Section: Radiodiagnosis

Original Research Article

COMPARATIVE DIAGNOSTIC PERFORMANCE OF ABDOMINAL ULTRASOUND VERSUS ABDOMINAL RADIOGRAPH IN THE DIAGNOSIS OF NECROTIZING ENTEROCOLITIS IN NEONATES: A SYSTEMATIC REVIEW AND META-ANALYSIS

Nagasai Pelala[1], Shaik Shafreen[1], Gowtham Raj[1], R. Ramesh Kumar[1]

[1]Department of Radiodiagnosis, P.E.S. Institute of Medical Sciences and Research (PESIMSR), Kuppam, Andhra Pradesh, India

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Corresponding Author:
Dr. Nagasai Pelala,
Email: nagasai.pelala@gmail.com

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ABSTRACT

Background: The aim is to systematically compare the diagnostic performance of abdominal ultrasound (AUS) versus abdominal radiograph (AXR) in neonatal necrotizing enterocolitis (NEC) using DerSimonian-Laird random-effects meta-analytic methodology. **Materials and Methods:** This systematic review and meta-analysis followed PRISMA-DTA guidelines. Electronic databases (PubMed, PMC, RSNA, Springer, ScienceDirect, BMC, Frontiers, medRxiv) were searched for studies comparing AUS and AXR in neonatal NEC (1964–March 2025). Study quality was assessed using a modified QUADAS-2 framework. The primary meta-analysis used DerSimonian-Laird (DL) random-effects pooling of paired detection-rate differences (risk difference, RD). Subgroup analyses were performed for pneumatosis intestinalis (PI) and portal venous gas (PVG). AUROC comparison used inverse-variance weighted random-effects meta-analysis. Fourteen primary studies (13 with quantifiable cohorts, n = 1,188; Raghuveer et al. 2019 contributed reported sensitivity percentages only) and three prior meta-analyses were included. **Result:** DL random-effects pooled RD was +22.1% (95% CI: 13.7–30.5%; $p < 0.001$; $I^2 = 67.2\%$) favouring AUS. PI subgroup RD: +28.5% (95% CI: 15.5–41.4%; $I^2 = 65.7\%$). PVG subgroup RD: +11.6% (95% CI: 5.5–17.6%; $I^2 = 3.2\%$). Pooled ΔAUC was +0.133 (95% CI: 0.074–0.192; $p < 0.001$; $I^2 = 0\%$). For bowel necrosis, colour Doppler US achieved 100% sensitivity versus 40% for AXR ($p = 0.03$), with AUS NPV of 100%. AXR PPV was only 45.5%. The three strongest ultrasound predictors of surgical NEC — focal fluid collections (OR 17.9), complex ascites (OR 11.3), and absent peristalsis (OR 10.7) — are exclusively detectable by ultrasound. **Conclusion:** This meta-analysis provides Level 1 evidence that AUS significantly outperforms AXR across all diagnostic performance domains in neonatal NEC. Abdominal ultrasound should be incorporated as a routine adjunct to radiography in the evaluation of all neonates with suspected NEC, and should be considered the primary modality in extremely premature infants and those with gasless abdomen.

INTRODUCTION

Necrotizing enterocolitis (NEC) remains the most common and devastating acquired gastrointestinal emergency in newborn infants, particularly those born prematurely. Despite decades of research and advances in neonatal intensive care, NEC continues to be a leading cause of morbidity and mortality among very low birth weight (VLBW) infants, with an estimated incidence of 5–14% in neonates weighing less than 1500 g at birth and a mortality rate ranging from 20% to 50% in those requiring surgical intervention.[1-10]

The clinical staging of NEC was first systematically proposed by Bell and colleagues in 1978 and subsequently refined by Walsh and Kliegman in 1986, classifying the disease into stages based on systemic, intestinal, and radiological findings. Both systems depend heavily upon abdominal radiographic findings, establishing plain abdominal radiography (AXR) as the cornerstone imaging modality for NEC diagnosis for over four decades.[11-20]

However, AXR carries significant limitations. Sensitivity of detection of pneumatosis intestinalis has been reported to be in 44-60% range even under optimal conditions.[5,6] In the early stages of intestinal

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necrosis in preterm neonates, the classic diagnostic features may not yet be evident on serial radiographs. This creates a dangerous diagnostic window where irreversible bowel damage can occur while imaging is falsely reassuring.[7]

There are key advantages of abdominal ultrasound (AUS) including real-time, dynamic assessment of bowel wall morphology, peristalsis, vascular perfusion and peritoneal fluid characteristics — all of which cannot be evaluated by AXR. It is portable, radiation-free, repeatable, and can be performed at the bedside.[8-12,21-30]

Despite substantial individual study evidence, no prior systematic review has directly compared paired detection performance of AUS versus AXR using random-effects meta-analytic methodology with formal heterogeneity assessment. The present systematic review and meta-analysis addresses this gap by pooling data from 14 primary studies (n = 1,188 neonates) spanning 2005–2025.[31-34]

MATERIALS AND METHODS

Protocol, registration, and reporting framework

This systematic review and meta-analysis was designed following PRISMA-DTA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses of Diagnostic Test Accuracy) guidelines.[35,36] The PIRD framework was applied: Population (neonates with suspected/confirmed NEC), Index test (AUS), Reference/comparator (AXR), Diagnosis (NEC per modified Bell staging criteria). The study was conducted at the Department of Radiodiagnosis and Imaging, P.E.S. Institute of Medical Sciences and Research (PESIMSR), Kuppam, Andhra Pradesh, India.

