Optimising the Use of Computed Radiography in Pediatric Chest Imaging

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The objective of this study was to analyze image quality of chest examinations in pediatric patients using computed radiography (CR) obtained with a wide range of doses to suggest the appropriate parameters for optimal image quality. A sample of 240 chest images in four age ranges was randomly selected from the examinations performed during 2004. Images were obtained using a CR system and were evaluated independently by three radiologists. Each image was scored using criteria proposed by the European Guidelines on Quality Criteria in Pediatrics. Mean global scoring and scoring of individual criteria more sensitive to noise were used to evaluate image quality. Agfa dose level (DL) was in the range 1.20 to 2.85. It was found that there was not significant correlation ($R < 0.5$) between image quality and DL for any of the age ranges for either global score or for individual criteria more related to noise. The mean value of DL was in the ranges 1.9–2.1 for the four age bands. From this study, a DL value of 1.6 is proposed for pediatric CR chest imaging. This could yield a reduction of approximately a factor of 2.5 in mean patient entrance surface doses.

KEY WORDS: Radiation dose, image quality, chest radiography, computed radiography

Abbreviations:

DL Dose level
CR Computed radiography
ICRP International Commission on Radiological Protection
PSP Photostimulable phosphor plate
ESD Entrance surface dose
HMD Hyaline membrane disease

INTRODUCTION

The European Commission Council Directive on medical exposures 97/43/Euratom¹ considers, in its Article 9, pediatric radiology as a “special

practice,” requiring member states of the European Union to dedicate special attention to the quality assurance program and patient dose evaluation.

Don² highlighted in a recent paper that “with the advent of computed radiography (CR), the dose to patients is higher than screen–film radiography and overexposure is quite common.” He reported that, at the St. Louis Children’s Hospital, 43% of pediatric patient examinations were overexposed. Similar conclusions were obtained by Peters and Brennan.³

In pediatric radiography as in any other diagnostic modality using ionizing radiation, obtaining adequate image quality for diagnosis should be the first priority, but patient radiation doses are of special concern in children because of the increased probability to induce stochastic effects (mainly cancer).²

To define “diagnostic image quality” is a challenge. In 1996, the European Commission published Guidelines on Quality Criteria for diagnostic radiographic images in pediatrics after several years of research with the corresponding meetings and

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surveys aimed at obtaining a consensus among European pediatric radiologists.⁴

With the introduction of digital techniques, radiologists are still challenged in good management of patient doses. Digital detectors have a wide dynamic range, allowing a good image quality to be obtained in a range of patient doses greater than 500.⁵ The risk to increase patient doses is higher in digital radiology. In 2004, *International Commission on Radiological Protection* (ICRP) published a document with recommendations on this topic,⁶ stating that "If careful attention is not paid to the radiation protection issues of digital radiology, medical exposure of patients will increase significantly and without concurrent benefit. Conversely, if the radiation protection issues are adequately addressed, medical exposures may decrease without decreasing the diagnostic benefit to the patient."

Conventional film–screen radiography (speed class 200) typically requires an incident dose of about 5 μGy to result in satisfactory film blackening.⁵ CR can, in theory, generate satisfactory images using radiation doses from 100 times less (0.05 μGy) to 100 times more (500 μGy).

Patient doses are not routinely measured for all examinations and especially in pediatrics, with a few rare exceptions. The use of mobile systems for infants and other practical difficulties (e.g., the use of radiographic systems without built-in dosimeters and the low number of pediatric patients in some general hospitals) means that typical pediatric dose values for the different age ranges are not known in many centers.

Fortunately, the industry involved in digital imaging is introducing tools to audit image receptor doses to help radiologists and radiographers in the best management of radiation risk.^{3,5,7}

CR is now the most used digital imaging modality in many centers. However, this technology does not have a physical link between the image detector (photostimulable phosphor plate [PSP]) and the x-ray generator. Consequently, the radiographic parameters and the patient dose cannot automatically be transferred to the image file (as part of the Digital Imaging and Communications in Medicine [DICOM] header). CR manufacturers offer a certain "dose index" related with the light emitted by the PSP during the reading process, to control the level of plate exposure. Kodak systems use the exposure index. Fuji systems use the sensitivity number, and Agfa systems use the dose level (DL).

