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REVIEW ARTICLE

Diagnostic Accuracy of Ultrasonography for Identification of Elbow Fractures in Children; a Systematic Review and Meta-analysis

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Abstract: **Introduction:** In spite of the results of previous studies regarding the benefits of ultrasonography for diagnosis of elbow fractures in children, the exact accuracy of this imaging modality is still under debate. Therefore, in this diagnostic systematic review and meta-analysis, we aimed to investigate the accuracy of ultrasonography in this regard. **Methods:** Two independent reviewers performed systematic search in Web of Science, Embase, PubMed, Cochrane, and Scopus for studies published from inception of these databases to May 2023. Quality assessment of the included studies was performed using Quality Assessment Tool for Diagnostic Accuracy Studies (QUADAS-2). Meta-Disc software version 1.4 and Stata statistical software package version 17.0 were used for statistical analysis. **Results:** A total of 648 studies with 1000 patients were included in the meta-analysis. The pooled sensitivity and specificity were 0.95 (95% CI: 0.93-0.97) and 0.87 (95% CI: 0.84-0.90), respectively. Pooled positive likelihood ratio (PLR) was 6.71 (95% CI: 3.86-11.67), negative likelihood ratio (NLR) was 0.09 (95% CI: 0.03-0.22), and pooled diagnostic odds ratio (DOR) of ultrasonography in detection of elbow fracture in children was 89.85 (95% CI: 31.56-255.8). The area under the summary receiver operating characteristic (ROC) curve for accuracy of ultrasonography in this regard was 0.93. Egger's and Begg's analyses showed that there is no significant publication bias (P=0.11 and P=0.29, respectively). **Conclusion:** Our meta-analysis revealed that ultrasonography is a relatively promising diagnostic imaging modality for identification of elbow fractures in children. However, clinicians employing ultrasonography for diagnosis of elbow fractures should be aware that studies included in this meta-analysis had limitations regarding methodological quality and are subject to risk of bias. Future high-quality studies with standardization of ultrasonography examination protocol are required to thoroughly validate ultrasonography for elbow fractures.

Keywords: Child; Diagnosis; Elbow Fractures; Meta-analysis; Ultrasonography

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1. Introduction

Elbow trauma in childhood is a common reason for visits to acute care settings and pediatric emergency department. Previous studies have shown that elbow fractures make up approximately 15% of all fractures in children (1, 2). Since the diagnosis of children with elbow trauma can be confounded by their inability to participate in the physical examination and history, they are routinely evaluated using diagnostic testing with standard two-plane X-rays. Due to the pain and fear in infants and young children with elbow fracture, obtaining the exact standard views is challenging. Moreover, cartilaginous ossification centers, minimally displaced fractures, and unmineralized epiphysis can also reduce the accuracy of radiography for diagnosis of elbow fractures (3-5). Although the majority of elbow fractures can be diagnosed using standard two-plane X-rays, the interpretation of the radiographs is dependent on the physician and these fractures cannot always be easily diagnosed. In cases that the elbow fractures are not definable by radiographs, computed tomography (CT) scan can be used as an alternative imaging technique. However, CT scan and radiography should be minimized in children to reduce radiation exposure (6-8). Previous studies have shown that ultrasonography can be used as a radiation-free, easily accessible, and real-time bedside evaluation for diagnosis of elbow fracture. In the majority of these studies, sonographic fat pad sign and cortical disruption and irregularity were detected, which directly propose the elbow fractures. Furthermore, sonographic evaluation can find some indirect signs of elbow fractures such as elevated posterior fat pad and lipohemarthrosis. Indeed, an elevated posterior fat pad as a sign of intracapsular fractur can be better diagnosed via ultrasonography (9-11). In spite of the results of previous studies regarding the benefits of ultrasonography for diagnosis of elbow fractures in children, the exact accuracy of this imaging modality is still under debate, mostly on account of its dependency on the operator's experience. Therefore, in this diagnostic systematic review and meta-analysis, we aimed to investigate the accuracy of ultrasonography for diagnosis of elbow fractures in children.

2. Methods

2.1. Search strategy

We performed this diagnostic systematic review and meta-analysis according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) (12).

Two independent reviewers performed systematic search in Web of Science, Embase, Medline (via PubMed), Cochrane, and Scopus for studies published from inception of these databases to May 2023. There was no restriction on the language of publications. The reference lists of the included

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studies were screened to find other relevant papers left out in the systematic search. The following MeSH terms, keywords, and their combinations were used: "Fracture" OR "Trauma" OR "Injury" OR "Injuries" AND "Pediatric" OR "Children" OR "Child" OR "Young Adults" AND "Elbow" AND "Ultrasonography" OR "Ultrasound" OR "Sonography" OR "Ultrasonic" OR "Sonographic" OR "Ultrasonographic" AND "Sensitivity" OR "Specificity" OR "Accuracy".

2.2. Study selection

Two independent investigators (MF and SMK) assessed all identified studies based on the defined inclusion criteria that encompassed the following criteria: 1) the aim of the study was to investigate the diagnostic performance of ultrasonography for detection of elbow fracture in children under 18 years of age; 2) true positive (TP), false positive (FP), true negative (TN), and false negative (FN) were used for calculating the sensitivity and specificity and these data could be found in the paper; and 3) reference standard including elbow radiograph or CT scan or magnetic resonance imaging (MRI) was clearly defined for the diagnosis of elbow fracture. The exclusion criteria were as follows: 1) studies without sufficient data to calculate diagnostic accuracy estimates of ultrasonography; 2) studies with diagnostic data duplicated in other papers; 3) reviews, guidelines, letters, comments, editorials, and conference abstracts. Any disagreement between the two investigators was discussed and then resolved by a third investigator.

2.3. Data extraction and quality assessment

For every included study, two independent investigators extracted the following variables and disagreements were resolved by consensus: first author, year of publication, country, sample size, mean age, gender distribution, number of centers, number of fractures, sonographic performer, gold standard, TP, FP, TN, FN, and data required for quality assessment. Quality assessment of the included studies was performed using Quality Assessment Tool for Diagnostic Accuracy Studies (QUADAS-2) which consists of four domains of risk of bias and three domains of applicability concern.

