Diagnostic accuracy of point-of-care ultrasound for paediatric testicular torsion: a systematic review and meta-analysis

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ABSTRACT

Background Previous studies have examined the utility of ultrasonography performed by radiologists for diagnosing paediatric testicular torsion. While point-of care ultrasound (POCUS) is used in paediatric emergency medicine, its diagnostic accuracy is still unknown.

Objectives The present systematic review and meta analysis aimed to clarify the accuracy of POCUS in diagnosing testicular torsion in children.

Methods Following the Preferred Reporting Items for Systematic Review and Meta-analysis of Diagnostic Test Accuracy guidelines, a systematic review was performed using the indices of MEDLINE, EMBASE plus EMBASE classics, PubMed and the Cochrane database from inception to November 2020. Any study investigating the diagnostic accuracy of POCUS for paediatric testicular torsion was extracted. The primary outcome was the assessment of the diagnostic accuracy of POCUS for paediatric testicular torsion. The pooled sensitivity and specificity were calculated. Quality analysis was conducted using Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2).

Results Four studies enrolling 784 patients in total were included. The pooled sensitivity, specificity, and positive and negative likelihood ratios of POCUS were 98.4% (95% CI: 88.5% to 99.8%), 97.2% (95% CI: 87.2% to 99.4%), 34.7 (95% CI: 7.4 to 164.4) and 0.017 (95% CI: 0.002 to 0.12), respectively. Risk-of-bias assessment using QUADAS-2 revealed that two of the studies had a high risk of bias in patient selection. **Conclusion** The present systematic review and meta analysis showed that POCUS had high sensitivity and specificity for identifying testicular torsion in paediatric patients although the risk of bias was high in the studies analysed.

INTRODUCTION

Misdiagnosing or delaying treatment of testicular torsion can lead to irreversible complications, such as the loss of the testis or infertility. Testicular torsion accounts for 10%–15% of acute scrotum in the paediatric population.[1] Acute scrotal pain, erythema and scrotal swelling are common presen tations of testicular torsion in children but can have other aetiologies, such as torsion of the appendix testis and epididymo-orchitis.[1] Moreover, nausea, vomiting and loss of the cremasteric reflex, which are relatively specific findings,[2] are not consistently recognised in paediatric testicular torsion.[3] Testic ular Workup for Ischemia and Suspected Torsion (TWIST), a prediction scoring system combining

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Ultrasonography performed by radiologists has

high sensitivity and specificity for diagnosing

paediatric testicular torsion, but the diagnostic

accuracy of point-of-care ultrasound (POCUS) is

still unknown.

WHAT THIS STUDY ADDS

⇒ The present systematic review and meta-analysis showed that POCUS had high sensitivity and specificity for identifying

testicular torsion in paediatric patients although

the risk of bias in the studies analysed was high.

HOW THIS STUDY MIGHT AFFECT RESEARCH,

PRACTICE OR POLICY

⇒ The high specificity of POCUS for detecting

paediatric testicular torsion demonstrated

that children with a positive ultrasonography

⇒ However, prospective studies enrolling only

the accuracy of POCUS in diagnosing testicular

result should immediately undergo exploratory

paediatric patients are warranted to evaluate

torsion in children, as the quality of evidence in

surgery.

this meta-analysis is not high.

necessity of urological consultation,[4] had a positive

respectively.[5] Nonetheless, diagnosing testicular

symptoms and physical findings to predict the

and negative predictive value of 93.5% and 100%,

torsion remains challenging.

The diagnostic gold standard is exploratory surgery, but its invasiveness and requirement for general anaesthesia are undesirable. MRI and scintigraphy are sometimes used, but the need for proce

dural sedation in the former and radiation exposure in the latter also make them less than desirable.[6]

Thus, ultrasonography (US), especially colour

Doppler US (CDUS), is now preferred owing to an increasing reliance on non-ionising radiation. Grey scale US evaluates the size, shape, and echotexture

of the testis and can detect twisted spermatic cord, a specific feature of testicular torsion known as the whirlpool sign.[7] CDUS is used for evaluating blood

flow in the testes where an absence or decrease in blood flow may indicate testicular torsion.[8] US conducted by radiologists to diagnose testicular torsion in adults has a sensitivity and specificity

of 86% and 95%, respectively.[9] In paediatric patients as well, its sensitivity and specificity exceed 90%.[10] Point-of-care ultra

Method of searching for the studies

sound (POCUS) is also used at the bedside to facilitate timely diagnosis in paediatric care and by physicians before referring patients to specialists or to guide invasive procedures for acute appendicitis and endotracheal tube placement.[11 12] However, the accuracy of POCUS in diagnosing paediatric testicular torsion is still unknown. The present systematic review and meta-analysis aimed to evaluate the accuracy of POCUS in diagnosing paedi
atric testicular torsion quantitatively and qualitatively.

MATERIALS AND METHODS

The present systematic review and meta-analysis was performed in accordance with the recommendations of the guidelines of the Preferred Reporting Items for Systematic Review and Meta analysis of Diagnostic Test Accuracy.[13] The study protocol was registered with the International Prospective Register of System atic Reviews at the National Institute for Health Research and Centre for Reviews and Dissemination (CRD) of the University of York (registration number: CRD42021208684).

Participants

Studies involving children younger than age 19 years who visited a hospital with symptoms suggestive of acute scrotum were included.

Inclusion/exclusion criteria

Any study investigating the diagnostic accuracy of US in paedi atric testicular torsion was included, except case reports, case series with sample sizes below 10, comments, animal studies and studies without original data. If enough studies enrolling only children were not able to be found, studies enrolling both adults and children were included for meta-analysis provided that more than half the cases were paediatric. All abstracts satisfying these criteria were reviewed as a full manuscript. Studies which were found to meet the eligibility criteria on full-text review were included in the final data analysis.

