ORIGINAL ARTICLE

https://doi.org/10.3126/njms.v11i2.98449

Optimization of Neonatal Chest Radiography Exposure Parameters Using a Gammex 610 Phantom: A Cross Sectional Study

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Received: June 17, 2026 **Accepted: July 15, 2026** **Published: August 12, 2026**

Cite this paper: Dhungana S, Sharma K, Subedi S, Paudel S. Optimization of Neonatal Chest Radiography Exposure Parameter Using a Gammex 610 Phantom: A Cross-Sectional Study. *Nepal Journal of Medical Sciences.* 2026;11(2):71-81. https://doi.org/10.3126/njms.v11i2.98449

ABSTRACT

Introduction: Neonatal chest radiography is essential but carries risks due to high radiation sensitivity and recurrent requirement for imaging. This study identifies optimal exposure parameters for visualizing stipulated pathologies—pneumothorax and hyaline membrane disease—using Gammex 610 phantom to balance image quality and exposure factors.

Methods: The study was conducted using the Gammex 610 neonatal chest phantom, which included inserts simulating normal lung, pneumothorax, and hyaline membrane disease (HMD). A total of 16 radiographs were acquired using different combinations of kVp (45, 50, 55) and mAs (6.3, 4.0, 3.2, 2.5, 2.0, 1.6, 1.3, 1.0). Objective metrics were assessed by calculating signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) using ImageJ. Subjective image quality: visual grade analysis (VGA) was evaluated by five radiologists using a 4-point Likert scale. The inter-rater agreement was measured using Fleiss' Kappa.

Results: The higher exposure settings yielded superior mean CNR and SNR; they also increased radiation burden. The 45 kVp / 2 mAs setting provided acceptable image quality, with a mean CNR of 5.86 and SNR of 26.75. Furthermore, radiologist-assessed VGA scores (3.61) at this level were comparable to those achieved at higher exposure settings (>50 kVp / 1.6 mAs).

Conclusion: This phantom-based experimentation demonstrates that exposure parameter (kVp and mAs) reduction is possible while maintaining image quality. Based on CNR, SNR and VGA scores and in alignment with the ALARA principle, the authors recommend 45 kVp /2.0 mAs as the most appropriate exposure factors for the institutional settings.

Key Words: *Newborn; Phantoms; Radiography*

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INTRODUCTION

Radiography is the diagnostic procedure performed to obtain an image of the anatomical structures by allowing the X-ray to pass through them. [1,2] Neonatal chest radiography is one of the most frequently performed radio-diagnostic examination. The neonatal period comprises the first 28 completed days of life. [3] As X-ray is an ionizing radiation, it causes molecular changes in biological cells leading to different stochastic and deterministic effects. The stochastic-effect probability increases with dose without an assumed threshold, whereas tissue reactions have a threshold and severity increases with dose. Among all the age groups, neonates are the most prone and highly susceptible to radiobiological effects as they have highly proliferating cells. [4,5,6] Being such a critical population undergoing frequent radiographic examination, it is necessary to make a justifiable use of X-ray in the neonates. The exposure factors utilized for the radiographic examination should be minimized as much as possible to reduce the risk of radiobiologic effects. As the diagnosis depends on the quality of the radiograph obtained, it is necessary to maintain optimal diagnostic quality of the radiograph while lowering the patient's radiation dose. [7] Image parameters like Contrast, Noise, and Resolution describe the image quality. Signal to Noise Ratio (SNR), Contrast to Noise Ratio (CNR) is used for the comparative analysis of signal and contrast with background tissues respectively. [8] Although standard protocols are followed, radiographers can further manipulate exposure factors based on several patient and equipment-related variables. These include the neonate’s weight, positioning, and the type of radiographic equipment used such as the detector system and the X-ray tube. By making such adjustments, it is possible to achieve minimal radiation exposure while still maintaining optimal image quality. [7,9]

This study aims to determine the optimal exposure factor for effective visualization of neonatal chest pathologies: pneumothorax and hyaline membrane disease (HMD). The Gammex 610 anthropomorphic neonatal chest phantom (Figure 1) is used in this research as a medical subject for experimentation. The phantom simulates the neonatal population weighing up to 2 kg.

