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Structured lung ultrasound training, clinician competence and chest radiograph use in a level 3 neonatal unit: a pre-post implementation study

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Abstract

Objective

To evaluate whether structured lung ultrasound (LUS) training increased clinician competence and was associated with fewer chest radiographs.

Study Design:

Single-center pre-post implementation study in a level 3 neonatal unit. A 12-month training program was delivered between September 2022 and August 2023. We compared 100 consecutive neonates with respiratory distress in each period, before and after implementation. Primary outcomes were the proportion of clinicians achieving competence and the proportion of infants receiving ≥ 1 chest radiograph, analyzed by modified Poisson regression.

Results

Of 38 clinicians, 28 (74%) achieved competence. Infants receiving ≥ 1 radiograph decreased from 98% to 66% (risk ratio 0.67; 95% CI 0.58–0.78; P < 0.001), and mean dose area product per infant fell by 47%. No scan-related adverse events were documented.

Conclusion

Structured LUS training increased competence across most of the clinical workforce and was associated with fewer chest radiographs and lower radiation exposure.

Introduction

Point-of-care ultrasound (PoCUS) is increasingly regarded as the "modern stethoscope," an extension of the clinical examination.(1) The European Society of Paediatric and Neonatal Intensive Care endorsed lung ultrasound (LUS) in its first evidence-based PoCUS guidelines for neonatal and pediatric critical care.(2) LUS diagnoses respiratory distress syndrome (RDS) with a reported sensitivity of 0.92 and specificity of 0.95 (3) and identifies transient tachypnea of the newborn, pleural effusion, and pneumothorax with accuracy comparable or superior to chest radiograph.(4, 5) LUS scores obtained shortly after birth predict the need for surfactant within the first 3 h of life, potentially enabling earlier treatment.(6) Early rescue surfactant administration in preterm infants with established RDS reduces mortality, air leak, and the composite of bronchopulmonary dysplasia or death at 36 weeks' postmenstrual age. (7, 8)

Nevertheless, chest radiography remains the default imaging modality in most neonatal units. More than one in ten preterm infants receive cumulative diagnostic radiation exceeding recommended thresholds, raising concern about long-term malignancy risk.(9) Uptake of LUS remains low: in a UK-wide survey, only 6% of clinicians used it routinely, although 85% wanted to learn. While 59% had access to suitable equipment, only 35% had received any LUS training.(10) The main barrier to wider adoption therefore appears to be the lack of structured training rather than equipment availability.

Before September 2022, only three consultant neonatologists performed LUS in our unit, and infants with respiratory distress were assessed predominantly by chest radiography. Between September 2022 and August 2023, we implemented a structured LUS training program for all neonatal intensive care unit (NICU) clinicians.

In this pre-post implementation study, we evaluated whether the program was associated with an increase in the proportion of LUS-competent clinicians and a reduction in the proportion of infants receiving at least one chest radiograph (primary outcomes). Secondary outcomes were LUS adoption, fidelity and acceptability, chest radiographs and dose area product (DAP) per infant, and time to surfactant administration.

Methods

Study design

We conducted a single-center pre-post implementation study using a hybrid type 2 effectiveness-implementation design,(11) with defined implementation and clinical outcomes. The Before PoCUS period (March 29–August 31, 2022) preceded the training program, when LUS was performed by three consultants only. The After PoCUS period was September 1, 2023–February 2, 2024. Each period included 100 consecutive eligible neonates. A 12-month implementation period (September 1, 2022–August 31, 2023) was excluded so that the After PoCUS period reflected established practice. The study is reported according to the STROBE and StaRI statements.(12, 13)

Setting and Participants

The study was conducted in a 32-bed level 3 NICU in the UK, a regional referral center within the Southeast England Neonatal Network with more than 2 700 deliveries annually.

Eligible clinicians were all medical staff and advanced neonatal nurse practitioners working on the unit during the implementation year without prior formal LUS training (n = 38: 7 consultants, 26 resident doctors, 5 nurse practitioners).

Infants were eligible if admitted with respiratory distress defined as one or more of: respiratory rate > 60 breaths/min, intercostal or subcostal recession, nasal flaring, grunting or supplemental oxygen

requirement. Infants with major congenital thoracic or airway anomalies, or whose only radiographs were for non-respiratory indications (e.g., line or tube position), were excluded. Of 119 and 123 eligible infants, 100 consecutive infants per period (a number fixed in advance) were included, sampled backwards from the start and forwards from the end of implementation (Fig. 1).

Intervention

Implementation strategy

The program was delivered by three consultant neonatologists experienced in LUS (the PoCUS team) and comprised a ratified unit guideline with embedded scanning videos, bedside teaching, weekly image review PoCUS meetings using the Indication, Acquisition, Interpretation and Medical decision-making framework(14); and a secure National Health Service email account for image sharing and advice.