2.4. Data synthesis and statistical analysis

We used meta-Disc software version 1.4 (Ramona Cajal Hospital, Madrid, Spain) and Stata statistical software package (Stata Corp., College Station, TX, USA) (version 17.0) to conduct this diagnostic meta-analysis. The heterogeneity among the included studies was evaluated using the I2 and P-value of Cochran's Q-statistic. I2>50% or P<0.05 was considered as a significant heterogeneity between the included studies and then DerSimonian-Laird approach (random-effects model) was used. Spearman correlation coefficient between the log of sensitivity and the log of (1-specifcity) was used to investigate the threshold effect as a cause of the heterogeneity. Publication bias was assessed using Egger's test, Begg's test, and funnel plot. Subgroup analyses and meta-regressions were performed to find the potential sources of the heterogeneities.

3. Results

3.1. Characteristics of the included studies

A total of 648 studies were yielded after the systematic search of five databases. Of these, 325 duplicate studies were excluded using EndNote software, and 366 papers remained. After screening the title and abstracts, another 267 papers were excluded, and 99 papers remained for full-text evaluation for eligibility. Eighty-five of the remaining 99 studies did not meet the inclusion criteria, and finally 14 papers were included in this meta-analysis. The flow-chart of this meta-analysis is depicted in Figure 1.

The included studies were published between 1994 and 2021 and a total of 1000 patients were evaluated. In seven studies, ultrasonography was conducted by pediatric emergency physician, two by pediatric orthopedic surgeon, two by musculoskeletal radiologist, two by other specialists, and one unclear. In 14 studies investigating the diagnostic performance of ultrasonography, 11 studies were single-center and three were multicenter. Six studies were conducted in Europe, five in America, and three in Asia. The majority of included studies used elbow radiograph as the gold standard for diagnosis of elbow fracture. Other characteristics of the included studies are summarized in table 1.

3.2. Results of quality assessment and publication bias

Evaluation of the included studies using QUADAS-2 revealed that none of the studies had concerns regarding three domains of applicability. Three studies used MRI or CT scan in addition to elbow radiograph as gold standard, indicating high risk of bias with regard to the reference standard domain. The detailed quality assessments of the included studies are reported in table 2. Egger's and Begg's analyses showed that there was no significant publication bias (P=0.11 and P=0.29, respectively). Similarly, the funnel plot revealed no evidence of publication bias (Fig. 2).

3.3. Meta-analysis

We did not find a typical "shoulder arm-like" distribution in summary receiver operating characteristic (SROC) curve and Spearman correlation coefficient was -0.39 (P=0.16), indicating that there is no threshold effect in this meta-analysis. The pooled sensitivity was 0.95 (95% CI: 0.93-0.97) and pooled specificity was 0.87 (95% CI: 0.84-0.90) (Figs. 3 and 4). Pooled positive likelihood ratio (PLR) was 6.71 (95% CI: 3.86-11.67), negative likelihood ratio (NLR) was 0.09 (95% CI: 0.03-0.22), and pooled diagnostic odds ratio (DOR) was 89.85 (95% CI: 31.56-255.8) (Figs. 5-7). The area under the SROC curve for accuracy of ultrasonography to diagnose elbow fractures was 0.93 (Fig. 8). There was significant heterogeneity in sensitivity (I2=75.2% and P<0.01), specificity (I2=75.1% and P<0.01), PLR (I2=79.7% and P<0.01), NLR (I2=82.1% and P<0.01), and DOR (I2=62.8% and P<0.01) between the included studies.

3.4. Meta-regression

Since we found significant heterogeneity in the diagnostic parameters of ultrasonography for diagnosis of elbow fracture, we performed subgroup analyses and meta-regressions to find the potential sources of these heterogeneities. Study center, country, sample size, ultrasonographic performer, and gold standard were assessed as the potential sources of heterogeneity in the meta-regression. However, meta-regressions did not find the source of heterogeneity using the above-mentioned variables (P>0.05).

4. Discussion

This systematic review and meta-analysis with the aim of investigating the diagnostic performance of ultrasonography for elbow fractures found that its accuracy is 0.93. Moreover, the sensitivity and specificity of ultrasonography for identification of elbow fractures are 0.95 and 0.87, respectively. We found significant heterogeneity between the included studies with respect to the diagnostic parameters. One possible explanation for this significant heterogeneity could be the operator-dependent nature of ultrasonography, but our meta-regression analysis showed that this parameter is not the source of heterogeneity. Furthermore, evaluating other variables such as number of centers, country, sample size, and gold standard could not clarify the source of heterogeneity. Although the majority of studies used sonographic pad sign and cortical disruption and irregularity as the direct signs of elbow fractures, indirect signs such as lipohemarthrosis and posterior fat pad may also be used in some cases. These differences in the definitions of threshold can result in the heterogeneity of diagnostic results (13, 14). Taken together, these findings support the use of ultrasonography as an alternative imaging modality for identification of elbow fractures in children. Ultrasonography has an appropriate PLR of 6.71 and NLR of 0.09, making it a proficient test to rule in or rule out elbow fractures in children. Only nine out of 100 cases with a distal elbow fracture will be missed using this imaging modality.

A previously published systematic review assessed the diagnostic performance of ultrasonography for upper extremity fractures (14).

They performed a systematic search in three databases from their inception to September 2015 to identify studies that evaluated the accuracy of ultrasonography for diagnosis of distal forearm fractures. They included 16 studies with 1204 children in their meta-analysis. The pooled sensitivity and specificity of ultrasonography were estimated to be 0.97 and 0.95, respectively. Therefore, their findings were in line with our results that showed ultrasonography can be used for diagnosis of upper extremity fractures in children. They also investigated the source of heterogeneity using meta-regression and subgroup analysis. They found that only methods of viewing images and comparing radius with ulna were statistically significant. We could not conduct meta-regression using methods of viewing as this data was not reported in most of the studies included in our meta-analysis. Similar to the results of our meta-regression, all other subgroup analyses conducted in their study showed no significant differences. The diagnostic parameters found in our study were lower of value than those reported in their meta-analysis. This inconsistency may be explained by the fact that ultrasonographic performers in their included studies were not blinded to the clinical data of children, which is a pivotal limitation and can affect the results.