Index test

The index test consisted of US performed by the diagnosing physician. Positivity was based on a combination of specific signs of testicular torsion, such as decreased echogenicity of the testis, absence of blood flow in the testicular vessels and whirlpool sign. Whirlpool sign is defined as a spiral-like appearance of the sper
matic cord on US and is highly specific to testicular torsion.[14]

Reference standard

The reference test consisted of US performed either solely or jointly with radiologists and/or intraoperative findings during exploratory surgery and/or clinical follow-up. A positive result on radiologist-performed ultrasound consisted of a combination of specific signs of testicular torsion, such as decreased echoge
nicity of the testis, absence of blood flow in the testicular vessels and whirlpool sign.

Primary outcome

The primary outcome was the assessment of the diagnostic accu racy of POCUS for paediatric testicular torsion. The pooled sensitivity, specificity, and positive and negative likelihood ratios (LRs) and their 95% CIs were calculated.

The relevant literature was comprehensively reviewed using the Ovid medical research platform database, including MEDLINE, EMBASE plus EMBASE classics, PubMed and the Cochrane database from inception to November 2020. Search strategies were developed using medical subject headings and terms related to “testicular torsion”, “children” and “ultrasonography” (online supplemental appendix 1). Our search strategy was reviewed by experienced librarians (YM and KO) at the National Center for Child Health and Development. The search was conducted for studies in all languages. As the relevant studies were identified, the reviewers looked for additional, relevant, cited and citing articles in the references of the eligible studies. The principal investigators of the studies were contacted to clarify the study’s eligibility if needed. The primary author was contacted to supply missing or unpublished data or information about other studies not retrieved in our initial research. Studies in languages other than English were reviewed using DeepL translator.

Quality assessment

The studies included were assessed for their quality using Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS 2),[15] which assessed the four domains of patient selection, index test, reference test, and flow and timing for biases. Two separate investigators then independently assessed the studies (TM and TI).

Data extraction

Two reviewers (TM and TI) independently screened the titles and abstracts of all the retrieved bibliographical records. The inclusion and exclusion criteria were applied at each step of the screening. If no abstract was available, the full text was retrieved unless the article was able to be excluded with confidence by its title alone. If there was any doubt as to whether a study should be excluded, it was examined on a full-text screen. The full text of potentially eligible studies was independently retrieved by the two reviewers.

Decision process

The eligibility assessment, quality assessment and data extraction were performed by two independent reviewers (TM and TI). Differences in assessment were resolved through discussion or via adjudication by a third reviewer (ON).

Strategy for data synthesis

The pooled sensitivity, specificity, positive and negative predictive values, and positive and negative LRs with 95% CIs were calculated. A bivariate model was used to derive summary effect estimates. A hierarchical summary receiver operating characteristics (SROC) curve plotting sensitivity versus 1-specificity was constructed. The heterogeneity of the studies was graphically evaluated using a forest plot. Deek's funnel plot asymmetry test was planned to assess publication bias. Subgroup or sensitivity analysis was planned to assess the differences in the accuracy of POCUS in diagnosing paediatric testicular torsion depending on the US operators. The quality of the evidence was assessed in accordance with the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) for diagnostic test studies.[16]

Statistical analysis and construction of a forest plot were performed using RevMan (The Nordic Cochrane Centre, Copenhagen, Denmark) V.5.3, and other statistical analyses were performed using MetaDTA: Diagnostic Test Accuracy

