLR and DOR was not significant ($I^2 < 50\%$ and $p > 0.05$). To investigate potential determinants of heterogeneity, a meta-regression analysis was applied using gold standard method, sample size, year of publication, and prevalence of skull fracture as covariates. The analysis identified the prevalence of skull fracture as a significant contributor to heterogeneity in specificity ($p < 0.01$) (Figure 4).

4. Discussion

This meta-analysis investigated accuracy of ultrasonography for diagnosis of skull fractures in children, which demonstrated a pooled sensitivity of 0.89 and a specificity of 0.97. The overall diagnostic accuracy of ultrasonography was estimated at 0.96. The assessment of its clinical applicability suggests that ultrasonography is more applicable for confirming skull fractures than for ruling them out. A positive ultrasonography finding increases the pre-test probability of skull fracture from 29% to 93%, whereas a negative result reduces it to 4%. Overall, ultrasonography shows excellent specificity and accuracy, along with good sensitivity, for identifying skull fractures in pediatric patients.
There is some evidence in the literature proposing that ultrasound may serve as an accurate diagnostic imaging modality for identifying small fractures that cannot be detected by CT scan (10, 11). Since certain small skull fractures may be missed by CT alone, some authors recommend performing both ultrasonography and CT scan when ruling out skull fractures in children. This recommendation is partly contrary to our findings, as we observed a lower sensitivity compared to specificity, and our results indicated that ultrasonography is more applicable for confirming skull fractures rather than ruling them out. The main strength of this imaging method was its PLR, which was higher than 10, while its NLR was not below 0.1. Along with the higher specificity compared to sensitivity, these results suggest a lower rate of false-positive but a higher rate of false-negative, making ultrasonography more appropriate for confirmation of skull fractures rather than exclusion of these cases.
In a similar meta-analysis by Alexandridis et al. (7), a systematic search was conducted in Web of Science, Ovid Medline, Embase, Google Scholar, and Cochrane from inception to 2020 to include publication on the accuracy of ultrasonography for detecting skull fractures in children. They included seven studies and estimated a sensitivity of 91% and a speci-

ficity of 96%. Their estimated sensitivity was higher than the sensitivity we found, while their estimated specificity was lower than the rate observed in our meta-analysis. These differences may be explained, at least in part, by the greater number of studies with varying diagnostic performance included in our analysis (13 versus 7 studies). This larger number in our review may be due to the more updated search and the inclusion of Scopus, which is a major source for articles on this topic. Another possible explanation is the difference in exclusion criteria, as Alexandridis et al. excluded studies that used reference standards other than CT scan.

The study by Gordon et al. (8) is another systematic review and meta-analysis in this area, which was conducted through a systematic search of Web of Science, Embase, and PubMed from 1996 to 2020. On the other hand, we searched Web of Science, PubMed, and Scopus, which shows a difference in the databases used. We searched Scopus, while they included Embase. In their meta-analysis, similar to Alexandridis et al., they estimated a sensitivity of 91% and a specificity of 96% based on six included studies. These two meta-analyses suggest that, up to 2020, the pooled results of original studies supported ultrasonography as a diagnostic imaging modality with high sensitivity and specificity. However, our updated meta-analysis, which includes studies published after 2020, shows reduced sensitivity and a slightly higher specificity for this imaging method. Furthermore, Alexandridis et al. rated most of their included studies as having a high risk of bias for patient selection. This is similar to our quality assessment. In contrast, the meta-analysis by Gordon et al. rated all included studies as having a low risk of bias for patient selection.

Since the sensitivity and specificity of ultrasonography are strongly influenced by the sonographer's level of experience, the lower sensitivity estimated in our meta-analysis may also be related to the experience of the operators in the included studies. In a study by McCormick et al. (12) on infants, traumatic intracranial hemorrhage was diagnosed using ultrasonography. Their findings showed a wide range of sensitivity, from 50% to 100%, depending on the physician who performed the scan. However, the small sample size of that study was an important source of this wide variation in sensitivity and was a major limitation that reduces the generalizability of its results.

