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ARTICLE

Radiation exposure by digital radiographic imaging in very low birth weight infants

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Abstract

Objective The aim of this study was to determine the cumulative effective doses (CED) from digital radiographic imaging in very low birth weight infants treated in a tertiary care neonatal intensive care unit (NICU).

Study design The CED for each infant was retrospectively calculated using a voxel-based model. The results were compared with previous studies applying conventional radiography.

Results Two hundred and six preterm infants were included into this study. Neonates received a median of four radiographs (range: 1–68) and a CED of 50 μSv (4–883 μSv). Overall mean CED was lower than in previously published data applying conventional radiography. Factors contributing to a lower radiation dose per infant in our study were a lower number of radiographs and smaller field sizes per radiographic image.

Conclusions The number of conducted radiographs per patient and the employed field size had a higher impact on the CED than the applied radiographic technology.

Introduction

During their hospital stay in the neonatal intensive care unit (NICU), premature infants are repeatedly exposed to radiation as a result of diagnostic imaging. Because of their vulnerable age and a long life expectancy, young patients are particularly at high risk for delayed radiation-induced malignancies [1].

Over the last two decades the introduction of digital radiography has significantly transformed the performance of medical imaging. Although digital technology has the potential to reduce radiation exposure, there is also a risk of significant doses increase when radiology departments switch to digital equipment [2].

Several studies published in the last two decades have examined the radiation exposure in neonates [3–13]. However, all these studies analyzed conventional radiographic imaging. This is, to our knowledge, the first study investigating the cumulative ionizing dose delivered to preterm neonates by digital radiography.

Patients and methods

Patients

All preterm neonates with a birth weight < 1500 g treated in our NICU (Division of Neonatology, University Children's Hospital Hamburg-Eppendorf, Germany) between 1 April 1 2011 and 31 January 2016 were retrospectively evaluated.

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Table 1 Patient demographics and morbidity

Characteristics	Birth weight categories, g				All patients
	≤750	751–1000	1001–1250	1251–1500	
Number of patients (%)	27 (13.1)	62 (30.1)	53 (25.7)	64 (31.1)	206 (100.0)
Demographics					
Female, No. (%)	18 (66.6)	32 (51.6)	26 (49.1)	32 (50.0)	108 (52.4)
Birth weight, median (range), g	640.0 (410–743)	923.5 (760–996)	1180.0 (1010–1245)	1414.0 (1263–1495)	1108.0 (410–1495)
GA, median (range), weeks	25.0 (23.1–32.4)	27.9 (24.6–32.0)	29.0 (26.6–33.0)	30.3 (28.4–32.1)	29.0 (23.1–33.0)
LHS, median (range), days	118.0 (57–195)	75 (42–124)	60 (29–233)	48 (18–297)	65 (18–297)
Morbidity, No. (%)					
SGA	10 (37.0)	9 (14.5)	6 (11.3)	3 (4.7)	28 (13.6)
Infection	16 (59.2)	29 (46.8)	18 (34.0)	15 (23.4)	78 (37.9)
PDA	17 (63.0)	26 (41.9)	14 (26.4)	10 (15.6)	67 (32.5)
NEC	7 (25.9)	3 (4.8)	3 (5.7)	1 (1.6)	14 (6.8)
Malformation	0 (0.0)	2 (3.2)	3 (5.7)	1 (1.6)	6 (2.9)

GA gestational age, *LHS* length of hospital stay, *SGA* small for gestational age, *PDA* patent ductus arteriosus, *NEC* necrotizing enterocolitis

Clinical patient data were obtained from a review of the digital medical chart (Soarian®, Siemens Healthcare, Erlangen, Germany). Extracted information included gestational age, birth weight, gender, length of hospital stay, small for gestational age (SGA, defined as birth weight below the 10th percentile of the gestational age and sex), infectious complications, patent ductus arteriosus (PDA), necrotizing enterocolitis (NEC), malformations, and need of invasive or non-invasive ventilation (synchronized intermittent mandatory ventilation (SIMV), nasal continuous positive airway pressure (CPAP)).

The study was approved by the local ethics committee with waived informed consent.

Radiographic device and technical setting

Radiographs were taken using a mobile x-ray tube (Practix 400 or Convenio, Philips, Eindhoven, The Netherlands) in combination with a computed radiography imaging system (01.04.2011 until 16.12.2013: Kodak Direct View CR 850, Eastman Kodak Company, Rochester, USA; 17.12.2013 until 31.01.2016, Agfa DX-G with needle based detector, Agfa Health Care NV, Mortsel, Belgium). The exposure settings were determined according to the infant's weight and adapted to the specific system. A focus-to-film distance of 100 cm was applied. The dose-area product (DAP) was measured with a permanently installed DAP meter on the mobile radiographic device.