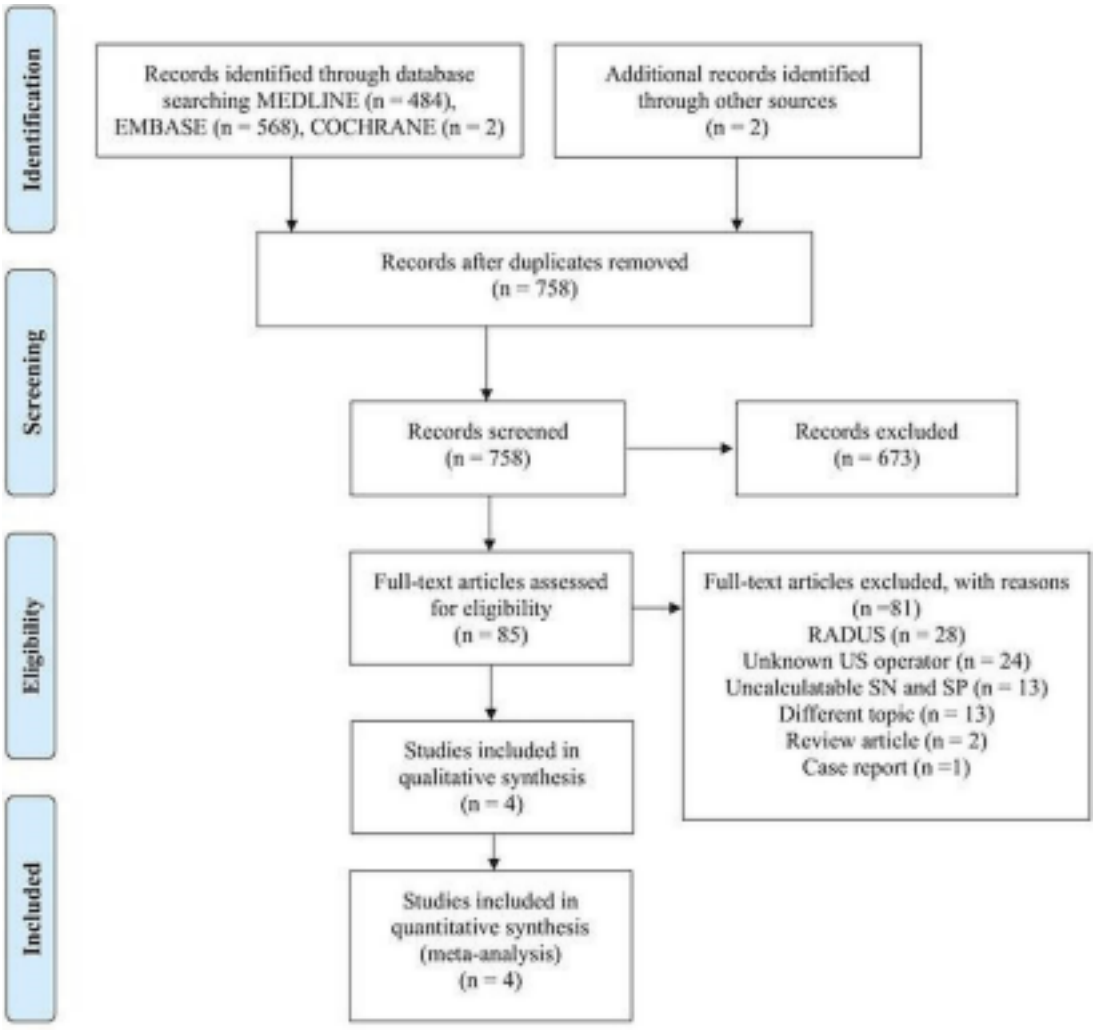

Figure 1 Study flow diagram. Flow diagram of the study selection process and exclusion criteria. RADUS, radiologist-performed ultrasound; SN,

sensitivity; SP, specificity; US, ultrasonography.

Meta-Analysis V.2[17] and Stata V.17 (Stata Corp, College Station, Texas, USA). GRADEpro GDT was used to create a table summarising the findings. P<0.05 was considered to indicate statistical significance.

RESULTS

Figure 1 shows the study selection flow. After applying the selec tion criteria to 758 studies identified as potentially eligible for enrolment, 4 studies were found to be suitable for a full analysis (figure 1).[18–21]

Test characteristics

Table 1 shows the characteristics of the studies included. In three of the four studies (Altinkilic *et al*,[18] Stehr and Boehm,[20] and Waldert *et al*[21]), POCUS was performed by a urologist, whereas in the fourth study (Friedman *et al*[19]), it was performed by a paediatric emergency medicine (PEM) physician. Table 2 shows the US protocol used in the included studies. Three studies used CDUS to diagnose testicular torsion,[18 20 21] while the protocol of one study was unclear.[19] None of the studies contained a detailed description of the physicians' use of US[18–21] and only one study included information about the training level of the operators, as shown in table 2.[19]

Accuracy of POCUS in diagnosing testicular torsion

Figure 2 shows the forest plot of the studies investigating the accuracy of POCUS in diagnosing testicular torsion. The four studies included 784 patients, and testicular torsion was iden tified in 205 patients, including 202 and 3 with a true positive and false positive result, respectively. The sensitivity and speci ficity of the included studies ranged 92%–100%and 75%–99%, respectively, as shown in table 3.[18–21] The quality of the evidence as assessed by GRADE was moderate, as shown in online supple mental appendix 2. The quality of evidence was downgraded for risk of bias and indirectness but upgraded for high diagnostic accuracy.

Meta-analysis of included studies

The four studies in figure 2 were included in the meta-analysis. The pooled sensitivity, specificity, positive and negative LRs, and false positive rate of POCUS were 98.4% (95% CI: 88.5% to 99.8%), 97.2% (95% CI: 87.2% to 99.4%), 34.7 (95% CI: 7.4 to 164.4) and 0.017 (95% CI: 0.002 to 0.12), and 2.8% (95% CI: 0.6% to 12.8%), respectively, as shown in table 3. The SROC curve demonstrated good test operating character istics, as shown in online supplemental appendix 3. Publication bias was not able to be assessed because only four studies were

Table 1 Characteristics of the studies included

Author/year	Design	Sample size	Median or mean age (age range or SD)	Prevalence of TT (%)	Setting	Inclusion criteria	Exclusion criteria
1 Altinkilic *et al*, 2013[18]	P	236	13 (0–53)	50.4 (119/236)	Tertiary university hospital	Patients referred for suspected TT	Not reported
2 Friedman *et al*, 2019[19]	R	120	10 (5–13)	10.0 (12/120)	Children's hospital	Patients who received POCUS then RADUS for suspected TT	Patients with POCUS after RADUS Patients with traumatic scrotal pain Patients who visited PED in previous 7 days Patients with incomplete POCUS documentation
3 Waldert *et al*, 2009	R	296	11.4 (4.1)	20.8 (62/298)	Tertiary university hospital	Patients with exploratory surgery for suspected TT or trauma	Not reported
4 Stehr and Boehm, 2003[20]	Not reported	132	Not reported (1-19)	9.1 (12/132)	Tertiary university hospital	Patients admitted with acute scrotum	Not reported

P, prospective; PED, paediatric ED; POCUS, point-of-care ultrasound; R, retrospective; RADUS, radiologist-performed ultrasound; TT, testicular torsion.

included. Neither a subgroup analysis nor a sensitivity analysis was performed for the same reason.

Risk of bias

Biases in the included studies were evaluated using QUADAS-2. Figure 3 shows the results of the assessment.

Patient selection

Two studies were rated as having a high risk of bias.[18 21] In all the studies, consecutive patients were enrolled without exception, but Altinkilic *et al*[18] and Waldert *et al*[21] only included patients who were referred by paediatricians or emergency physicians and those who underwent exploratory surgery, respectively. In terms of clinical applicability, the studies conducted by Altinkilic *et al*[18] and Waldert *et al*[21] might have had a selection bias.[21]

Index test

Three studies were rated as having a low risk of bias.[18 20 21] The risk of bias in the study by Friedman *et al* was unclear because the threshold of the US examination was not documented.[19] In terms of clinical applicability, three studies were considered to have a low risk of bias.[19–21] The risk of bias in one study (Altinkilic *et al*[18]) was unclear as information from the referring physicians may have affected the interpretation of the index test.