By defining ultrasonography as a confirmatory rather than exclusionary modality, this study advances clinical decision making and refines the operational boundaries of point-of-care imaging in pediatric emergency settings. The results provide a directly applicable implication for practice, namely that ultrasonography is best deployed to substantiate a suspected skull fracture when clinical suspicion is high and when rapid bedside confirmation is required. A focused next step is the generation of methodologically rigorous studies that incorporate high-quality patient selection and standardized imaging interpretation to strengthen the external validity of future evidence. A more definitive evidence base will clarify the precise diagnostic contribution of ultrasonography in pediatric trauma care.

5. Limitations

Our study had several limitations. One major limitation was that most of the included publications had a substantial risk of bias for patient selection and some also demonstrated substantial bias related to flow and timing. About half of the studies had small sample sizes with fewer than one hundred patients. There was also considerable variation among the studies in terms of their exclusion criteria. Although we identified the prevalence of skull fracture as a source of heterogeneity for specificity, no other sources of heterogeneity were detected based on the available variables. These limitations may reduce the generalizability of our findings regarding the confirmatory role of ultrasonography in diagnosing skull fractures in children.

Therefore, we suggest that future studies include larger sample sizes, use exclusion criteria that do not limit the generalizability of the sample, rely solely on CT scan as the gold standard, and ensure complete blinding of ultrasonography interpreters to CT results and blinding of CT interpreters to ultrasonography findings. In addition, scans should be performed and interpreted by experienced radiologists. Such improvements would allow for more reliable conclusions regarding the applicability of ultrasonography for diagnosing skull fractures in pediatric patients.

6. Conclusions

Ultrasonography demonstrated high diagnostic accuracy for identifying skull fractures in children, with the evidence indicating stronger performance for confirmation than exclusion. This finding addresses the persisting uncertainty regarding whether ultrasonography can reliably support fracture assessment in acute pediatric head trauma and clarifies its role within contemporary diagnostic pathways.

7. Declarations

7.1. Acknowledgments

None.

7.2. Authors' contributions

All authors contributed to study design, data collection, and writing the draft of the study. All authors read and approved final version of manuscript.

7.3. Funding/Support

None.

7.4. Conflict of interest

None.

7.5. Data Availability

Not applicable.

7.6. Using Artificial Intelligence Chatbots

We used ChatGPT version 5.1 to check grammar and enhance the academic quality and clarity of the text, which was primarily written by the authors. The final version of the text, after incorporating ChatGPT-assisted improvements, was thoroughly reviewed and approved by the authors.

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Table 1: Characteristics of the included studies

Author/Year	Country	Patients	Age	Gold standard	Prevalence (%)	Sensitivity (%)	Specificity (%)
Khan et al.; 2024	Pakistan	78	Mean 5.9 y	CT scan	47.4	70.2	95.1
Huang et al.; 2023	China	152	Median 2.9 y	CT scan	7.89	91.7	98.6
Peter et al.; 2023	Switzerland	325	Median 3 m	Mix*	16.6	93	98
Nihan et al.; 2023	Turkey	112	Median 4 y	CT scan	41.9	93.7	96.8
Choi et al.; 2020	South Korea	87	Mean 21 m	CT scan	15	77	100
Dehbozorgi et al.; 2020	Iran	168	Mean 6.21 y	CT scan	6.5	81.8	100
Masaeli et al.; 2019	Iran	538	Mean 6 y	CT scan	14	92	96
Gokcen et al.; 2019	Turkey	62	Mean 7.29 y	CT scan	41.9	84.6	94.4
Parri et al.; 2018	Italy, USA	115	Mean 8 m	CT scan	77	91	85
Parri et al.; 2013	Italy	55	Mean 5 y	CT scan	64	100	95
Rabiner et al.; 2013	USA	69	Mean 7 y	CT scan	12	88	97
Riera et al.; 2012	USA	46	Median 2 y	CT scan	24	82	94
Weinberg et al.; 2010	USA	21	Median 13 y	CT scan/X Ray	10	100	100

*: Clinical, CT, magnetic resonance imaging (MRI), Skull Radiographs; #: prevalence of Skull Fracture;
CT: computed tomography; y: year; m: month.