Clinicians were deemed competent after completing a logbook of at least 20 scans judged adequate by a PoCUS team member for independent scanning. The logbook was voluntary but required for competence.

Clinical intervention

Under the guideline, LUS was performed within 3 h of birth in all preterm admissions and in term infants with respiratory distress, using a Vivid S70 ultrasound system (GE HealthCare, Chicago, IL, USA) with a linear probe (9L-D, 3–11 MHz) for late preterm and term infants, or a hockey-stick probe (L8–18i, 8–18 MHz) for preterm infants, at a depth of 3–4 cm. A 6-zone (anterosuperior, anteroinferior and lateral zones bilaterally) LUS score was used.(15) A score of 8 or more, together with the clinical picture, prompted consideration of surfactant.(16, 17) Chest radiography remained at the treating clinician's discretion.

Safety precautions

As specified in the guideline, hands were washed with soap and water, and the machine and probe were disinfected with Clinell wipes (GAMA Healthcare, Hemel Hempstead, UK) before and after each scan. Single-use prewarmed sterile gel sachets and sterile probe covers were used. Temperature was monitored continuously, and infants in incubators were scanned through portholes. Scans were stopped if temperature fell below 36.5°C, oxygen saturation fell below 90% for more than 20 s, or heart rate fell below 100 beats/min without spontaneous recovery within 10 s.

Outcomes

Primary outcomes. The primary implementation outcome was the proportion of eligible clinicians achieving competence by the end of the implementation period (pre-specified target 70%). The primary clinical outcome was the proportion of infants receiving at least one chest radiograph for a respiratory indication during NICU admission. Combined films assessed for both line position and lung pathology were counted; radiographs taken solely for tube or line position were excluded.

Secondary outcomes. Secondary implementation outcomes, defined according to Proctor et al,(18) were adoption (monthly number of LUS examinations, and total LUS examinations per period), fidelity (proportion of infants with at least one LUS examination) and acceptability (anonymous post-training survey of clinicians who achieved competence; Supplementary Survey instrument). Secondary clinical outcomes were chest radiographs per infant, cumulative DAP (mGy·cm²) per infant, and time from birth to first surfactant dose.

Safety outcomes. Desaturation, bradycardia and hypothermia during scans, as defined above.

Data sources and measurement

Data sources and bias

Clinical data were extracted retrospectively from the electronic health record; radiograph numbers and DAP from the Picture Archiving and Communication System; and competence from PoCUS team's assessment. To reduce bias, consecutive infants were sampled as close in time to implementation as possible, radiograph data came from an objective source independent of the clinical team. No changes were made to the respiratory management, imaging policy and radiology equipment during the study, and no adaptations were made to the program during implementation.

Study size

Based on routine practice, we assumed that 99% of Before PoCUS infants would receive at least one chest radiograph. Detecting a reduction to 69% with two-sided $\alpha = 0.05$ and 90% power required 37 infants per period. We enrolled 100 per period, which allowed multivariable adjustment and the surfactant analyses (Fig. 1).

Statistical analysis

Continuous data are presented as mean (SD) or median (IQR), according to normality (histograms and Shapiro–Wilk test), and compared using t tests or Mann–Whitney U tests. Categorical data were compared using χ^2 or Fisher's exact tests. The primary clinical outcome was analyzed using modified Poisson regression with robust standard errors, adjusted for gestational age, birth weight, sex and RDS, selected a priori, and reported as an adjusted risk ratio with 95% CI. Risk ratios were used because odds ratios exaggerate effect sizes when the outcome is common. Radiographs per infant were compared by negative binomial regression (incidence rate ratios). Time to surfactant was compared using the log-rank test and Cox regression (hazard ratio > 1 indicating earlier administration). Competence is reported as a

proportion with 95% CI. Adoption was displayed as a monthly run chart of LUS examinations, with a shift defined as at least 6 consecutive points on one side of the Before PoCUS median.(19) Prespecified subgroup analyses compared DAP and time to surfactant across seven gestational age categories (22 + 0–23 + 6, 24 + 0–25 + 6, 26 + 0–27 + 6, 28 + 0–31 + 6, 32 + 0–33 + 6, 34 + 0–36 + 6 and ≥ 37 + 0 weeks). There were no missing data for outcomes or covariates. Tests were two-sided with $P < 0.05$ considered significant, using IBM SPSS Statistics (IBM Corp, Armonk, NY, USA).

