Pediatr Radiol
DOI 10.1007/s00247-011-2290-1

ORIGINAL ARTICLE

Quality assurance: a comparison study of radiographic exposure for neonatal chest radiographs at 4 academic hospitals

Mervyn D. Cohen · Richard Markowitz · Jeanne Hill · Walter Huda · Paul Babyn · Bruce Apgar

Received: 24 June 2011 / Revised: 4 October 2011 / Accepted: 7 October 2011

Abstract
Background Little is known about exposure differences among hospitals. Large differences might identify outliers using excessive exposure.
Objective We used the newly described *exposure index* and *deviation index* to compare the difference in existing radiographic exposures for neonatal portable chest radiographs among four academic children's hospitals.
Materials and methods For each hospital we determined the mean exposure index. We also set target exposure indices and then measured the deviation from this target.
Results There was not a large difference in exposure index among sites. No site had an exposure index mean that was more than twice or less than half that of any other site. For all four sites combined, 92% of exposures had a deviation index within the range from −3 to +3. Thus exposures at each hospital were consistently within a reasonable narrow spectrum.
Conclusion Mean exposure index differences are caused by operational differences with mean values that varied by less than 50% among four hospitals. Ninety-two percent of all exposures were between half and double the target exposure. Although only one vendor's equipment was used, these data establish a practical reference range of exposures for neonatal portable radiographs that can be recommended to other hospitals for neonatal chest radiographs.

Keywords ALARA · Radiation exposure · Neonatal chest imaging · Deviation index

M. D. Cohen (✉)
Department of Radiology, Indiana University,
Riley Hospital for Children,
702 Barnhill Drive, Rm. 1053,
Indianapolis, IN 46202, USA
e-mail: mecohen@iupui.edu

R. Markowitz
Department of Radiology, Children's Hospital of Philadelphia,
Philadelphia, PA, USA

J. Hill · W. Huda
Radiology and Radiological Science,
Medical University of South Carolina,
Charleston, SC, USA

P. Babyn
Department of Radiology, Hospital for Sick Children,
Toronto, Canada

B. Apgar
Digital Radiography, Agfa Healthcare,
Greenville, SC, USA

Present Address:
P. Babyn
Department of Medical Imaging, Royal University Hospital,
Saskatoon, Canada

Introduction

Using a dose that is as low as reasonably achievable (ALARA) should always be the goal in pediatric radiography. One disadvantage of using digital computed radiography systems for portable imaging is that upward dose drift can occur [1–7]. Radiation dose can increase markedly without any detectable change in the final image, so exposures greater than desirable might be used without being recognized [2–5]. This is especially important in neonates, as they often receive multiple films and because of their age they have increased sensitivity to long-term risks of radiation exposure.

The appropriateness of the selected exposure factors can be estimated by measuring exposure at the detector plate

Published online: 06 November 2011

Table 1 Deviation index. This table shows how the deviation index varies for fixed percentage changes in the exposure index

Exposure index	Target exposure index	Deviation index	Exposure factor	% Change
1,300	500	4	2.6	160%
1,000	500	3	2	100%
800	500	2	1.6	60%
630	500	1	1.26	26%
500	500	0	1	0%
400	500	−1	0.8	−20%
300	500	−2	0.6	−40%
250	500	−3	0.5	−50%
200	500	−4	0.4	−60%

[9]. Until recently each manufacturer had its own index for expressing this exposure. In 2008 and 2009, the International Electrotechnical Commission (IEC) and the American Association of Physicists in Medicine (AAPM), respectively, separately developed the exposure index (EI) to set an international standard to indirectly measure the radiation exposure to a digital detector [8, 9]. The EI is designed to generate a linear relationship between the index value and detector exposure. The IEC 62494–1 EI standard was used for this study.

