# Diagnostic Performance of Ultrasonography for Detection of Pediatric Elbow Fracture: A Meta-analysis

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**Study objective:** We evaluate the diagnostic performance of ultrasonography for detection of elbow fracture in pediatric patients with trauma.

**Methods:** PubMed and EMBASE databases were searched for diagnostic accuracy studies that used ultrasonography for detection of elbow fracture in pediatric patients. Bivariate modeling and hierarchic summary receiver operating characteristic (ROC) modeling were conducted to evaluate diagnostic performance. The pooled proportions of the false-negative rate were assessed with a DerSimonian-Laird random-effects model. We performed meta-regression analyses for heterogeneity exploration.

**Results:** Ten articles involving a total of 519 patients were included. The summary sensitivity, summary specificity, and area under the hierarchic summary ROC curve were 96% (95% confidence interval 88% to 99%), 89% (95% confidence interval 82% to 94%), and 0.97 (95% confidence interval 0.95 to 0.98), respectively. The pooled proportion of the false-negative rate of ultrasonography was 3.7%. Among the various potential covariates, ultrasonographic performer (pediatric emergency physician versus others) and presence of extra musculoskeletal ultrasonographic training (trained versus not reported) were associated with heterogeneity of the specificity.

**Conclusion:** Elbow ultrasonography demonstrated high performance in the diagnosis of pediatric elbow fracture, particularly in studies of physicians with extra training in musculoskeletal ultrasonography. Ultrasonography may be performed by trained physicians as a first-line diagnostic tool to diagnose pediatric elbow fracture. [Ann Emerg Med. 2019;74:493-502.]

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## INTRODUCTION

### Background

Elbow injuries are a common presenting complaint to the emergency department (ED), and elbow fractures account for approximately 15% of fractures in pediatrics.[1] In most cases, radiographs, including standard 2-way anteroposterior and lateral views, are required for primary evaluation.[2,3] However, there are some difficulties in detecting pediatric elbow fractures because of nonossified epiphyses and nonstandard views taken in uncooperative children.[4] In addition, although radiography uses low-dose radiation, exposure to this hazard has a cumulative effect on pediatric patients and growing bone is vulnerable to radiation injury.[5] Alternative imaging methods, such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography, have been considered to enhance diagnostic accuracy.[6,7] CT shows high sensitivity and specificity, but the same concerns about radiation exposure exist and its use should be minimized in pediatric patients.[6] In contrast to radiography and CT, MRI is helpful for detecting soft tissue injuries and posttraumatic bone marrow change of elbow fractures without radiation hazards.[8,9] However, routinely performing MRI is not cost-effective, and it is not readily available in the ED setting.

Although ultrasonography is an operator-dependent modality, it has a sensitivity comparable to that of radiograph and CT in detecting limb fracture in pediatric patients.[10] Ultrasonography can detect cortical disruption and irregularity, which directly indicates fractures, and elevated posterior fat pad formed by hematoma, which indirectly supports intracapsular fractures often not visualized by radiography.[11-13] In addition, ultrasonography can be immediately performed and is easily accessible in the ED or outpatient clinic, without radiation hazard.[11-13]

**Editor's Capsule Summary**

*What is already known on this topic*

Point-of-care ultrasonography has been demonstrated to be useful in diagnosing pediatric elbow fractures, but no synthesis of the literature exists.

*What question this study addressed*

Meta-analysis of 10 articles involving 519 patients found a pooled summary sensitivity of 96% (95% confidence interval 88% to 99%), specificity of 89% (95% confidence interval 82% to 94%), and false-negative rate of 3.7% (95% confidence interval 2.5% to 6.5%). Performers of ultrasonography who have extra training in musculoskeletal ultrasonography demonstrated higher specificity.

*What this study adds to our knowledge*

This study summarizes the literature, reporting pooled test characteristics for point-of-care ultrasonography to diagnose pediatric elbow fractures.

*How this is relevant to clinical practice*

Point-of-care ultrasonography may be useful in diagnosing pediatric elbow fractures, particularly when reducing radiation exposure is preferred or in low-resource settings.

## Importance

To our knowledge, no studies have performed a comprehensive synthesis of the literature on pediatric elbow fracture diagnosis using elbow ultrasonography. In addition, data in regard to the diagnostic performance of elbow ultrasonographic technique have revealed broad ranges of sensitivity and specificity. Hence, thorough analysis and comparison of the currently available data in regard to the diagnostic performance and false-negative rate of elbow ultrasonography for pediatric elbow fracture are needed. This high-level evidence synthesis is of interest to all physicians working in urgent pediatric care and to global health physicians working in resource-poor areas.

## Goals of This Investigation

The first aim of this meta-analysis was to assess the pooled diagnostic performance of elbow ultrasonography for detecting pediatric elbow fracture. The second aim was to evaluate the pooled proportion of the false-negative rate of elbow ultrasonography.