Table 2: Prehospital large vessel occlusion (LVO) scale scores categorized by occlusion status and proportion of patients meeting pre-specified cut-off points

Study	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Khan et al.	☹	☺	☺	?	☺	☺	☺
Huang et al.	☹	☺	☺	☺	☺	☺	☺
Peter et al.	☹	☺	☹	☹	☺	☺	☹
Nihan et al.	☹	☺	☺	☺	☺	☺	☺
Choi et al.	☹	☺	☺	☺	☺	☺	☺
Dehbozorgi et al.	☹	☺	☺	☺	☺	☺	☺
Masaeli et al.	☹	☺	☺	☺	☺	☺	☺
Gokcen et al.	☹	☺	☺	☺	☺	☺	☺
Parri et al. (2018)	☹	☺	☹	☹	☺	☺	☺
Parri et al. (2013)	☺	☺	☺	☹	☹	☺	☺
Rabiner et al.	☹	☺	☺	☺	☺	☺	☺
Riera et al.	☹	☹	☺	☹	☺	☺	☺
Weinberg et al.	☹	☺	☺	☹	☺	☺	☺

☺: Low Risk; ☹: High Risk; ?: Unclear Risk.

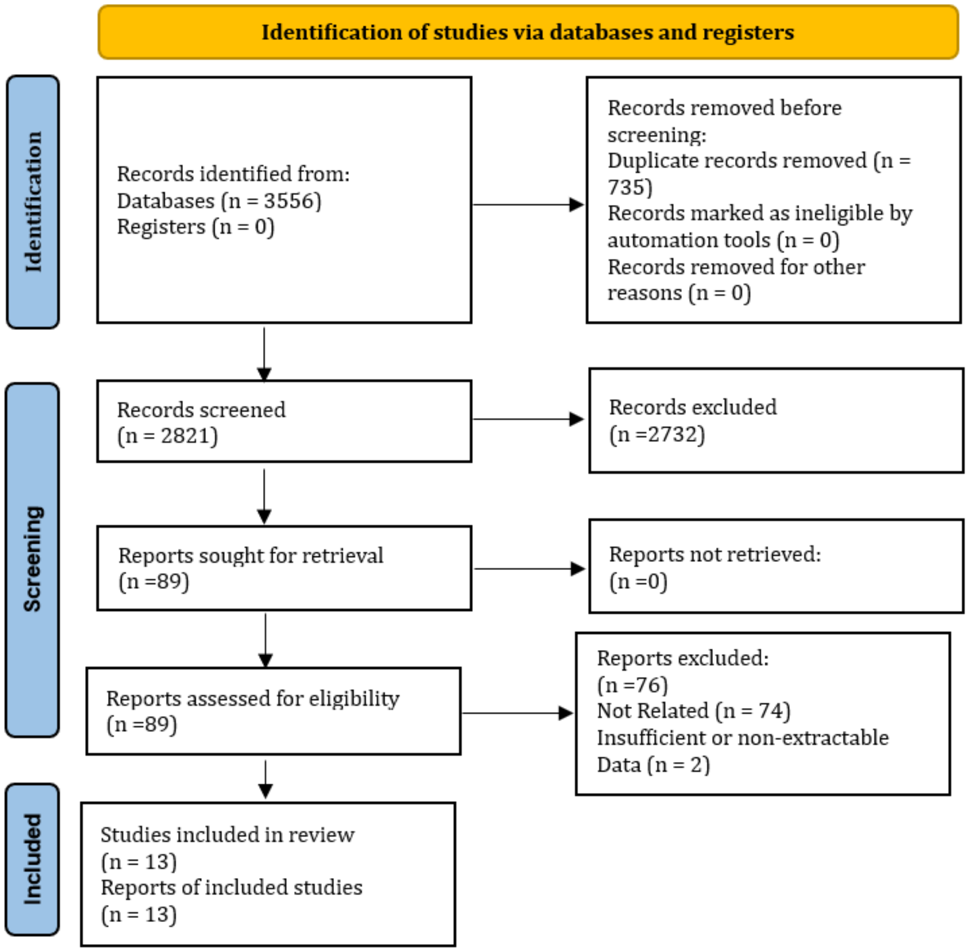

Figure 1: Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart of the included studies.

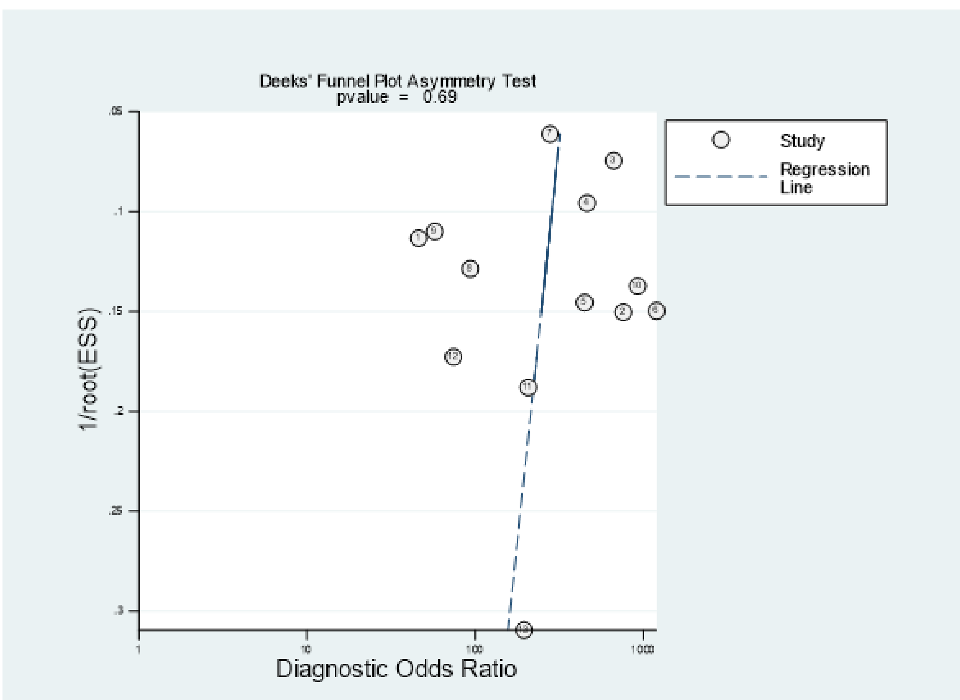

Figure 2: Deeks' funnel plot indicating no significant publication bias.

