Technical Note

Assessment of Diagnostic Reference Level in Radiography of Neonatal Chest Anteroposterior Examination: A Hospital-based Study

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Abstract

Radiological imaging is an important modality of today's overall practicum. Imaging can begin as early as the 1st day of life. Neonates are 3–4 times more sensitive to radiation than adults. The purpose of the work was to assess the diagnostic reference level (DRL), the radiation organ dose, and effective organ dose for both sexes from chest anteroposterior radiograph, which is the most common radiographic examination performed at the Neonatal Intensive Care Unit (NICU). The entrance air kerma was measured using a solid-state PIN type detector, and the value was used as the input factor to PCXMC-2.0 software to calculate the entrance surface air kerma (ESAK), patient-specific organ dose, and effective dose originated from chest anteroposterior examinations of neonates at NICU. The mean value of ESAK is taken as a diagnostic reference level (DRL) for neonates (both male and female). The mean ESAK value of male neonates is (79.6 ± 1.4) μGy and for female is (79.9 ± 1.9) μGy, and the institutional diagnostic reference level (DRL) is 80.35 μGy for male and 81.2 μGy for female (i.e., third quartile value). A statistical dependency (correlation) between neonates body mass index (BMI) and ESAK was defined for both the sexes. Significant positive correlation was found between ESAK per patient with respect to BMI of both male (R = 0.83, $P = 0.00001$) and female (R = 0.72, $P = 0.00055$) neonates. The results for neonatal dose in NICU were compatible with the literature. The result presented will serve as baseline data for the selection of technical parameters in neonatal chest anteroposterior X-ray examination.

Keywords: Chest X-ray, neonatal intensive care units, PCXMC, radiation doses, radiation risks

Received on: 28-03-2018 **Review completed on: 09-07-2018** **Accepted on: 27-07-2018**

Introduction

The chest X-ray is the most valuable modality in the assessment of the neonatal respiratory disorder.[1] In a study reported by Spitzer *et al*., routine screening chest radiographs were found to be significantly beneficial in one-third of the neonates, identifying, among other things, potential pulmonary problems before patient's clinical status deteriorated.[2] The International Commission on Radiological Protection (ICRP) has encouraged "authorized bodies to set diagnostic reference levels (DRL) that best meet their specific needs and are consistent for the regional, national, or local area to which they apply." DRLs were determined through the 3rd quartile of the distribution of mean dosimetric values.[3] Therefore, DRL is not a dose limit, but a guide for doing well. DRLs essentially act as the initial standard in a local radiology audit process for identifying situations where patient doses are unusually high. Local reviews should be undertaken whenever relevant DRLs are consistently exceeded and appropriate corrective actions should be taken to improve practice and avoid unnecessary risk due to radiation health effects.[4] A previous study carried out by Sonawane *et al*.[5] has established DRL value for all radiographic examination including pediatric, where DRL of chest anteroposterior of 5-year-old patients was obtained. Until now, no DRL has been established for neonates (below 1 month of age) of chest anteroposterior examination in India. In our study, we are trying to implement

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Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.JMP_37_18

How to cite this article: Sharma J, Sarma J, Agarwal S. Assessment of diagnostic reference level in radiography of neonatal chest anteroposterior examination: A hospital-based study. J Med Phys 2018;43:200-3.

the concept of DRL for chest anteroposterior of neonates in terms of field-related dosimetric quantity (e.g., entrance surface air kerma [ESAK]) as per the guideline given in ICRP publication. In diagnosis, the ALARA principle means that the radiation burden to the patient should be as low as reasonably achievable consistent with obtaining the required diagnostic information. Therefore, the dose received by neonates in any radiological examination needs to be weighed against the anticipated benefits from the diagnostic information that is obtained.[6]

In radiological diagnostic examination, risk is generally taken to be proportional to the cumulative organ dose. The radiation risk from two radiographs, for example, would be approximately twice the risk of a single scan, irrespective of the time interval between the two radiographs.[7]

The biological effects of low doses (<100 mSv) of ionizing radiation are still a subject of debate. Risk assessments are complicated by the fact that human beings have a relatively high natural cancer risk (25%–33%) and are exposed to natural background radiation, which varies between populations. Even large epidemiological studies will not provide reliable excess risk factors for low doses. It is therefore necessary to use the linear no-threshold hypothesis, which states that cancer risk from the low linear energy transfer doses increases proportionally as the radiation dose increases, as extrapolated from the risks of higher doses.[8]

Evidence of an increased risk of mortality for all cancers, excluding leukemia and lung cancer, has been reported with increasing radiation doses.[9] Very young children are 3–4 times more sensitive to ionizing radiation than adults.[8] An increased susceptibility of children to radiation-induced cancer is biologically plausible because their tissues are still growing and therefore the dividing cells are more prone to somatic genetic damage. In addition, children have a longer life expectancy during which oncogenic effects may develop.[9]

The ICRP has specifically warned not to use the diagnostic X-ray exposure for arriving at cancer deaths and risk factors. The reason stated is that the linear nonthreshold dose hypothesis is a hypothesis with no proof and has been used only for arriving the dose limits for operational radiation protection but not for cancer risk. This has been discussed in several publications.[10,11]

Monte Carlo simulation is the established method for determining patient radiation doses for radiographic examinations.[12]

The patient-specific organ doses were calculated with the PCXMC-2.0 Monte Carlo simulation software available in the department.