## MATERIALS AND METHODS

This meta-analysis followed the revised guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-analyses of Diagnostic Accuracy Studies statement.[14]

The PubMed and EMBASE databases were searched up to November 1, 2018, to identify English-language reports on ultrasonography for detecting pediatric elbow fracture. Search terms that were related to "elbow," "fracture," and "ultrasound" were combined with "sensitivity," "specificity," or "receiver operating characteristic" as follows: ((child) OR (children) OR (pediatric) OR (paediatric) OR (adolescent)) AND ((elbow)) AND ((fracture) OR (injury) OR (injuries) OR (trauma)) AND ((ultrasound) OR (ultrasonography) OR (ultrasonographic) OR (sonogram) OR (sonography) OR (sonographic)) AND ((accuracy) OR (sensitivity) OR (specificity) OR (receiver operating characteristic) OR (ROC curve)) (Table E1, available online at http://www.annemergmed.com). The bibliographies of the identified articles were also screened to find additional relevant studies. Two investigators screened the titles and abstracts for potential eligibility, and disagreements were resolved through discussion.

### Selection of Participants

We included studies that fulfilled the following criteria: pediatric patients with elbow trauma, elbow ultrasonography as the index test, use of radiologic follow-up as the reference standard for confirmation of the elbow fracture, and publication type of original research article.

The exclusion criteria were as follows: case report or case series; review articles, guidelines, consensus statements, letters, editorials, clinical trials, and conference abstracts; studies not pertaining to the field of interest; studies with insufficient data for reconstruction of a 2×2 table; and overlapped population.

### Data Collection and Processing

Two investigators (S.H.L. and S.J.Y.) independently extracted data about patient and study characteristics. The same investigators evaluated methodologic quality with the Quality Assessment of Diagnostic Accuracy Studies–2 tool.[15] Inconsistencies between the reviewers were resolved through discussion.

A standardized form was used to collect data about patient characteristics (number of patients, proportion with elbow fracture, mean age, age range, and sex), study characteristics (study location, publication year, study design, reference standard, blinding to reference standard, and study cohort), and ultrasonographic characteristics (probe, technical parameters, ultrasonographic performer, and extra musculoskeletal ultrasonographic training before the study). Study outcomes were also extracted to create the 2×2 tables (ie, true-positive, true-negative, false-positive, and false-negative results). These tables were calculated with the Bayesian method (data were back-calculated according to prevalence and sample size) if only sensitivity and specificity were presented for an eligible study. If 2 or more reviewers independently assessed the diagnostic accuracy, the result with the highest accuracy was extracted.

**Primary Data Analysis**

Patient demographic characteristics and extracted covariates are summarized with standard descriptive statistics. Continuous variables are expressed as means and 95% confidence intervals (CIs), and categoric variables are expressed as frequencies or percentages unless stated otherwise.

We used a bivariate random-effects model to analyze and pool the diagnostic performance (sensitivity and specificity) measurements across studies. To derive summary estimates of diagnostic performance, we plotted estimates of the observed sensitivities and specificities for each test in forest plots and hierarchic summary receiver operating characteristic (ROC) curves derived from individual study results.[16-18] These results were plotted with hierarchic summary ROC curves with 95% confidence and prediction regions.

Heterogeneity was determined with Cochran's $Q$ test ($P<.05$ indicated the presence of heterogeneity) and the $I^2$ test (0% to 40%, heterogeneity might not be present; 30% to 60%, moderate heterogeneity; 50% to 90%, substantial heterogeneity; and 75% to 100%, considerable heterogeneity).[19] When heterogeneity was noted, that caused by a "threshold effect" was analyzed by visual assessment of the coupled forest plots of sensitivity and specificity. A meta-analysis of diagnostic test accuracy studies simultaneously evaluated a pair of outcomes (ie, sensitivity and specificity). Sensitivity and specificity are commonly inversely correlated and influenced by the threshold (cutoff) value.[16-18] In addition, Spearman's correlation coefficient between the sensitivity and false-positive rate was calculated to determine any threshold effect; a coefficient greater than 0.6 was considered to indicate a considerable threshold effect.[20] We omitted the funnel plot by Deeks et al[21] of individual studies for detection of publication bias according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses of Diagnostic Accuracy Studies.

For analyzing the false-negative rate of elbow ultrasonography, the meta-analytic pooling was based on the inverse variance method for calculating weights, and the unadjusted pooled proportions and their 95% CIs were determined with the DerSimonian-Laird random-effects model.[16-18] Publication bias–adjusted pooled estimates (ie, adjusted pooled proportions) were obtained with the trim-and-fill method.[22] If an agreement between the unadjusted and adjusted pooled proportions existed, we considered the results to be robust against publication bias.

