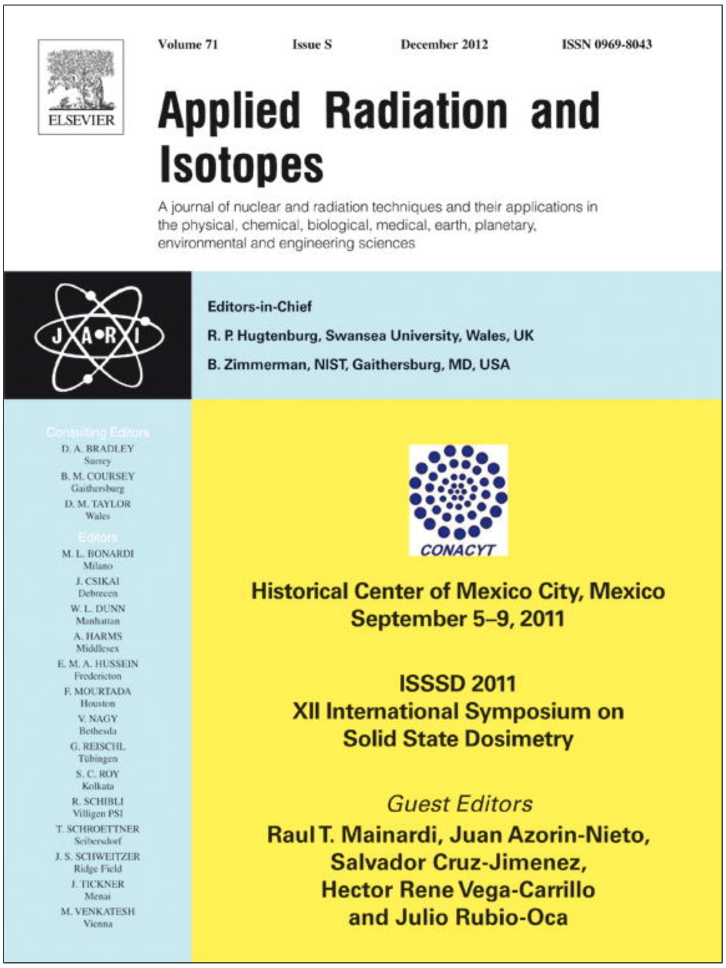
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Radiation dose reduction in a neonatal intensive care unit in computed radiography

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ABSTRACT

The purpose of this study was to evaluate the dose received by chest x-rays in neonatal care with thermoluminescent dosimetry and to determine the level of exposure where the quantum noise level does not affect the diagnostic image quality in order to reduce the dose to neonates. In pediatric radiology, especially the prematurely born children are highly sensitive to the radiation because of the highly mitotic state of their cells; in general, the sensitivity of a tissue to radiation is directly proportional to its rate of proliferation. The sample consisted of 208 neonatal chest x-rays of 12 neonates admitted and treated in a Neonatal Intensive Care Unit (NICU). All the neonates were preterm in the range of 28–34 weeks, with a mean of 30.8 weeks. Entrance Surface Doses (ESD) values for chest x-rays are higher than the DRL of 50 μGy proposed by the National Radiological Protection Board (NRPB). In order to reduce the dose to neonates, the optimum image quality was achieved by determining the level of ESD where level noise does not affect the diagnostic image quality. The optimum ESD was estimated for additional 20 chest x-rays increasing kVp and reducing mAs until quantum noise affects image quality.

1. Introduction

The purpose of this study was to evaluate the dose received by chest x-rays in neonatal care and to determine the level of exposure where the quantum noise level does not affect the diagnostic image quality in order to reduce the dose to neonates. A survey of the entrance surface doses (ESD) received by neonates having CR digital radiography in a Neonatal Intensive Care Unit (NICU) in a General Hospital of Mexico City, using thermoluminescence detectors for different preterm infants of 28–34 weeks and to compare them with the current DRLs (Duggan et al., 2003; Hart et al., 2000).

In pediatric radiology, especially the prematurely born children are highly sensitive to the radiation because of the highly mitotic state of their cells; in general, the sensitivity of a tissue to radiation is directly proportional to its rate of proliferation (Prasad, 1995). A frequent practice in neonatal radiography is the exposure to whole body and other critical organs such as thyroid, gonads and red bone marrow are also directly irradiated and longer life expectancy of neonates compared with any other patient group, there is a greater period for the potential expression of delayed detrimental radiation-related effects, such as cancer and particularly leukemia (Prasad, 1995; UNSCEAR 2000). Thus, the risk of a radiation-induced malignancy is increased (CEC, 1996; ICRP, 1990).