Ethics

This study was registered with the hospital's Clinical Audit Department as a service evaluation (ID WHPAEDS-2025-383). According to the Health Research Authority decision tool, it did not require National Health Service Research Ethics Committee review. Parental consent was not required. The study was conducted in accordance with the Declaration of Helsinki.

Results

Participants

Of 119 and 123 eligible infants, the 100 admitted closest to implementation were included in each period (Before PoCUS: March 29–August 31, 2022; After PoCUS: September 1, 2023–February 2, 2024; Fig. 1). Baseline characteristics were similar (Table 1).

Table 1
Baseline maternal and neonatal characteristics in the Before PoCUS and After PoCUS periods

Characteristic	Before PoCUS (n = 100)	After PoCUS (n = 100)	P value
Maternal			
Maternal age, years, mean (SD)	29.6 (5.7)	30.1 (5.4)	0.53
Antenatal corticosteroids, n (%)	81 (81)	78 (78)	0.60
Cesarean delivery, n (%)	67 (67)	66 (66)	0.88
PPROM duration, h, mean (SD)	18.4 (26.3)	17.9 (24.8)	0.92
Chorioamnionitis, n (%)	9 (9)	11 (11)	0.63
Neonatal			
Gestational age, weeks, mean (SD)	33.0 (5.9)	33.4 (5.5)	0.62
Birth weight, g, median (IQR)	2100 (1200–3150)	2150 (1250–3200)	0.77
Male sex, n (%)	60 (60)	49 (49)	0.12
Suspected RDS, n (%)	68 (68)	70 (70)	0.76
P values from independent-samples t test, Mann–Whitney U test or χ^2 test, as appropriate.			
IQR, interquartile range; PoCUS, point-of-care ultrasound; PPROM, preterm prelabor rupture of membranes; RDS, respiratory distress syndrome.			

Primary Implementation outcome

Of 38 eligible LUS-naive clinicians, 28 (74%; 95% CI 57–87%) achieved competence by the end of the implementation period, meeting the pre-specified 70% target: 6 consultants, 17 resident doctors and 5 advanced neonatal nurse practitioners. Including the 3 consultants already performing LUS, the number of competent clinicians increased from 3 to 31. The remaining 10 did not complete training because of rotation to another unit (8) or insufficient adequate-quality scans (2).

Secondary Implementation outcomes

Monthly LUS examinations rose from a median of 3 (range 1–6) in the Before PoCUS period to 26.5 (range 7–35) in the After PoCUS period, with all 6 After PoCUS months above the baseline median, meeting the criterion for a shift (Fig. 2A). February 2024 was a partial month, as enrolment ended on February 2. In the study cohorts, LUS examinations increased from 20 in 15 infants (15%) to 150 in 75 infants (75%) (incidence rate ratio 5.27, 95% CI 3.56–7.78) (Fig. 2B–C).

All 28 competent clinicians completed the survey (Fig. 2D). Twenty-six (93%) found weekly image review beneficial, and 20 (71%) reported confidence in performing and interpreting LUS, including calculating

the Brat LUS score. The proportion reporting LUS as first-line imaging rose from 11% to 93%, while chest radiography as first-line fell from 82% to 18%.

Primary Clinical outcome

The proportion of infants receiving at least one chest radiograph decreased from 98% Before PoCUS to 66% After PoCUS (absolute difference 32 percentage points, 95% CI 22–42; risk ratio 0.67, 95% CI 0.58–0.78; $P < 0.001$) (Table 2). The association persisted after adjustment for gestational age, birth weight, sex and RDS (adjusted risk ratio 0.62, 95% CI 0.45–0.85; $P = 0.003$; Supplementary Table S1).

Table 2
Implementation and clinical outcomes in the Before PoCUS and After PoCUS periods

Outcome	Before PoCUS (n = 100)	After PoCUS (n = 100)	Effect estimate (95% CI)	P value
Primary implementation outcome				
Eligible clinicians achieving LUS competence, n/N	0/38	28/38	73.7% (56.9–86.6)[1]	—
Primary clinical outcome				
≥ 1 chest radiograph, n (%)	98 (98)	66 (66)	RR 0.67 (0.58–0.78)	< 0.001
≥ 1 chest radiograph, adjusted			aRR 0.62 (0.45–0.85)[2]	0.003
Secondary implementation outcomes				
LUS examinations, total (mean per infant)	20 (0.2)	150 (1.5)	IRR 5.27 (3.56–7.78)	< 0.001
Infants examined by LUS, n (%)	15 (15)	75 (75)	—	< 0.001[3]
Secondary clinical outcomes				
Chest radiographs, total (mean per infant)	224 (2.2)	102 (1.0)	aIRR 0.56 (0.46–0.69)[4]	< 0.001
DAP per infant, mGy·cm^2, mean (SD)	5.8 (2.2)	3.1 (1.5)	MD − 2.7 (− 3.2 to − 2.2)	< 0.001
Time to first surfactant, h, median (IQR); n = 58 / 55	3.2 (2.1–4.4)	2.1 (1.5–3.2)	HR 1.54 (1.12–2.12)	0.008[5]
Safety outcomes				
Scan-related adverse events, n	0	0	—	—

