Evaluation of radiation dose to neonates in a special care baby unit

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HIGHLIGHTS

- Neonate radiation dose has been evaluated using mathematical equation.
- Neonates are exposed to unnecessary radiation due to use of unsuitable X-ray machines.
- Radiation dose is of concern due to neonate sensitivity and multiple exposures during neonate treatment.
- Mathematical equation based on exposure factors is suitable for neonate dose measurements.

ARTICLE INFO

ABSTRACT

The purpose of this study was to evaluate the patient entrance surface dose (ESD), organ dose and effective dose for neonates in the special care baby unit (SCBU) up to 28 days after birth. A total of 135 patients were examined during 4 months. ESDs were calculated from patient exposure parameters using DosCal software. Effective doses were calculated using software from the National Radiological Protection Board (NRPB). The mean patient ESD per procedure was 80 ± 0.02 μGy. The mean and range of the effective dose per procedure were 0.02 (0.01–0.3) mSv. The radiation dose in this study was higher compared to previous studies. A dedicated X-ray machine with additional filtration is recommended for patient dose reductions.

1. Introduction

Pre-term birth, which is defined as childbirth occurring at less than 37 completed weeks of gestation, has been estimated to be 9.6% of all births worldwide (Beck et al., 2010). Newborn pre-term infants up to 28 days after birth have higher rates of medical disorders and respiratory illnesses compared with neonates born at term (Spiegel, 1995). Therefore, an incubator is used to maintain environmental conditions suitable for a neonate (Spiegel, 1995). Neonates in a special care baby unit (SCBU) often require frequent chest and abdomen radiographs in a short period of time to monitor the treatment progress of the neonate and to check the postion of the various tubes and catheters used in SCBU (Spiegel, 1995). Radiographic exposure of neonates attracts particular interest because of their greater cell proliferation rate and the increased opportunity for expression of delayed cancer effects as a consequence of relative longer life expectancy. Neonates may also receive a higher radiation dose than necessary if exposure factor settings are not adjusted for their smaller body size (ICRP 90, 2003). It is therefore important to evaluate neonates' radiation exposure in order to ensure that the neonate doses are kept to a minimum whilst maintaining the quality of radiographic images. The International Commission on Radiological Protection (ICRP) (ICRP 2007) recommended the use of a diagnostic reference level (DRL) for patients in order to determine whether the protection has been adequately optimized. The use of DRL has been shown to reduce the overall dose and the range of doses observed in clinical practice. Although the radiation risk for neonates is well known (ICRP 90, 2003), still few studies have been performed in the field of measurement of radiation dose and the related risk during neonate management in baby care units compared to the frequency of the procedures (Olgar et al., 2008; Dougeni et al., 2007; Mutch and Wentworth, 2007; Şorop and Dădulescu, 2011; Thierry-Chef et al., 2013; Puch-Kapst et al., 2009; Govender et al., 2013; Iyer et al., 2013; Toossi and Malekzadeh, 2012). Wide variations of patient doses were reported in the previous studies, suggesting that optimization is not fulfilled yet. To our knowledge, no study

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has been published in open literature in our country and DRL is not adopted yet. The objectives of this study were to measure patient entrance surface dose (ESD) for neonates in special care baby units (SCBU) and to evaluate the organ and effective doses.

2. Materials and methods

2.1. Patient samples

A total of 135 patients were examined at Omduran Maternity Hospital. The ethics and research committee approved the study and an informed consent was obtained in advance from the parents. The exposure factors were selected manually by the radiographer. All procedures were performed with the neonate in the supine position inside the incubator. The following parameters were recorded: age, weight, height, and body mass index (BMI) derived from weight (kg)/(height (m))^2 in addition to the exposure factors. The dose was measured for chest and abdomen procedures.

2.2. X-ray machine

In the present study, the X-ray machine was used as described in Table 1.

2.3. Absorbed dose calculations

ESD was determined using DoseCal software and patients' exposure factors, X-ray tube output and backscatter factors (BSFs), in accordance with the following formula (Davies et al., 1997):

$$ESD = OP\left(\frac{kVp}{80}\right)^2 mAs \left(\frac{100}{FSD}\right)^2 BSF$$

where OP is the output in mGy $(m\,As)^{-1}$ of the X-ray tube at 80 kV at a focus distance of 1 m normalized to 10 mA s, kVp is the X-ray tube potential, mA s is the product of the tube current (in mA) and the exposure time (in s), FSD the focus-to-skin distance (in cm), BSF is calculated using DoseCal software after all input data are entered manually in the software.