Another meta-analysis by Schmid et al. (15) was performed to compare the accuracy of ultrasonography with that of conventional imaging for diagnosis of fractures in both children and adults. They conducted a systematic search in three databases and they finally included a total of 48 studies in the meta-analysis. The sensitivity and specificity of ultrasonography for diagnosis of fractures were estimated to be 0.91 and 0.94, respectively. Moreover, their subgroup analyses showed that the accuracy of ultrasonography was higher for diagnosis of the fractures of ankle, humerus, and forearm in children. They also included studies that investigated the diagnostic accuracy of ultrasonography for diagnosis of elbow fractures, but the results of ultrasonography for this fracture were not reported separately. Consistent with our findings that showed the high accuracy of ultrasonography for diagnosis of elbow fracture in children and young adults, they also showed that ultrasonography has higher accuracy in children than adults. Another systematic review by Joshi et al. (16) was carried out using the results of eight studies that assessed accuracy of ultrasonography for the diagnosis of extremity fractures. Their findings proposed the use of ultrasonography in addition to radiography. The results of eight studies investigating the diagnostic performance of ultrasonography for forearm fractures in children were pooled in another systematic review (17). This study found that ultrasonography has some other superiorities over radiography. However, our included studies did not report the results of time required to conduct ultrasonography, patient comfort, and cost-efficiency.

Our meta-analysis had some limitations. First, although we found that sonographic performer was not the source of heterogeneity among the included studies, ultrasonography is operator-dependent, which can affect the results of different studies. Therefore, the results of ultrasonography for elbow fracture may not be generalizable to all settings. Second, evaluation of the included studies revealed that there is a lack of standardization regarding the scanning protocols and ultrasonography views for identification of elbow fractures. Third, we could not conclude regarding the accuracy of ultrasonography for differentiating the types of Salter-Harris fractures of elbow. Future studies with larger sample sizes and standardization regarding the training and performance of ultrasonographers are required to establish the accuracy of ultrasonography for diagnosis of elbow fractures and differentiating types of Salter-Harris fractures.

5. Conclusion

Our meta-analysis revealed that ultrasonography is a relatively promising diagnostic imaging modality for identification of elbow fractures in children. However, clinicians employing ultrasonography for diagnosis of elbow fractures should be aware that studies included in this meta-analysis had limitations regarding methodological quality and are subject to risk of bias. Future high-quality diagnostic studies with standardization of ultrasonography examination protocols are required to thoroughly validate ultrasonography for elbow fractures.

6. Declarations

6.1. Acknowledgments

The authors thank all those who contributed to this study.

6.2. Conflict of interest

None.

6.3. Funding and support

None.

6.4. Authors' contribution

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

6.5. Data Availability

Not applicable.

6.6. Using artificial intelligence chatbots

None.

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Table 1: Characteristics of the included studies

Author	Year	Country	Sample Size	Age (Year)	No. of Centers	Male (%)	No. of Fractures	Fracture (%)	Sonography Performer	Gold Standard	TP	FP	FN	TN
Azizkhani et al. (18)	2021	Iran	75	6.5	Multicenter	74.7	28	37.3	Emergency medicine specialist	Initial or follow-up radiographs with clinical follow-up examination and CT scan findings	26	5	2	42
Varga et al. (19)	2020	Hungary	365	1-14	Single-Center	NR	165	45.2	Trained resident and orthopedic surgeon	Elbow radiograph	165	12	0	188
Tokarski et al. (20)	2018	USA	100	7.9	Single-center	55	43	43.0	Pediatric emergency physician	Elbow radiograph	38	14	5	43
Burnier et al. (5)	2016	France	34	8.0	Single-center	55.9	13	38.2	Pediatric orthopedic surgeon	Elbow radiograph	12	2	1	19
Supakul et al. (21)	2015	USA	16	8.6 m	Single-center	62.5	4	67.0	Pediatric radiologist	Elbow radiograph	4	0	4	4
Eckert et al. (a) (4)	2014	Germany	79	6.5	Single-center	NR	38	48.1	Pediatric emergency physician	Elbow radiograph	37	4	1	37
Eckert et al. (b) (22)	2014	Germany	106	5.9	Single-center	56.6	60	56.6	Pediatric emergency physician	Elbow radiograph	60	3	0	43
Rabiner et al. (3)	2013	USA	130	7.5	Multicenter	55.4	43	33.1	Pediatric emergency physician	Elbow radiograph	42	26	1	61
Weinberg et al. (23)	2010	USA	30	NR	Multicenter	NR	15	50.0	Pediatric emergency physician	Elbow radiograph	12	2	3	13
Cho et al. (24)	2010	South Korea	9	7.3	Single-center	100	9	50.0	Musculoskeletal radiologist	Elbow radiograph, bone scan, or elbow MRI	9	0	0	9
Zuazo et al. (25)	2008	France	14	8.5	Single-center	64.3	8	57.1	Musculoskeletal radiologist	Elbow MRI	7	0	1	6
Zhang et al. (26)	2008	China	9	NR	Single-center	NR	9	50.0	Pediatric orthopedic surgeon	Elbow radiograph or elbow MRI	9	0	0	9
Pistor et al. (27)	2003	Germany	25	NR	Single-center	NR	15	60.0	NR	Elbow radiograph	12	5	3	5
Davidson et al. (28)	1994	USA	8	1.9	Single-center	75	6	75.0	Pediatric orthopedic surgeon	Elbow radiograph	6	0	0	2

TP: true positive; FP: false positive; TN: true negative; FN: false negative; NR: not reported; MRI: magnetic resonance imaging; CT: computed tomography.