Meta-regression analyses using several covariates were performed to investigate the potential causes of heterogeneity: study location (United States versus other countries), number of study centers (multicenter versus single center), total patients (≥50 versus <50), proportion of elbow fracture (≥50% versus <50%), mean age (≥7 versus <7 years), reference standard (only elbow radiograph versus including elbow MRI), ultrasonographic performer (pediatric emergency physicians versus others), extra musculoskeletal ultrasonographic training before the study (yes versus not reported), and study cohort (different cohort [comparison with different patients without elbow trauma] versus same cohort [comparison of same patient's symptomatic versus normal elbows]). Board-certified musculoskeletal radiologists were considered to have had extra musculoskeletal ultrasonographic training. Meta-regression analysis is more statistically sound when the number of studies is as evenly distributed as possible between covariate groups; the cutoff values of 50 patients and aged 7 years were chosen to result in as even a split of number of studies into each group (eg, ≥50 versus <50 patients) as possible.

All statistical analyses were performed by one author, who has experience in performing systematic reviews and meta-analyses. The statistical analyses were performed with the midas and metandi modules in Stata (version 10.0; StataCorp, College Station, TX) and the mada and metafor packages in R (version 3.4.1; R Foundation for Statistical Computing, Vienna, Austria). Results were considered statistically significant at $P<.05$.

## RESULTS

Figure 1 shows a flow diagram summarizing the literature search. During the initial search, 139 studies were identified. After removing 16 duplicates, we reviewed 123 titles and abstracts and then excluded 109 studies for the following reasons: they were case reports, letters, editorials, and conference abstracts (n=9); review articles, guidelines, and consensus statements (n=11); and not in the field of interest (n=89). After reviewing the full text of 14 eligible articles,

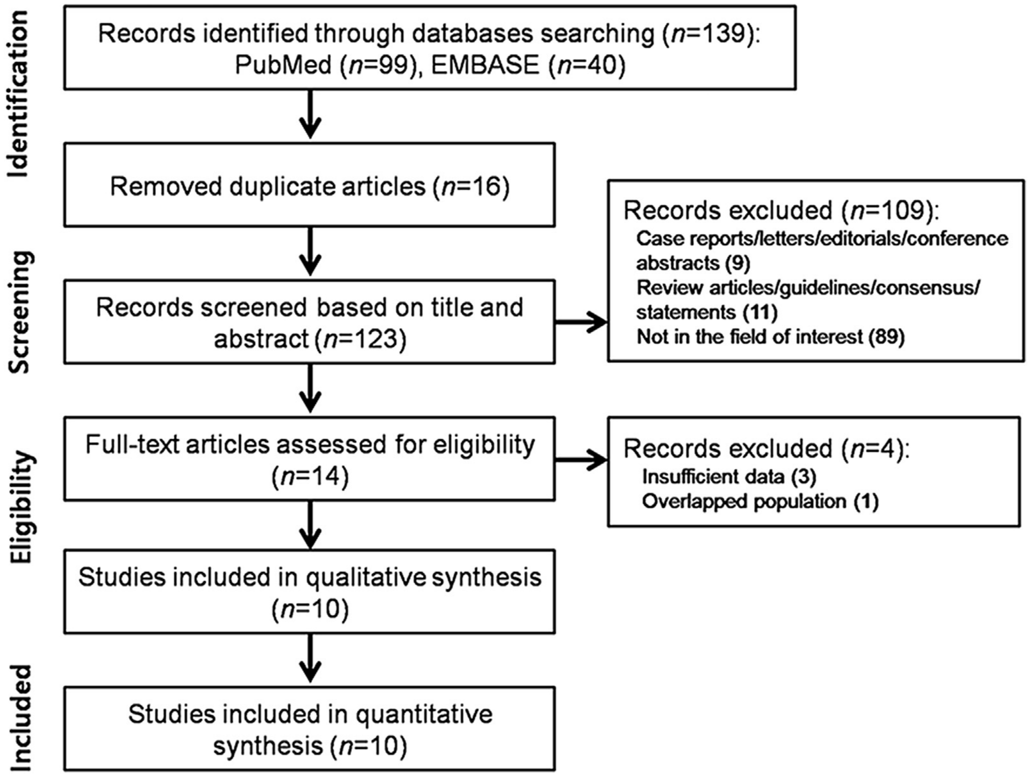


**Figure 1.** Study selection process for the meta-analysis.

we excluded 4 for the following reasons: they were studies with insufficient data for a 2×2 table (n=3)[11,23,24] and overlapped population (n=1).[12] Finally, 10 original research articles[6,13,25-32] including a total of 519 patients (537 elbows) were included in the meta-analysis. Eight studies[6,13,26-29,31,32] evaluated the diagnostic performance of ultrasonography with a different cohort (comparison with different patients), and 2 studies[25,30] evaluated the diagnostic performance of ultrasonography with symptomatic versus normal elbows in the same patients (paired data).

