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A comparative study of collimation in bedside chest radiography for preterm infants in two teaching hospitals

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ABSTRACT

Objective: Unnecessary exposure of the abdomen, arms or head may lead to a substantial increase of the radiation dose in portable chest X-rays on the neonatal intensive care unit. The objective was to identify potential factors influencing inappropriate exposure of non-thoracic structures in two teaching hospitals.
Methods: The study analysed 200 consecutive digital chest radiographs in 20 preterm neonates (mean gestation 25 ± 1 weeks). Demographical data, tube settings and exposure parameters were recorded. To grade the collimation, we used a scoring system with a maximum of 12 exposed non-thoracic structures. Length of gestation, age, the radiographer, years of experience in performing X-rays and the number of in situ catheters or lines, were correlated with collimation quality.
Results: There was no significant difference between the rates of optimal images obtained in the two hospitals (0.32 vs 0.39, n.s.). Scores showed that most suboptimal images had only mildly reduced image quality (1.40 ± 1.38 vs 1.20 ± 1.43, n.s.). Length of gestation or presence of surgical drains, catheters and tubes had no obvious effects on the exposure of non-thoracic structures. Large intra-individual variation in optimal collimation (14–86%) was noted for the radiographers in both hospitals; this was unrelated to their respective years of experience.
Conclusion: In our study, the only identifiable factor influencing the collimation of portable chest radiographs in preterm infants was the radiographer's dedication and awareness. There were no apparent differences between the hospitals investigated. Exposure of non-thoracic structures was relatively frequent and mainly involved the proximal humeri.

1. Introduction

Chest radiography is one of the most widely used diagnostic examinations in children [1–3]. In a special care baby unit, premature neonates have serious and life-threatening diseases that may require a large number of X-rays for diagnosis and treatment [4,5]. Increased neonatal radiosensitivity and longer life expectancy increase the risk of radiation-induced cancer, which emphasises the importance of minimising the dose while maintaining a clinically satisfactory image quality [6].

The radiation dose during bedside examinations can be increased without a visible change in the final image due to incorrect (free) exposure settings. It is therefore possible that different hospitals, using different image parameters, show a substantial variation in radiation dose [7–9].

However, inappropriate irradiation may be quite obvious when it comes to the incorrect collimation of the image field or incorrect positioning of the infant on the detector or film plate. Unnecessary exposure of the abdomen, arms or head can lead to a substantial increase of radiation dose, mainly due to the irradiation of red bone marrow or abdominal viscera [10]. Effects on the cumulative dose in preterm infants may be quite severe and independent of technical parameters. Reduction of the overall image quality with respect to the radiation dose could be influenced by multiple factors. Some of them may be specific to the infant, including weight, age and disease severity. Other intrinsic factors, such as the education and

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awareness of the radiographer actually taking the X-ray on the intensive care unit, may also be relevant [10,11].

The aim of the present study was to compare radiation exposure and image quality, in terms of the collimation, in two teaching hospitals. Our goal was to identify potential factors influencing inappropriate exposure of non-thoracic structures in portable chest X-rays on the intensive care unit.

2. Materials and methods

The study consisted of a retrospective analysis of 200 mobile digital AP chest X-rays (stored on phosphor plates) carried out on 20 preterm neonates at two different hospitals, including patients with multiple X-rays (performed on separate occasions). One hundred images were acquired from a university hospital (site 1) and another 100 images were obtain from a community teaching hospital (site 2). We extracted demographical data from the case notes, including the length of gestation (weeks) and the age of the neonate on the date of the X-ray. Tube settings and exposure parameters, including tube voltage, tube current and dose-area product (DAP) were recorded. The radiography systems used were a Philips Mobile Diagnost (Philips Healthcare, The Netherlands) at site 1, and a Siemens Mobilette (Siemens, Erlangen, Germany) at site 2. The radiographers were noted, as well as their years of experience in performing X-rays. In addition, we recorded the presence of tubes and catheters as a surrogate of disease severity. The data were anonymised before image evaluation. Radiographs used for the study were included sequentially and not preselected. We did not take the diagnosis into account. Both hospitals monitored the rate of repeat X-rays. Repeat images on neonates were not allowed without the permission of a consultant radiologist. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent was not required. Informed consent was obtained from all individual participants included in the study.