In this paper, we analyze image quality of chest examinations in pediatric patients using CR obtained with a wide range of doses to suggest the optimal dose value compatible with good image quality.

MATERIALS AND METHODS

The CR used in our center is the Agfa system with PSP model MD40 (Agfa-Gevaert, Mortsel, Belgium). Readers are ADC Compact models with their corresponding workstations. Images are processed with Multi-scale Imaging Contrast Amplification (MUSICA), also a software product by Agfa. In addition, specific dose-monitoring software, also produced by Agfa-Gevaert,⁸ is used to monitor the light emitted by the PSP, deriving a DL measured as the median of the logarithmic pixel values in the main histogram lobe of the image.

The dose exposure level provided by Agfa is not related directly to patient entrance surface dose (ESD) but to the light emitted during the plate read-out process. The digitizer produces an histogram where the pixel content is proportional to the emitted light (see Fig. 1). Nevertheless, when similar patient thickness x-ray beam quality is used (kilovolts and filtration), DL can be related with ESD.⁹ Because of the logarithmic definition of DL, an increase of 0.3 in DL doubles the dose to the PSP.

For simplification throughout this paper, we will use ESD to mean the air dose (or air kerma) at the surface of the patient with backscatter.

Several x-ray units from different manufacturers (mobile, fixed wall, and table buckys) are used for pediatric patients. All x-ray systems and the complete CR imaging chain are submitted to periodic quality control by the medical physics service of the hospital.

The hospital where the study has been carried out is a general university hospital with a Diagnostic Radiology Department (fully digital since 1999) performing approximately 300,000 examinations per year. A central picture archiving and communication system (PACS) archives all the images produced in the hospital. From the year 2000, a homemade quality control online system was installed.⁹ At present, the system is updated, receiving from the PACS, in real time, all the images, and extracting the information contained in the DICOM header to be transferred into a database. The system is configured so that every image acquired is sent to the PACS, so the technologists cannot delete errant images. This

Fig 1. Histogram of the typical pixel content in a CR image.

database has been used to select the pediatric images used in this work, applying the corresponding filters by examination and by age.

From a population of 702 chest images (PA or AP) archived in the database in the last 4 months of 2004, a sample of 260 examinations in four age ranges¹⁰ (<1, 1 to <5, 5 to <10, and 10 to <16 years) was randomly selected from the database (using Microsoft Excel 2003 RAND function), having DL between 1.20 and 2.85 (meaning a factor of 45 in the dose value to the PSP). Once the images randomly selected from the database were retrieved from the PACS, 21 images of the 260 random sample were excluded from the study because of different problems with the digitalization process (e.g., no output image at all), defective phosphor plates,^{6,11} or mistakes in the study identification (e.g., abdomen identified as a thorax).

Images were evaluated blindly and independently by three radiologists on the same PACS workstation and with the same room light. Radiology Department is under a quality assurance program with its technical aspects developed by the Medical Physics Department of the hospital, including viewing conditions and output of the workstations. The workstations are adjusted according local protocols with a maximum brightness of 300 cd/m² and a minimum brightness of 0.3 cm/m², following DICOM curve. Window and level of the images were changed by each radiologist depending on the structure examined,

as done in routine visualization. Each image was scored using the criteria proposed by the *European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Pediatrics*^{4,12,13} (Table 1). Each of the seven criteria was scored with 1 or 0 (1 point if the criterion is fulfilled, 0 point if it is not fulfilled). The global scoring of the images was calculated by simple addition of the scoring obtained for the individual criteria. The arithmetic mean of the three radiologists was used as final scoring for each image. Some of the image criteria are more related to the level of noise in the image (criteria from 4 to 7 in Table 1), and a separate scoring has been calculated for these criteria.