METHODS

This phantom-based cross-sectional study was conducted at the Department of Radiology and Imaging, Gandaki Medical College Teaching Hospital and Research Centre (GMCTHRC) after approval from GMC-IRC (Registration number 98/081/082). Image acquisition and processing for all exposures were performed using a BPL (M-RAD 5.0) mobile X-ray system, an AGFA HealthCare CRMD1.0 General Set detector, and an AGFA NX (version 3.0) acquisition workstation. Gammex 610 Neonatal Chest Phantom with lung inserts of non-diseased lung with normal texture, simulated pneumothorax and hyaline membrane disease were included in this study. The torso, bronchial tree, skeletal structure, and carbide ball (serving as a positioning guide and consistent landmark) remained constant during all exposure factor combinations used in radiography. The Gammex 610 phantom mimics a real 1-2 kg neonate in terms of tissue attenuation, anatomical structure, physical size, and histogram properties. This phantom meets international standards set by organizations such as AAPM and IPEM for comprehensive quality assurance of the entire imaging chain in digital radiography. It effectively addresses concerns regarding patient exposure and image quality by enabling the determination of the lowest possible exposure factors that still produce diagnostically useful images. [7,8,10,11]

A total of 16 radiographs were acquired using different combinations of kVp (45, 50, 55) and mAs (6.3, 4.0, 3.2, 2.5, 2.0, 1.6, 1.3, 1.0); the combinations were not a full factorial set. The image quality was accessed objectively using CNR and SNR and subjectively by visual grading analysis (VGA) and marking the Likert scale by five consultant radiologists. The 4-point Likert scale used was 1: Poor, 2: Fair, 3: Good,4: Excellent. Objective Analysis includes measurement of the mean grey value of pixels, the maximum grey value of pixels, the minimum grey value of pixels and Standard Deviation (SD) in different regions of interest. These measurements were used to calculate SNR and CNR in all 16 radiographs. ImageJ Fiji is an open-source software used for medical image analysis. The collected data were analyzed using a combination of ImageJ FIJI, Microsoft Excel, and IBM SPSS (Version 30.0). Both objective image quality metrics (CNR and SNR) and subjective evaluations (VGA scores) were statistically analyzed to determine the optimal exposure factor for neonatal chest radiography. Circular ROIs (ROI I: pneumothorax, ROI II: HMD, ROI III: background tissue) were defined within ImageJ with a diameter of 10 pixels, wherein the software's internal mask identified an average sampling area of 80 pixels per area, and the mean signal intensity was calculated from all pixels within the selection boundary (Figure 2). Mean VGA values were calculated for all 16 radiographs to evaluate the set of exposure parameters that provided good image quality and to identify the set of lowest exposure factors that provided optimal diagnostic image quality. Mean SNR and mean CNR were calculated for three different ROIs to evaluate the set of exposure parameters providing optimal SNR and CNR. The SNR and CNR were calculated as per the segmented ROI method using the following equations. [12,13]

SNR = Average Pixel Values in Signal ROI / SD of Background ROI CNR = (Average Signal ROI – Average Background Signal) / SD of Background ROI

Descriptive statistics were calculated for all 16 radiographs to assess image quality across different exposure settings. Fleiss Kappa agreement was used to measure the level of agreement between 5 radiologists. The value of Fleiss's kappa ranges from -1 to +1.