Two experienced radiologists (JCS and IK-S) evaluated the image quality, based on the exposure of non-thoracic structures. They determined the most superior and inferior parts of the body, as well as the lateral structures, which had been included within the boundaries of collimation on each chest X-ray. The readers performed their evaluations according to the European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics [12]. A grading system was used to measure image quality in terms of correct collimation. Inappropriate exposure of abdominal viscera was assumed when the caudal imaging field extended below the level of L1/2 (1 point). Exposure of the cranial structures was considered inappropriate when the collimated field included more than the tip of the mandible (1 point). Inappropriate exposure of the arms was assumed when more than the diametaphyseal junction of the proximal humerus came within the field of view: part of the diaphyseal humerus (1 point); entire humerus (2 points); part of the forearm (1 point); entire forearm (2 points); hand (1 point). The maximum score was 12 points. The image quality in terms of correct collimation was graded arbitrarily as follows: 0 points = optimal image quality; 1–2 points = slightly reduced; 3–4 = moderately reduced; 5–6 = markedly reduced; and >7 points = severely reduced (Fig. 1). Rotation and tilting were also recorded. Radiographic errors were recorded on individual tick sheets and the information was captured in an Excel spreadsheet (Microsoft, Redmond, WA). The readers resolved any differences by consensus.

The exposure of non-thoracic structures was correlated with factors potentially influencing image quality. The chi^2 test (uncorrected for continuity) was used to calculate differences between the hospitals, as well as between optimal and suboptimal images with respect to age, gestation, number of tubes and catheters, radiographer, and the number of years' experience. Student's t test was used to calculate differences between DAPs. The Spearman rank correlation coefficient was used to analyse the correlation between the radiographer's experience in performing X-rays and collimation quality. A level of $p < 0.05$ was regarded as statistically significant. Analyses were performed using SAS statistical software (version 9.1; SAS Institute, Cary, NC).

Table 1
Frequency and distribution of exposure of non-thoracic structures in two different hospitals. The number of structures and the points scored are shown for the two hospitals. There was no significant difference (*n.s.) between site 1 (university hospital) and site 2 (community teaching hospital).

Exposure of non-thoracic structures		Site 1 [n (points)]	Site 2 [n (points)]
Head		5/5	7/7
Right upper limb	Part of upper arm	32 (32)	24 (24)
	Entire upper arm	20 (40)	12 (24)
	Part of forearm	7 (7)	4 (4)
	Entire forearm	0 (0)	1 (2)
	Hand	1 (1)	0 (0)
Left upper limb	Part of upper arm	17 (17)	28 (28)
	Entire upper arm	19 (38)	12 (24)
	Part of forearm	4 (4)	4 (4)
	Entire forearm	1 (2)	2 (4)
	Hand	1 (1)	2 (2)
Abdomen		7 (7)	8 (8)
Total		114 (154)*	104 (131)*

Table 2
Comparison of image quality at the two institutions in terms of collimation. The chi^2 test showed no statistically significant difference in the number of correctly collimated images (*n.s.). The number of exposed non-thoracic parts (head, abdomen, arms and hands) in the suboptimal images is also given as a semiquantitative measure of image quality.