The digital radiographic images were reviewed within the local radiological information and picture archiving system (Centricity^{TM} RIS/PACS, GE Healthcare, Solingen, Germany). For each radiographic image, the tube voltage, tube current, field size, DAP, and patient weight at the time of imaging were recorded.

Estimation of effective dose

The estimation of the effective dose was calculated with help of a voxel-based model (Voxel Model BABY) [14], representing the dimensions of an 8 week old (height of 57 cm and weight of 4200 g). The original voxel sizes were rescaled to reproduce typical dimensions of preterm babies at three different gestational ages [15, 16]. Organ dose conversion coefficients (DCC) normalized to air-kerma free-in-air at the film position were determined following the history of 100 million initial photons for each of the four models and three examinations (combined thorax and abdomen, thorax, and abdomen radiography). To deduce air-kerma free-in air of each examination, the actual DAP was divided by the actual field size. The ED was obtained by multiplying air-kerma free-in-air with the effective DCC of that model that corresponds closest to the specific body weight of the infant at the time of examination.

Statistical analysis

Data on patient demographics, morbidity and radiation exposure are expressed as median, minimum and maximum values or as mean and standard deviation for continuous variables and as counts and category percentages for categorical variables. The strength of associations among clinical parameters (gestational age, birth weight, length of hospital stay), number of radiographic images and

Table 2 Radiation exposure according to birth weight

	Birth weight categories, g				All patients
	≤750	751–1000	1001–1250	1251–1500	
Number of radiographs	16 (5–68)	5 (1–29)	5 (1–49)	3 (1–52)	4 (1–68)
Cumulative effective dose, μSv	210.6 (68.4–882.6)	60.2 (9.9–304.7)	49.7 (8.2–537.6)	29.7 (3.6–534.4)	50.0 (3.6–882.6)

Numbers are medians (ranges)

cumulative effective dose (CED) was determined by Spearman rank correlations. Relationships among dichotomous categorical variables and continuous variables (gestational age, birth weight, length of hospital stay, CED) were analyzed by means of Mann–Whitney *U*-tests. Univariate and multivariate general linear modelling were employed to estimate the effects of categorical and continuous independent variables on the CED, after having log-transformed the dependent variable CED to normalize its distribution. General linear modelling was followed by post hoc LSD tests for group-wise comparisons. Comparison of radiation exposure with other studies was performed using One-sample *T*-Test.

All tests were two-tailed. A p value < 0.05 was considered statistically significant. Data analysis was performed using IBM SPSS Version 24 software (SPSS, Chicago, USA).

Results

Patient demographics

During the observational period, 206 very low birth weight infants admitted to our NICU were included into this study. The median birth weight was 1108 g (410–1495 g), median gestational age was 29.0 weeks 0 (23.1–33.0 weeks), and median length of hospital stay was 65 days (18–297 days). Patient demographics and morbidity data according to four birth weight categories are summarized in Table 1.

Radiographic imaging

During the hospital stay, a median number of four radiographs was performed per patient, ranging between one and 68 radiographs per patient (Table 2). All patients required at least one radiograph. More than 10 and more than 20 radiographs were needed in 21.8% (45 of 206 patients), and 6.3% (13 of 206 patients) of patients, respectively.

The most frequent indication for radiographic imaging was the verification of central venous catheter positions (31.2%) followed by respiratory symptoms (26.8%) and the verification of tracheal tube positions (20.0%).

A lower birth weight was significantly associated with a higher number of radiographic images (birthweight < 750 g and >750 g, median 65.9 vs. 19.7 radiographs, p value < 0.001). Further independent risk factors for a higher number of radiographic images and higher CED were the diagnosis of NEC (p value < 0.001), the presence of malformations (p value < 0.001), and the need for mandatory ventilation (p value < 0.001).

Organ DCC

Using a voxel-based model, we determined specific organ DCC of each birth weight group and the potential impact on the effective dose. Calculated effective DCCs for the different preterm groups for thorax, abdomen and thorax and abdomen radiographs ranged from 0.502–0.508 mGy/mGy, 0.548–0.557 mGy/mGy, and 0.892–0.908 mGy/mGy, respectively.

Estimation of CED

During hospital stay, our patients received a median CED of 50.0 μSv (range: 3.6–882.6 μSv) (Table 2). The median CED in birth weight groups < 750 g and >750 g were 210.6 μSv (range: 68.4–882.6 μSv) and 43.5 μSv (range: 3.6–537.6 μSv), respectively (p value < 0.001). The median effective dose per image for thorax radiographs was 10.4 μSv (range: 1.7–48.5 μSv), for abdomen radiographs 12.5 μSv (range: 2.8–38.7 μSv), and for the combination of thorax and abdomen 18.6 μSv (range: 3.8–48.0 μSv).