[1]Exact binomial 95% CI. [2]Adjusted for gestational age, birth weight, sex and RDS; modified Poisson regression with robust standard errors. [3]χ^2 test. [4]Negative binomial regression adjusted for gestational age and birth weight. [5]Log-rank test.

aIRR, adjusted incidence rate ratio; aRR, adjusted risk ratio; CI, confidence interval; DAP, dose area product; HR, hazard ratio; IQR, interquartile range; IRR, incidence rate ratio; LUS, lung ultrasound; MD, mean difference; PoCUS, point-of-care ultrasound; RDS, respiratory distress syndrome; RR, risk ratio.

Secondary Clinical outcomes

Total chest radiographs decreased by 54%, from 224 to 102 (mean 2.2 vs 1.0 per infant; adjusted incidence rate ratio 0.56, 95% CI 0.46–0.69; P < 0.001) (Table 2; Fig. 3A; Supplementary Table S2). In exploratory analysis, radiographs decreased in every gestational age group, with relative reductions

increasing with gestational age, from 44% at 22 + 0–23 + 6 weeks to 73% at 34 + 0–36 + 6 weeks and 86% at ≥ 37 + 0 weeks (Fig. 3A).

Mean DAP per infant decreased from 5.8 (SD 2.2) to 3.1 (SD 1.5) mGy·cm² (mean difference − 2.7, 95% CI − 3.2 to − 2.2; P < 0.001), a 47% reduction. In prespecified subgroup analyses, the largest absolute reduction in DAP was in infants born at 22 + 0–23 + 6 weeks (12.8 vs 6.1 mGy·cm²) (Fig. 3B).

Median time to first surfactant decreased from 3.2 (IQR 2.1–4.4) to 2.1 (IQR 1.5–3.2) h among infants receiving surfactant (n = 58 vs 55) (hazard ratio 1.54, 95% CI 1.12–2.12; log-rank P = 0.008) (Table 2; Fig. 3C). The effect was greatest at 22 + 0–23 + 6 weeks (hazard ratio 1.89, 95% CI 1.12–3.18) (Supplementary Table S3).

Safety outcomes

No scan-related adverse events (desaturation, bradycardia or hypothermia) were documented in either period (Table 2).

Discussion

In this single-center pre-post implementation study, a structured LUS training program enabled 74% of eligible, previously LUS-novice clinicians to achieve competence during the implementation year. Implementation was associated with a lower proportion of infants receiving a chest radiograph (98% vs 66%), 54% fewer chest radiographs overall and a 47% lower radiation dose per infant, with no documented scan-related adverse events. Surfactant was administered approximately 1 h earlier.

Despite strong national and international interest in lung ultrasound, adoption remains inconsistent. A 2024 European survey of 560 NICUs across 24 countries found highly variable uptake (20%–98%), with lack of experience and training identified as the principal barrier.(20) An Italian survey found that although 82% of NICUs used lung ultrasound, only 23% relied on it as first-line imaging for respiratory distress,(21) showing that availability does not equate to routine use. Our program targeted this gap through structured, bedside-supervised training consistent with the European Society of Paediatric and Neonatal Intensive Care recommendations.(22, 23) Overall, 74% of eligible clinicians achieved competence during the implementation year. This rapid acquisition of skills by novice operators is consistent with previous reports,(24, 25) and with the multicenter SLURP study.(26)

Ultrasound skills are known to decay without regular scanning and supervision.(27–29) A 2025 systematic review of 1 638 participants found that short-course PoCUS training without continued supervision led to rapid decline in image acquisition and interpretation.(30) To sustain competence, we introduced weekly unit PoCUS meetings, a standard practice since 2022, led by senior consultants using the Indication, Acquisition, Interpretation and Medical decision-making framework, with feedback on images and their clinical correlation. This sustained-practice approach contributed to a wider cultural shift towards routine PoCUS use in our unit. The meetings were valued by 93% of surveyed clinicians.

The lower count in February 2024 reflects a partial month, as enrolment ended on February 2 once 100 infants had been included, rather than a decline in practice.

Adoption followed training closely: 71% of competent clinicians reported confidence in performing and interpreting LUS score to guide surfactant decisions in suspected RDS. LUS replaced chest radiography as the reported first-line investigation rising from 11% to 93%. This shift may have contributed to both the reduction in radiograph use and earlier surfactant administration.