SPSS (version 13.0, 2004; <http://www.spss.com>) was used for the statistical analysis. Cohen's kappa coefficient was used to measure the agreement in the image quality scoring among the three radiologists. Kolmogorov-Smirnov test (<http://www.spss.com>) was calculated to assess if the variables fitted a normal distribution. Then both Pearson and Spearman's rho correlation coefficients¹⁴ for scoring and DL were calculated for each age range. The Pearson correlation coefficient measures the linear relationship between two random variables. The Spearman's rho is a nonparametric correlation coefficient of the ranks (the relative order) based on continuous data. Finally, Microsoft Excel 2003 (<http://www.microsoft.com>) was used to represent scatterplot graphs of the data sets.

Table 1. Image Quality Criteria for Chest Images Proposed by the European Guidelines⁴ and Mean Scoring Obtained for the Different Age Bands

	<1 year (N = 60)		1–5 years (N = 60)		5–10 years (N = 62)		10 to <16 years (N = 57)	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
1.1. Performed at peak of inspiration, except for suspected foreign body aspiration (over 1)	0.87	0.29	0.82	0.30	0.93	0.20	0.89	0.26
1.2. Reproduction of the thorax without rotation and tilting (over 1)	0.32	0.30	0.47	0.37	0.63	0.37	0.71	0.34
1.3. Reproduction of the chest must extend from just above the apices of the lungs to T12/L1 (over 1)	0.83	0.33	0.81	0.34	0.76	0.36	0.82	0.28
1.4. Reproduction of the vascular pattern in central 2/3 of the lungs (over 1)	0.61	0.42	0.70	0.32	0.88	0.21	0.85	0.29
1.5. Reproduction of the trachea and the proximal bronchi (over 1)	0.24	0.28	0.62	0.37	0.79	0.32	0.67	0.33
1.6. Visually sharp reproduction of the diaphragm and costo-phrenic angles (over 1)	0.64	0.39	0.81	0.29	0.92	0.16	0.85	0.27
1.7. Reproduction of the spine and paraspinal structures and visualization of the retrocardiac lung and the mediastinum (over 1)	0.59	0.31	0.78	0.31	0.90	0.18	0.83	0.28
Global mean scoring (over 7)	4.11	1.37	5.01	1.20	5.80	0.87	5.58	1.47
Noise-related mean scoring (1.4 to 1.7 criteria, over 4)	2.09	1.04	2.91	0.88	3.48	0.56	3.21	0.96
Mean dose level	2.06	0.36	2.14	0.35	1.96	0.31	1.89	0.23

In addition, other qualitative analysis of the images with the most extreme DL values existing in the database (702 chest images) was made to identify the boundaries of DL range giving enough diagnostic quality. A total of 22 images with DL <1.2 and 23 images with DL >2.85 were individually analyzed. In this qualitative analysis, all images were considered, including those not valid for diagnosis.

RESULTS

Table 1 presents, together with the European quality criteria, the mean scoring and standard deviation of each criteria and the mean values and standard deviation of DL for the four age ranges. A second scoring for the individual criteria (4 to 7) more sensitive to the noise (and theoretically to the DL) is also

Table 2. Correlation Coefficients of the Four Age Groups

	<1 year (N = 60)	1–5 years (N = 60)	5–10 years (N = 62)	10 to <16 years (N = 57)
Pearson correlation coefficient between global scoring and dose level	<i>0.312 (p=0.015)</i>	<i>0.457 (p=0.000)</i>	–0.081 (p = 0.530)	–0.295 (p = 0.026)
Pearson correlation coefficient between noise-related scoring and dose level	<i>0.278 (p=0.033)</i>	<i>0.420 (p=0.001)</i>	0.065 (p = 0.613)	–0.344 (p = 0.009)
Spearman's rho correlation coefficient between global scoring and dose level	0.304 (p = 0.018)	0.428 (p = 0.001)	–0.212 (p=0.098)	–0.202 (p=0.132)
Spearman's rho correlation coefficient between noise-related scoring and dose level	0.274 (p = 0.034)	0.399 (p = 0.002)	<i>0.074 (p=0.568)</i>	–0.241 (p=0.070)
Kolmogorov–Smirnov Z statistic for global scoring; dose-related scoring and dose level, respectively	0.879; 0.523; 0.305	0.148; 0.152; 0.398	0.011*; 0.008*; 0.350	0.014*; 0.007*; 0.507

*Kolmogorov–Smirnov Z statistic below 0.05 means that the distribution is not normal. Correlation coefficient of 0.2 means weak correlation, 0.5 moderate correlation, and 0.8 strong correlation.¹² The most appropriate correlation is italicized.