Table 2: Quality assessment of the included studies using Quality Assessment Tool for Diagnostic Accuracy Studies (QUADAS-2) tool

Study	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Azizkhani et al.	☹	☺	☹	☺	☺	☺	☺
Varga et al.	?	☺	☺	?	☺	☺	☺
Tokarski et al.	☺	☺	☺	☺	☺	☺	☺
Burnier et al.	☺	☺	☺	☺	☺	☺	☺
Supakul et al.	☺	☺	☺	☺	☺	☺	☺
Eckert et al. (a)	☺	☺	☺	☺	☺	☺	☺
Eckert et al. (b)	☺	☺	☺	☺	☺	☺	☺
Rabiner et al.	☺	☺	☺	☺	☺	☺	☺
Weinberg et al.	☺	☺	☺	☺	☺	☺	☺
Cho et al.	☹	☺	☹	☺	☺	☺	☺
Zuazo et al.	☺	☺	☹	☺	☺	☺	☺
Zhang et al.	☹	☺	☺	☺	☺	☺	☺
Pistor et al.	☺	☺	☺	☺	☺	☺	☺
Davidson et al.	☺	☺	☺	☺	☺	☺	☺

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

Table 3: The results of meta-regression and subgroup analysis

Subgroups	Covariates	No. of studies	Sensitivity	Specificity	PLR	NLR	Accuracy	DOR
Study	Single-center	11	0.96 (0.93-0.98)	0.90 (0.87-0.93)	7.48 (3.65-15.32)	0.08 (0.02-0.28)	0.94	108.39 (25.88-453.91)
	Multicenter	3	0.93 (0.85-0.97)	0.78 (0.70-0.84)	5.08 (2.35-10.99)	0.10 (0.03-0.35)	0.94	67.95 (22.89-201.70)
Country	Europe	6	0.98 (0.96-0.99)	0.92 (0.88-0.95)	8.14 (2.98-22.24)	0.05 (0.01-0.34)	0.93	186.98 (18.10-1932.16)
	Other countries	8	0.91 (0.85-0.95)	0.80 (0.74-0.85)	4.47 (3.04-6.57)	0.13 (0.05-0.33)	0.92	43.56 (21.23-89.41)
Sample size	<75	8	0.86 (0.76-0.92)	0.88 (0.79-0.94)	5.99 (2.35-15.28)	0.21 (0.10-0.45)	0.91	32.54 (9.91-106.83)
	≥75	6	0.98 (0.96-0.99)	0.87 (0.83-0.90)	7.45 (3.58-15.50)	0.04 (0.01-0.14)	0.91	222.06 (43.53-1132.78)
Sonography performer	Pediatric emergency physician	5	0.95 (0.91-0.98)	0.80 (0.75-0.85)	5.51 (3.05-9.98)	0.07 (0.02-0.23)	0.91	91.57 (21.84-383.91)
	Others	9	0.96 (0.93-0.98)	0.92 (0.89-0.95)	7.80 (3.17-19.20)	0.10 (0.02-0.44)	0.94	89.79 (17.76-453.95)
Gold standard	Only elbow radiograph	10	0.96 (0.93-0.97)	0.86 (0.82-0.89)	5.91 (3.12-11.17)	0.08 (0.02-0.29)	0.91	79.88 (20.55-310.44)
	Including other imaging	4	0.94 (0.85-0.99)	0.93 (0.84-0.98)	10.01 (4.79-20.89)	0.10 (0.04-0.24)	0.96	131.34 (34.24-503.79)

All data are provided as pooled analysis with 95% confidence interval. DOR: diagnostic odds ratio; PLR: positive likelihood ratio; NLR: negative likelihood ratio.