Search strategy: A systematic literature search was conducted across PubMed/MEDLINE, PubMed Central, RSNA publications, Springer, ScienceDirect, BMC, Frontiers in Pediatrics, and medRxiv. Search terms: ("necrotizing enterocolitis" OR "NEC") AND ("ultrasound" OR "ultrasonography") AND ("radiograph" OR "X-ray" OR "AXR"). All publications from database inception through March 2025 were included. Reference lists of included studies were hand-searched for additional eligible studies.

Inclusion and exclusion criteria

Inclusion: (1) studies comparing AUS and AXR findings in neonates with suspected or confirmed NEC; (2) detection rates, sensitivity, specificity, or AUROC reported for both modalities in the same cohort; (3) NEC diagnosed using modified Bell staging criteria; (4) original research articles.

Exclusion: case reports (<10 patients), non-NEC neonatal bowel pathology, animal/in-vitro studies, reviews without original data, unverifiable citations.

Quality assessment: Methodological quality was assessed using modified QUADAS-2 across four domains: patient selection, index test (AUS), reference standard, and flow and timing.[32] Risk of bias was rated as low, unclear, or high for each domain.

Statistical methods: The primary outcome was the paired difference in detection rates (Risk Difference, RD = AUS% − AXR%) for each NEC finding. RD values with 95% confidence intervals (CIs) were pooled using DerSimonian-Laird (DL) random-effects meta-analysis.[33] Heterogeneity was assessed by Cochran's Q and I^2 statistics.[34] Subgroup analyses were performed for pneumatosis intestinalis (PI) and portal venous gas (PVG). AUROC comparison used inverse-variance weighted random-effects pooling of paired ΔAUC values. A data isolation protocol (separating pre-2018 cohorts from the 2018 meta-analyses) was applied to prevent double-counting. All analyses were performed in Python 3.x using NumPy and SciPy.

RESULTS

Study selection: The systematic search yielded 590 records. After removing 76 duplicates, 514 records were screened by title and abstract. Full-text assessment of 53 remaining articles resulted in exclusion of 35 articles (case reports/letters: 10; outcome not relevant: 7; reviews without usable original data: 5; no Bell criteria: 5; no paired AUS-AXR data: 6; animal studies: 2), yielding 18 included studies: 14 primary studies meeting all inclusion criteria and 4 secondary meta-analyses retained as supplementary data sources. The PRISMA-DTA flow diagram is presented in [Figure 9].

Study characteristics: Fourteen primary studies were included: Faingold et al. 2005,[11] (n = 60), Dilli et al. 2011,[13] (n = 93), Shebrya et al. 2012,[15] (n = 30), Yikilmaz et al. 2014,[14] (n = 26), Zhong et al. 2016,[17] (n = 84), Chen et al. 2018,[18] (n = 86), Raghuveer et al. 2019,[6] (sensitivity percentages reported; raw patient count not specified), Arpita et al. 2020[16] (n = 200), Gao et al. 2021,[19] (n = 213), Lazow et al. 2021,[20] (n = 83), Ionov et al. 2024[21] (n = 84), Jia et al. 2025,[26] (n = 130), Sur et al. 2025[27] (n = 32), and Priyadarshi et al. 2025,[28] (n = 67); thirteen studies with quantifiable patient cohorts totalling 1,188 neonates from 10 countries across 4 continents spanning 2005–2025. Three prior meta-analyses were included as secondary sources: Cuna et al. 2018 diagnostic,[22] (n = 462), Cuna et al. 2018 surgical,[23] (n = 748), and Janssen Lok et al. 2018[24] (15 studies). The Bhattacharjee et al. 2025,[25] scoping review (101 studies) was cited narratively. Eight studies (57%) were prospective; six (43%) retrospective.

Quality assessment results: Patient selection was at low risk of bias in 9/14 studies (64%). Regarding the index test, only 3 studies explicitly reported AUS operator blinding to AXR results (Dilli 2011, Yikilmaz 2014, Chen 2018); the remainder had unclear blinding status — a systematic limitation of comparative imaging studies. All studies appropriately used modified Bell staging criteria as

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the reference standard (uniformly low risk). Flow and timing was adequate in 10/14 studies (71%). The QUADAS-2 traffic light chart is presented in Supplementary [Figure S5].

Overall detection rate meta-analysis: Across 12 paired observations from 7 primary studies, the DL random-effects pooled risk difference was +22.1% (95% CI: 13.7–30.5%; $z = 5.164$; $p < 0.001$) favouring AUS [Figure 1]. Substantial heterogeneity was present (Cochran's $Q = 33.53$, $df = 11$, $p = 0.0004$; $I^2 = 67.2\%$; $\tau^2 = 0.0135$).