## Characteristics of Study Subjects

The patient characteristics are summarized in Table 1. The number of patients in the study ranged from 8 to 130. Mean age ranged from 1.9 to 8.5 years. The study and ultrasonographic characteristics are summarized in Tables 2

**Table 1.** Patient demographic characteristics.

| Author | No. of Patients | No. of Examined Elbows | No. With Fractures | Fracture (%) | Mean Age, Years | Age Range | Male Patients (%) |
|---|---|---|---|---|---|---|---|
| Davidson et al[26] | 8 | 8 | 6 | 75.0 | 1.9 | NR | 75.0 |
| Zuazo et al[31] | 14 | 14 | 7 | 50.0 | 8.5 | NR | 64.3 |
| Zhang and Chen[30] | 9 | 18 | 9 | 50.0 | NR | 2–9 y | NA |
| Weinberg et al[13] | 30 | 30 | 15 | 50.0 | NR | NR | NA |
| Cho et al[25] | 9 | 18 | 9 | 50.0 | 7.3 | 2–12 y | 100 |
| Rabiner et al[6] | 130 | 130 | 43 | 33.1 | 7.5 | 3 mo–21 y | 55.4 |
| Eckert et al[27] | 79 | 79 | 38 | 48.1 | 6.5 | 14 mo–13 y | NA |
| Eckert et al[28] | 106 | 106 | 60 | 56.6 | 5.9 | 1–13 y | 56.6 |
| Burnier et al[32] | 34 | 34 | 13 | 38.2 | 8 | NR | 55.9 |
| Tokarski et al[29] | 100 | 100 | 42 | 42.0 | 7.9 | 0.9–19 y | 55.0 |

*NR*, Not reported; *NA*, not available.

**Table 2.** Characteristics of the included studies.

| Author | Year | Locale | Study Period | No. of Study Centers | Reference Standard | Study Cohort |
|---|---|---|---|---|---|---|
| Davidson et al[26] | 1994 | United States | 5/1989–8/1992 | Single center | Elbow radiograph | Different cohort |
| Zuazo et al[31] | 2008 | France | 7/2005–3/2007 | Single center | Elbow MRI | Different cohort |
| Zhang and Chen[30] | 2008 | China | 2003–NR | Single center | Elbow radiograph or elbow MRI | Same cohort with symptomatic and normal elbow |
| Weinberg et al[13] | 2010 | United States | 7/2007–5/2008 | Multicenter (2 centers) | Elbow radiograph | Different cohort |
| Cho et al[25] | 2010 | South Korea | 4/2002–3/2008 | Single center | Elbow radiograph, elbow MRI, or bone scan | Same cohort with symptomatic and normal elbow |
| Rabiner et al[6] | 2013 | United States | 9/2010–12/2011 | Multicenter (2 centers) | Elbow radiograph | Different cohort |
| Eckert et al[27] | 2014 | Germany | 6/2012–1/2013 | Single center | Elbow radiograph | Different cohort |
| Eckert et al[28] | 2014 | Germany | 5/2010–12/2011 | Single center | Elbow radiograph | Different cohort |
| Burnier et al[32] | 2016 | France | 1/2014–4/2014 | Single center | Elbow radiograph | Different cohort |
| Tokarski et al[29] | 2018 | United States | 10/2014–8/2016 | Single center | Elbow radiograph | Different cohort |

and 3. All studies were of prospective design with blinding of ultrasonographic operators from the reference standard and consecutive patient recruitment. Two studies[6,13] were double center and 8 studies[25-32] were single center. All studies used radiologic assessments (radiograph, CT, MRI, or bone scan) with or without clinical follow-up as the reference standard.

In all studies, presence of elbow fracture was defined as a posterior fat pad sign, cortical disruption, growth plate widening, or hematoma interposed between fracture fragments. Absence of elbow fracture was defined as neither a posterior fat pad sign nor cortical disruption.

Figure 2 shows the risk of bias and poor applicability for the 10 included studies. Overall, no studies were considered to be seriously flawed according to the Quality Assessment of Diagnostic Accuracy Studies–2 tool. All of the studies satisfied greater than or equal to 4 of the 7 items.