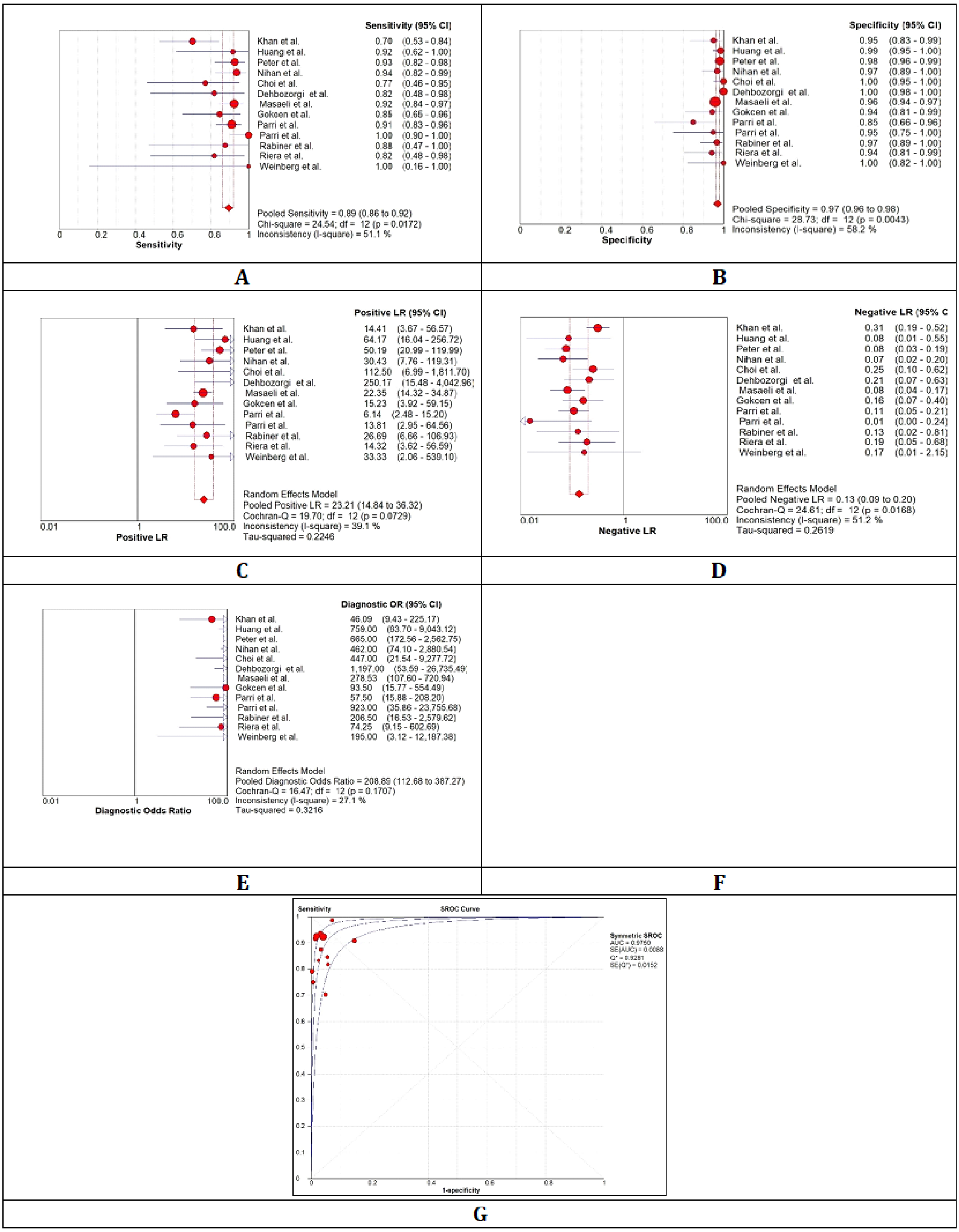

Figure 3: Pooled estimated sensitivity (A), specificity (B), positive likelihood ratio (LR) (C), negative LR (D); diagnostic odds ratio (OR) (E); and accuracy (F); as well as area under the summary receiver operating characteristic (SROC) curve (AUC) (G) of ultrasonography in detection of skull fracture in children. CI: confidence interval; ES: extreme spread; SE: standard error.