The optimization of radiographic procedures plays an essential role in pediatric radiology and diagnostic reference levels are a helpful tool to optimize patient dose for standard radiographic procedures (CEC, 1996; Hart et al., 2000). For many years the International Commission for Radiological Protection (ICRP) recommends that the medical activities involving ionizing radiation should fulfill the two basic principles of justification and optimization (ICRP, 1990, 1996). In the neonatal intensive care unit (NICU) and especially those prematurely born, with a gestational age (GA) as low as 28 weeks and a birthweight (BW) as low as 700 g, clinical justification also plays an important role in the number of x-rays examinations to neonates in the NICU. The prematurely born children suffer from a variety of serious complications which usually result from diseases in the respiratory and cardiovascular system and survival rate of neonates depends upon both timely diagnosis and prompt therapy. Neonatal chest x-ray is an indispensable tool that contributes significantly to the initial clinical diagnosis and evaluation of neonatal diseases.

When a radiologist or a pediatrician interpreting a chest x-ray in the neonate, he should be sure to examine the entire film, and not just the chest. Use of the "ABC" approach by the radiologist ensures that all areas of the film are systematically examined.

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A—Abdomen, check for bowel gas pattern suggesting ileus or obstruction, free air, abnormal calcification, abdominal situs. B—Bone, check for fractures, lytic or blastic lesions, metabolic bone diseases. C—Chest, check for midline trachea and mediastinum, abnormal mediastinal and cardiac contours, position of the aortic arch, pleural effusions, pulmonary vascularity, pneumomediastinum, pneumothorax, pneumopericardium, infiltrates, atelectasis.

CR digital radiographic receptors do not have a fixed sensitivity like film-screen receptors. One of the valuable characteristics of digital receptors is a wide exposure dynamic range. This means that images with good contrast characteristics can be produced over a wide range of exposure values. It is not like radiographs recorded on film where any deviation from the correct or optimum exposure results in under or over exposed films. There are definite advantages of this wide dynamic exposure range. Exposition errors do not result in images with loss of contrast like with film. Another advantage is the ability to capture the full range of exposure coming from the patient's body where there are large variations in body density and penetration, such as in the chest. When the full exposure range is captured digital processing can then be used to enhance and optimize the contrast. This is the normal procedure in CR digital radiography.

In CR digital radiography it is important that appropriate exposure and technique factors be used for each chest procedure. An optimum (correct) exposure is one that produces an image with an acceptable noise level without unnecessary or excessive exposure to the neonates. Excessive quantum noise is a potential problem in CR digital radiography because it is possible to produce images with low exposures that will still look good as far as contrast is concerned. A low technique factors indicated the image was formed with a low exposure and excessive noise would be expected. A high technique factor indicates that unnecessarily high exposure was used. The image quality is good because of the low noise but the neonate was subjected to unnecessary exposure. Most x-ray procedures are conducted at a point of reasonable compromise between these two very important factors (optimum exposure with optimum image quality).

2. Methods and materials

The sample consisted of 208 neonatal chest x-rays of 12 neonates (5 male and 7 female) admitted and treated in the NICU of General Hospital of Mexico City "Dr. Manuel Gea González". Lateral or other projections were excluded from the study. All the neonates were preterm in the range of 28–34 weeks, with a mean of 30.8 weeks. The birthweights of the neonates included in the study varied between 700 g and 1718 g, with a mean value of 1158.9 g. Because patient dose can be significantly dependent on patient size, it was considered necessary to study the variation in ESD and the quality of the image obtained for neonates of approximately the same weight.

Neonates were categorized into the following three groups, depending on their birthweight (w) (Ono et al., 2003): (1) extremely low birthweight ($w \leq 1000$ g, 71 radiographs); (2) very low birthweight ($1000\,g < w \leq 1500$ g, 107 radiographs); (3) low birthweight ($w > 1500$ g, 30 radiographs). Neonates were categorized into groups by birthweight to know if we should use different setting exposure parameters. The majority of chest x-rays (51.4%) used in this study belonged in the second group. The frequency of x-rays is highly dependent upon the clinical situation of the neonate, thus the number of x-rays per neonate may be over 25 (Table 1). The mean number was 17 chest x-rays per neonate.

For each neonate the following data were collected: date of birth, date of entrance, duration of stay, gestational age, sex, height, weight, date and time of radiographic examination, number of radiographs taken and diagnosis (Table 1). This is similar to the data used by Chapple et al. (1994), with some additions. Radiographic data for each exposure, such as projection, Focal Film Distance, tube voltage, mAs settings, and field size were also recorded.