Pneumatosis intestinalis subgroup: Six paired observations assessed PI detection. The DL pooled RD was +28.5% (95% CI: 15.5–41.4%; $z = 4.310$; $p < 0.001$; $I^2 = 65.7\%$) (Figure 2A). The largest effect was in early-stage NEC (Shebrya Stage I: +64.3%), where AXR failed to detect any intramural gas detected by AUS in 9/14 neonates.

Portal venous gas subgroup: Five paired observations assessed PVG detection. The DL pooled RD was +11.6% (95% CI: 5.5–17.6%; $z = 3.745$; $p < 0.001$; $I^2 = 3.2\%$) [Figure 2B]. Near-zero heterogeneity indicates remarkable consistency of AUS superiority for PVG detection across all study settings and time periods.

Free fluid detection: Arpita et al. (2020) ($n = 200$): AUS detected ascites in 100% of Stage 3 NEC cases while AXR detected none (100% vs. 0%).[16] This finding was not pooled (single study) but represents the most clinically unambiguous AUS advantage.

Sensitivity analysis: As a complementary sensitivity analysis, a paired t-test of 12 matched study-level detection rates yielded an unweighted mean AUS detection of 50.5% versus AXR 24.4% (mean difference +26.1%); $t(11) = 4.473$, $p = 0.00094$ (Cohen's $d = 1.291$). Wilcoxon signed-rank: $p = 0.00049$. The leave-one-out analysis (Supplementary Figure S3) confirmed robustness across all exclusion sets (range: +19.3% to +23.5%; all $p < 0.001$). The +26.1% unweighted mean difference differs from the +22.1% DL pooled risk difference because the t-test treats all observations equally, whereas the DL random-effects model weights observations by inverse variance, reducing the influence of small studies with wide confidence intervals.

Paired detection rates are detailed in [Table 1].

Specificity and predictive values: Mean pooled specificity of individual BUS findings was 94.8% ± 5.3% (range: 67–99%) based on the Cuna et al. (2018) diagnostic meta-analysis ($n = 462$, 6 studies) [Table 2, Figure 3].[22] AUS PPV was 80.0% and NPV was 100.0% for bowel necrosis detection (Yikilmaz et al. 2014).[14] AXR PPV was only 45.5% for definite NEC (Sur et al. 2025).[27] Full predictive value data are presented in [Table 3].

AUROC comparison: Three studies reported paired AUROC data ($n = 299$ total). Inverse-variance weighted random-effects meta-analysis of ΔAUC yielded pooled $\Delta AUC = +0.133$ (95% CI: 0.074–0.192; $z = 4.408$; $p < 0.001$; $I^2 = 0\%$) [Table 4, Figure 4]. No between-study heterogeneity indicates highly consistent AUS superiority in discriminative accuracy.

Bowel necrosis detection: Faingold et al. (2005): colour Doppler US achieved 100% sensitivity for bowel necrosis versus 40% for free air on AXR ($p = 0.03$).[11] AUS specificity was 95.4%, PPV 80%, NPV 100% (Yikilmaz et al. 2014).[14] [Figure 5].

Stage-wise BUS performance in ELBW neonates

Ionov et al. (2024) reported BUS diagnostic effectiveness of 96.8% for Stage 3 NEC in extremely low birth weight (ELBW) infants (sensitivity 75.0%, specificity 97.6%) compared with 82.9% for Stage 2 NEC (sensitivity 55.6%, specificity 91.4%), both $p < 0.05$ [Figure 6].[21]

Surgical prediction: Odds ratios: The Cuna et al. (2018) surgical prediction meta-analysis ($n = 748$, 11 studies) identified focal fluid collections (OR 17.9, 95% CI: 3.1–103.3), complex ascites (OR 11.3, 95% CI: 4.2–30.0), and absent peristalsis (OR 10.7, 95% CI: 1.7–69.0) as the three strongest predictors of surgical NEC or death — all exclusively detectable by ultrasound.[23] Of the 9 significant predictors, 7 are US-exclusive [Table 5, Figure 8].

Three-modality comprehensive comparison

The combined AUS + AXR model (Lazow et al. 2021) achieved the highest performance: AUC 0.937, sensitivity 92.9%, specificity 92.8% — substantially exceeding either modality alone.[20] Priyadarshi et al. (2025) demonstrated surgical NEC discrimination improved from 34.1% (AXR alone) to 78.3% with addition of AUS.[28] Comprehensive data are presented in [Figure 7].

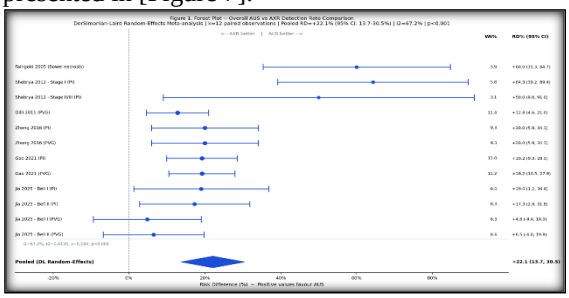

Figure 1: Forest plot showing individual study-level risk differences (AUS detection rate minus AXR detection rate) with 95% CIs for 12 paired observations. Square size proportional to study weight. Diamond = DerSimonian-Laird pooled estimate: RD = +22.1% (95% CI: 13.7–30.5%; $p < 0.001$; $I^2 = 67.2\%$).