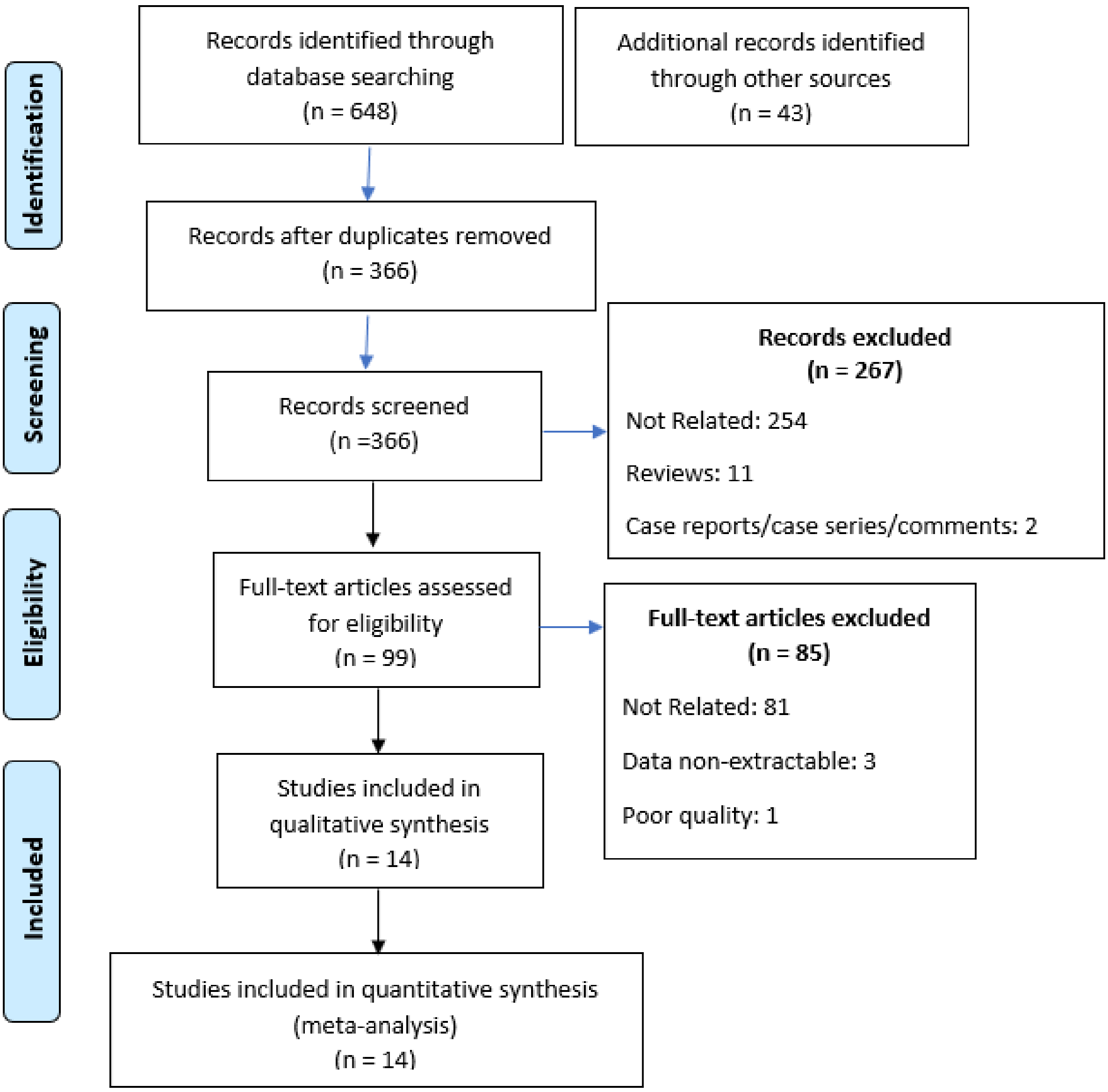

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flowchart of the literature search and selection of studies that evaluated accuracy of ultrasonography for diagnosis of elbow fractures in children.

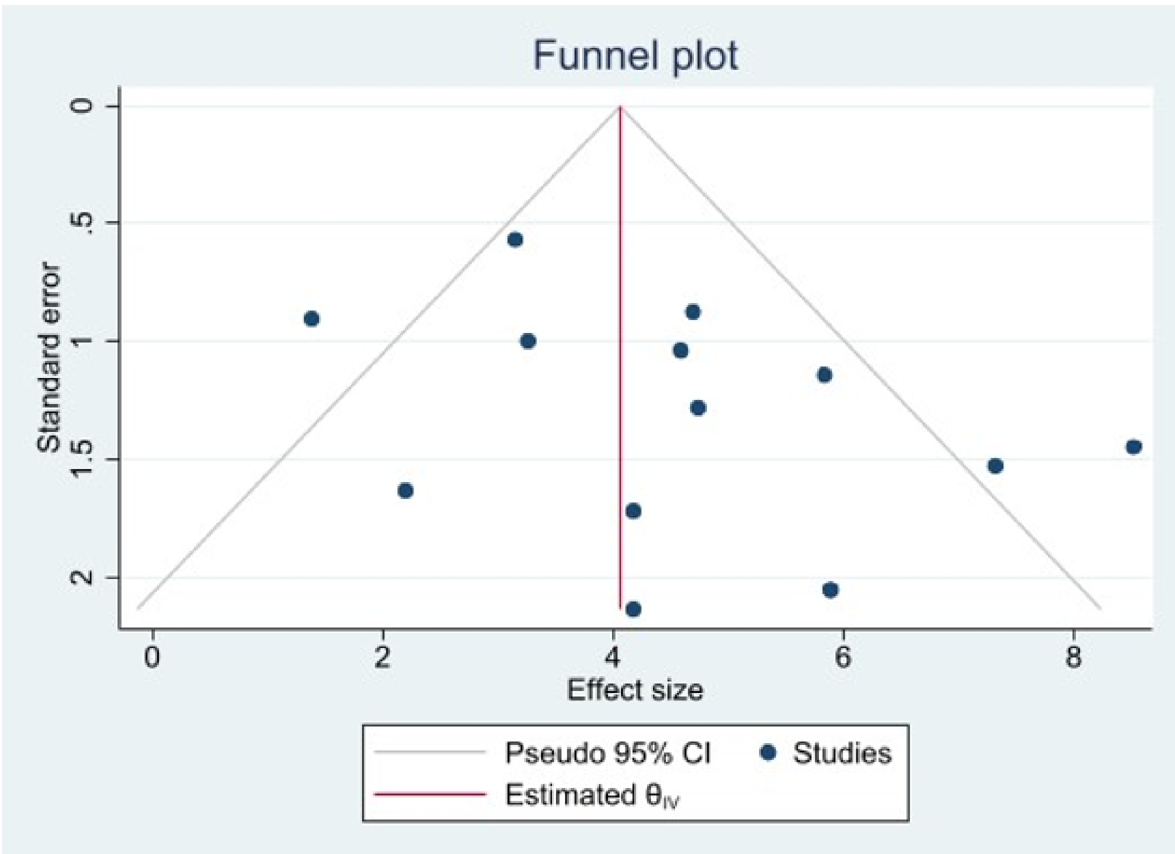

Figure 2: Funnel plot of publication bias on the pooled diagnostic odds ratio (DOR) of ultrasonography for diagnosis of elbow fractures in children. CI: confidence interval.