The risk of bias in regard to the patient selection domain was considered high in 2 studies[25,30] because they used symptomatic and normal elbows in the same patients (paired data) to evaluate the diagnostic performance of ultrasonography. In regard to the index test domains, all studies were considered to have a low risk of bias. In regard to the reference standard domain, 2 studies[25,30] were considered at high risk because they used 2 or more radiologic modalities for the reference standard. In regard to the flow and timing domain, one study[25] had an unclear risk of bias because the mean interval between ultrasonography and the reference

**Table 3.** Technical parameters and interpretative characteristics of the included studies.

| | Technical Parameters | | | Interpretation | |
|---|---|---|---|---|---|
| Author | Vendor | Model | Frequency (MHz) | Ultrasonographic Performer | Extra Musculoskeletal Ultrasonographic Training |
| Davidson et al[26] | Philips | UltraMark4 | 7.5 | Pediatric OS | NR |
| Zuazo et al[31] | Philips | iU22 | 13–17 | Musculoskeletal radiologist | Yes* |
| Zhang and Chen[30] | Siemens | NR | 7–12 | Pediatric OS | NR |
| Weinberg et al[13] | Sonosite/Siemens | Micromaxx/GS60 | 7.5–10 | Pediatric emergency physician | Yes |
| Cho et al[25] | Philips | HDI 5000, iU22 | 5–12 | Musculoskeletal radiologist | Yes* |
| Rabiner et al[6] | Sonosite | M-turbo or MicroMaxx | 5–10 | Pediatric emergency physician | Yes |
| Eckert et al[27] | NR | NR | 12 | Pediatric emergency physician | Yes |
| Eckert et al[28] | NR | NR | 12 | Pediatric emergency physician | Yes |
| Burnier et al[32] | Philips | iU22 | 12.5 | Pediatric OS | NR |
| Tokarski et al[29] | Sonosite | Edge | 5–10 | Pediatric emergency physician | Yes |

*OS*, Orthopedic surgeon.
*Board-certified musculoskeletal radiologists were considered to have extra musculoskeletal ultrasonographic training.

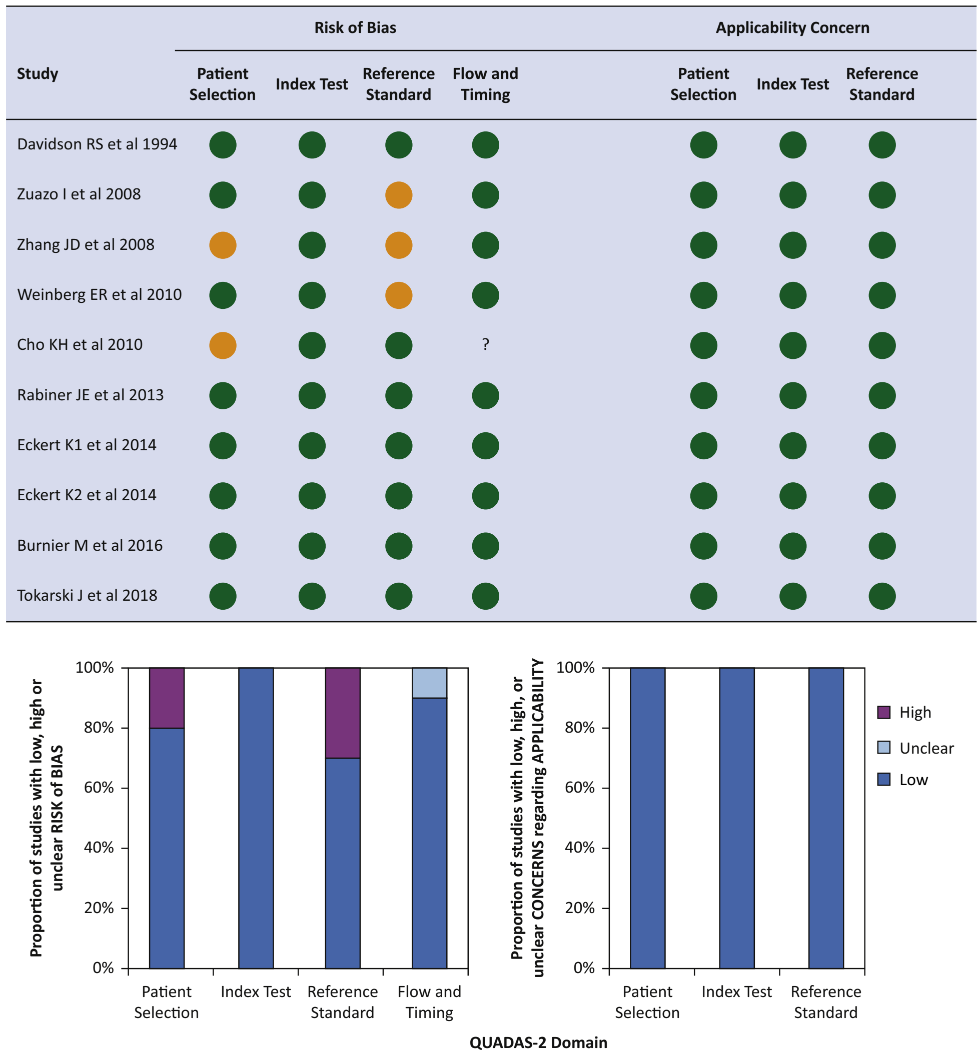


**Figure 2.** Grouped bar charts showing the risk of bias (left) and applicability concerns (right) for the 10 included studies, using the Quality Assessment of Diagnostic Accuracy Studies–2 domains. ●, Low risk; ●, high risk; ?, unclear risk.

standard was not reported. All studies exhibited low concern for lack of applicability to the research question in terms of patient selection, index test, and reference standard domains.