Table 1
Some important data collected for each neonate.

Neonate	Gestational age (weeks)	Birthweight (g)	Number of chest x-rays procedures	Duration of stay in NICU (days)
1	31.0	1045	26	25
2	26.0	735	17	13
3	32.5	1060	5	5
4	28.0	1231	38	30
5	31.5	1247	15	15
6	32.5	1573	17	17
7	33.4	1718	4	13
8	31.2	1063	20	7
9	32.6	1000	42	35
10	30.0	1010	3	3
11	32.6	1525	9	5
12	28.0	700	12	9

TLD-100 detectors were used for the estimation of Entrance Surface Doses (ESD) in neonates, TLD dosimeters (four TLD-100 crystals in a plastic wrapper) were placed in the right axillary line above level T6 in the space intercostal where the dosimeters do not interfere with the radiological image. During the x-ray examination and placement of dosimeters the staff use white dressing-gown, hand disinfectant gel, disinfection of the CR cassette and package of dosimeters with disinfectant gel, no infections were reported by the radiological study and placement of dosimeters.

During the sampling of the doses received by neonates in chest x-rays several technologists set up specific x-ray procedures according to their level of training, so that the results would be representative of routine practice.

All x-rays examinations were performed using the same capacitor discharge mobile unit (Mobilett XP Hybrid) with HVL of 3.2 mm Al, focal spot size of 0.8 mm. This unit was exclusively used for neonatal radiography. Chest x-rays were acquired using CR digital radiography Agfa system. To ensure the correct performance of the equipment and the reliability and reproducibility of exposure parameters, a complete quality control check was initially and periodically performed, based on National Protocols (NOM, 2002). Dose estimation for neonatal radiography is expressed in terms of ESD with thermoluminescent dosimetry (TLD-100) (Duggan et al., 2003, 2004). Direct dose measurements utilizing TLDs during the x-ray provide the best indication of actual clinical practice, although, the lower limit of detectability of TLDs-100 was very close to the values that occur in neonatal radiography. In order to minimize the TLDs measurements uncertainties to low dose, TLDs measurements values were compared to those obtained by ionization chamber.

Image quality digitally of CR radiography films and chest x-rays in neonates have been evaluated by one radiologist and two pediatricians all of them specifically trained to supervise and interpret chest x-ray using a viewbox with an intensity at least 1500 nits. They only have two options in the image quality, the image has diagnostic quality (where level noise does not affect the diagnostic image quality) or does not have.

3. Results

At the beginning of the study the entrance surface doses values for chest x-rays are higher than the DRL of 50 μGy proposed by the National Radiological Protection Board (NRPB) as the reference values for an chest x-ray (Hart et al., 2000) (Table 2).

The image quality is good because of the low noise but the neonate was subjected to unnecessary exposure. In most situations, neonatal exposure can be reduced, but at the expense of increased quantum noise and, possibly, reduced visibility. It is also possible, in most situations, to decrease image noise, but a higher exposure would be required. Most x-ray procedures are conducted at a point of reasonable compromise between these two very important factors. The obtaining of high ESDs is attributed to the use of low kilovolts; and very high milliampere-second (mAs) values (Table 3). The tube voltage varied between 43 kVp and 61 kVp (mean value 48.9 kVp), with a range of 0.9 to 2.0 mAs (mean value 1.51 mAs).

During chest x-rays several technologists set up specific x-ray procedures according to their level of training and the results show a wide variation in doses received within the same neonate and is the result of lack of any form of standardization in the x-rays procedures in the routine practice (Fig. 1).

Patients' dose can be significantly dependent on the birthweight of neonates, however in our study the mean dose received by each birthweight group was not significantly different for $p > 0.05$ (Fig. 2) and setting exposure parameters (kVp and mAs) can be the same for all groups.

In order to reduce the dose to neonates, the optimum image quality was achieved by determining the level of ESD where level noise does not affect the diagnostic image quality. The optimum ESD was estimated for additional 20 chest x-rays (from second group and different neonates) increasing kVp and reducing mAs until quantum noise affects image quality. The collected data were used to estimate retrospectively the ESD for each neonatal additional radiograph in accordance with the methodology proposed in the literature (Armpilia et al., 2002; Dougeni et al., 2007; McParland et al., 1996) and using ionization chamber dosimeter with calibration traceable to national standards and technology, USA (NIST). Diagnostic reference levels (chest x-rays) for hospital have been proposed with optimum exposure and optimum quality image (60 kV, 0.9–1.1 mAs, FFD = 100 cm) in a Neonatal Intensive Care Unit with digital radiography CR using ionization chamber dosimeter with traceable to NIST. Optimum exposure parameters is shown in Table 4. The difference between the doses averages from TLD system and dosimeter, with ionization chamber being less than 10% (Gaona et al., 2007).