A target exposure index value is set for each examination type. This target exposure index (TEI) might be different for each body part (chest, abdomen, foot, etc.), and vary by examination room (dependent on factors such as filtration, sensitivity of detector plate, etc.). Thus the actual value of the exposure index should not be used by technologists or radiologists to track patient exposure. The deviation index (DI) expresses the variation of the exposure index from a set target exposure index. It is a measurement of how far the exposure index, for a given patient, is from a target exposure value. It provides a relative indication for under-exposure or over-exposure. The DI was also developed by the IEC and the AAPM.

The units used to describe the degree of deviation are clearly defined (Table 1) [8, 9]. Using the table it can easily be seen, for example, that for any digital CR radiograph, a deviation index of 3 indicates that the technologist used an exposure double that of the target for that body part. A deviation index of −3 indicates an exposure that is 50% below the desired target exposure index.

The formula for calculating the deviation index is:

$$\text{Deviation Index} = 10 \times (\text{Log10}(\text{Exposure Index}/\text{Target Exposure Index})$$

A recent study demonstrated that the exposure index and deviation index can be effectively used to track exposure for neonatal portable chest radiographs [10]. There are no clear published standards for exposure factors for the performance of digital portable chest radiographs in neonates. It is possible that different hospitals could be using very different exposures. The objective of our study was to utilize the newly described exposure and deviation indices to evaluate the variation in detector plate exposures used for neonatal portable chest radiography at four academic children's hospitals. We used existing operations at each hospital. We were not trying to optimize techniques or image quality.

Materials and methods

All image data were handled according to the Health Insurance Portability and Accountability Act (HIPAA), and the study was approved by the review boards at each institution.

Each of the four hospitals utilizes the Agfa Healthcare's NX technologist workstation and exposure-monitoring quality-assurance software. This software allows automatic storage of the exposure index for every image and also calculates the deviation index. Sites 1 and 2 used Agfa DXS plate readers, with CsBr needle phosphor plates, sites 3 and 4 used Agfa Solo plate readers with BaFBr powder phosphor plates.

Using their existing established exposure factors we determined the mean exposure index for 50 consecutive recent neonatal chest radiographs performed at each hospital. This mean was used to set a target exposure index

Table 2 Recommended exposure factors for neonatal chest radiographs at each of the four study hospitals

Radiographic technique factors for NICU patients					
Site	Portable	Cassette location	Small	Average - Medium	Large
1	GE AMX-4	Tray	62 kVp 0.8 mAs	64 kVp 0.8 mAs	66 kVp 0.8 mAs
2	GE AMX-4	Tray - 80%	54 kVp 1.2 mAs	58 kVp 1.6 mAs	60 kVp, 1.6 mAs
2	GE AMX-4	Directly under −20%	52 kVp 1.25 mAs	54 kVp 1.25 mAs	56 kVp, 1.6 mAs
3	Siemens	Directly under −100%	60 kVp, 0.8 mAs	60 kVp, 1.25 mAs	60 kVp, 2 mAs
4	GE AMX-4	Directly under −100%	64 kVp, 2.0 mAs	64 kVp, 2.5 mAs	66 kVp, 2.5 mAs

Table 3 Entrance air kerma and exposure index for the phantom at the four hospitals

Multi-hospital Gammex phantom exposure conditions						
Site	kVp	mAs	Total filtration mm AL	HVL mm AL	Entrance air Kerma uGy	Exposure index
1	66 kVp	0.8	3.4	2.71	34.62	608
2	56 kVp	1.25	2.5	1.83	44	562
3	60 kVp	1.3	2.5	2	36.6	384
4	64 kVp	2	6.1	3.35	22.7	275

for each hospital. We then measured the deviation from this target exposure at each hospital. The deviation index was calculated using the previously published formula [8, 9].

Each hospital determines the exposure factors to be used for a specific neonatal portable radiograph in a similar fashion. Technologists are given discretion. They are given recommended exposure factors for an "average/about 1,500-gram neonate" (Table 2) and then asked to adjust these factors for smaller or larger babies. These guidelines are not rigid. Technologists do not check the baby's weight prior to each exposure. To determine the exposure variation among hospitals, we imaged a neonatal phantom designed to simulate the chest of a 1,500-g baby (Gammex Corp., Middleton, WI, USA). At each hospital we used exposure factors based on the lead technologist's choice for a 1,500-g infant.