Image quality (collimation)		Site 1 (%)	Site 2 (%)
Optimal		0.32*	0.39*
Sub-optimal		0.68	0.61
1–2 parts exposed	Slightly reduced	0.48	0.49
3–4 parts exposed	Moderately reduced	0.17	0.08
5–6 parts exposed	Markedly reduced	0.02	0.04
>7 parts exposed	Severely reduced	0.01	0.00

3. Results

All images were obtained with the neonate in a supine position. Imaging parameters were 60 (60–62) kVp and 1.96 (1.6–2.5) mAs at the university hospital, and 72 (70–77) kVp and 0.71 (0.56–0.80) mAs at the community hospital, with no grid and a 20×25 cm image plate. The DAPs were 0.08 ± 0.04 cGy cm^2 and 0.10 ± 0.05 cGy cm^2, respectively (n.s.). The monitored repeat rates were low at both units. Only one repeat X-ray was recorded at site 2 and none at site 1.

Table 1 shows all exposed non-thoracic structures in both hospitals. The upper arm was most commonly observed, while exposure of all other parts was relatively infrequent. The overall frequency and distribution were quite similar in the two hospitals (154 vs 131 points, n.s.). Table 2 presents the number of images with optimal and suboptimal collimation. Evaluation shows a comparable rate of optimal images in the two hospitals with no significant difference (32% vs 39% for site 1 and 2, respectively). The majority of suboptimal radiographs demonstrated only 1–2 errors per film, accounting for 48% and 49% of the X-rays evaluated at sites 1 and 2, respectively.