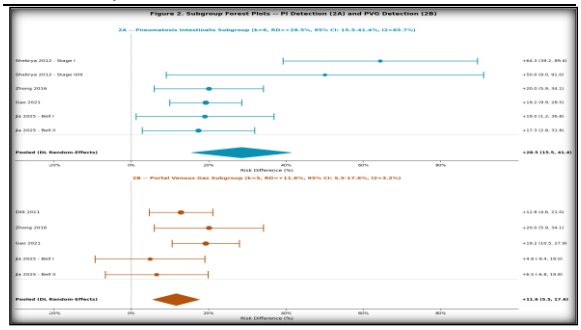

Figure 2. Subgroup forest plots. (2A) Pneumatosis intestinalis subgroup ($k = 6$): pooled RD = +28.5% ($I^2 = 65.7\%$). (2B) Portal venous gas subgroup ($k = 5$): pooled RD = +11.6% ($I^2 = 3.2\%$).

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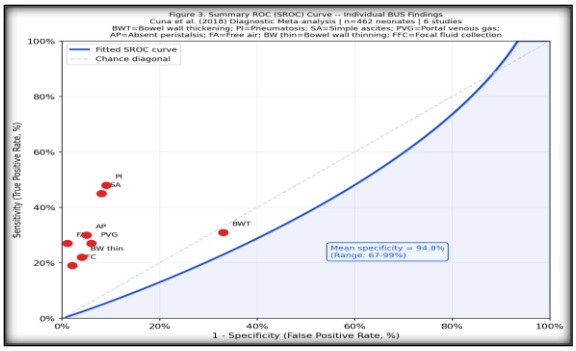

Figure 3: Summary ROC (SROC) curve for individual BUS findings. Data from Cuna et al. (2018) diagnostic meta-analysis, n = 462. Mean specificity 94.8%. BWT = bowel wall thickening; PI = pneumatosis intestinalis; SA = simple ascites; PVG = portal venous gas; AP = absent peristalsis; FA = free air; BW thin = bowel wall thinning; FFC = focal fluid collection.

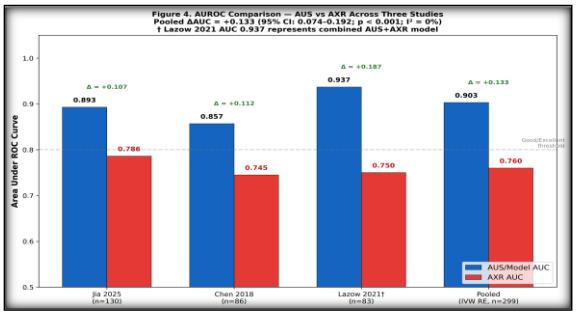

Figure 4: AUROC comparison across three studies (Jia 2025, Chen 2018, Lazow 2021). Pooled ΔAUC = +0.133 ($I^2 = 0\%$).

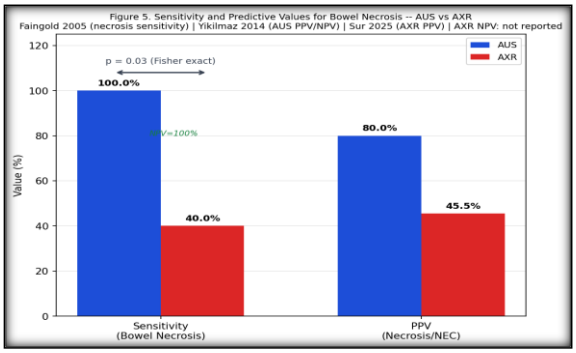

Figure 5: Sensitivity and predictive values for bowel necrosis: AUS 100% vs. AXR 40% (p = 0.03, Fisher's exact). AUS NPV = 100%; AXR PPV = 45.5%.

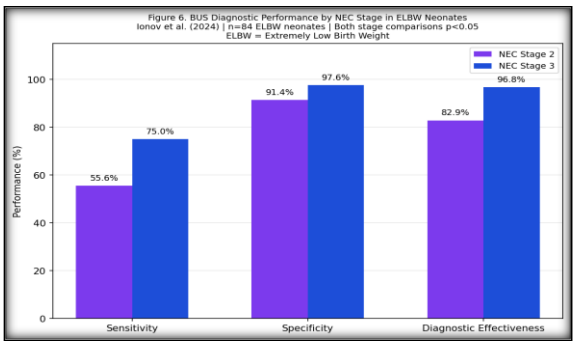

Figure 6: BUS diagnostic performance by NEC stage in ELBW neonates (Ionov et al. 2024, n = 84). Stage 3 outperforms Stage 2 across all metrics (both $p < 0.05$).