Kappa (k)= (Po – Pe) / (1 – Pe)

Where Kappa (k) represents the agreement coefficient, Po represents the observed agreement, and Pe represents the expected agreement. [14]

Figure:1 Neonatal Chest Phantom Gammex 610

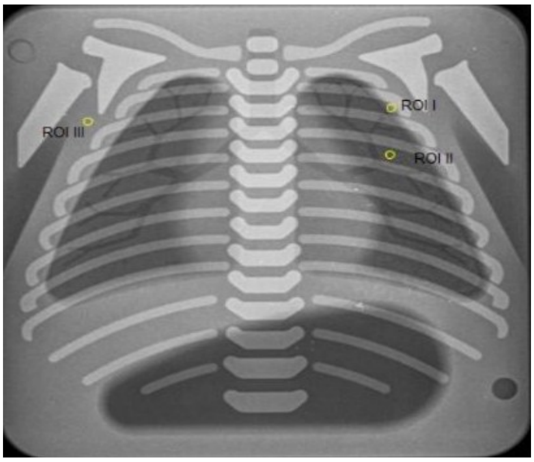

Figure: 2 ROI placements in radiograph

RESULTS

The findings of the study conducted to determine the optimal exposure factor for the effective visualization of neonatal chest pathologies using both objective and subjective image quality assessments. The results are presented in terms of descriptive statistics, comparative analysis across different sets of exposure factors, and inter-rater agreement, which was measured using Fleiss' Kappa.

Table 1: Mean CNR across different exposure settings.

Radio graph ID	Exposure parameters	CNR I Pueumo thorax	CNR II (HMD)	Mean CNR
1	45kVp, 4.0mAs	8.41	4.46	6.44
2	45kVp, 3.2 mAs	8.46	4.83	6.79
3	45kVp, 2.5 mAs	7.36	3.76	5.56
4	45kVp, 2.0 mAs	8.27	3.45	5.86
5	45kVp, 1.6 mAs	7.96	3.17	5.56
6	45kVp, 1.3 mAs	6.47	2.51	4.50
7	45kVp, 1.0 mAs	4.71	2.61	3.66
8	50kVp, 4.0 mAs	9.40	4.86	7.13
9	50kVp, 3.2 mAs	8.53	4.55	6.54
10	50kVp, 2.5 mAs	7.49	3.98	5.73
11	50kVp, 2.0 mAs	7.16	3.78	5.47
12	50kVp, 1.6 mAs	8.19	3.48	5.83
13	50kVp, 1.3 mAs	8.85	3.54	6.20
14	50kVp, 1.0 mAs	8.73	3.53	6.13
15	55kVp, 6.3 mAs	1.52	18.11	9.91
16	55kVp, 4.0 mAs	0.59	13.81	7.20

Table 1 shows the mean CNR value across different sets of exposure (in descending order of mAs for each set of kVp). CNR values were calculated in both pneumothorax (ROI I) and hyaline membrane disease regions (ROI II) for all 16 radiographs. The highest mean CNR of 9.81 was observed at 55 kVp/ 6.3mAs, while the lowest mean CNR of 3.66 was found at 45 kVp / 1. 0 mAs. Among clinically acceptable lower exposure sets of 45 kVp, the 45 kVp / 2 mAs group achieved a relatively acceptable mean CNR of 5.86, suggesting a near-optimal trade-off between contrast quality and patient radiation safety.

Table 2: Mean SNR across different exposure settings

Radio graph ID	Exposure parameters	SNR I Pueumo thorax	SNR II (HMI)	Mean SNR
1	45kVp, 4.0mAs	35.61	22.73	29.17
2	45kVp, 3.2 mAs	37.73	24.15	30.94
3	45kVp, 2.5 mAs	30.96	19.83	25.39
4	45kVp, 2.0 mAs	32.61	20.89	26.75
5	45kVp, 1.6 mAs	27.58	17.75	22.66
6	45kVp, 1.3 mAs	25.40	16.40	20.90
7	45kVp, 1.0 mAs	23.89	16.56	20.22
8	50kVp, 4.0 mAs	42.15	27.90	35.02
9	50kVp, 3.2 mAs	37.77	24.69	31.23
10	50kVp, 2.5 mAs	32.57	21.10	26.84
11	50kVp, 2.0 mAs	28.74	17.80	23.27
12	50kVp, 1.6 mAs	31.35	19.68	25.52
13	50kVp, 1.3 mAs	33.90	21.51	27.71
14	50kVp, 1.0 mAs	33.51	21.25	27.38
15	55kVp, 6.3 mAs	44.65	28.05	36.35
16	55kVp, 4.0 mAs	34.76	21.54	28.15

The signal-to-noise ratio (SNR) was evaluated in both pneumothorax and hyaline membrane disease regions for all 16 radiographs. The mean SNR ranged from a minimum of 20.22 (45kVp/ 1.0mAs) to a maximum of 36.35 (55 kVp / 6.3mAs), as shown in Table 2.