Reference standard

Two studies were rated as having a low risk of bias.[18 21] This was unclear in two studies by Friedman *et al* and Stehr and Boehm,[19 20] as indicated above. One study did not indicate if the interpreters of the reference tests, including exploratory surgery and clinical follow-up, were blinded.[20] Studies including

Table 2 Characteristics of POCUS protocol in included studies

Author/year	Ultrasound machine used	US transducer used	US operator	Training level	US protocol	Index findings	Reference standard
1 Altinkilic *et al*, 2013[18]	Combision 420 (Kretz Medical, Kraichtal, Germany) Pro Focus (BK Medical, Quickborn, Germany) SA 8800 MT, (Sonoace, Mari, Germany)	Linear transducer (7.5–10 MHz)	URO Senior urologist	Perfusion of testicular parenchyma analysed	CDUS	Surgical findings	
2 Friedman *et al*, 2019[19]	Zonare z.one (Mindray, Mahwah, New Jersey, USA) A Xzonare zs3 (Mindray, Mahwah, New Jersey, USA)	Linear transducer (5–14 MHz)	PEM PEM fellow PEM attending POCUS fellow Resident	Not reported	US diagnosis by PEM	Final diagnosis in medical records (RADUS, hospital discharge diagnosis and clinic follow-up reports)	

3 Stehr and Boehm, 2003[20]	Not reported	Linear transducer (7–12 MHz)	URO	Trained urologist	Perfusion of testicular parenchyma was analysed in testicular arteries and veins (absent or decreased perfusion was considered as TT)	CDUS Surgical findings
4 Waldert *et al*, 2009[21]	GE Logic 400 MD (GE Medical Systems, Germany)	Linear transducer (11–13.5 MHz)	URO	Not reported	Perfusion of testicular parenchyma evaluated, and resistance indices calculated (>0.7 hypoperfusion) Absent or decreased perfusion was considered to indicate TT	CDUS Surgical findings and clinical follow-up reports

CDUS, colour Doppler ultrasound; PEM, paediatric emergency medicine; POCUS, point-of-care ultrasound; TT, testicular torsion; URO, urologist; US, ultrasonography.

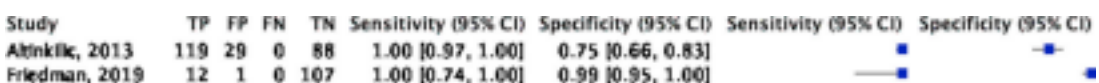

Figure 2 Forest plot of the sensitivity and specificity of studies of POCUS for diagnosing paediatric testicular torsion. FN, false negative; FP, false positive; POCUS, point-of-care ultrasound; TN, true negative; TP, true positive.

a clinical follow-up in the reference standard may have intro duced a bias by excluding patients in whom testicular torsion was later diagnosed.[19 20] In terms of clinical applicability, all the studies were rated as having a low risk of bias.

Flow and timing

Three studies were considered as having a low risk of bias.[18–20] However, this was unclear in the study by Waldert *et al*, which did not document the timing between US examination and exploratory surgery.[21]

DISCUSSION

The present systematic review and meta-analysis examined the accuracy of POCUS in diagnosing paediatric testicular torsion. POCUS has the potential to enable physicians to diagnose paediatric testicular torsion rapidly and safely thanks to its non-invasiveness and portability. It is therefore appropriate to investigate the evidence currently available for recommending POCUS as the principal tool for detecting testicular torsion. Our findings were encouraging; POCUS was found to have a high sensitivity of 98.4% and specificity of 97.2% in identifying testicular torsion. Our assessment of the risk of bias using QUADAS-2 revealed that two of the studies included had a high risk-of-bias rating in patient selection.

Strengths and limitations

One strength of the present analysis is its emphasis on paediatric studies evaluating the efficacy of POCUS in diagnosing testic ular torsion. Unlike previous reviews,[9 14] our analysis excluded studies of adult patients, those evaluating the diagnostic accu racy of radiologist-performed ultrasound, and those without a description of the US operators, thus making our findings more relevant to evaluating the accuracy of US performed by treating physicians to diagnose paediatric testicular torsion. Age

Table 3 Individual and pooled diagnostic accuracy of the studies included

in testicular torsion shows a bimodal distribution comprising the neonatal and adolescent periods,[22] and for paediatricians and PEM physicians, understanding the feasibility of POCUS is crit ical to enhancing the quality of their daily practice.

Furthermore, the present analysis demonstrated that the sensitivity and specificity of POCUS in diagnosing paediatric testicular torsion were high. Previous studies demonstrated that the sensitivity and specificity of radiologist-performed ultrasound in diagnosing paediatric testicular torsion fell into the 63%–100%and 68%–100%range, respectively.[1 10 23–27] A study conducted in a paediatric ED demonstrated that a diagnosis based on POCUS was highly compatible with that of radiologists.[19] The current review demonstrated that non-radiologists were able to perform scrotal US to diagnose paediatric testicular torsion.

The present systematic review has several limitations. Our methodology excluded studies with unpublished data, thus potentially limiting the scope of the data analysed. Furthermore, assessment for publication bias using Deek's funnel plot asymmetry test was planned, but the number of included studies (four) was too small for analysis. In terms of the studies included in the meta-analysis, first, the number of studies included was limited, and half of the studies included were retrospective, which may affect the generalisability of the results.[19 21] Only one study demonstrated the utility of POCUS when performed by PEM physicians.[19] Second, patients in three different age groups (neonates, adolescents and adults) were included, also affecting the generalisability of the results, as the differential diagnosis among these groups varied. Third, none of the studies included a detailed description of the physicians' use of US.[18–21] POCUS is an operator-dependent procedure, and a certain amount of

training is necessary to obtain adequate images for diagnostic purposes. Further investigation is needed to determine the optimal manner and length of training a sonographer needs to ensure high-quality POCUS findings.[28]