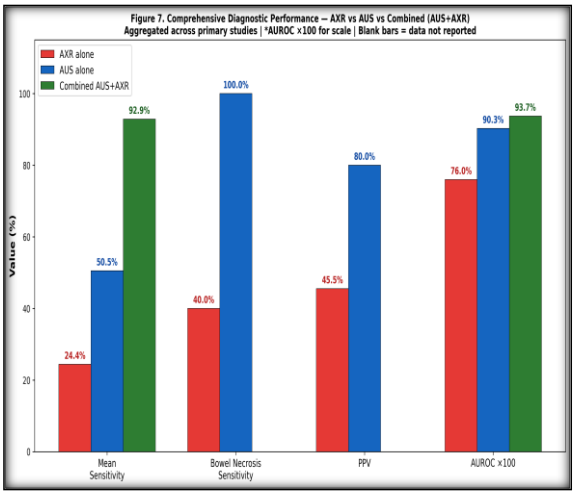

Figure 7: Three-modality comparison: AXR alone vs. AUS alone vs. combined AUS + AXR. Combined model achieves highest performance.

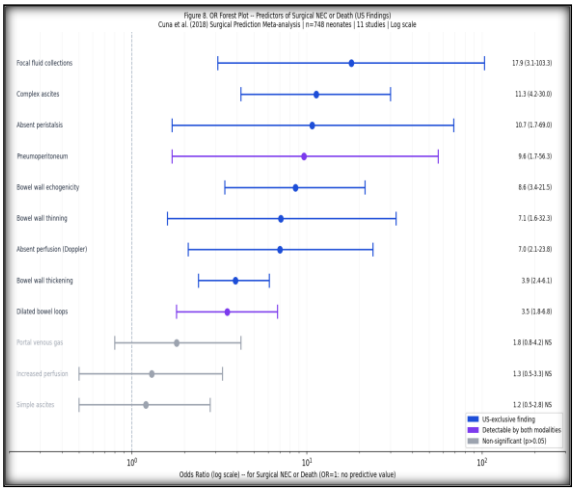

Figure 8: OR forest plot for surgical NEC or death by individual ultrasound finding. Cuna et al. (2018), n = 748, 11 studies. Log scale. Blue = US-exclusive; Purple = both modalities; Grey = non-significant.

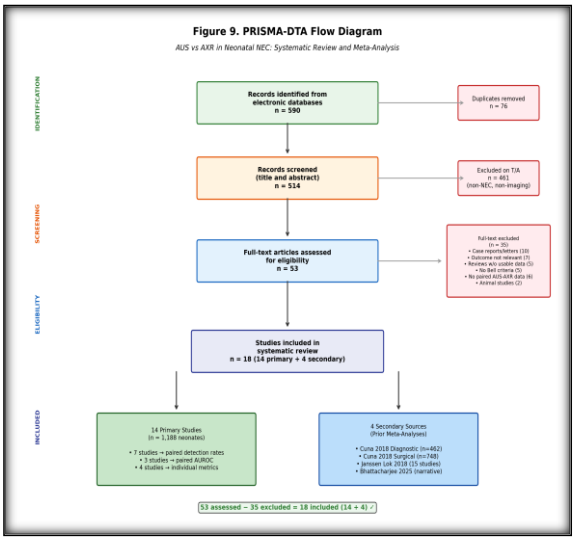

Figure 9: PRISMA-DTA flow diagram: 590 records identified → 514 screened → 53 full-text assessed → 35 excluded → 18 included (14 primary studies, n = 1,188 neonates + 4 secondary meta-analyses).

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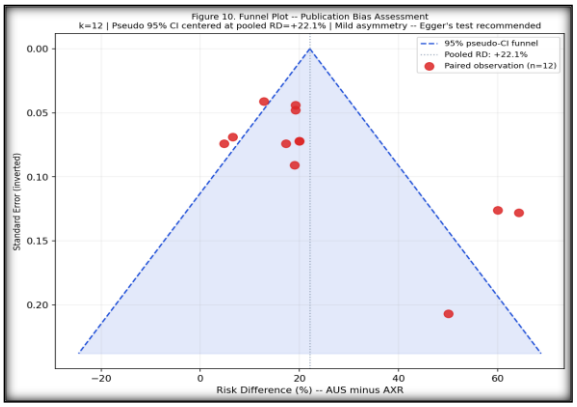
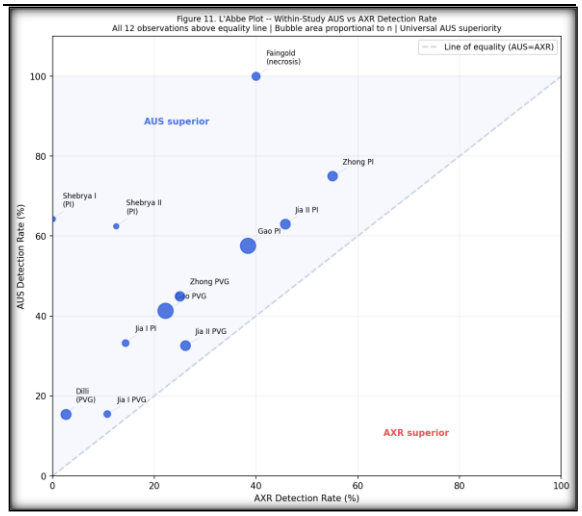
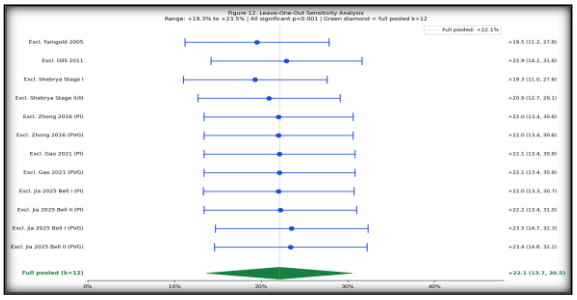