Notably, the highest mean SNR was recorded at 55kVp / 6.3mAs, while the lowest occurred at the lowest exposure (45kVp / 1.0mAs). This trend reflects that SNR increases with higher exposure settings. However, beyond 50 kVp / 3.2mAs, the improvement in SNR seems to become less significant compared to the increase exposure parameters. Among lower exposure sets, the 45kVp / 2 mAs group achieved a relatively high mean SNR of 26.75, closely matching higher exposure sets up to 50 kVp /2.5mAs.

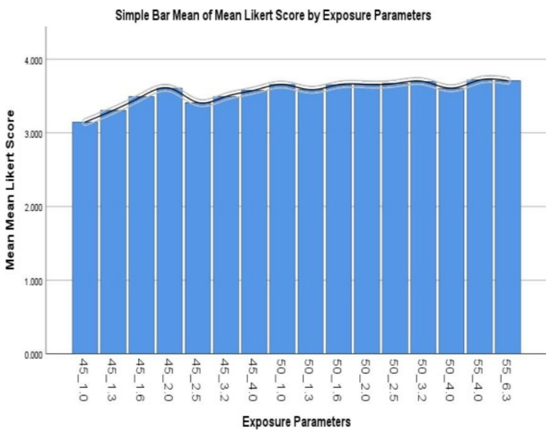

Figure 1: Bar Chart of Mean VGA Score for Varying kVp and mAs Combinations

The figure 1 presents the average Likert scores representing visual grading of image quality for identifying both pneumothorax and hyaline membrane disease (HMD) across different exposure combinations.

At the lowest exposure setting (45 kVp / 1.0 mAs), image quality was rated just above 3.0, suggesting good clarity for identifying both pathologies. As exposure parameters increased, the mean scores increased which indicates a clearer visibility of anatomical features and pathologies. The exposure setting of 45 kVp / 2 mAs showed Likert score near to the peak scores. This demonstrates the possibility of achieving optimal image quality at this range of exposures. No substantial increase in Likert score was demonstrated on further increasing the exposure beyond the range of 45 kVp / 2.0 mAs to 50 kVp / 3.2 mAs. This trend supports the idea that a moderate range of exposure parameters can enhance diagnostic clarity for pneumothorax and HMD, without unnecessarily elevating the exposure factors.

DISCUSSION

This study explores the possibility of reduction of exposure factors in neonatal chest radiography using the Gammex neonatal chest phantom. We aimed to determine the minimal exposure factors at which radiographs are clinically acceptable in accordance with the ALARA principle and initiatives such as the Image Gently Campaign by the Alliance for Radiation Safety in Pediatric Imaging. The regular in use exposure factor for neonatal chest x-ray at GMCTH is 50 kVp and 3.2 mAs; and is adopted as institutional standard for comparing this research results. The prime attempt was to experiment in a phantom and lower the exposure factors to obtain a similar level of image quality and pathology visibility. According to this study results, high SNR and CNR values as well as higher VGA scores were obtained with higher exposure sets but these all will increase the radiation burden. Objective image quality measures, SNR (26.75) and CNR (5.86) were acceptable for this exposure set of 45 kVp / 2 mAs. Similarly, the mean Likert scores from five radiologists were 3.61 for this exposure, indicating a near “excellent” rating. The authors on mutual consensus and careful weighing of CNR, SNR, VGA scores and aligning with ALARA principle; the exposure combination of 45 kVp / 2 mAs seemed to provide adequate image quality for the visualization of neonatal chest pathologies at lesser exposure factors. Furthermore, to support the practical application of this finding, a follow-up chest X-ray was performed on the real neonatal patient using the optimized exposure of 45 kVp / 2 mAs after obtaining verbal consent from the patient's party and the pediatric department. The radiograph obtained was clinically acceptable to all five radiologists and a pediatrician in the care of the patient.