Individual diagnostic accuracy						
Authors	**SN (%) (95%CI)**	**SP (%) (95%CI)**	**PPV (%) (95%CI)**	**NPV (%) (95%CI)**	**Positive LR (%) (95%CI)**	**Negative LR (%) (95%CI)**
Altinkilic *et al*[18]	100 (97.2 to 100.0)	76.2 (72.4 to 75.2)	80.4 (78.2 to 80.4)	100.0 (96.3 to 100.0)	4.0 (3.5 to 4.0)	0.0 (0.0 to 3.8)
Friedman *et al*[19]	100.0 (83.1 to 100.0)	99.1 (97.2 to 99.1)	92.3 (76.7 to 92.3)	100.0 (98.1 to 100.0)	108.0 (29.6 to 108.0)	0.0 (0.0 to 17.4)
Stehr and Boehm[20]	91.7 (72.6 to 97.7)	99.2 (97.3 to 99.8)	91.7 (72.6 to 97.7)	8.4 (2.3 to 28.2)	110.0 (26.4 to 424.4)	0.08 (0.023 to 0.28)
Waldert *et al*[21]	96.8 (91.2 to 99.0)	97.9 (96.4 to 98.5)	92.3 (87.0 to 94.5)	99.1 (97.6 to 99.7)	45.3 (25.3 to 64.4)	0.03 (0.01 to 0.09)
Pooled diagnostic accuracy						
	SN	**SP**	**False positive rate**	**PPV**	**NPV**	**Positive LR**

Parameter	(%) (95%CI)	(%) (95%CI)	(%) (95%CI)	(%) (95%CI)	(%) (95%CI)	(%) (95%CI)	Negative LR (%) (95%CI)
POCUS 98.4	(88.5 to 99.8)	97.2 (87.2 to 99.4)	2.80 (0.6 to 12.8)	84.9 (82.8 to 85.7)	99.5 (98.5 to 99.8)	34.7 (7.4 to 162.4)	0.017 (0.002 to 0.12)

LR, likelihood ratio; NPV, negative predictive value; POCUS, point-of-care ultrasound; PPV, positive predictive value; SN, sensitivity; SP, specificity.

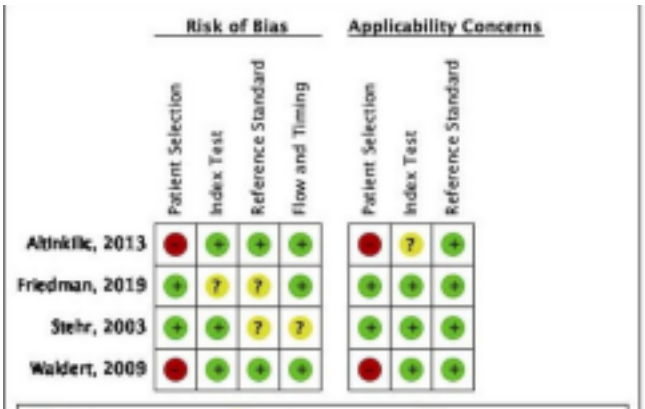

Figure 3 Methodological assessment of the included studies using QUADAS-2. QUADAS-2, Quality Assessment of Diagnostic

Clinical application and relevance

In terms of the clinical applicability of our findings, our review was able to offer suggestions for improving paediatric emergency care. The high specificity of POCUS for detecting testicular torsion demonstrated that children with a positive US result should immediately undergo exploratory surgery, thereby reducing the time from the ED examination to surgery by removing the need for radiologist-performed ultrasound to confirm the diagnosis. A previous study demonstrated that the median hospital time in patients who underwent radiologist performed ultrasound was 235min.[29] Considering the limited time frame available for salvaging a twisted testis, the decision to perform surgery based on POCUS findings has the potential to increase the salvage rate of the affected testis in children with testicular torsion. For patients with a negative US result, the high sensitivity of POCUS may help rule out testicular torsion. POCUS findings should of course not be relied on exclusively to rule out testicular torsion given the risk of testicular damage resulting from misdiagnosis. Moreover, radiologist-performed ultrasound and other diagnostic modalities may still be indi cated as there are other important aetiologies to consider, such as torsion of the appendix testis and epididymo-orchitis, even when POCUS findings are negative. A previous study demonstrated 67%–91%agreement between the findings of POCUS performed by PEM physicians and the final diagnosis in cases of epididymo-orchitis, varicocele and hydrocele.[19] Moreover, another study demonstrated that the assessment of patients with acute scrotum using CDUS significantly decreased the rate of exploratory surgery

from 92% to 8% without increasing the number of testes lost.[26] Furthermore, the TWIST score, used to rule out testicular torsion, had a negative predictive value ranging from 96% to 100%.[4 5 30] Combining a physical exam ination using the TWIST score with US may enhance diagnostic accuracy and thus reduce patients' length of hospitalisation.

Implications for further research

The heterogeneity of the inclusion criteria, the US protocol and the reference standard may have contributed to the lack of generalisability of the results. In future research, all patients with suspected paediatric testicular torsion should be included to eliminate selection bias, and a unified US protocol and reference standard should be used.

With regard to the US protocol, all the included studies used a high-frequency linear transducer. Although the ideal frequency range depends on testicular size, a high-frequency transducer (above 7 MHz) should be used. In our meta-analysis, US protocols, including greyscale US and/or CDUS based on a combination of specific signs of testicular torsion, such as decreased echogenicity of the testis, absence of blood flow in the testicular vessels and whirlpool sign, were searched for. Of the four included studies, three studies used CDUS to diagnose testicular torsion.[18 20 21] CDUS is often used to detect testicular torsion by assessing intratesticular perfusion, and the current meta-analysis demonstrated a high sensitivity and specificity for identifying paediatric testicular torsion, but radiologist-performed ultrasound scanning of twisted spermatic cords (ultrasonographic whirlpool sign) demonstrated higher sensitivity than CDUS in diagnosing paediatric testicular torsion.[10] In addition, a meta-analysis assessing the accuracy of the whirlpool sign demonstrated a 92% sensitivity and 99% specificity for paediatric and adult testicular torsion[14] although the US operator was a radiologist or unknown. However, no studies evaluating the accuracy of POCUS of the whirlpool sign have been reported. Thus, a step-by-step protocol analysing anatomy and flow (spectral analysis) is essential and future research aimed at establishing the optimal US protocol is warranted.

Furthermore, the current review included only one study of POCUS performed by PEM physicians. PEM physicians initially encounter patients with suspected testicular torsion in the emergency or outpatient setting. To improve paediatric care, a prospective study should be conducted to investigate the diagnostic accuracy of POCUS when used by PEM physicians.