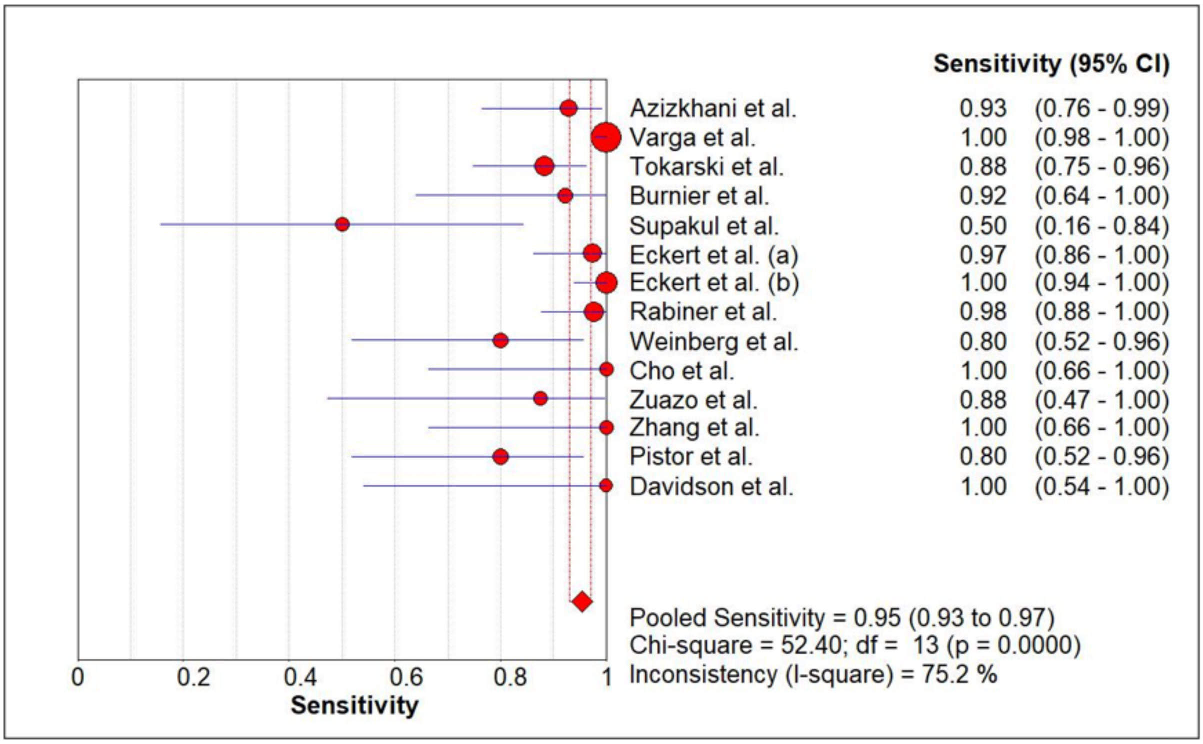

Figure 3: Forest plot of the pooled sensitivity of ultrasonography for diagnosis of elbow fracture in children. CI: confidence interval.

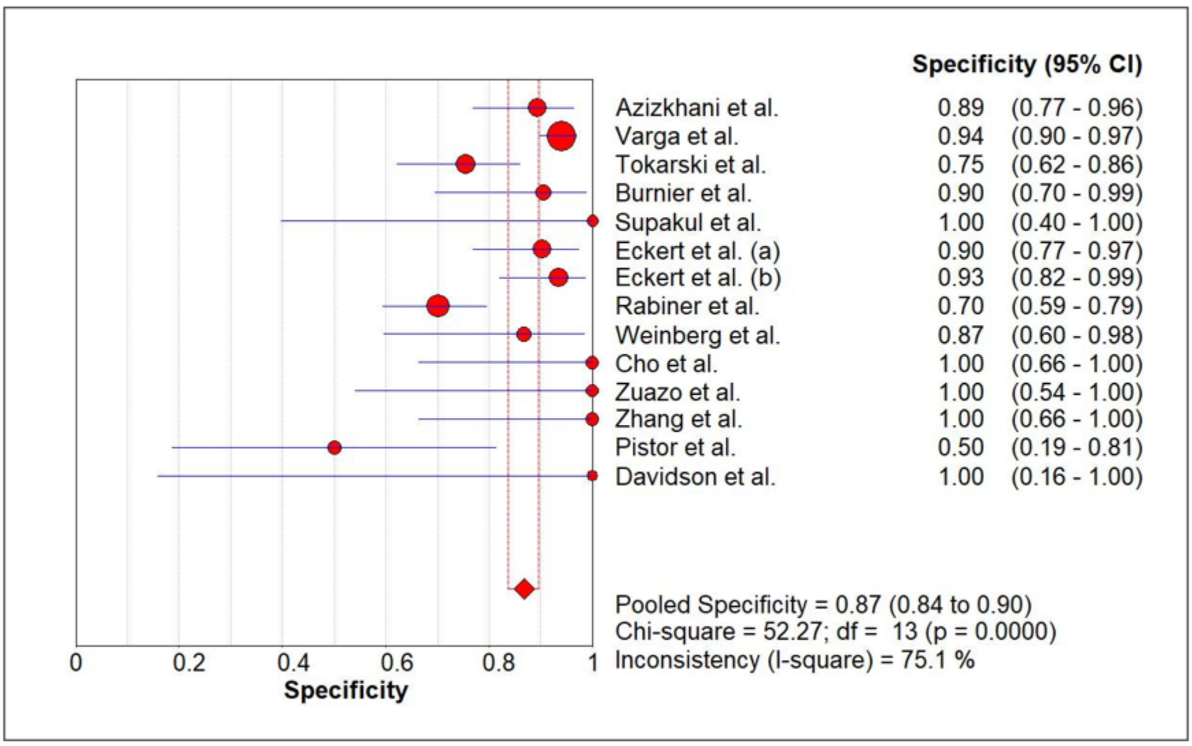

Figure 4: Forest plot of the pooled specificity of ultrasonography for diagnosis of elbow fracture in children. CI: confidence interval.