These findings align nearly with the results of Schäfer et al, it demonstrated that images of diagnostic quality could be obtained using copper filtration along with low exposures such as 44 kVp / 1.56–3.36 mAs. [11] Similarly, Oglat reported that most phantom structures remained visible across a variety of kVp and mAs settings, highlighting the feasibility of using lower exposure values without compromising diagnostic visibility. [15] Al-Murshedi et al. found wide variation in both radiation dose and pathology visibility across hospitals and concluded that optimized low-dose protocols could maintain acceptable image quality while reducing unnecessary exposure. [7] Although the lowest exposure settings (45 kVp at 1.0, 1.3, and 1.6 mAs) yielded VGA scores slightly above 3—indicating good image quality—they were ultimately excluded from the final recommendations. The authors acknowledge that while these low-dose settings performed adequately in a controlled phantom environment, they may not consistently translate to clinical practice due to patient-specific variables in neonatal radiography. [8,16,17] furthermore, their corresponding SNR and CNR values approached to the lower limits. Conversely, while higher exposure settings yielded superior objective SNR, CNR and subjective VGA metrics, they were rejected to avoid unnecessary radiation burden to this highly radiosensitive neonatal cohort.

The radiologists' ratings demonstrated poor reproducibility, as indicated by a Fleiss' Kappa of 0.097. This low inter-rater reliability severely limits the validity of any definitive conclusions drawn from the subjective VGA scores. However, the overall consistency observed between the VGA trends and the objective CNR and SNR values helps mitigate this limitation, supporting the reliability of objective quality indicators when subjective metrics are highly variable.

Despite the use of low exposure parameters, the neonates tend to gain more radiation due to the necessity of undergoing multiple examinations in a short time frame for pathologies like pneumothorax and HMD. [18] This significantly increases the cumulative dose. The newborn's specific local and national diagnostic reference levels (DRLs) remain historically sparse and has limited the standardization of optimizing the neonatal exposure factors. [9,18,20,] Further research using phantom is essential for developing evidence- based exposure factors for neonatal chest X-ray, that balances the diagnostic quality of the radiograph with lower exposure parameters.

CONCLUSIONS

This phantom - based experimentation demonstrates that exposure parameter (kVp and mAs) reduction is possible while maintaining image quality. The findings demonstrated that the highest image quality metrics were obtained at elevated exposure settings (e.g., 55 kVp / 6.3 mAs), however the corresponding increase in radiation imposes unnecessary radiation burden to neonates. Based on evaluation of CNR, SNR and VGA scores and in alignment with the ALARA principle, the authors recommend 45 kVp / 2.0 mAs as the most appropriate exposure setting. This optimized radiography setting delivers acceptable image quality with lower exposure parameters, providing a safe, effective parameter for diagnosing pneumothorax and hyaline membrane disease in neonatal chest radiography.

CONFLICT OF INTEREST

The author declared no conflicts of interest.

SOURCE OF FUNDING

The Gammex 610 neonatal chest phantom was provided by Assoc Prof: Mrs. Borgney Ween and Dr Knut Skyberg from Norway