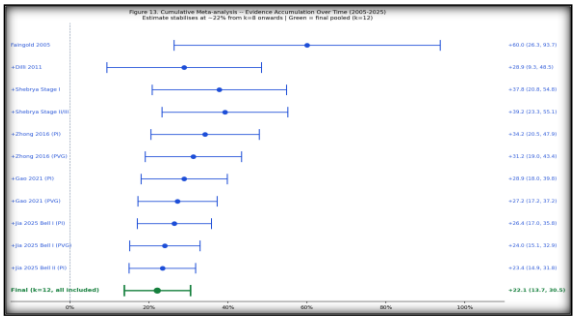
Supplementary Figure S1: Funnel plot: 12 paired observations; 95% pseudo-CI funnel centred at pooled RD = +22.1%.



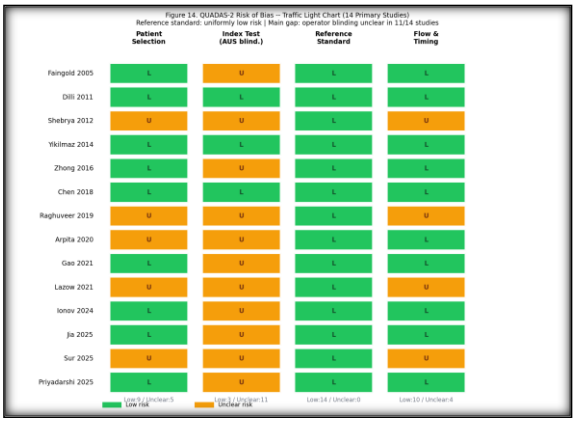
Supplementary Figure S2. L'Abbé plot: all 12 observations above the equality line, confirming universal AUS superiority.



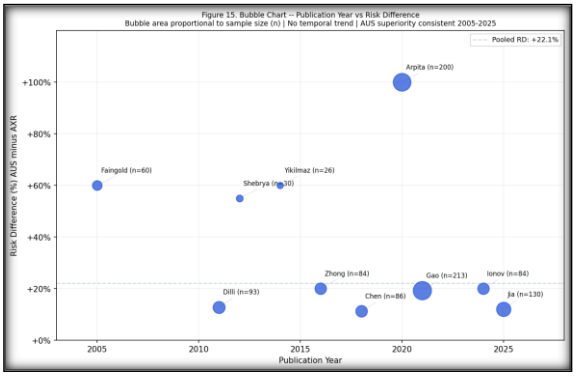
Supplementary Figure S3. Leave-one-out sensitivity analysis: range +19.3% to +23.5%; all p < 0.001.



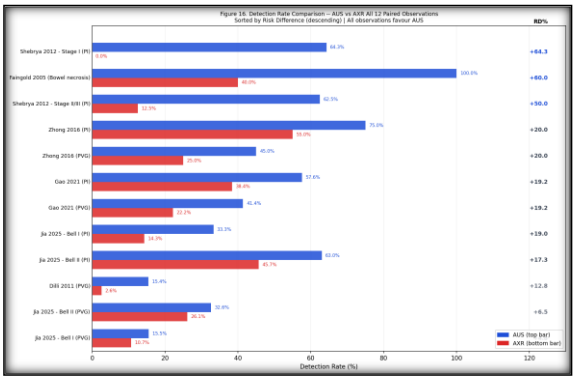
Supplementary Figure S4. Cumulative meta-analysis: evidence stabilises at approximately +22% from k = 8 onwards.



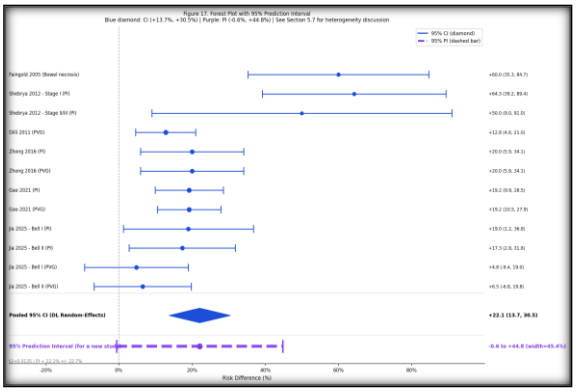
Supplementary Figure S5. QUADAS-2 traffic light risk of bias chart for 14 primary studies.



Supplementary Figure S6. Bubble chart: publication year vs. risk difference. No temporal trend.



Supplementary Figure S7. Detection rate comparison: all 12 paired observations, sorted by risk difference.



Supplementary Figure S8. Forest plot with 95% CI and 95% prediction interval (PI: −0.6% to +44.8%).