The purpose of the work was to assess the diagnostic reference level (DRL), radiation organ dose, and effective dose for both sexes from the chest anteroposterior radiograph in the Neonatal Intensive Care Unit (NICU).

Materials and Methods

The variables (both radiographic technique and demographic) used for the chest radiography anteroposterior examination of newborn babies were obtained from the NICU. The radiographic technique variables included the X-ray tube voltage (kVp), tube-current time product (mAs), source–skin distance (SSD), filtration, and the actual collimator settings (field size). The demographic variables included patient sex, hospital identity, body mass index (BMI), and height.

The entrance air kerma (EAK) was measured using a calibrated solid-state PIN type dosimeter (IBA model-magic-maxx) at a standard SSD, i.e., 48 cm (SSD) for X-ray portable machine (model-MARS 3.5; make-Allenger) with a high-frequency generator, which is generally used only in NICU for patient diagnosis. The output of the X-ray machine was recorded in milliroentgen (mR) and converted to milli-gray (mGy) (1 mR is equivalent to 8.73 μGy in air for X-ray and Gamma ray) and divided by the mAs to obtain the output ratio (mGy/mAs). The measured output is corrected for all patient. During radiography source to image distance was kept fixed (i.e.60 cm). The EAK was estimated using equation (1) with a known focus-to-skin distance (FSD) and mAs per examination. ESAK was estimated by multiplying EAK with a selected backscatter factor depending on kV, filtration of the radiation, and the beam field size (patient thickness related: PCXMC calculates the field size on top of the patient based on the focus to film distance, patient weight, and height) as given by Petoussi-Henss *et al*.[13] and Prince *et al*.[14]

$$EAK = [\text{Output (mGy/mAs)} \times (100/FSD)^2 \times \text{mAs}]\ \text{mGy} \ldots\ldots (1)$$

The EAK was used as the input factor to PCXMC-2.0 (A Monte Carlo simulation program) software to calculate the patient-specific organ dose, effective dose, and risk of death due to radiation cancer incidence originating from the chest anteroposterior examinations.

PCXMC-2 software,[12] developed by STUK (Radiation and Nuclear Safety Authority in Finland), was used to simulate projections and calculate the resulting effective doses from the projections. The software calculated both organ doses for a large number of organs/tissues and the resulting effective dose to the patient using anatomical data from the mathematical phantom models. The latest version of PCXMC (PCXMC version 2.0) was released in 2008 and uses organ weighting factors of both ICRP publication 60[15] and ICRP publication 103.[16]

Input data for calculation were as follows: SSD, field size, kVp, EAK, coordinates of the point inside the phantom through which point the central axis of the X-ray beam is directed, total filtration, and anode angle. The PCXMC was constructed with six different phantom sizes, representing patients of different ages, from new born to standard adult.[17] These models are sex and age dependent. A more thorough explanation of the calculation details of the program can be found in a technical program document.[12]

The values of ESAK for both genders are presented as third quartile value. Organ doses are presented as mean and standard deviation. The values of respective uncertainty are also presented as percentage calculated by PCXMC-2.0 software. Correlation coefficients for the relationships between patient's dose (ESAK) and BMI are tested. In addition, the relationship between these two variables is tested for significance.

Results

In this study, total 38 numbers of neonates (19 males and 19 females) were included. The mean age of male was 6.7 ± 7.5 days and of female was 5.9 ± 9.5 days. The mean height of both male and female was 42.88 ± 1.1 cm and 40.96 ± 2.0 cm and weight was recorded 1.8 ± 0.22 kg and 1.73 ± 0.23, respectively. The mean ESAK value of male neonates is 79.6 ± 1.4 μGy and for female is 79.9 ± 1.9 μGy, and the institutional diagnostic reference level (DRL) is 80.35 μGy for male and 81.2 μGy for female (i.e., third quartile value). Table 1 represents the ESAK values for both male and female neonates with third quartile value which represents the diagnostic reference level for chest anteroposterior of neonates.

The highest organ doses in radiography of chest anteroposterior examinations as calculated by PCXMC-2.0 software are shown in Table 2. Effective doses were calculated from these organ doses. Table 3 summarizes the mean value of effective doses (E).