REFERENCES

1. Abe T, Iizuka Y, Mieda T, Minami A, Tajika T, Tsutsumi S, et al. Validity and reliability of plain radiography for the assessment of structural abnormalities in clinical practice. J Orthop Sci 2022;27(4):892-6. [DOI]
2. Ham S, Choi G, Je BK, Oh S. Development of a deep-learning model for estimating newborn gestational age via lumbar vertebral segmentation on plain radiography. Korean J Radiol 2025;26(9):867-76. [DOI]
3. Dol J, Huges B, Bonet M, Dorey R, Dorling J, Grant A, et al. Timing of neonatal mortality and severe morbidity during the postnatal period: a systematic review. JBI Evid Synth 2022;21(1):98-119. [DOI]
4. Duran A, Duran S, Linetzky V, Perez M. Radiation protection in diagnostic and interventional radiology: a review of basic concepts. Radiation 2024;4(2):112-25. [DOI]
5. Agbaje AO, Al-Murshedi S, England A. Radiation biological effects and the principles of radiation protection in diagnostic radiology. Radiography (Lond) 2024;30(3):784-91. [DOI]
6. International Atomic Energy Agency. Radiation protection and safety of radiation sources: international basic safety standards. Vienna: International Atomic Energy Agency; 2014. [DOI]
7. Al-Murshedi S, Hogg P, England A. Neonatal chest radiography: influence of standard clinical protocols and radiographic equipment on pathology visibility and radiation dose using a neonatal chest phantom. Radiography (Lond) 2020;26(4):282-7. [DOI]
8. Shahgeldi K, Sjöberg T, Nordström J, Lesanu R, Svahn TM. Optimizing image quality, radiation dosage to the patient and to the detector in pediatric chest radiography: a phantom study of a portable digital radiography system. Radiat Prot Dosimetry 2019;185(4):414-20. [DOI]
9. Gilley R, David LR, Leamy B, Moloney D, Moore N, England A, et al. Establishing weight-based diagnostic reference levels for neonatal chest X-rays. Radiography (Lond) 2023;29(4):812-7. [DOI]
10. Gammex Inc. Physics behind the phantom, volume 2: the neonatal chest phantom [White

Paper]. Middleton (WI): Gammex Inc.; 2008 Sep 23. [DOI]

11. Schäfer SB, Papst S, Fiebich M, et al. Modification of chest radiography exposure parameters using a neonatal chest phantom. Pediatr Radiol 2020;50(1):28-37. [DOI]
12. Strauss, L. J., & Rae, W. I. (2012). Image quality dependence on image processing software in computed radiography. South African Journal of Radiology, 16(2), 44-48. [DOI]
13. Goode AR, Snyder C, Snyder A, Collins P, DeLorenzo M, Lin PJ. Signal and contrast to noise ratio evaluation of fluoroscopic loops for interventional fluoroscope quality control. J Appl Clin Med Phys. 2019 Oct;20(10):172-80. [DOI]
14. Fleiss JL, Levin B, Paik MC. Statistical Methods for Rates and Proportions. 3rd ed. Hoboken (NJ): John Wiley & Sons; 2003. [DOI]
15. Oglat AA. Comparison of X-ray films in terms of kVp, mA, exposure time, and distance using a radiographic chest phantom as a measure of radiation quality. J Radiol Res Appl Sci 2022;15(1):100479. [DOI]
16. Hinojos-Armendáriz VI, Vaño-Reyna S, Chevalier SC. Optimisation of radiation dose and image quality in mobile neonatal chest radiography. Radiography (Lond) 2018;24(1):e1-6. [DOI]
17. Smet MH, Breysem L, Mussen E, Bosmans H, Marshall NW, Cockmartin L. Visual grading analysis of digital neonatal chest phantom X-ray images: impact of detector type, dose and image processing on image quality. Eur Radiol 2018;28(7):2951-9. [DOI]
18. Aramesh M, Zanganeh KA, Dehdashtian M, Malekian A, Fatahiasl J. Evaluation of Radiation Dose Received by Premature Neonates Admitted to Neonatal Intensive Care Unit. J Clin Med Res 2017;9(2):124-129. [DOI]
19. Dougeni ED, Delis HB, Karatza AA, Kalogeropoulou CP, Skiadopoulos SG, Mantagos SP, et al. Dose and image quality optimization in neonatal radiography. Br J Radiol 2007;80(9`58):807-815. [DOI]
20. Bahreyni Toossi MT, Malekzadeh M. Radiation dose to newborns in neonatal intensive care units. Iran J Radiol 2012;9(3):145-9. [DOI]