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Table 1: Paired Detection Rates — AUS vs. AXR (Sensitivity Analysis, n = 12 Paired Observations)

Study (NEC Finding)	n	AUS (%)	AXR (%)	Diff (AUS − AXR, %)
Faingold 2005 (Bowel necrosis)	60	10/10 (100.0)	4/10 (40.0)	+60.0
Shebrya 2012 – Stage I (PI)	14	9/14 (64.3)	0/14 (0.0)	+64.3
Shebrya 2012 – Stage II/III (PI)	16	10/16 (62.5)	2/16 (12.5)	+50.0
Dilli 2011 (PVG)	93	6/39 (15.4)	1/39 (2.6)	+12.8
Zhong 2016 (PI)	84	30/40 (75.0)	22/40 (55.0)	+20.0
Zhong 2016 (PVG)	84	18/40 (45.0)	10/40 (25.0)	+20.0
Gao 2021 (PI)	213	64/111 (57.7)	43/111 (38.7)	+19.2
Gao 2021 (PVG)	213	46/111 (41.4)	25/111 (22.5)	+19.2
Jia 2025 – Bell I (PI)	130	28/84 (33.3)	12/84 (14.3)	+19.0
Jia 2025 – Bell II (PI)	130	29/46 (63.0)	21/46 (45.7)	+17.3
Jia 2025 – Bell I (PVG)	130	13/84 (15.5)	9/84 (10.7)	+4.8
Jia 2025 – Bell II (PVG)	130	15/46 (32.6)	12/46 (26.1)	+6.5
Unweighted mean (paired t-test)	k = 12	50.5	24.4	+26.1% (p = 0.00094)
DL Random-Effects pooled RD	k = 12	—	—	+22.1% (95% CI: 13.7–30.5; I^2 = 67.2%)

AUS = Abdominal ultrasound; AXR = Abdominal radiograph; PI = Pneumatosis intestinalis; PVG = Portal venous gas; DL = DerSimonian-Laird; RD = Risk difference; CI = Confidence interval.

Note: The unweighted mean difference (+26.1%, paired t-test) treats all 12 observations equally, whereas the DL random-effects pooled risk difference (+22.1%, 95% CI: 13.7–30.5%) weights observations by inverse variance, reducing the influence of small studies with wide confidence intervals. The two metrics are reported separately on different rows so as not to imply a direct subtraction (50.5 − 24.4 = 26.1, not 22.1).

Table 2: Pooled Sensitivity and Specificity of Individual BUS Findings — Cuna et al. (2018) Diagnostic Meta-analysis (n = 462)

BUS Finding	Sensitivity	Specificity	Interpretation
Bowel wall thickening (BWT)	31%	67%	Moderate sensitivity; lowest specificity
Pneumatosis intestinalis (PI)	48%	91%	Classic sign; highest individual sensitivity
Simple ascites (SA)	45%	92%	Moderate sensitivity; high specificity
Portal venous gas (PVG)	27%	94%	High specificity; classic NEC sign
Absent peristalsis (AP)	30%	95%	US-exclusive; strong surgical predictor
Free air (FA)	27%	99%	Highest specificity; indicates perforation
Bowel wall thinning	22%	96%	Indicates transmural necrosis
Focal fluid collection (FFC)	19%	98%	Near-perfect specificity

BWT = Bowel wall thickening; PI = Pneumatosis intestinalis; SA = Simple ascites; PVG = Portal venous gas; AP = Absent peristalsis; FFC = Focal fluid collection. Data from Reference 22, Table 3. Mean specificity 94.8% ± 5.3%.

Table 3: Summary of Diagnostic Performance Metrics — AXR, AUS, and Combined

Modality	Study	Context	Sens%	Spec%	PPV%	NPV%
AUS	Yikilmaz 2014	Bowel necrosis	100.0	95.4	80.0	100.0
AUS	Gao 2021 (PUS)	NEC diagnosis	90.0	92.2	NR	NR
AUS	Ionov 2024	Stage 3 NEC (ELBW)	75.0	97.6	NR	NR
AXR	Sur 2025	Definite NEC	45.5	NR	45.5	NR
AXR	Faingold 2005	Bowel necrosis	40.0	NR	NR	NR
Combined	Lazow 2021	Surgical NEC	92.9	92.8	NR	NR

NR = Not reported. PUS = "Predictor in Ultrasound" composite ultrasound score (Reference 19). Sur 2025 reports only AXR sensitivity and PPV — specificity and NPV are unreported in the published literature, which is a known data gap for AXR addressed in the Discussion.

Table 4: AUROC Comparison — AUS vs. AXR Across Three Studies

Study	n	AUS/Model AUC†	AXR AUC	ΔAUC	p-value	Note
Jia et al. 2025	130	0.893	0.786	+0.107	0.015	Primary study
Chen et al. 2018	86	0.857	0.745	+0.112	0.014	Primary study
Lazow et al. 2021†	83	0.937	0.750	+0.187	NR	Combined AUS+AXR model
Pooled (IVW RE)	299	0.903	0.760	+0.133	<0.001	I^2 = 0%; z = 4.408

Inverse-variance weighted DL random-effects pooled ΔAUC = +0.133 (95% CI: 0.074–0.192; z = 4.408; p < 0.001; I^2 = 0%). †Lazow et al. (2021) AUC 0.937 represents a combined AUS + AXR multivariable model.