The proposed ESD values are lower than the DRL of 50 μGy proposed by the National Radiological Protection Board (NRPB) as the reference values for chest x-ray neonatal (Hart et al., 2000). The results suggest that the use of high tube voltage techniques could result in further reductions in neonatal dose. In conclusion, for neonatal chest Imaging 60 kVp gives better image quality than the regularly used 40–50 kVp.

Table 2
ESD received by neonates having Computed Radiography (CR) with Agfa system in a Neonatal Intensive Care Unit in the routine practice.

Neonate	Mean* (μGy)	Number of chest x-rays	Total dose** (μGy)	Std. error of mean
1	81.6	26	2121.4	8.8
2	40.6	17	689.7	4.3
3	40.2	5	200.8	7.1
4	43.0	38	1632.5	2.4
5	62.9	15	942.8	17.5
6	80.6	17	1370.6	9.3
7	242.3	4	969.0	45.3
8	95.6	20	1911.9	10.6
9	99.6	42	4181.7	14.9
10	174.6	3	523.8	60.5
11	70.8	9	637.3	14.5
12	81.5	12	977.8	12.0

* Mean per chest x-ray.
** The sum of all separate doses for each x-ray procedure.

Table 3
Techniques and the exposure parameters in survey of the entrance surface doses; this reflects the lack of standardization of the exposure parameters applied in all of x-rays procedures.

	Minimum	Maximum	Mean	Std. error of mean
kVp	43	61	48.89	0.24
mAs	0.9	2.0	1.51	0.02
Focal film distance (cm)	70	104	89.73	0.59
Field size (L), (cm)	13	30	17.84	0.59
Field size (W), (cm)	9	24	13.03	0.46

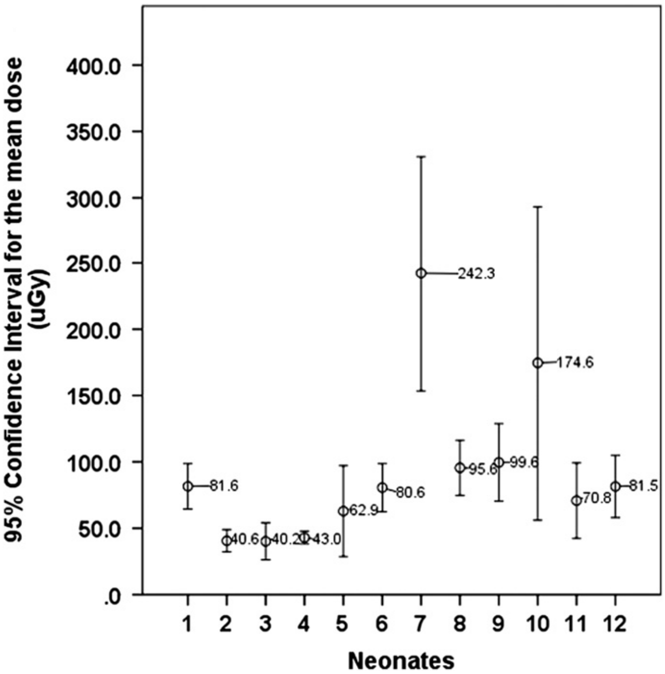

Fig. 1. Lack of the reproducibility of exposure parameters causes wide variations in ESD.

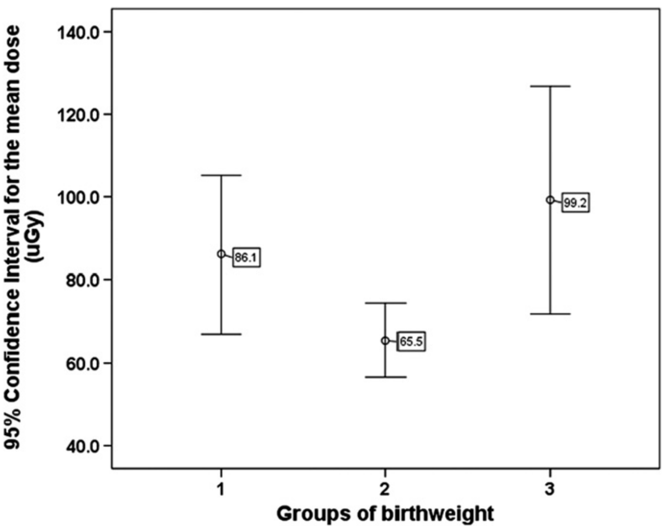

Fig. 2. Confidence Interval for mean dose received by group of birthweight.