The mean, median and range of EI values were determined for each site.

An Anderson Darling Normality test was done to determine whether the deviation index values or exposure index values from each site were normally distributed.

The mean deviation index was also computed for each site. In an ideal situation this value should be 0. If the exposure drifts up or down this value will show that drift as either a positive or negative number.

The standard deviation and range of the deviation index were also computed for each site.

Results

The results of the phantom study are given in Table 3. The entrance air kerma ranged from 22.7 uGy at site 4 to 44 uGy at site 2. The differences are caused by variations in exposure settings and filtration among the hospitals.

The number of patient studies at each of the four sites was 1,884, 974, 423 and 65. The results for the exposure index measurements are given in Table 4. For each site the mean for the exposure index was 372, 557, 521 and 343. The target exposure index for each site was 338, 613, 492 and 347. No site had an exposure index mean or median value that was more than twice or less than half that of any other site.

The deviation index values from each site were normally distributed when tested using an Anderson Darling Normality test, with only a slight variation at the tails of the distribution. The distribution of the exposure index values was log normal.

For each site the mean deviation index was 0.08, -0.82, -0.07 and −0.48 (Table 5). The value of −0.82 from site 2 indicates that the average exposure index is less than the target exposure index. The mean values from sites 1 and 3 are very close to zero and indicate good performance. The mean value from site 4 indicates a possible drop in exposure but the number of samples is limited so no action should be taken until more data are gathered.

The majority of the exposures at each hospital were within a narrow spectrum. For all four sites combined, 92% of exposures had a deviation index within the range from −3 to +3. This would correspond to an exposure 50% below or 100% above the target exposure index. This indicates that technologists do keep their exposures within a narrow range and that major over-exposure (upward dose drift) is not occurring. The deviation index from each hospital also follows a normal distribution (Fig. 1). The deviation indices for each patient are shown in Fig 2.

Table 4 Exposure index results for the four hospitals

Table AA exposure index summary statistics							
	Mean	Median	TEI=Avg. of 50	Maximum	Minimum	Range	Count
Site 1	372	338	338	1,584	73	1,511	1,884
Site 2	557	501	613	1,614	92	1,522	974
Site 3	521	468	492	1,671	109	1,561	423
Site 4	343	299	347	733	125	608	65

Table 5 Deviation index results for the four hospitals

Table BB deviation index			Deviation index distribution			
	Mean	St Dev	−1 to 1	−2 to 2	−3 to 3	−4 to 4
Site 1	0.08	1.68	46%	78%	93%	98%
Site 2	−0.82	1.89	36%	68%	87%	95%
Site 3	−0.07	1.67	49%	79%	91%	98%
Site 4	−0.48	1.94	31%	58%	92%	98%
Combined normalized results	0	1.75	45%	76%	92%	98%

Discussion

We used two newly described indices (the exposure index and the deviation index) to compare exposures used for neonatal portable chest radiographs at four hospitals. The exposure index provides an indication of the actual exposures used [8, 9]. The deviation index is an indicator of how much the exposures at each hospital differed from the preset target exposure [8, 9]. There are a number of ways to determine the target exposure index. Ideally the exposure factors used and the resulting target EI values are set to optimize patient dose and image quality for each exam. For this study the assumption was made that this had been done and that the departments were operating correctly. The target exposure index was determined by taking the mean exposure index from 50 consecutive images [10].

The deviation index is designed to easily express deviations from the target exposure—the correlation between the deviation index number and the percentage change in exposure from the target exposure is given in Table 1.