To conclude, the present systematic review and meta-analysis demonstrated that POCUS had high sensitivity and specificity in identifying testicular torsion in paediatric patients. However, the quality of the evidence of the studies analysed was moderate owing to a high risk of bias and heterogeneity. The present findings should be considered as preliminary in view of the small number of studies analysed and the inclusion of only one paediatric ED. Before recommendations can be issued for the use of POCUS, larger, prospective paediatric studies are needed to clarify the training, requirements, techniques, protocols and accuracy of the modality for identifying testicular torsion.

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Contributors TM conceptualised and designed the study, collected the data, carried out the initial analysis, drafted the initial manuscript, and reviewed and revised the manuscript. TI collected the data, supervised the initial analysis and critically reviewed the manuscript for important intellectual content. ON critically reviewed the manuscript for important intellectual content. All the authors have read and approved the final manuscript. TM accepts full responsibility for the work and/ or the conduct of the study, had access to the data, and controlled the decision to publish as quarantor.

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Patient consent for publication Not required.

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the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

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146 Mori T, et al. Emerg Med J 2023;**40**:140–146. doi:10.1136/emermed-2021-212281

Appendix 1: Searching strategy

1 MEDLINE®

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1 exp Ultrasonography/ or exp Ultrasonography, Doppler/ (442392)
2 (Echotomograph* or "Echo tomograph*" or Ultrasound or "ultra sound" or ultrasonic or "ultra sonic" or ultrasonogra* or sonogra* or echograph* or doppler).mp. (574398)
3 1 or 2 (680161)
4 "Point-of-Care Testing"/ or exp "POINT-OF-CARE SYSTEMS "/ (15170)
5 ("Point-of-Care" or "Point of Care" or Bedside or "bed side" or POC or POCT or POCUS or "POC US").mp. (57605)
6 exp "Emergency Service, Hospital"/ or exp Emergencies/ (119076)
7 (Emergency or Emergencies or nonradiologist* or nonradiologists or "non radiologist*" or nonurologist* or "non urologist*").mp. (347657)
8 4 or 5 or 6 or 7 (406714)
9 exp "Sensitivity and Specificity"/ or exp "Area Under Curve"/ or exp "Predictive Value of Tests"/ or ROC Curve/ or Likelihood Functions/ (640164)
10 (accuracy or DTA or specificity or Sensitivity or likelihood).mp. (2155888)
11 ((False adj (negative or positive)) or ("Area Under" adj2 Curve*) or ROC or (Receiver adj3 Characteristic*) or (predictive adj3 value)).mp. (497722)
12 9 or 10 or 11 (2475951)
13 8 or 12 (2841364)
14 exp Scrotum/ or exp "Spermatic Cord Torsion"/ (11032)
15 (scrotum* or scrotal or (Spermatic Cord adj3 Torsion*) or (Torsion$2 adj4 Cord) or (testicular adj Torsion$2)).mp. (20697)
16 exp testis/ or (Testicle$ or Testes or spermar$4 or orchis).mp. (94438)
17 14 or 15 or 16 (109304)
18 3 and 13 and 17 (949)
19 limit 18 to children (484)
****

【OVID Childre Filter 】

exp adolescent/ or exp child/ or exp infant/ or (infant disease* or childhood disease*).ti,ab,kf. or (adolescen* or babies or baby or boy? or boyfriend or boyhood or child* or girl? or infant* or juvenil* or kid? or minors

or minors* or neonat* or neonat* or newborn*

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or new-born* or paediatric* or peadiatric* or pediatric* or perinat* or preschool* or puber* or pubescen* or school* or teen* or
toddler? or underage? or under-age? or youth*).ti,ab,kf.
****

2 EMBASE
No. Query Results Date
#1 'echography'/exp 853,495 27-Nov-20
#2 'doppler ultrasonography'/exp 71,981 27-Nov-20
#3 #1 OR #2 853,495 27-Nov-20
#4 echotomograph*:ti,ab,kw,de OR 'echo tomograph*':ti,ab,kw,de OR ultrasound:ti,ab,kw,de OR 'ultra sound':ti,ab,kw,de OR ultrasonic:ti,ab,kw,de OR 'ultra sonic':ti,ab,kw,de OR ultrasonogra*:ti,ab,kw,de OR sonogra*:ti,ab,kw,de OR echograph*:ti,ab,kw,de OR doppler:ti,ab,kw,de 937,456 27-Nov-20
#5 #3 OR #4 1,225,481 27-Nov-20
#6 'point of care testing'/exp 14,379 27-Nov-20
#7 'point of care system'/exp 2,277 27-Nov-20
#8 'point-of-care':ti,ab,kw,de OR 'point of care':ti,ab,kw,de OR bedside:ti,ab,kw,de OR 'bed side':ti,ab,kw,de OR poc:ti,ab,kw,de OR poct:ti,ab,kw,de OR pocus:ti,ab,kw,de OR 'poc us':ti,ab,kw,de 83,080 27-Nov-20

#9 'hospital emergency service'/exp 5,594 27-Nov-20 #10 'emergency'/exp 55,502 27-Nov-20

#11 emergency:ti,ab,kw,de OR emergencies:ti,ab,kw,de OR nonradiologist*:ti,ab,kw,de OR nonradiologists:ti,ab,kw,de OR 'non radiologist*':ti,ab,kw,de OR nonurologist*:ti,ab,kw,de OR 'non urologist*':ti,ab,kw,de 557,829 27-Nov-20

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#12 #6 OR #7 OR #8 OR #9 OR #10 OR #11 629,973 27-Nov-20

#13 'sensitivity and specificity'/exp 372,472 27-Nov-20

#14 'area under the curve'/exp 149,559 27-Nov-20

#15 'predictive value'/exp 179,740 27-Nov-20

#16 'receiver operating characteristic'/exp 137,397 27-Nov-20

#17 'statistical model'/exp 248,234 27-Nov-20

#18 accuracy:ti,ab,kw,de OR dta:ti,ab,kw,de OR specificity:ti,ab,kw,de OR sensitivity:ti,ab,kw,de OR likelihood:ti,ab,kw,de