Discussion

Studies reporting on radiation exposure in the neonates are relatively few and, to our knowledge, included only conventional radiography [3–11]. Digital radiography has been introduced to most neonatal units and a major benefit may be the potential to reduce patient dose.

The distribution of the type of radiographs in our study was in accordance with findings of previous studies in VLBW and ELBW neonates [10, 12, 13]. Chest radiographs represented 69.4% of all radiographs performed and were responsible for 61.4% of CED. Abdominal radiography and combined imaging of chest and abdomen were less frequent (16.2 and 13.2%) accounting for 17.1 and 20.2% of the CED in our collective.

Also consistent with earlier articles, we observed a strong relationship between birth weight and the CED [5, 6, 9, 10]. Infants with a birth weight ≤ 750 g had a median CED that was 3.5-fold compared to infants with a birth weight of 751–1000 g and even seven-fold compared to infants with a birth weight of 1251–1500 g. The patient with the highest radiation exposure in our cohort (68 radiographic images, CED of 883 μSv) was a SGA twin with a birth weight of 609 g who suffered from infant respiratory distress syndrome (IRDS), bronchopulmonary dysplasia (BPD), respiratory candida infection, and underwent surgery for meconium ileus. All these morbidities are strongly related to extreme prematurity [17]. Also the presence of congenital malformations was significantly associated with a higher CED (mean: 245 μSv vs. 88 μSv, p value < 0.001).

Previously reported cumulative radiation exposure applying conventional radiography in neonates ranged from 71.5–717 μSv [3–13]. However, the majority of these studies cannot be directly compared to our data as a number of older publications reported only entrance skin dose (ESD) [6, 7, 9, 13]. Other previous reports lacked detailed information of patient characteristics like gestational age or birth weight [3, 4, 8, 11].

Three studies during the last two decades met the criteria for reasonable comparison [5, 10, 12]. In a similar patient collective comprising VLBW and ELBW infants Puch-Kapst et al. [10] and Donadieu et al. [5] reported a CED during NICU stay applying conventional radiography which were 71.5 and 138 μSv and thereby 43–176% higher than in our study. The substantially higher CED in the study by Donadieu et al. can primarily be attributed to a higher number of radiographs per patients (median: 10.6 radiographs) and a higher rate combined examinations of the chest and abdomen than in our study. Wilson-Costello et al. [12] reported only on dose exposure in children below ≤750 g birth weight. The reported CED was almost threefold higher compared to children in the same weight group in our study (717 μSv vs. 272 μSv). The increased CED was attributed to a both higher number of radiographs per infant and a higher ED per radiograph.

Information regarding the applied field size was only specified in the study of Puch-Kapst et al. [10]. Infants in the study by Puch-Kapst et al. had received a similar median number of four radiographs per patient. But the exposed field size was in average larger compared to our study. When calculating the theoretical value of ED per field size a similar radiation exposure to our study could be noted. For example, for thorax images ED per field size in our study and in the study by Puch-Kapst were 0.124 and 0.125 μSv/cm^2, respectively (p value 0.886). This finding highlights the importance of attentive selection of the field to achieve notable reduction of radiation exposure.

Substantial variations between studies regarding numbers of radiographs per infant performed in the NICU are not solely a reflection of inherent patient populations but strongly suggest that more standardized protocols for imaging in the NICU are necessary. In addition, alternative diagnostic approaches lacking radiation exposure are needed to reduce the number of radiographs. With improving imaging frequency and resolution, ultrasonography has shown to be an effective and reliable method for the diagnosis of neonatal respiratory distress syndrome [18], the verification of peripherally inserted central catheter position [19] and endotracheal tube position [20] in neonates.

Digital radiography systems have the potential of substantial patient dose reduction compared to conventional screen-film systems [21]. However, monitoring of patient dose and adherence to diagnostic reference levels are important components to avoid dose levels that do not contribute to the clinical purpose of a medical imaging task [22].

Our study has the following limitation: The study design is retrospective, and is therefore dependent on medical documentation and principally prone to selection bias.

Conclusion

To our knowledge, this is the first study that analyzes radiation exposure of VLBW infants during their NICU stay by digital radiographic imaging. Compared with historical collectives applying conventional radiography, lower CED were noted. We found that the number of conducted radiographs per patient and the employed field size had a considerably higher impact on the CED than the applied radiographic technology.

Our study emphasizes the necessity of effective dose monitoring protocols in young infants as significantly increased radiation exposure was noted with very low birth weight and the presence of comorbidities.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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