The overall chest radiographs fell by 54%. This is comparable to a recent before-after study in this journal, in which standardized lung ultrasound implementation in infants born at 23–32 weeks reduced chest radiography by 52%,(31) and to Rodriguez et al, who reported a 65% reduction following lung ultrasound implementation in Spain.(32) Gao et al described complete replacement of radiography by lung ultrasound over 3 years.(33)

Reductions in radiographs were seen across all gestational age groups. In exploratory analysis, the greatest relative reductions were in infants born at 34 + 0–36 + 6 weeks (73%) and ≥ 37 + 0 weeks (86%), in whom respiratory disease is the most common reason for admission.(34, 35) This is the population in which De Luca et al validated the Brat score threshold of 8 used in our protocol,(36) and in whom LUS can more readily replace radiography for diagnosis. By contrast, extremely preterm infants still require radiographs to confirm endotracheal tube and line position, which may explain their smaller proportional reduction in our study.

Mean DAP per infant fell by 47%. Cumulative ionizing radiation exposure is associated with an increased risk of pediatric solid-organ cancer that continues to rise after the initial exposure,(37) and with lower Bayley-III cognitive and motor scores in infants born before 34 weeks.(38) Preterm infants born before 34 weeks receive a median of 10 radiographs during their NICU stay,(39) and those weighing < 500 g a mean of 13.(40) The largest absolute reduction in DAP in our study was in infants born at 22 + 0–23 + 6 weeks, the group with the highest cumulative exposure from prolonged NICU stay and the most to gain.

Early selective surfactant administration reduces morbidity and mortality in moderate to severe RDS.(7) A fraction of inspired oxygen (FiO_2) threshold of 0.3 at 2 h of life is a proxy for later failure of continuous positive airway pressure rather than a true marker of surfactant deficiency.(41) A 2023 meta-analysis of randomized trials found lung ultrasound had a sensitivity of 0.89 for predicting surfactant need, compared with 0.73 for an FiO_2 threshold alone.(16) In our study, median time to surfactant fell from 3.2 to 2.1 h after implementation without an increase in the number of infants treated. This is consistent with the ULTRASURF trial, in which the ultrasound-guided group received surfactant within 1 h of life compared with 6 h in the comparison group.(42)

Raschetti et al reported that earlier ultrasound-guided surfactant reduced total oxygen exposure and duration of invasive ventilation compared with FiO_2-guided timing.(43) The ongoing LUNG trial is evaluating whether ultrasound-guided surfactant timing reduces bronchopulmonary dysplasia and mortality in infants born before 30 weeks, compared with an FiO_2 threshold of 0.3.(44) We did not assess

these outcomes, and whether earlier surfactant in our cohort translated into clinical benefit remains to be determined.

This study has several strengths. We offered training to the entire eligible workforce, including consultants, resident doctors and advanced neonatal nurse practitioners, reflecting how LUS would be adopted in a typical NICU. The hybrid type 2 design linked implementation outcomes (competence, adoption, fidelity and acceptability) to clinical outcomes. The program used existing ultrasound equipment and was delivered within routine clinical activity, without additional costs. The cohort spanned the full gestational range, outcomes and sample size were defined in advance of data extraction, consecutive infants were sampled as close to implementation as possible, and the implementation year was excluded so that the After PoCUS period reflected established practice. Radiograph counts and DAP were obtained from the Picture Archiving and Communication System, independent of the clinical team. Finally, weekly image review PoCUS meetings are now standard practice, supporting the sustainability of the program.

This study has several limitations. First, as a single-center pre-post implementation cohort study without a concurrent control group, our findings may be influenced by secular trends, although we confirmed no other changes to respiratory management or imaging policy occurred during the study period. Second, scan adequacy was judged by expert review rather than a validated tool.

Third, the survey was self-reported, completed only by clinicians who achieved competence with before-training responses recalled retrospectively. Fourth, gestational age subgroups were small, so subgroup findings are exploratory. Fifth, missed diagnoses resulting from reduced radiography were not systematically assessed. Finally, follow-up after implementation was limited to 6 months. A longitudinal evaluation of LUS use and radiograph trends from September 2023 to March 2026 is under way in our unit.

Conclusion

A structured, bedside-supervised LUS training program with ongoing weekly PoCUS meetings enabled most of a neonatal clinical workforce to achieve competence and was associated with fewer chest radiographs and lower radiation exposure, with no documented scan-related harm.

Declarations

Conflict of interest:

The authors declare no competing interests.