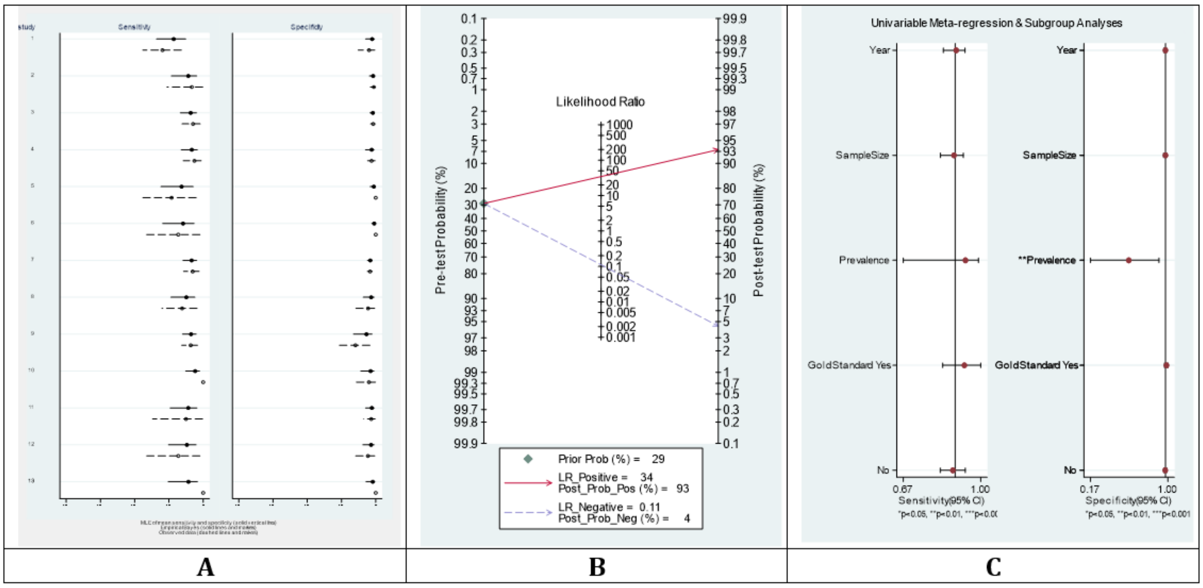

Figure 4: A: Paired Forest plot comparing empirical Bayes–predicted and original sensitivity and specificity; B: Fagan plot for investigating the clinical applicability of ultrasonography for diagnosis of skull fractures in children; C: Forest plot of multiple univariable meta-regression and subgroup analyses. Gold standard – Yes refers to studies that used additional methods alongside CT scanning. LR: likelihood ratio.