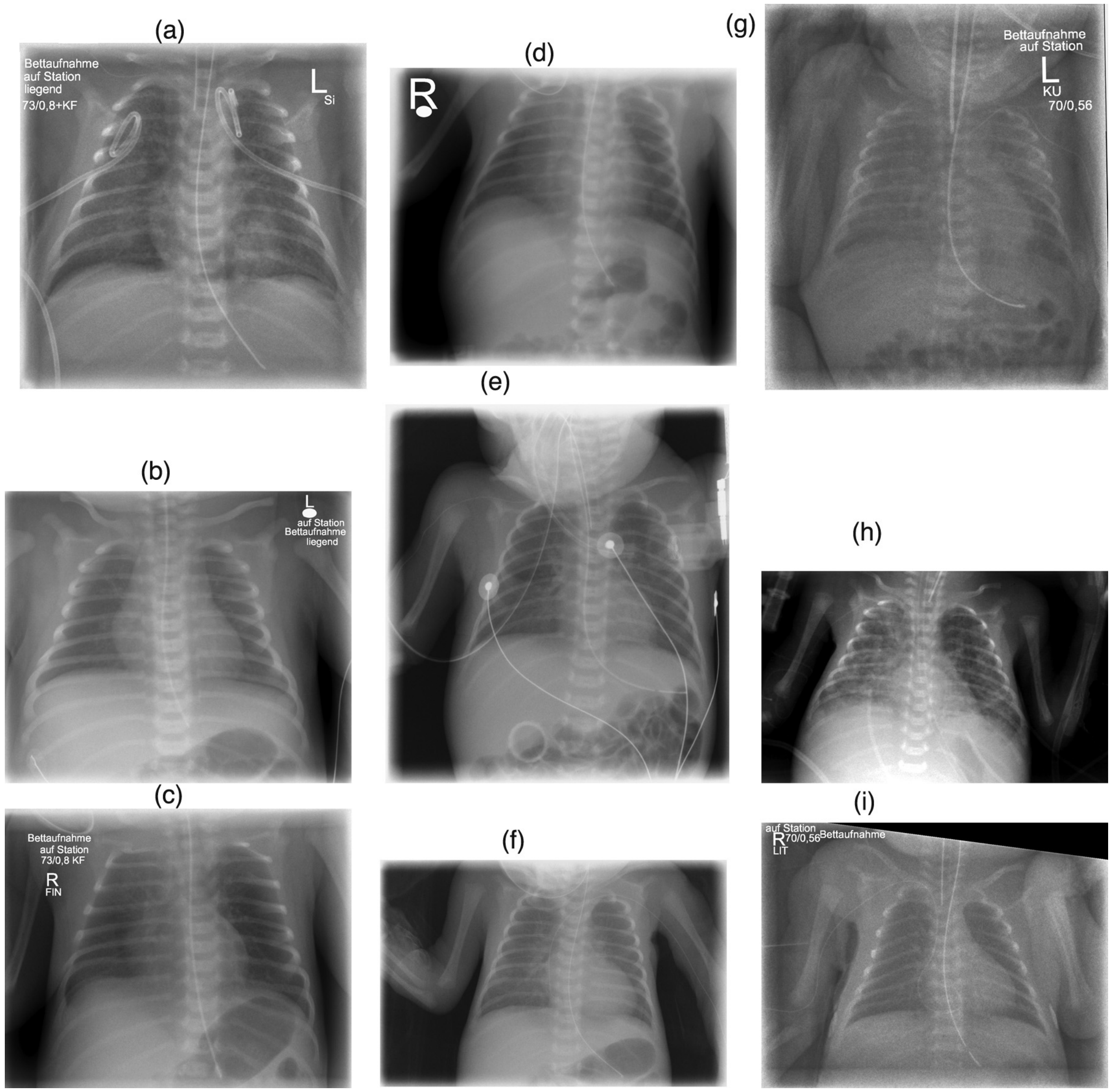

Fig. 1. Anterior–posterior portable digital radiographs, stored on phosphor plates. (a) (0 points): optimal collimation; (b) (1 point) and (c) (2 points): slightly reduced image quality due to exposure of the proximal marrow cavity of the left humerus; (d) (3 points) and (e) (4 points): moderately reduced image quality with exposure of the entire right humerus and part of the forearm; (f) (5 points) and (g) (6 points): markedly reduced image quality in a case showing the entire humerus on both sides and part of left hand; (h) (7 points; and (i) (8 points): severely reduced quality observed in two cases that exposed multiple extra-thoracic structures.

Table 3
Correlation of image quality and gestational age. Using the chi² test, there was no statistically significant difference in mean gestation (weeks) between the two institutions (*n.s.). There is no obvious difference in image quality, in terms of exposed non-thoracic structures, due to the length of gestation.

Image quality (collimation) and length of gestation (in weeks)		Site 1 [week ± SD]	Site 2 [week ± SD]
Optimal images		32 ± 3.2	29 ± 3.7
Sub-optimal images		32 ± 3.3	30 ± 3.9
1–2 parts exposed	Slightly reduced	28 ± 3.4	31 ± 4.2
3–4 parts exposed	Moderately reduced	28 ± 3.7	30 ± 2.1
5–6 parts exposed	Markedly reduced	28 ± 0.7	30 ± 1.6
>7 parts exposed	Severely reduced	30 ± 0.0	–

Based on the number of points scored, therefore, the image quality in most of the suboptimal images was only mildly reduced. Table 3 shows a correlation of collimation and gestation week, the latter serving as a surrogate of size and weight of the infants, as these data were not routinely recorded in the case notes. The length of gestation had no obvious influence on image quality. The same was true for the number of surgical drains, catheters, tubes, and central lines taken as a surrogate of disease severity (Table 4). However, a large variation in the collimation could be seen when looking at the points scored by different radiographers. The rates of optimal images varied between 14% and 86%. The range of mean scores for each radiographer was 0.44–2.50 at site 1 and 0.14–2.50 at site 2. This phenomenon was not significantly related to the years of experience, as shown in Fig. 2. The mean collimation scores at site 1 and

Table 4
Correlation of image quality and the number of surgical drains, catheters, tubes and central lines that may potentially hinder collimation. There is no statistically significant difference between the two institutions in the number of these devices inserted (chi^2 test: *n.s.). There is no obvious difference in the number of insertions and image quality related to exposed non-thoracic structures.