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Author Contributions:

KG designed the data collection templates, collected the data, performed the initial analysis with the data analyst, drafted the initial manuscript, and critically reviewed and revised the manuscript. SD conceptualized the study, supervised data collection, analysis and critically reviewed the manuscript.

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Figures

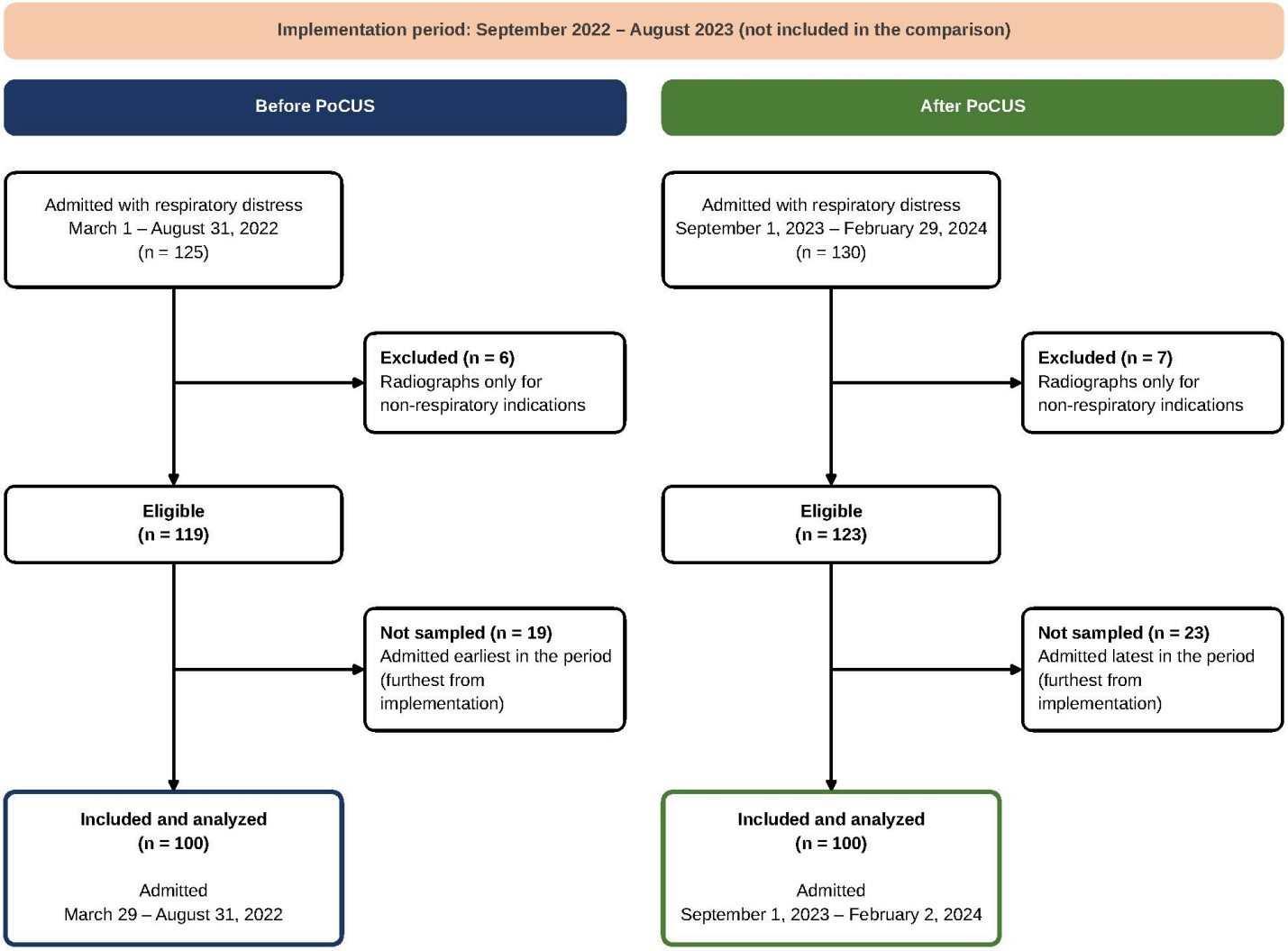


Figure 1

Participant flow. Infants admitted with respiratory distress during the Before PoCUS (March 1–August 31, 2022) and After PoCUS (September 1, 2023–February 29, 2024) screening periods. Infants whose only radiographs were for non-respiratory indications were excluded. Of the eligible infants, the 100 admitted closest to the implementation period (September 2022–August 2023, not included in the comparison) were included in each period: Before PoCUS, March 29–August 31, 2022; After PoCUS, September 1, 2023–February 2, 2024. PoCUS, point-of-care ultrasound.