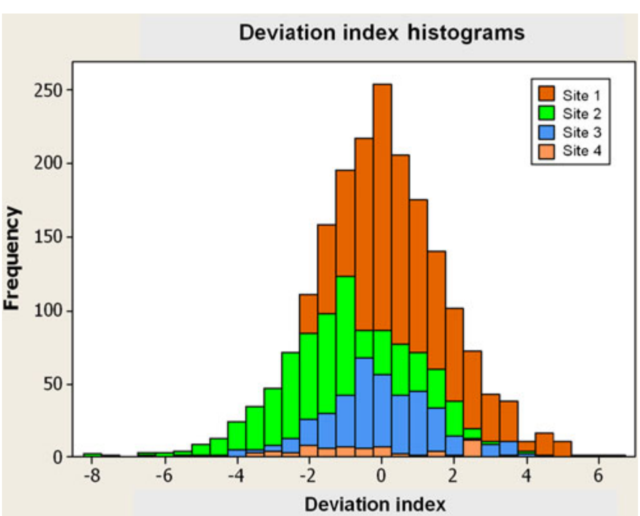


Fig. 1 Graph shows the distribution of the deviation index at each hospital

All four of our study hospitals use manual exposure techniques and all have a similar method for providing exposure guidelines to the technologists.

The differences in the exposure index among our four study hospitals are probably within an acceptable range. It is to be expected that some differences in exposure and exposure index will always be found, for many reasons. Technical factors include reliability of tube output from the portable X-ray machine, the nature of the beam filtration and the construction and sensitivity (DQE) of the detector plates. Technologist factors include collimator position, difficulty in always getting a fixed distance from the tube to the detector for babies in incubators and subjective assessment of patient size. Radiologists vary in their tolerance of image noise, and the visibility of noise can be influenced by the type of image processing used.

The amount of noise each radiologist is willing to accept can contribute to differences in exposure technique and exposure index among sites as much or more than any other factor. Within a site if all other factors are equal more efficient detectors with higher DQE can enable users to reduce exposure and EI while maintaining or improving image quality.

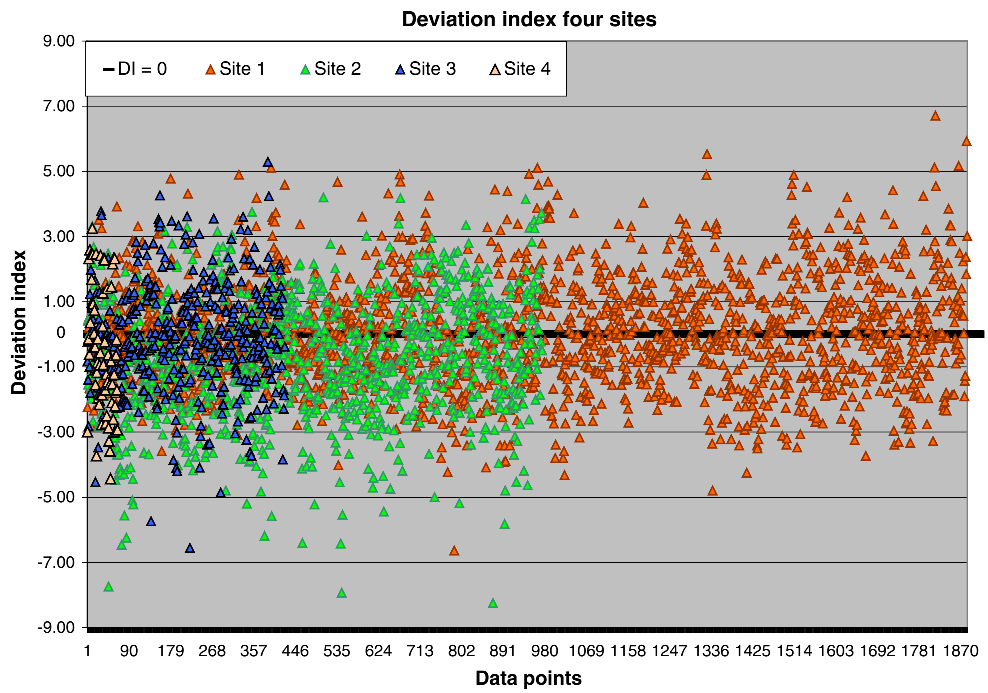
While the exposure index should not be used as an absolute value to compare exposures across facilities, our study has found that exposure index can be a good guideline.