Image quality (collimation) and number of surgical drains, catheters, tubes and central lines		Site 1 [week ± SD]	Site 2 [week ± SD]
Optimal images		2.2 ± 0.9*	1.9 ± 0.8*
Suboptimal images		2.2 ± 0.9	1.9 ± 1.1
1–2 parts exposed	Slightly reduced	2.1 ± 1.0	1.6 ± 1.1
3–4 parts exposed	Moderately reduced	2.4 ± 0.7	2.3 ± 0.5
5–6 parts exposed	Markedly reduced	1.5 ± 0.7	2.3 ± 1.3
>7 parts exposed	Severely reduced	3.0 ± 0.0	–

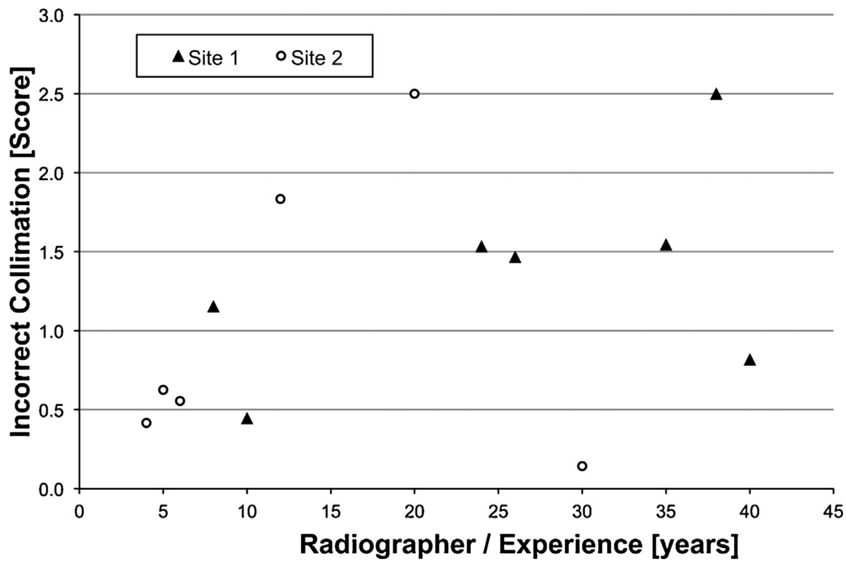

Fig. 2. Distribution of image collimation scores in the two institutions (site 1—university hospital; site 2—community teaching hospital). Large variation was observed in the scores, although there was neither a significant difference in the mean rate of correct collimation nor a correlation to the individual radiographer's years of experience in performing X-rays (Spearman rank correlation coefficient: $r = 0.40$; $p = 0.15$; n.s.).

site 2 were 1.40 ± 1.38 and 1.20 ± 1.43, respectively (n.s.). Significant rotation and tilting was observed in 19% of the cases at site 1 and 21% of those at site 2 (n.s.).

4. Discussion

Numerous reports have suggested that infants and young children are more sensitive to radiation exposure than older children and adults, so there is a greater potential for harmful side effects. Although radiographic imaging results in a relatively small dose compared with computed tomography, the vast number of X-rays taken represents an increased risk to the population as a whole [13].

In general, there are two major issues in radiography quality assurance: one that addresses the quality of the diagnostic X-ray equipment and the other that reviews the quality of the radiographs performed [7,14]. Numerous technical strategies to reduce patient dose have been discussed in the literature. The effects of parameter settings, shielding, incorrect positioning, grid use, and exposure indicator targets have been extensively investigated [9,15].

However, independently of technical parameter settings, correct collimation is an important practical issue in radiography. Collimation reduces the volume of tissue irradiated and decreases patient exposure. It also reduces the amount of scatter radiation produced (although the effect in neonates is relatively small compared to adults). However, reduction of scatter radiation reaching the image receptor increases image contrast and quality. Including extra-thoracic structures in the field does not usually provide any useful information on a chest X-ray but may result in a substantial increase in radiation exposure.