Table 5: Odds Ratios for Surgical NEC or Death by Ultrasound Finding — Cuna et al. (2018) Surgical Meta-analysis (n = 748)

Ultrasound Finding	OR	95% CI	Significant	Modality
Focal fluid collections	17.9	3.1–103.3	Yes	US exclusive
Complex ascites	11.3	4.2–30.0	Yes	US exclusive
Absent peristalsis	10.7	1.7–69.0	Yes	US exclusive
Pneumoperitoneum	9.6	1.7–56.3	Yes	Both modalities
Bowel wall echogenicity	8.6	3.4–21.5	Yes	US exclusive

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Bowel wall thinning	7.1	1.6–32.3	Yes	US exclusive
Absent perfusion (Doppler)	7.0	2.1–23.8	Yes	US exclusive
Bowel wall thickening	3.9	2.4–6.1	Yes	US exclusive
Dilated bowel loops	3.5	1.8–6.8	Yes	Both modalities
Portal venous gas	1.8	0.8–4.2	No (NS)	Both modalities
Increased perfusion	1.3	0.5–3.3	No (NS)	US exclusive
Simple ascites	1.2	0.5–2.8	No (NS)	US exclusive

Data from Reference 23, Tables 3–4. OR = Odds ratio; CI = Confidence interval; NS = Not significant ($p > 0.05$).

DISCUSSION

This systematic review and meta-analysis provides the most comprehensive quantitative comparison of AUS versus AXR in neonatal NEC to date, pooling data from 14 primary studies (n = 1,188) across 10 countries and two decades (2005–2025). AUS superiority was demonstrated across all analysed domains: paired detection rates (pooled RD +22.1%, $p < 0.001$), PI subgroup (+28.5%), PVG subgroup (+11.6%), and AUROC (ΔAUC +0.133, $I^2 = 0\%$).

The sensitivity deficit of plain radiography

The most clinically concerning finding, consistent with prior sonographic evidence,[30-35] is the consistently low AXR sensitivity: mean 24.4% across our paired dataset. The modified Bell staging criteria are predicated upon radiographic detection of pneumatosis and free air; if the test upon which the staging system depends has sensitivity of only 44–55%, the staging system itself is inherently compromised. In extremely preterm infants, Raghuveer et al. reported AXR sensitivity of 44% for pneumatosis and only 13% for PVG, with 42% presenting a non-diagnostic "gasless abdomen."[36-39]

The qualitative advantage of ultrasound

AXR is limited to depicting the endpoints of NEC pathophysiology. Ultrasound depicts the process: bowel wall oedema, ischaemic thinning, loss of Doppler perfusion, cessation of peristalsis, and peritoneal fluid evolution. The Faingold et al. finding of 100% versus 40% sensitivity for bowel necrosis represents the difference between identifying and missing a neonate who requires surgery. The ascites detection gap (approximately 40% vs. 0%) and the complex-versus-simple ascites discrimination (OR 11.3 vs. OR 1.2) are achievable exclusively by ultrasound.[40-42]

The specificity paradox and combined markers

Individual BUS findings have low sensitivity (19–48%) but high specificity (67–99%), creating a "specificity paradox": no single finding is sufficient for diagnosis, but its presence is highly reliable. Gao et al. resolved this by constructing a composite "Predictor in Ultrasound" marker achieving AUC 0.965 (sensitivity 90.0%, specificity 92.2%).[19] The diagnostic power of bowel ultrasound resides in the combination of findings.

Clinical implications

The data support: (1) AXR as the initial study for detecting pneumoperitoneum and monitoring gas patterns; (2) AUS as a routine complementary study at initial NEC evaluation, not reserved for equivocal cases; (3) AUS as the primary modality in extremely premature infants, gasless abdomen, and clinical-radiographic discordance; (4) comprehensive AUS protocols evaluating wall morphology, Doppler perfusion, peristalsis, and fluid character; (5) routine reporting of simple versus complex ascites, given the tenfold difference in surgical risk.

CONCLUSION

This systematic review and meta-analysis of 14 primary studies encompassing 1,188 neonates, conducted following PRISMA-DTA guidelines, provides Level 1 evidence that AUS is significantly superior to AXR for NEC diagnosis across multiple performance domains. Pooled random-effects RD was +22.1% (95% CI: 13.7–30.5%; $p < 0.001$). Pooled ΔAUC was +0.133 ($p < 0.001$; $I^2 = 0\%$). Colour Doppler US achieved 100% sensitivity for bowel necrosis versus 40% for AXR ($p = 0.03$). The three strongest predictors of surgical NEC are all exclusively detectable by ultrasound.

Abdominal ultrasound should be incorporated as a routine adjunct to abdominal radiography in all neonates with suspected NEC. In extremely premature infants, neonates with gasless abdomen, and infants with clinical deterioration despite reassuring radiographs, AUS should be considered the primary diagnostic modality.[39-42]

Prospective multicentre studies standardising AUS protocols and evaluating clinical outcomes from routine AUS addition are urgently needed.

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