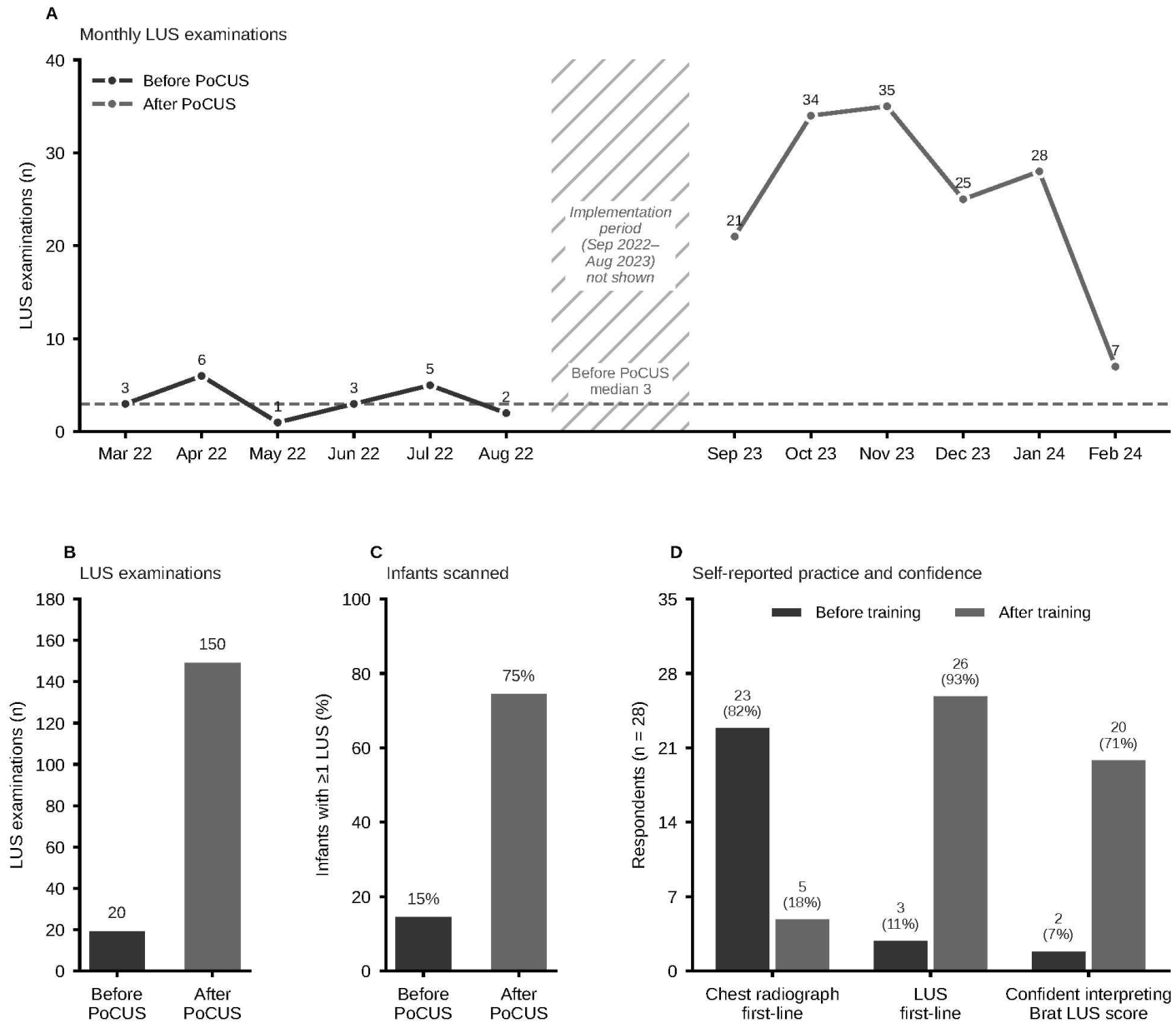


Figure 2

Implementation outcomes. (A) Monthly number of lung ultrasound (LUS) examinations in study infants. The dashed line shows the Before PoCUS median (3 examinations per month); a shift was defined as ≥6 consecutive points on one side of the median. The implementation period (September 2022–August 2023) is not shown. The lower count in February 2024 reflects a partial month, as enrolment ended on February 2 once 100 infants had been included. (B) Total LUS examinations and (C) proportion of infants with at least one LUS examination in each period (n = 100 per period). (D) Self-reported first-line imaging and confidence in interpreting the Brat LUS score before and after training among clinicians who achieved competence (n = 28); before-training responses were recalled retrospectively. LUS, lung ultrasound; PoCUS, point-of-care ultrasound.