The 10 studies[6,13,25-32] had sensitivity values that ranged from 0.80 to 1.00 and specificity values that ranged from 0.74 to 1.00. The summary sensitivity and specificity values were 0.96 (95% CI 0.88 to 0.99) and 0.89 (95% CI 0.82 to 0.94), respectively. The *Q* test revealed significant heterogeneity ($Q$=1.367; $P$=.02), with substantial heterogeneity detected for sensitivity ($I^2$=61.39%) and specificity ($I^2$=60.64%). A threshold effect was observed in the coupled forest plot of sensitivity and specificity and in the correlation between sensitivity and the false-positive rate (0.051; 95% CI −0.364 to 0.448). The area under the hierarchic summary ROC curve was 0.97 (95% CI 0.95 to 0.98) (Figure 3).

Overall false-negative rate of elbow ultrasonography demonstrated a pooled proportion of 3.7% (95% CI 2.5% to 6.5%). After adjusting for publication bias with the trim-and-fill approach, the adjusted pooled proportion was 4.2% (95% CI 2.7% to 6.7%), which was in agreement with the unadjusted pooled estimates.

The results of the meta-regression analyses are summarized in Table 4. The significant sources of heterogeneity in terms of sensitivity were locale and number of study centers. Specifically, we observed that the differences in sensitivity in regard to locale (United States versus countries other than United States) and number of study centers (multicenter versus single

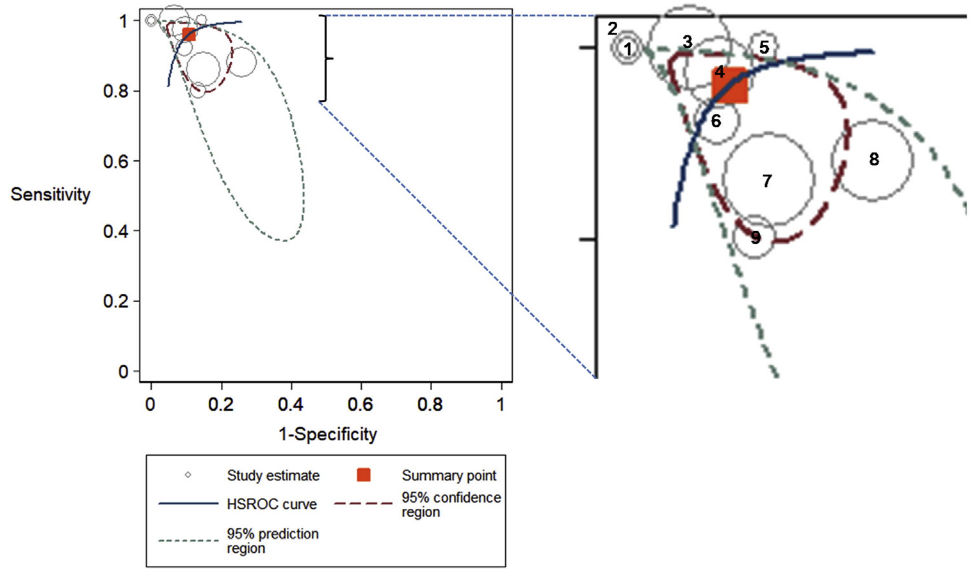


**Figure 3.** Hierarchic summary ROC curve for using elbow ultrasonography for pediatric elbow fracture. The summary point (red box) indicates that the summary sensitivity was 0.96 and the summary specificity was 0.89. The 95% confidence region represents the 95% CIs of summary sensitivity and specificity, and the 95% prediction region represents the 95% CIs of sensitivity and specificity for each included study. The study estimates indicate the sensitivity and specificity estimated with the data from each study. The size of the marker is scaled according to the total number of patients in each study. 1: Davidson et al[26] sensitivity 100% (6/6), specificity 100% (2/2). 2: Cho et al[25] sensitivity 100% (9/9), specificity 100% (9/9); Zhang et al[30] sensitivity 100% (9/9), specificity 100% (9/9). 3: Eckert et al[28] sensitivity 100% (60/60), specificity 93% (43/46). 4: Eckert et al[27] sensitivity 97% (37/38), specificity 90% (37/41). 5: Zuazo et al[31] sensitivity 100% (7/7), specificity 86% (6/7). 6: Burnier et al[32] sensitivity 92% (12/13), specificity 90% (19/21). 7: Rabiner et al[6] sensitivity 86% (37/43), specificity 85% (74/87). 8: Tokarski et al[29] sensitivity 88% (37/42), specificity 74% (43/58). 9: Weinberg et al[13] sensitivity 80% (12/15), specificity 87% (13/15).