Fig 2. Scoring of individual images versus DL values for the age band <1 year. Coefficient of determination (R^2) is included.

presented. Cohen's kappa coefficient values ranged from 0.61 to 0.85 for the individual image quality criteria scoring. The best agreement among the three radiologists was for criteria 1, 3, and 4 (kappa > 0.75) and the worst agreement for criteria 7 (kappa 0.61).

Table 2 presents the correlation coefficients (Pearson and Spearman's rho) of the four age ranges and Kolmogorov–Smirnov Z statistic of each variable. For the last two age groups, the nonparametric Spearman's rho is more adequate according to the non-normal distribution.

Figures 2, 3, 4, and 5 show the graphs of the individual image quality scoring versus DL, together with the coefficient of determination (R^2) for the four age ranges.

The analyzed images with extreme DL values (<1.2 or >2.85) give variable results with image quality scoring. It is not possible to give an exact lower or higher boundary for DL range because

there are only 45 images outside of these boundaries and some of the images were adequate for diagnosis, but others, with the same DL, are not adequate, depending of the age and weight of the patients. In the range of DL from 1.2 to 2.85, we did not find images (in the random sample analyzed) without diagnostic quality because of the noise or because of the saturation. Figures 6 and 7 present examples of images not valid for diagnosis: an image with excess noise (Fig. 6) and another with saturation in left lung base (Fig. 7).

DISCUSSION

Patient dosimetry in pediatric radiography is a difficult task. Especially for chest imaging, ESD is fortunately quite low and in the range of μGy from the tens to the hundreds. But, in some patients, the

Fig 3. Scoring of individual images versus DL values for the age band 1 to <5 years. Coefficient of determination (R^2) is included.

Fig 4. Scoring of individual images versus DL values for the age band 5 to <10 years. Coefficient of determination (R^2) is included.

number of serial examinations is quite high, as in the cases of premature babies, with sometimes more than 50 images taken in one month.

Measurement in such low doses is quite difficult with the conventional dosimeters used for adult patients. In addition, there are an important number of examinations performed in the intensive care unit with mobile systems where systematic registration of the radiographic technique (kV, mAs, and distance focus to skin) is not done. The consequence is that the audit of pediatric patient doses is difficult in many hospitals.

The tools offered by the manufacturers to inform radiologists and radiographers on the dose received by the PSP (DL in the case of Agfa) are the only method available to audit the effect of varying a parameter related to individual patient dose in large samples of patients. The advantage in transferring this DL value to the DICOM header allows the possibility of performing retrospective studies of image

quality versus DL, thus finding the optimum DL to obtain enough image quality.

A limitation of this methodology is the mistake that occurs with the automatic Agfa software to calculate the DL, especially when the selection of the part of the histogram is not done properly. The part of the pixel content histogram having the useful diagnostic information is the centered wide lobule (see Fig. 1). The very narrow peak on the right corresponds to the directly exposed part of the plate (without attenuation of the patient), and the other wide lobule on the left corresponds to the collimated area (low signal chiefly because of the scatter radiation arriving to this area of the plate). If the correct lobe of the histogram is not selected, the calculated DL will not be valid.

At our center, the mean DL for the four age ranges is approximately 2.0 (Table 1), and from the correlation study between image quality scoring and DL, it can be concluded that no strong correlation

Fig 5. Scoring of individual images versus DL values for the age band 10 to <16 years. Coefficient of determination (R^2) is included.

Fig 6. Example of clinical image nonvalid for diagnosis because of the high noise level ($DL = 1.05$); 3-week-old patient.