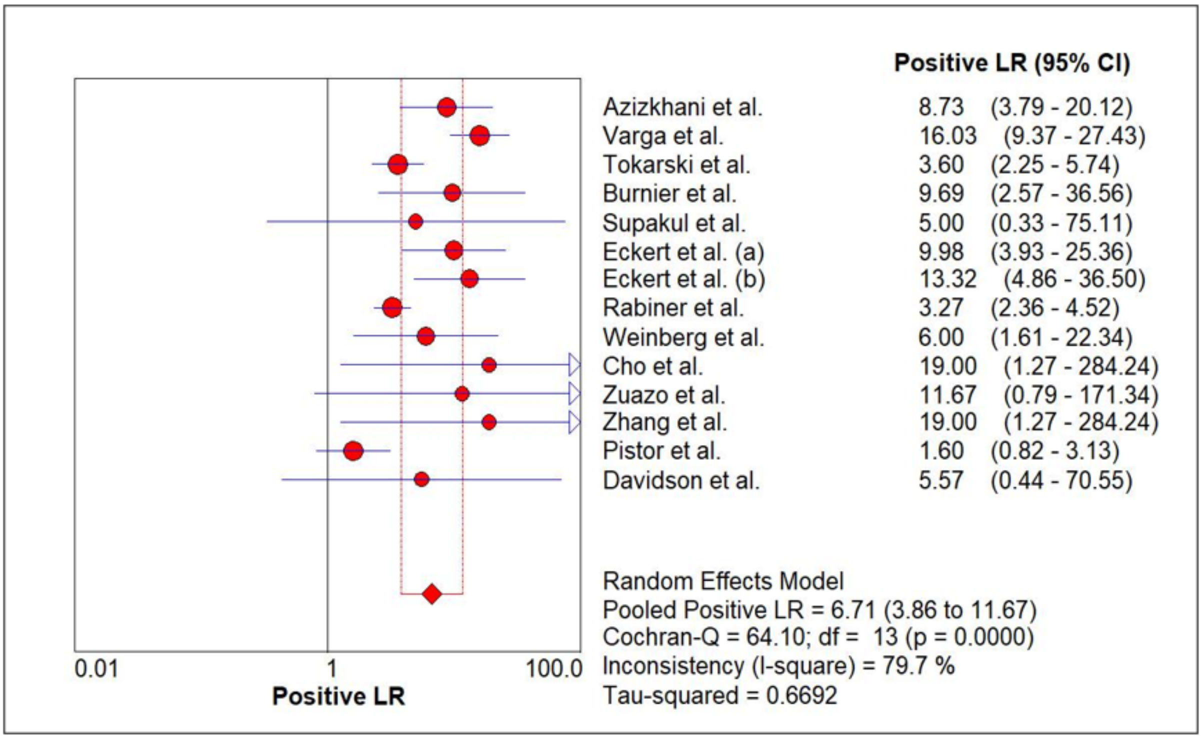

Figure 5: Forest plot of the pooled positive likelihood ratio (LR) of ultrasonography for diagnosis of elbow fracture in children. CI: confidence interval.

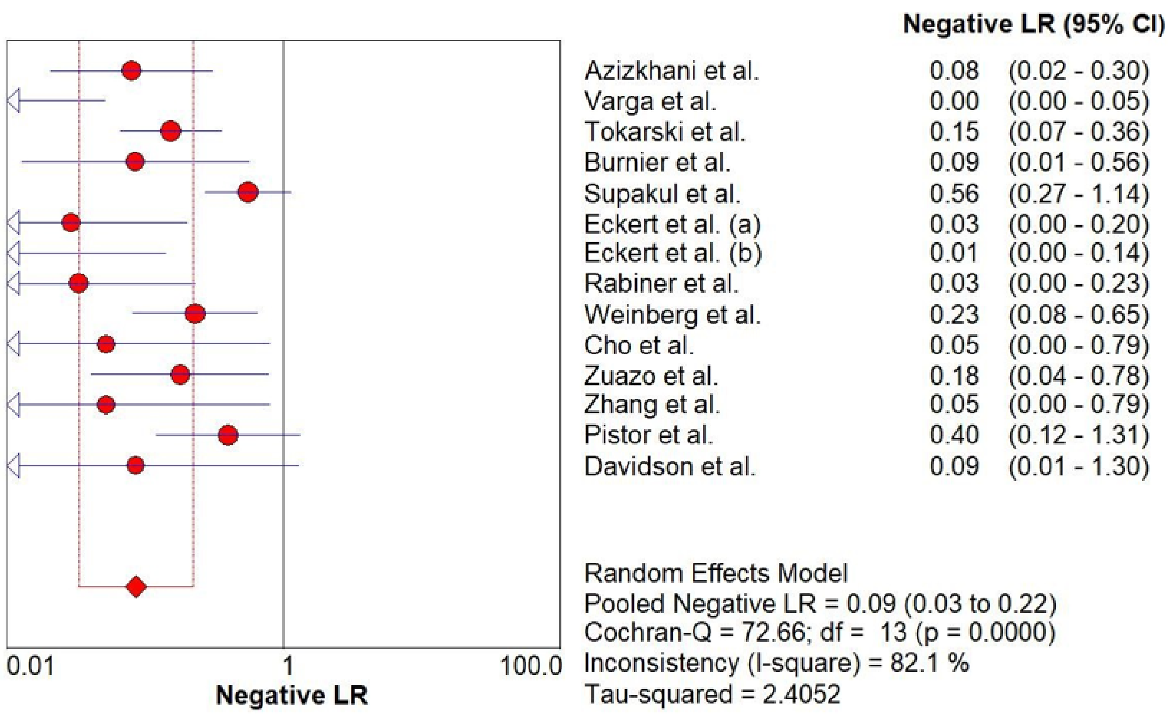

Figure 6: Forest plot of the pooled negative likelihood ratio (LR) of ultrasonography for diagnosis of elbow fracture in children. CI: confidence interval.