Table 4
Diagnostic reference levels (chest x-rays) for hospital have been proposed with optimum exposure and optimum quality image (60 kV, 0.9–1.1 mAs, FFD = 100 cm) in a Neonatal Intensive Care Unit with digital radiography CR using ionization chamber dosimeter with traceable to NIST.

	Mean dose	Minimum dose	Maximum dose	Std. error of mean
Entrance surface doses (μGy)	33.2	17.50	43.70	5.09

4. Conclusion

As with other medical procedures, chest x-rays in neonates are safe when used with care, but it is necessary that Radiologists, Pediatricians and x-ray technologists have been trained in radiation protection in patients and biological effects of x-rays to use the minimum amount of radiation necessary to obtain a chest x-ray with diagnostic quality and minimal risks. The staff also requires the advice of a medical physicist to optimize the dose to neonates in chest x-ray. Experimental results showed that Radiologists, Pediatricians and x-ray technologists have a poor education in digital radiology and radiological protection in neonates and they do not know how to use reduced doses in patients. Pediatricians and Radiologists believe that it is not necessary to have the advice of a medical physicist in Pediatric Radiology. The amount of radiation used in most chest x-rays is very small and the benefits greatly outweigh the risk of harm in Neonatal Radiography but it is necessary to reduce the number of chest x-rays and dose x-ray during neonatal care.

References

Armpilia, C.I., Fife, I.A.J., Croasdale, P.L., 2002. Radiation dose quantities and risk in neonates in a special baby care unit. Br. J. Radiol. 75, 590–595.

CEC, 1996. Commission of European Communities. European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics. Report EUR 16261. Office for Official Publications of the European Communities, Luxemburg.

Chapple, C.L., Faulkner, K., Hunter, E.W., 1994. Energy imparted to neonates during x-ray examinations in a special baby care unit. Br. J. Radiol. 67, 366.

Dougeni, E.D., Delis, H.B., Karatza, A.A., Kalogeropoulou, C.P., Skiadopoulos, S.G., Mantagos, S.P., Panayiotakis, G.S., 2007. Dose and image quality optimization in neonatal radiography. Br. J. Radiol. 80, 807–815.

Duggan, L., Hood, C., Warren-Forward, H., Haque, M., Kron, T., 2004. Variations in dose response with x-ray energy of LiF: Mg, Cu, P thermoluminescence dosimeters: implications for clinical dosimetry. Phys. Med. Biol. 49, 3831–3845.

Duggan, L., Warren-Forward, H., Smith, T., Kron, T., 2003. Investigation of dose reduction in neonatal radiography using specially designed phantoms and LiF: Mg, Cu, P TLDs. Br. J. Radiol. 76, 232–237.

Gaona, E., Nieto, J.A., Góngora, J.A.I.D., Arreola, M., Enríquez, J.G.F., 2007. TL dosimetry for quality control of CR mammography imaging systems. Radiat. Eff. Defects Solids 162, 759–763.

Hart, D., Wall, B.F., Shrimpton, P.C., Bungay, D.R., Dance, D.R., 2000. Reference doses and patient size in paediatric radiology. NRPB-R318. NRPB, Chilton UK.

ICRP, 1990. International Commission on Radiation Protection, 1990, Recommendations of the International Commission on Radiation Protection. Pergamon Press, Oxford ICRP publication 60.

ICRP, 1996. International Commission on Radiological Protection, 1996. Publication 73, Radiological Protection and Safety in Medicine. Pergamon Press, Oxford and New York.

McParland, B.L., Gorka, W., Lee, R., Lewall, D.B., Omojola, M.F., 1996. Radiology in the neonatal intensive care unit: radiation dose reduction and image quality. Br. J. Radiol. 69, 929–937.

NOM, 2002. Norma Oficial Mexicana NOM-229-SSA1-2002. Requisitos técnicos para las instalaciones, responsabilidades sanitarias, especificaciones técnicas para los equipos y protección radiológica en establecimientos de diagnóstico médico con rayos X, México.

Ono, K., Akahane, K., Aota, T., Hada, M., Takano, Y., Kai, M., Kusama, T., 2003. Neonatal doses from X-ray examinations by birth weight in a neonatal intensive care unit. Radiat. Prot. Dosimetry 103, 155–162.

Prasad, K.N. (Ed.), 1995. Handbook of Radiobiology. CRC Press, Boca Raton, FL.UNSCEAR, 2000. United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2000 Report-vol. II: Sources, effects and risks of ionizing radiation. United Nations, New York, NY.