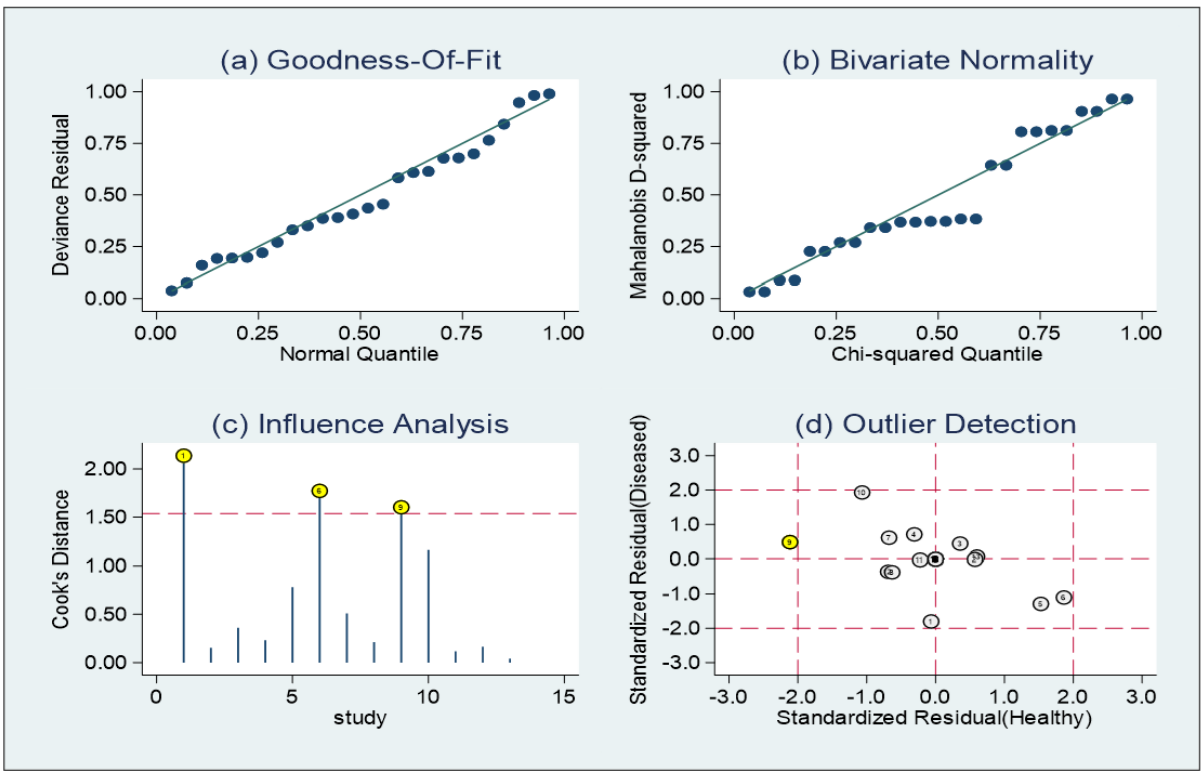

Figure 5: Residual-based goodness-of-fit, bivariate normality, influence, and outlier detection analyses.

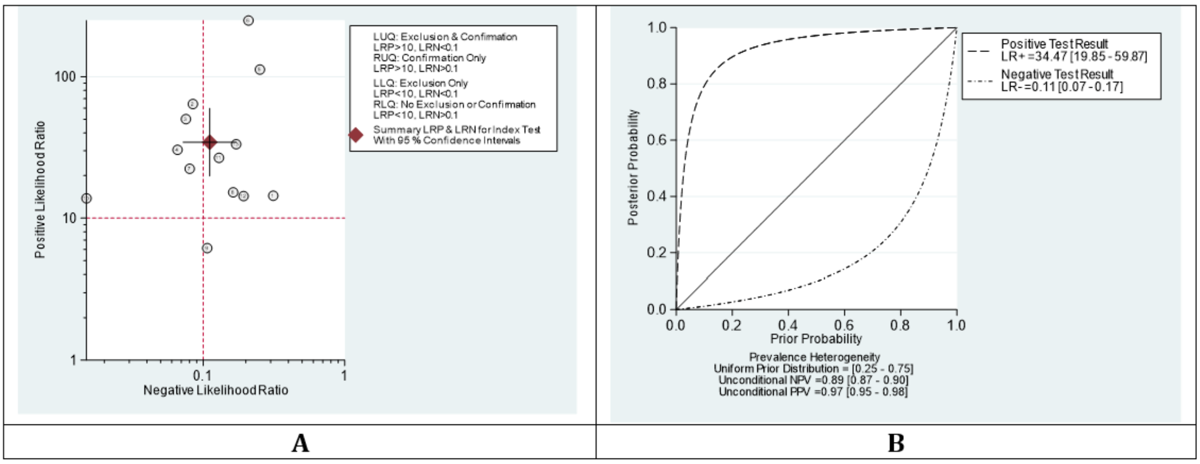

Figure 6: A: The likelihood ratio (LR) scattergram of ultrasonography for diagnosis of skull fractures; B: Probability modifying plot of ultrasonography. NPV: negative predictive value; PPV: positive predictive value; LUQ: left upper quadrant; RUQ: right upper quadrant; LLQ: left lower quadrant ; RLQ: right lower quadrant; LRP: positive likelihood ratio; LRN: negative likelihood ratio.