#19 ((false NEAR/1 (negative OR positive)):ti,ab,kw,de) OR (('area under' NEAR/2 curve*):ti,ab,kw,de) OR roc:ti,ab,kw,de OR ((receiver NEAR/3 characteristic*):ti,ab,kw,de) OR ((predictive NEAR/3 value):ti,ab,kw,de)

#20 #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 2,659,295 27-Nov-20 613,553

27-Nov-20

3,169,713 27-Nov-20

#21 #12 OR #20 3,726,569 27-Nov-20 #22 'scrotum'/exp 10,236 27-Nov-20 #23 'testis torsion'/de 4,144 27-Nov-20

#24 scrotum*:ti,ab,kw,de OR scrotal:ti,ab,kw,de OR (spermatic:ti,ab,kw,de AND ((cord NEAR/3 torsion*):ti,ab,kw,de)) OR ((torsion* NEAR/4 cord):ti,ab,kw,de) OR ((testicular NEAR/1 torsion*):ti,ab,kw,de) 28,841 27-Nov-20

#25 'testis'/exp 110,960 27-Nov-20

#26 testicle*:ti,ab,kw,de OR testes:ti,ab,kw,de OR spermar*:ti,ab,kw,de OR orchis:ti,ab,kw,de 47,787 27-Nov-20

#27 #22 OR #23 OR #24 OR #25 OR #26 151,799 27-Nov-20 #28 #3 OR #4 1,225,481 27-Nov-20 #29 #21 AND #27 AND #28 1,805 27-Nov-20

#30 #29 AND ([adolescent]/lim OR [child]/lim OR [infant]/lim OR [newborn]/lim OR [preschool]/lim OR [school]/lim OR [young 694 27-Nov-20

 adult]/lim)

#31 (infant:ti,ab,kw,de AND disease*:ti,ab,kw,de OR childhood:ti,ab,kw,de) AND disease*:ti,ab,kw,de OR

(((adolescen*:ti,ab,kw,de OR babies:ti,ab,kw,de OR baby:ti,ab,kw,de OR boy?:ti,ab,kw,de OR boyfriend:ti,ab,kw,de OR boyhood:ti,ab,kw,de OR child*:ti,ab,kw,de OR girl?:ti,ab,kw,de OR infant*:ti,ab,kw,de OR juvenil*:ti,ab,kw,de OR kid?:ti,ab,kw,de OR minors:ti,ab,kw,de OR minors*:ti,ab,kw,de OR neonat*:ti,ab,kw,de OR newborn* or:ti,ab,kw,de) AND 'new born*':ti,ab,kw,de OR paediatric*:ti,ab,kw,de OR peadiatric*:ti,ab,kw,de OR pediatric*:ti,ab,kw,de OR perinat*:ti,ab,kw,de OR preschool*:ti,ab,kw,de OR puber*:ti,ab,kw,de OR pubescen*:ti,ab,kw,de OR school*:ti,ab,kw,de OR teen*:ti,ab,kw,de) AND or toddler?:ti,ab,kw,de) OR underage?:ti,ab,kw,de OR 'under age?':ti,ab,kw,de OR youth*:ti,ab,kw,de	566,063	27-Nov-20	
#32	#29 AND #31	105	27-Nov-20
#33	#30 OR #32	701	27-Nov-20
#34	#33 AND ('Article'/it OR 'Article in Press'/it OR 'Review'/it)	568	27-Nov-20
#35	#33 NOT #34	133	27-Nov-20

3 Cochrane database
Date Run: 07/11/2020 04:30:15
Comment:

ID Search Hits

#1 [mh Ultrasonography] OR [mh "Ultrasonography, Doppler"] 13623
#2 (Echotomograph* OR Ultrasound OR ultra sound OR ultrasonic OR ultrasonogra* OR sonogra* OR echograph* OR doppler):ti,ab,kw 49674
#3 #1 OR #2 52624
#4 [mh "Point-of-Care Testing"] OR [mh "POINT-OF-CARE SYSTEMS"] 482
#5 ("Point-of-Care" OR "Point of Care" OR Bedside OR POC OR POCT OR POCUS OR "POC US"):ti,ab,kw 6046
#6 [mh "Emergency Service, Hospital"] OR [mh Emergencies] 3711
#7 (Emergency OR Emergencies OR nonradiologist* OR nonradiologists OR "non radiologist*" OR nonurologist* OR "non urologist*"):ti,ab,kw 25819
#8 #4 OR #5 OR #6 OR #7 31317
#9 [mh "Sensitivity and Specificity"] OR [mh "Area Under Curve"] OR [mh "Predictive Value of Tests"] 21861
#10 ("diagnostic test accuracy" OR DTA OR specificity OR Sensitivity OR "likelihood ratio" OR "Area Under Curve*" OR ROC OR "Receiver Operating Characteristic*" OR "predictive value"):ti,ab,kw 79533
#11 #9 OR #10 79631
#12 #8 OR #11 108947
#13 #3 AND #12 5995
#14 [mh adolescent] OR [mh child] OR [mh infant] OR [mh minors] 147709
#15 (child* OR adolescen* OR babies OR baby OR boy OR boies OR boyfriend OR boyhood OR child* OR infant* OR juvenil*):ti,ab,kw 277024
#16 (kid OR kids OR minor OR minors OR neonate OR newborn* OR "new-born" OR paediatric* OR peadiatric* OR pediatric*):ti,ab,kw 76234
#17 (preschool* OR pubertal OR pubescence OR pubescent OR school* OR teen* OR toddler OR underage OR "under-age" OR youth*):ti,ab,kw 75506
#18 #14 OR #15 OR #16 OR #17 308951
#19 #13 AND #18 1030
#20 [mh Scrotum] OR [mh "Spermatic Cord Torsion"] 50
#21 (scrotum* OR scrotal OR "Spermatic Cord Torsion*"):ti,ab,kw 411
#22 ((Torsion NEAR/4 Cord) OR (testicular NEAR/4 Torsion)):ti,ab,kw 5