center) were 0.1 (95% CI 0.07 to 0.14) and 0.11 (95% CI 0.04 to 0.18), respectively. The significant sources of heterogeneity in terms of specificity were ultrasonographic performer and extra musculoskeletal ultrasonographic training. In particular, we observed that differences in specificity in regard to ultrasonographic performer (pediatric emergency physicians versus others) and ultrasonographic operators with extra musculoskeletal ultrasonographic training (trained versus not reported) were 0.12 (95% CI 0.05 to 0.19) and 0.07 (95% CI 0.05 to 0.11), respectively. Other factors, including number of total patients, percentage of patients with elbow fracture, mean age, reference standard, and study cohort (different patients versus paired data), were not significantly different (sensitivity $P$=.33 to >.99; specificity $P$=.15 to .61).

## LIMITATIONS

The present study has several limitations. First, it has a relatively small number of included studies and we used broad search terms and included only easily accessible studies (published in English and available in the PubMed and EMBASE databases). Nevertheless, we were able to draw several important conclusions in regard to the diagnostic performance of ultrasonography and related factors. Second, all included studies revealed positive results that could be attributed to publication bias, which is impossible to quantify. Although we omitted funnel plots by Deeks et al[21] according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses of Diagnostic Accuracy Studies guidelines, we observed a low probability of publication bias (overall $P$=.96; subgroup analysis $P$=.74), which suggests that this factor did not undermine our results. Third, we could not evaluate the diagnostic performance of elbow ultrasonography according to Salter-Harris type because of the insufficient information in the included studies. Weinberg et al[13] reported that fractures involving only growth plate, such as Salter-Harris type V, may be difficult to diagnose with elbow ultrasonography. Fourth, methodological differences existed among the included studies, and extensive meta-regression analysis revealed that these variables were also significant sources of heterogeneity. This methodological diversity might have affected the pooled estimates, especially because the ultrasonographic technical parameters were not assessed in the meta-regression analysis because not all studies reported the values for gain, dynamic range, and mechanical index.

**Table 4.** Meta-regression analyses for potential sources of heterogeneity.

| Covariate | No. of Studies | Sensitivity (95% CI) | *P* Value | Specificity (95% CI) | *P* Value |
|---|---|---|---|---|---|
| **Locale** | | | <.01* | | .24 |
| United States | 4 | 0.87 (0.80–0.93) | | 0.85 (0.79–0.91) | |
| Countries other than United States | 6 | 0.97 (0.94–1.00) | | 0.90 (0.86–0.95) | |
| **Study center** | | | .01* | | .61 |
| Multicenter | 2 | 0.85 (0.71–0.98) | | 0.85 (0.74–0.96) | |
| Single center | 8 | 0.96 (0.93–0.99) | | 0.89 (0.83–0.95) | |
| **No. of patients** | | | .85 | | .15 |
| ≥50 | 4 | 0.95 (0.89–1.00) | | 0.87 (0.80–0.94) | |
| <50 | 6 | 0.92 (0.84–1.00) | | 0.93 (0.86–1.00) | |
| **Elbow fracture, %** | | | .84 | | .19 |
| ≥50 | 6 | 0.95 (0.90–1.00) | | 0.91 (0.84–0.97) | |
| <50 | 4 | 0.92 (0.85–0.99) | | 0.85 (0.78–0.91) | |
| **Mean age, y** | | | .33 | | .52 |
| ≥7 | 5 | 0.89 (0.83–0.95) | | 0.85 (0.79–0.92) | |
| <7 | 3 | 0.97 (0.95–0.99) | | 0.90 (0.84–0.96) | |
| **Reference standard** | | | <.99 | | .28 |
| Only elbow radiograph | 7 | 0.94 (0.89–0.99) | | 0.87 (0.81–0.93) | |
| Including elbow MRI | 3 | 0.94 (0.83–1.00) | | 0.96 (0.89–1.00) | |
| **Ultrasonographic performer** | | | .48 | | .02* |
| Pediatric emergency physician | 5 | 0.95 (0.87–1.00) | | 0.94 (0.88–1.00) | |
| Others | 5 | 0.93 (0.88–0.99) | | 0.86 (0.80–0.92) | |
| **Extra musculoskeletal ultrasonographic training** | | | .91 | | .03* |
| Yes | 7 | 0.94 (0.89–0.99) | | 0.94 (0.86–1.00) | |
| Not reported | 3 | 0.94 (0.85–1.00) | | 0.87 (0.81–0.93) | |
| **Study cohort** | | | .57 | | .45 |
| Different cohort | 8 | 0.95 (0.86–0.98) | | 0.87 (0.80–0.92) | |
| Same cohort | 2 | 1.00 (0.76–1.00) | | 1.00 (0.77–1.00) | |

*Statistical significance (*P*<.05).