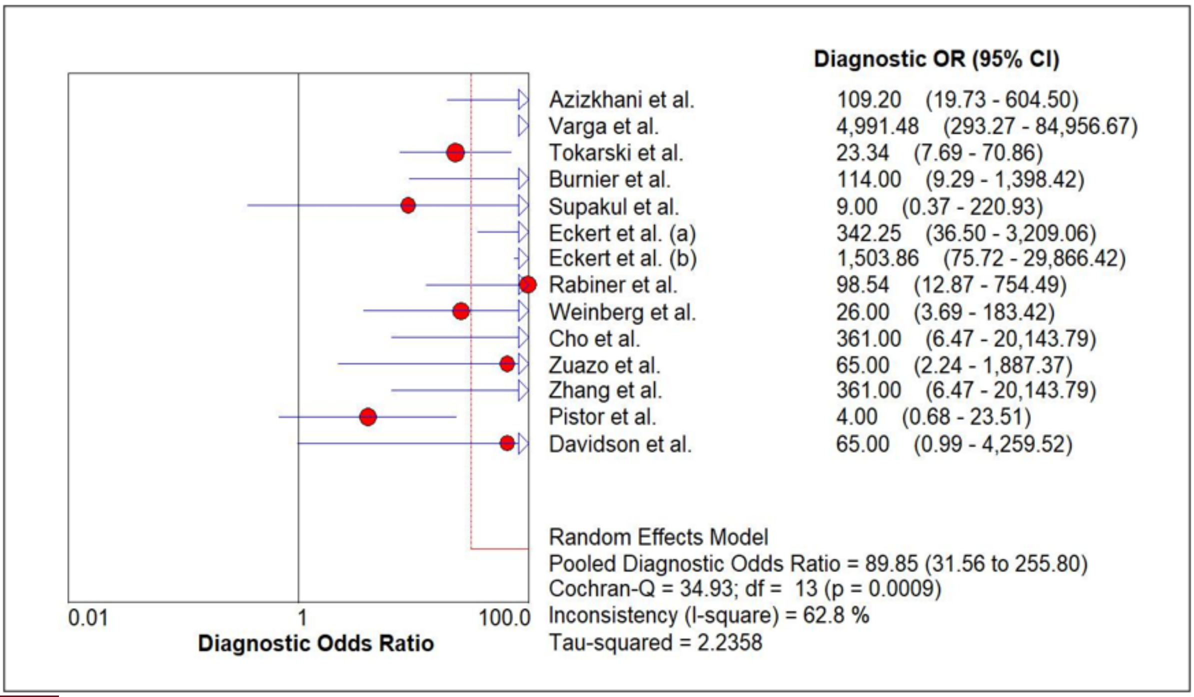

Figure 7: Forest plot of the diagnostic odds ratio (OR) of ultrasonography for diagnosis of elbow fracture in children. CI: confidence interval.

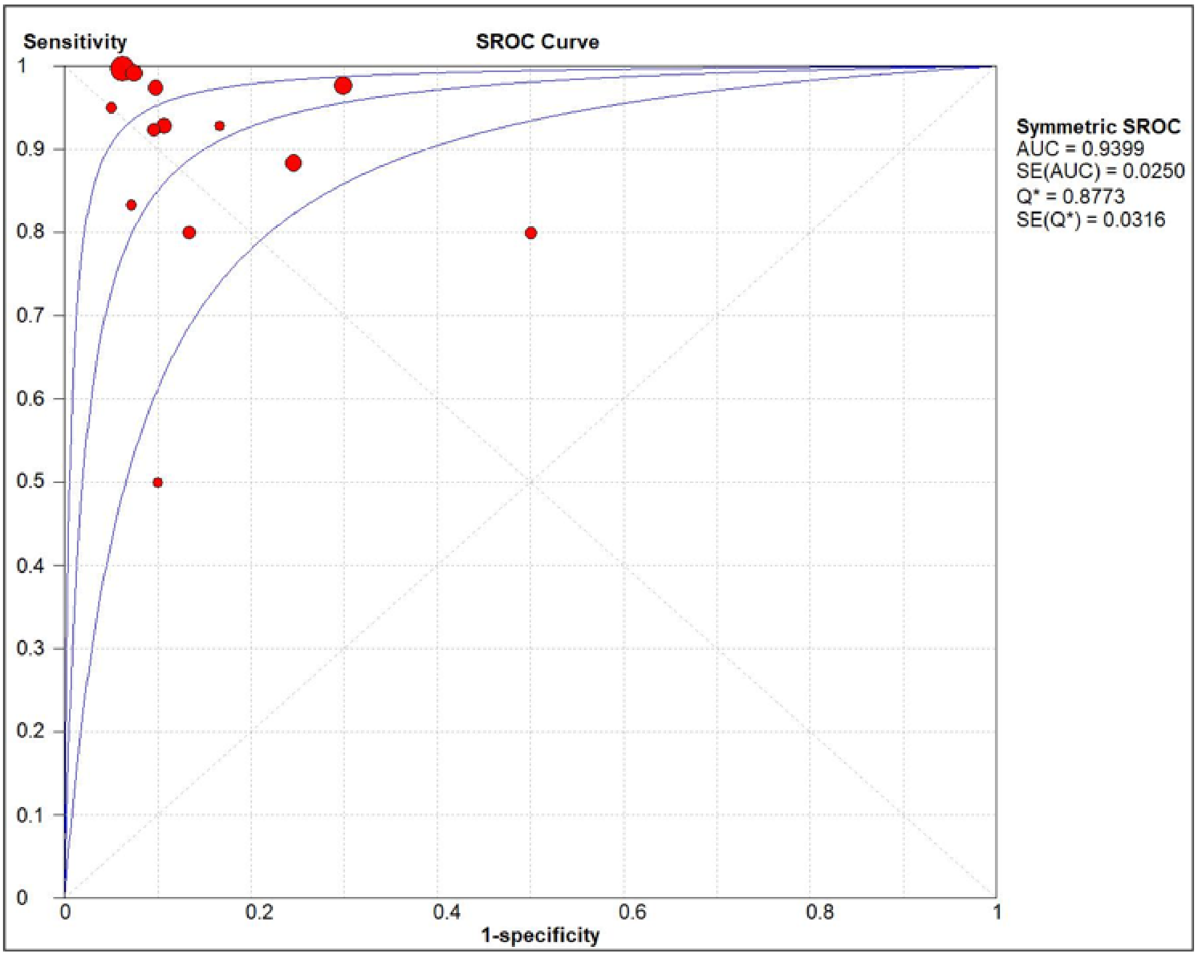

Figure 8: Summary receiver-operating characteristic (SROC) curve of ultrasonography for diagnosis of elbow fracture in children. SE: standard error; AUC: area under the curve.