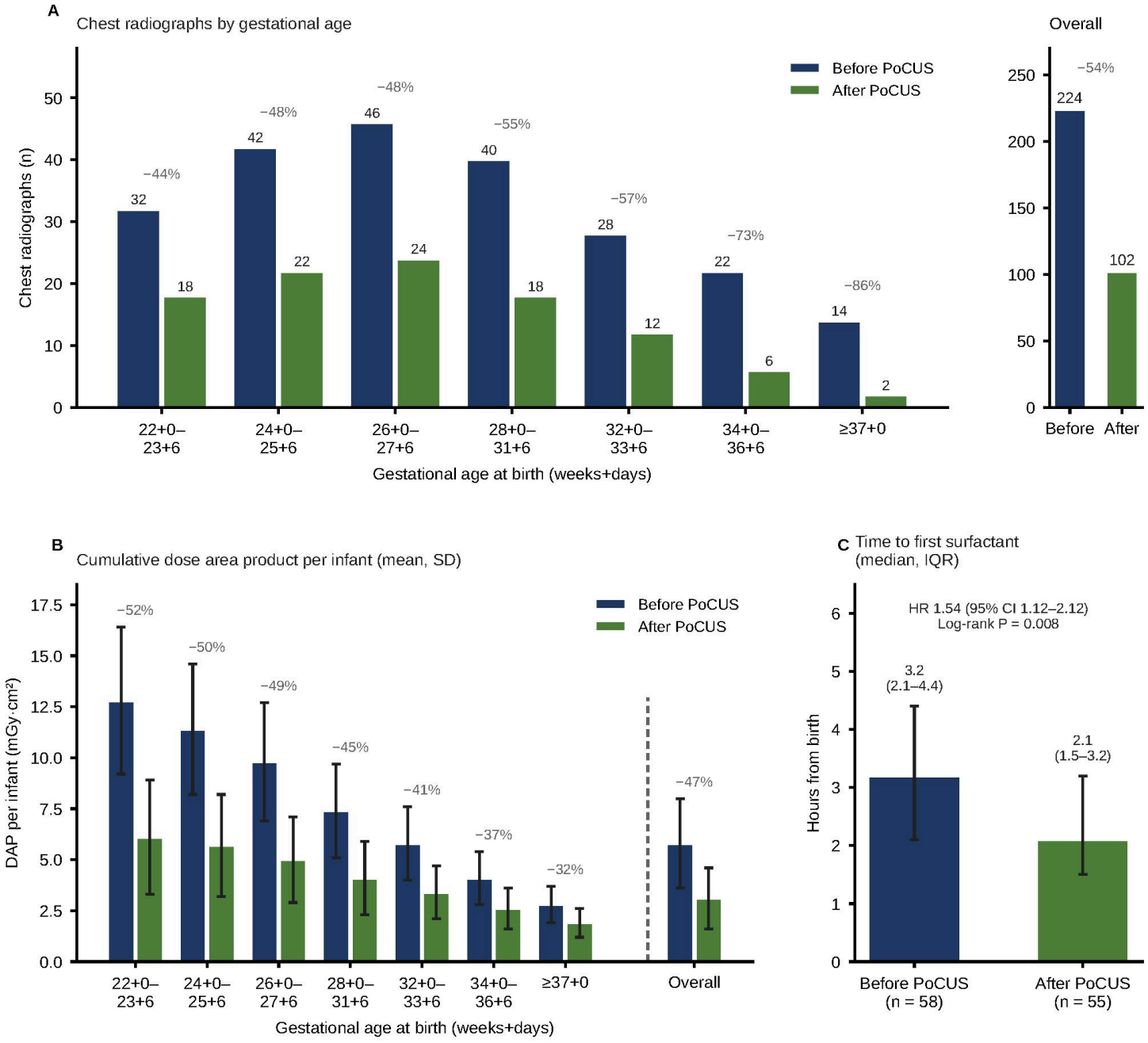


Figure 3

Clinical outcomes. (A) Total chest radiographs by gestational age group and overall (descriptive; percentages show relative change). (B) Mean (SD) cumulative dose area product (DAP) per infant by gestational age group and overall; error bars show SD. (C) Median (IQR) time from birth to first surfactant dose among infants receiving surfactant (Before PoCUS n = 58; After PoCUS n = 55); error bars show the interquartile range; hazard ratio from Cox regression and log-rank P value. n = 100 per period. CI, confidence interval; DAP, dose area product; HR, hazard ratio; IQR, interquartile range; PoCUS, point-of-care ultrasound; SD, standard deviation.

Supplementary Files

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- SupplementaryTables.docx
- SupplementarySurveyInstrument.pdf