Further prospective studies with larger sample sizes are needed to determine the optimal parameters for elbow ultrasonography in evaluating potential fracture.

## DISCUSSION

The present meta-analysis revealed that ultrasonography performed well for detecting pediatric elbow fracture (sensitivity 96%, specificity 89%). The pooled proportion of the false-negative rate of ultrasonography was 3.7%. In consideration of these findings, ultrasonography is a useful imaging modality for detecting pediatric elbow fracture.

The present study has 2 important strengths. First, we performed analyses considering the type of comparison (ie, different patients with and without fracture or the same patients with normal and symptomatic elbows [paired data]). Although the overall study quality was higher in studies with different patients with and without fracture, the pooled sensitivity and pooled specificity were not significantly different in meta-regression analysis. Second, we performed a meta-regression analysis to investigate causes of heterogeneity.

Elbow ultrasonography has advantages in terms of diagnostic accuracy according to the comparison of our meta-analysis results and results of previous included studies. Blumberg et al[33] reported that abnormal posterior fat pad on radiograph had a sensitivity of 87.5% and a specificity of 90.8%, whereas Rabiner et al[6] reported that it had a sensitivity of 93% and a specificity of 79%. In the study by Blumberg et al,[33] the pediatric emergency physician interpretations of the radiographs were 87.5% sensitive and 100% specific for elbow fracture, and abnormal radiographic findings on radiologist review were 96% sensitive and 100% specific. In a cadaveric study,[34] elbow effusions of 1 to 3 mL could be identified with elbow ultrasonography, whereas it took 5 to 10 mL of fluid to produce a positive posterior fat pad sign on radiographs.

Elbow ultrasonography also has advantages in terms of time effectiveness (decreased length of stay) and reduced radiation exposure (reduced elbow radiograph) according to previous studies. Ultrasonography is less time consuming compared with other modalities; this may be related to its performance at bedside, allowing clinicians to make quicker treatment decisions.[35] Tokarski et al[29] reported that completion and interpretation of point-of-care elbow ultrasonography takes a median of 3 minutes, whereas elbow radiography takes 60 minutes. Moreover, the use of ultrasonography may reduce radiation dose by reducing elbow radiography. In 2 previous studies,[6,29] the potential reduction in the use of elbow radiography ranged from 23% to 48%, which may reduce radiation exposure. Ultrasonographic applications may be particularly advantageous in pediatric patients because of small body size and density[7] and increased susceptibility to adverse effects of radiation.

Our meta-regression analysis revealed that ultrasonographic performer and presence of extra musculoskeletal ultrasonographic training before the study were sources of heterogeneity. In particular, the summary specificity was higher in studies with pediatric emergency physicians and ultrasonographic performers with extra musculoskeletal ultrasonographic training compared with studies with other performers or performers with no extra musculoskeletal ultrasonographic training. More recently, emergency ultrasonography has been formally incorporated into pediatric emergency medicine fellowship training because improved operator proficiency improves diagnostic performance.[36,37] We recommend that physicians with extra musculoskeletal ultrasonographic training perform the initial ultrasonography to detect pediatric elbow fracture.

In our results, specificity of elbow ultrasonography was relatively lower than sensitivity. This may have been due to the detection of more cases of subtle posterior fat pad signs in elbow ultrasonography compared with radiography. However, whether posterior fat pad signs truly indicate high likelihood of fracture is controversial, and a study with MRI follow-up showed that few patients had fracture on MRI.[8] Therefore, diagnosis of fracture by posterior fat pad sign on elbow ultrasonography may result in a higher false-positive rate than radiography.

Elbow ultrasonography, which is a noninvasive, radiation-free modality, demonstrated high performance in the diagnosis of pediatric elbow fracture, particularly in studies with physicians with extra musculoskeletal ultrasonographic training. Ultrasonography may be performed by trained physicians as a first-line diagnostic tool to more accurately diagnose pediatric elbow fracture.

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*Author contributions:* Both authors conceived the study, conducted online literature searches, and performed data extraction and quality assessment. SJY supervised the conduct of the trial and data collection and analyzed the data. SHL drafted the article, and both authors contributed substantially to its revision. SJY takes responsibility for the paper as a whole.

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