The X-ray tube outputs (mGy $(mA\,s)^{-1}$) were measured using Unfors Xi dosimeter (Unfors Inc., Billdal, Sweden). This dosimeter was calibrated by the manufacturer and reported to have accuracy better than 5%. DosCal software was previously used as a reliable method for patient dose measurements in diagnostic radiology (Olowookere et al., 2011; Suliman and Elshiekh, 2008; Davies et al., 1997).

Furthermore, the mathematical equation was verified against a calibrated ionization chamber (PTW-CONNY II) with the dimensions of $180 \times 100 \times 45\ mm^3$ using the plexiglas phantom of dimension $10 \times 10 \times 5\ cm^3$. The ESD calculated using mathemetical equations are within $\pm 7\%$ compared with ESD measured using TLDs.

2.4. Organ and effective dose estimation

Organ and effective doses have been estimated using computer software which provides estimates of organ doses and effective doses to pediatric patients undergoing diagnostic X-ray exposures

from the National Radiological Protection Board (NRPB) (Hart et al., 1996).

3. Results

The results were tabulated in the tables (mean $\pm$ standard deviation (std)) and the range of the readings in parentheses. The dose values in pediatric conventional radiography are relatively small, therefore the doses were presented in milli-Gray. Patient demographics were presented in Table 2. Table 3 gives exposure factors, the number of films and dose values. Patients' doses showed wide variations. The variation in patient dose could be attributed to the variation in patient weight, tube voltage and tube current time product (mA s).

4. Discussion

A total of 135 neonate patients were examined during 4 months. The neonates' demographic data were well within the low birth weight ratios as illustrated in Table 2. Although the range of the neonates' ages was 1.0–28.0 days, large variations were observed in patient weight, height and BMI (Table 2). The radiographic exposure factors used in this study ranged from 44.0 to 47.0 kVp and from 4.0 to 10.0 mA s during the examination, depending on the neonate's weight (Table 3). The exposure factors in this study were lower than those proposed by the Commission of the European Communities (CEC) (CEC, 1996), which ranged between 60 kVp and 65 kVp. Lower neonate ESDs were observed at higher tube potentials (Duggan et al., 2003). In this study, the mean of the ESD was 0.08 ± 0.02 while the range was 0.04–0.11 mGy per procedure for all the patient populations. ESD was higher compared to previous studies (Table 4). Strong correlations were found between ESD and tube current–time product (mA s) with $R^2 = 0.96$ (Fig. 1). Unoptimized exposure factors are accompanied always with unnecessary radiation exposure. This can be attributed to the mobile X-ray machine which was used in this study which was not originally designed for pediatric patients with ordinary filtration (2.5 mm Al) and the selection of exposure parameters (kV and mA s) does not fit to the small size of premature babies. The mean organ doses per procedure are illustrated in Fig. 2. The lung, thymus and thyroid glands are

Table 2
Patient demographic data.

Parameter	Age (day)	Weight (kg)	Height (m)	BMI (kg/m^2)
Min	1	0.66	0.20	4.57
Max	101	4.20	0.53	23.75
Mean $\pm$ std	19.41 ± 13	2.27 ± 0.8	0.42 ± 0.1	12.77 ± 3.9

Table 3
Mean and range of the exposure factors, number of films and dose values.

Parameter	Tube voltage (kV)	Tube current–time product (mA s)	No. of film	ESD (mGy)
	46.08 ± 0.9 (44.0–47.0)	7.72 ± 1.33 (4.0–10.0)	1.02 ± 0.19 (1.0–3.0)	0.08 ± 0.02 (0.04–0.11)

Table 1
Type and main characteristics of X-ray machine.

Type and molel	Manufacturer	Manufacturing date	Total filtration (mm Al)	Max tube voltage (kV$_P$)	Max tube current (mA)	Max time (s)	Installation date
Mobile 100/CBM	Allengers Medical	2011	2.5	100	100	8	2011