The differences in the deviation index among our four study hospitals are also probably within an acceptable range. The deviation indices were similar at each hospital, indicating that no hospital was having unique problems with major over-exposure. The same factors that affect the exposure index will also result in variations of the deviation index.

A limitation of the study is that the age, gestation and weights of our babies were not recorded. Also all our studies were done use Agfa equipment and the results might not be valid for other vendors' equipment.

Our results provide the methods for an ongoing quality control and patient safety program. Utilization of exposure

Fig. 2 Graph shows the deviation index data from patients at each hospital



index and deviation index would be particularly valuable at institutions where there are multiple technologists, portable machines and radiologists, making it difficult to track trends and potential upward dose drift. It is important to note that measuring the EI and DI are not substitutes for measuring the patient dose. They are estimates of plate detector plate exposure. A recent article emphasized the limitations of the EI and DI in routine clinical practice; possibly the only major role for EI will be as a tool to detect upward exposure drift for portable images [11]. It will have a limited role in the X-ray department when automatic exposure is being used.

Further, our results provide guidelines illustrating the range for an acceptable ballpark number for the exposure index for neonatal chest imaging. No absolutes can be stated. For all four sites combined, 92% of the exposures fell between −3 and +3 deviation units. This can be used as a guide for an approximate target for minimal and maximum exposure index values to be used. This results in a range of exposure index values from 171 to 686 at site 4 and from 289 to 1,114 at site 2.

This information should be helpful to academic children's centers and serve as a guide to general hospitals doing limited pediatric neonatal imaging.

Conclusion

At the four hospitals studied the exposure difference for neonatal chest radiographs is relatively minor. At each hospital deviations from predetermined target exposures were small and relatively similar. No outlier hospital has been identified. The data establish a practical range of exposures for neonatal portable radiographs that can be recommended to other hospitals for neonatal chest radiographs.

References

1. Goske MJ, Applegate KE, Boylan J et al (2008) The Image Gently campaign: working together to change practice. AJR 190:273–274
2. Don S (2004) Radiosensitivity of children: potential for overexposure in CR and DR and magnitude of doses in ordinary radiographic examinations. Pediatr Radiol 34(Suppl 3):S167–172, discussion S234-241
3. Uffmann M, Schaefer-Prokop C (2009) Digital radiography: the balance between image quality and required radiation dose. Eur J Radiol 72:202–208
4. Vaño E, Fernández JM, Ten Ignacio J et al (2007) Transition from screen-film to digital radiography: evolution of patient radiation doses at projection radiography. Radiology 243:461–466
5. International Commission on Radiological Protection (2004) Managing patient dose in digital radiology: a report of the International Commission on Radiological Protection. Ann ICRP 34:1–73
6. Seibert JA, Shelton DK, Moore EH (1996) Computed radiography X-ray exposure trends. Acad Radiol 3:313–318
7. Schaetzing R (2004) Management of pediatric radiation dose using Agfa computed radiography. Pediatr Radiol 34(Suppl 3): S207–S214
8. Shepard SJ, Wang J, Flynn M et al (2009) An exposure indicator for digital radiography: AAPM Task Group 116 (executive

summary). Med Phys 36:2898–2914. Erratum (2010). Med Phys 37:405
9. (2008) Medical electrical equipment—exposure index of digital x-ray imaging systems. Part 1: definitions and requirements for general radiography, International Electrotechnical Commission (IEC), international standard IEC 62494–1:2008–08 Geneva, Switzerland
10. Cooper M, Cohen M, Piersall K et al (2011) Using the exposure index to monitor radiation exposure for portable chest radiographs in neonates. Pediatr Radiol 41:592–601
11. Cohen MD (2010) Quality assurance: potential use for the newly described exposure index in clinical practice. J Am Coll Radiol 7:748–749