We compared the frequency of optimal imaging in two different hospitals and investigated potential factors influencing collimation. Our results indicate that the exposure of non-thoracic structures is a relatively frequent phenomenon. Complete or partial exposure of the upper arm was the most common finding. In the majority of cases, however, image quality in terms of collimation was only mildly reduced. The rates of optimal images were similar at the two hospitals, one of which has a dedicated paediatric imaging service (site 1).

Recent reports found clear differences between paediatric and mixed-patient radiography services (as at site 2), with respect to image acquisition, image-quality assessment, and general emphasis on radiation dose reduction [16]. In a survey of 493 radiographers, Morrison et al. found that patient motion is by far the most common reason for repeat exposures in all services. Other causes such as poor positioning, anatomical clipping, artefacts, and underexposure were much more commonly described in radiography services not based in children's hospitals. They concluded that the risk of patient movement encourages many technologists to widen their collimation with infants and children, in order to capture all the necessary anatomy. The ease of repeating examinations immediately with direct radiography may also contribute to an increased tendency to repeat less-than-perfect exposures [16]. However, compared with infants in general, motion was certainly a less important issue in the neonates investigated in our study and the repeat rates monitored were comparably low at the two institutions.

The gestation age (as a surrogate of weight and size) and the number of external lines or catheters (as a surrogate of disease severity) did not have any obvious effects on collimation. We found, somewhat unexpectedly, that the number of optimal images for each individual radiographer differed considerably. This phenomenon was not, however, significantly correlated to the years of experience in performing X-rays. Other intrinsic factors, such as educational level and awareness of the radiographer, may be responsible for the large variation observed. However, while these factors are difficult to measure on an objective basis, our results support the idea of individualised training for radiographers, to improve image quality and decrease radiation doses in paediatric radiography.

Morrisson et al. emphasised the need for better educational materials and training programmes for radiographers. They claim that broad commitment is required from manufacturers, educational institutions, speciality paediatric radiology organisations and individual imaging specialists [16]. In the study on the education of technologists, participants stressed the importance of immediate feedback on image quality and exposure, information about appropriate technical settings for paediatric patients, and more reliable measures of radiation exposure for patients in general.

In a recent report, Hlabangana and Andronikou investigated the impact of short lectures for radiographers in conjunction with poster material showing technical errors in the image quality of paediatric chest X-rays. They observed a statistically significant improvement in the quality of radiographs performed immediately after the educational intervention and a statistically significant subsequent decline in the quality of radiographs performed >2 months afterwards [11]. The rate of poorly collimated images (5.4%) was lower than we found in our study. However, their evaluation did not include any portable X-rays in neonates. They concluded that continuing education is needed on a regular basis (e.g. every 2 months). To the best of our knowledge, no information is available regarding image quality for individual radiographers or individual responses to an educational intervention.

Compared with the amount of literature addressing imaging parameters and other technical aspects in radiography, relatively few data are available on the individual (human) factors influencing radiation exposure in paediatric imaging. In view of the very large differences at baseline, we can conclude from our data that individualised quality assurance, training and follow-up are necessary. Given the different distribution of red bone marrow in children (contained in a relatively small imaging field), every centimetre of incorrect collimation accounts for a substantial increase in the radiation burden, whereas the effect on overall exposure in the adult is relatively small [17,18].

5. Limitations

Our study is limited by its retrospective design, relatively small number of patients, and the lack of a control group. Despite these limitations, our results show that the individual education of radiographers remains an important factor in paediatric radiation protection. The radiographer represents the last line of defence against the unnecessary irradiation of pre-term infants.

6. Conclusions

In our study, the only identifiable factor influencing the collimation of portable chest X-rays in preterm infants was the radiographer's dedication and awareness. There were no apparent differences between the hospitals investigated. In general, exposure of non-thoracic structures was relatively frequent and mainly involved the proximal humeri.

Conflict of interest

The authors declare that they have no conflict of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ejro.2015.07.002

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