#23 [mh testis] OR (Testicle*OR Testes OR spermar* OR orchis):ti,ab,kw 281

#24 #20 OR #21 OR #22 OR #23 668

#25 #19 AND #24 2

#26 #3 AND #8 1674

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Supplemental material placed on this supplemental material which has been supplied by the author(s) *Emerg Med J* #27 #26 AND

#24 1

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Appendix 2 Summary of findings table

Sensitivity	0.98 (95% CI: 0.88 to 1.00)							
Specificity	0.97 (95% CI: 0.87 to 0.99)							
Outcome	№ of studies (№ of patients)	Study design	Factors that may decrease certainty of evidence					
			Risk of bias	Indirectness	Inconsistency	Imprecision	Publication bias	pre-test probability 25.7%
True	4 studies 205	cross-sectional (cohort type	serious*	serious†	not serious	not serious	unevaluable	253 (226 to 2

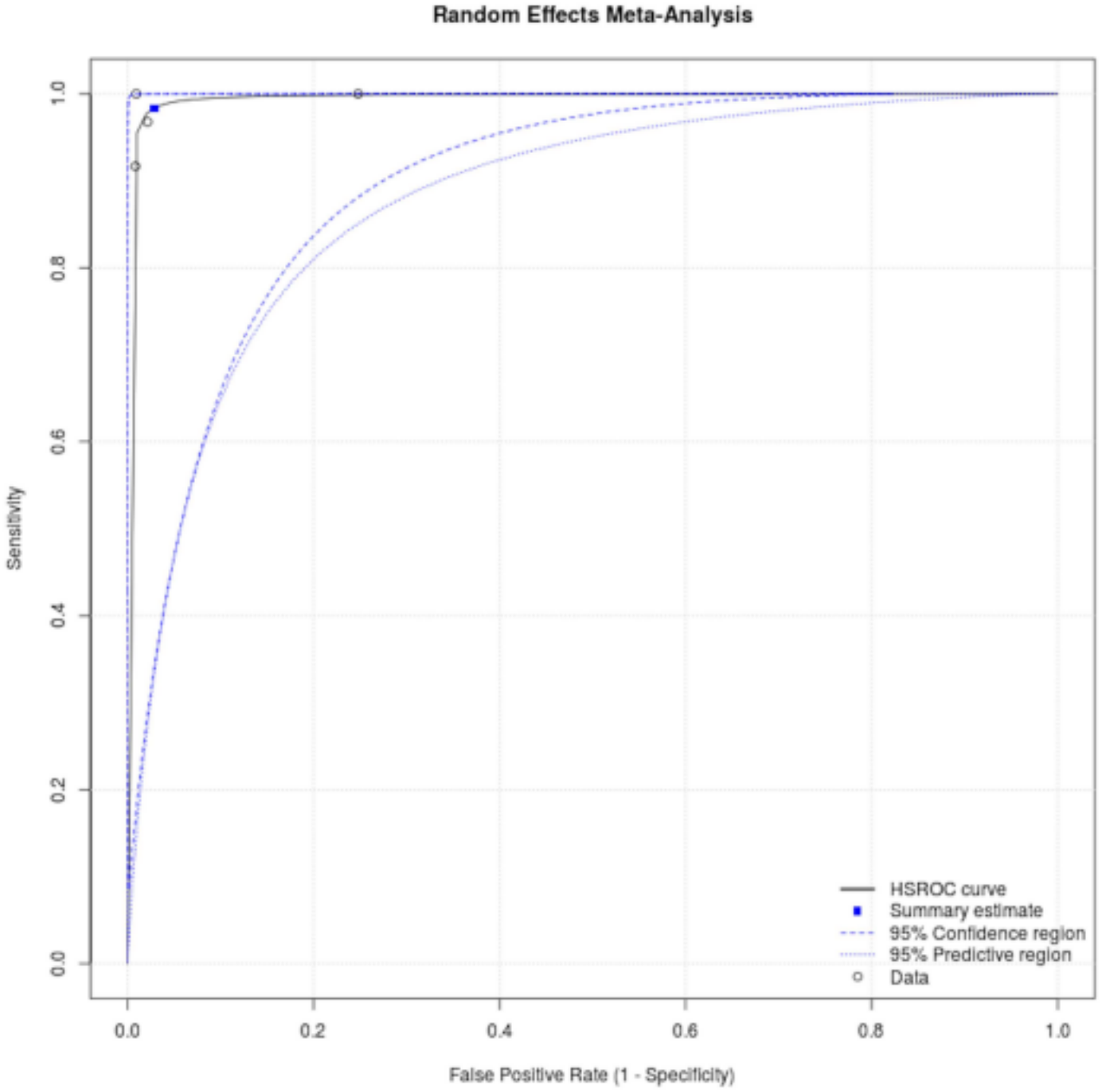
positives	patients	accuracy study)					‡	
False negatives								4 (0 to 31)
True negatives	4 studies 579 patients	cross-sectional (cohort type accuracy study)	serious*	serious†	not serious	not serious	unevaluable ‡	722 (648 to 7
False positives								21 (4 to 95)

True positives: patients with testicular torsion, false negatives: patients incorrectly classified as not having testicular torsion, true negatives: patients without testicular torsion, false positives: patients incorrectly classified as having testicular torsion.

* Patient selection concerns in two studies and unclear risk of bias in three studies.
† Variability in study design, and heterogeneity.
‡ Publication bias was not assessed due to the small number of included studies.
§ Certainty of evidence assessed by GRADE was moderate, downgraded for risk of bias and indirectness, upgraded for high diagnostic accuracy.

We present true positives, true negatives, false positives, and false negatives at the summary prevalence from included studies of 15.4% and two lower prevalence of 3.8% and 0.004% as prevalence lower than our summary prevalence has been reported in literature.

CoE certainty of evidence, GRADE Grading Recommendations Assessment, Development, and Evaluation.


Random Effects Meta-Analysis
Sensitivity
False Positive Rate (1 - Specificity)
0.0
0.2
0.4
0.6
0.8
1.0
HSROC curve
Summary estimate
95% Confidence region
95% Predictive region
Data