Fig 7. Example of clinical image nonvalid for diagnosis because of the saturation in some areas of the lung ($DL = 2.95$); 13-month-old patient.

exists for either the global score or for the individual noise-related criteria. Thus, it seems appropriate to recommend radiographers to reduce radiographic techniques (and ESD) in a factor of 2 (corresponding to a decrease in DL of 0.3) for pediatric patients

bringing the mean value of DL to 1.6–1.7 instead of the actual value of 1.9–2.0. Of course, individual DL higher than this recommended mean value should be avoided because it will not produce greater image quality.

Fig 8. (a) Image of a premature infant obtained with a DL of 2.1 (representing in this case a value of patient ESD of 50 μ Gy). (b) Image of the same premature infant obtained 4 days later with a DL of 1.8 (representing in this case a value of patient ESD of 25 μ Gy).

Specific pathologies such as the hyaline membrane disease² require the avoidance of any noise in the image for a good diagnosis. However, if such pathologies are not suspected, it is still not justifiable to increase doses for all the chest examinations to a level of noise that is acceptable for most of the clinical diagnoses.

From Table 1, it seems that the age range most critical to obtain good image quality is the range of <1 year of age (mean global score of 4.1 over 7). Standard deviations for the global scoring are quite high for all the age ranges (and even higher for patients <1 year of age). This is probably because of the intrinsic difficulty in managing these patients, the large variation in patient size, and the use of mobile systems and manual exposure modes. Furthermore, for the individual criteria related to noise (criteria 4 to 7), the scoring for this age range is also the lowest.

Figures 2, 3, 4, and 5 and Table 2 demonstrate that no strong correlation exists between individual image quality scoring (neither global nor individual noise-related criteria scoring) and DLs. We found weak or weak-to-moderate positive correlation factors¹⁴ for the 0–5 years of age and 1–5 years of age groups and weak negative correlation factors for the 5–10 and 10–16 years of age groups. It should be noted that the correlation coefficient is similar or even lower for the partial noise-related criteria score than for the global score. Coefficient of determination (R^2) for global score and for noise-related score is represented in the scatterplots for all the four age groups. However, it would not be appropriate to compute R^2 on the basis of rank correlation coefficients such as Spearman's rho, but they are commonly used in the literature. In any case, the conclusion of our study is that clinical image quality is similar for a wide range of plates' DL, and as a consequence, the use of CR in pediatric chest imaging should be set to a lower DL than the technique now used in our center.

It can also be concluded that, when DL are lower than 1.2 or higher than 2.85, image quality can be seriously degraded with the probable need for repeating some exposures. Exams with higher DL (>2.0) should be interpreted as mistakes in the selected radiographic technique. Image quality could be valid (up to DL=2.85) but with an unnecessary and substantially increased radiation dose for the patient. DL below 1.2 may also require repetitions. The suggested operational DL value for chest imag-

ing of 1.6–1.7 with the Agfa CR system seems a good compromise to assure adequate image quality with the reasonably low radiation dose to the patient. Figure 8 show examples of images for the same patient with a difference in patient ESD in a factor of 2. Both images are adequate for an accurate diagnosis. Our radiographers should be trained to work with the appropriate DL for our CR system. Thus, we recommended in our center to adjust the automatic exposure control systems for pediatric imaging to obtain DL in this range. Radiographers working in manual mode have been advised to decrease the mAs to obtain DL between 1.6–1.7.

Peters and Brennan³ had similar recommendations using the Kodak CR system. They found, in a retrospective study, a significant increase in exposure indices, especially if the examinations were performed out of hours, and emphasized the need for establishing their own optimum exposure indices for digital investigations rather than simply accepting manufacturers' guidelines. Willis¹⁵ examines a variety of measures for reducing doses in ordinary pediatric digital examinations. Don² also claims the need for "more research to identify the lowest exposure that maintains diagnostic accuracy." Other papers also emphasize as well this as-low-as-reasonable-achievable concept.^{16,17}

CONCLUSIONS

From the present study, it is concluded that the appropriate DL for pediatric chest imaging with the Agfa CR system is approximately 1.6. This includes a safety margin in DL of 0.4. This technique would yield an approximate reduction by a factor of 2.5 in the present mean value of patient ESD in our center.

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