A statistical dependency (correlation) between neonates BMI and ESAK was defined for both the sexes. Significant positive correlation was found between ESAK (μGy) per patient with respect to BMI (kg/m²) of both male ($R = 0.83$, $P = 0.00001$) and female ($R = 0.72$, $P = 0.00055$) neonates.

Table 1: Statistical summary of entrance surface air kerma (μGy)

Gender	Minimum	Mean	3rd quartile	Maximum
Male (*n*=19)	76	79.58±1.39	80.35	81.9
Female (*n*=19)	75.6	79.93±1.89	81.2	83

Table 2: Mean organ dose (μGy) and respective uncertainty resulting from chest anteroposterior

Organ	Mean weighted dose	
	Male	Female
Liver	66.25±1.05 (1.4%)	65.72±0.97 (1.5%)
Lung	56.04±1.047 (2.3%)	56.39±1.69 (1.9%)
Stomach	72.61±3.39 (4.6%)	73.95±4.12 (4.5%)
Heart	72.09±1.59 (2.2%)	72.61±1.79 (3.1%)
Thyroid	7.41±2.47 (24.9%)	6.70±2.46 (21.1%)
Bone marrow	14.73±1.15 (0.8%)	15.60±1.54 (1.2%)
Esophagus	36.51±3.48 (11.3%)	37.05±4.35 (10.2%)
Skeleton	59.67±4.21 (1.0%)	62.43±5.06 (.6%)
Skin	20.05±1.76 (2.5%)	21.61±2.76 (2.4%)
Kidney	23.51±1.74 (4.1%)	23.03±1.98 (4.3%)
Breast	-	100.16±31.59 (29.6%)

AP: Anteroposterior

Discussion

The analysis was conducted over 38 randomly selected neonates with equal numbers of male and female, who underwent chest anteroposterior radiograph in NICU of the hospital. It was observed that chest anteroposterior radiographs were most commonly requested (96.9%) followed by a combination of chest and abdominal radiographs (2.09%) and invertograms (1.01%). Since the chest radiographs were requested mostly, this could be ascribed to the fact that respiratory-related problems are common in premature neonates.

The result for neonatal diagnostic reference level for chest anteroposterior investigation (male: 80.35 μGy and for female: 81.2 μGy) in NICU agreed well with the value (88 μGy) found by Toosi MTB *et al.*[18] and European Commission (80 μGy) for mobile chest radiographs[19]. According to correlation analysis, considerable significance was noted between BMI and ESAK of both male and female neonates. Figure 1 shows ESAKs for individual patient for chest plotted as a function of BMI. In the figure equations of a linear relation between ESAK and BMI are shown for both male and female. No significant correlation was noted between ESAK and other variables such as height, age, tube voltage, and mAs. This might be attributed to the X-ray machine (mobile unit) and technique (fixed field size with fixed 52 kV and 2 mAs) employed in each investigation.

As shown in Table 2, the organs which have higher uncertainty values suggest that a small number of photons reach the organ, i.e., they were hit by scattered radiations.

Conclusions

The results for neonatal dose in NICU were compatible with the literature. The result presented will serve as a baseline data

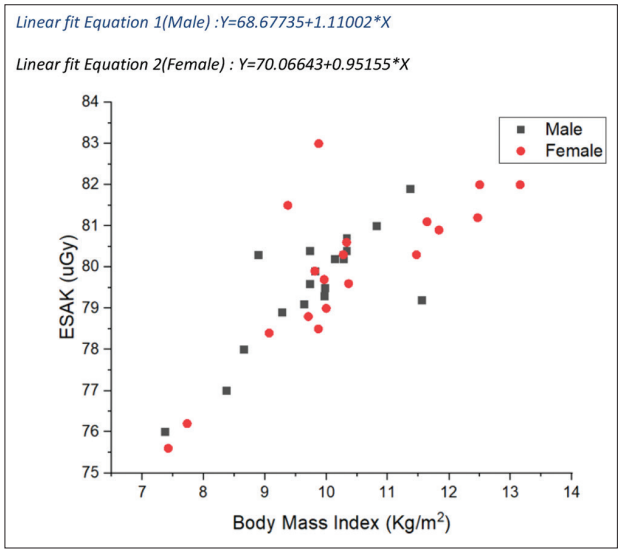

Figure 1: BMI vs. ESAK

Table 3: Mean values of effective doses (E) for male and female neonates

Sex	Mean effective dose (μSv)
Male	44.52±3.25
Female	44.88±4.01

for those who use CR-based radiography and should be used as a guide by medical practitioners for the justification of an X-ray examination before it is requested.

According to a recent Mayo clinic study presented at the annual meeting of the RSNA (December 9, 2014), it was found that many chest X-rays offer no benefit for children.[20] Therefore, a frequent request of chest examination should be avoided, when neonates are in the Intensive Care Unit.

Acknowledgment

We would like to express our sincere gratitude to radiographers and other staffs of NICU for their help in collection of data.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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