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Subjective Evaluation of a Novel Method of X-ray Dose Reduction by Optical Re-Exposure of Conventional Radiographs with a Multi-Observer R.O.I. Evaluation

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Abstract: A procedure been previously described that has an effect on the image quality and radiation dose of conventional radiographs already at the time of acquisition. This development is using X-ray sensitization by optical re-exposure. Aim of this study was to establish if the results of optical re-exposure measured with SNR and MTF also meant that the subjective quality of 50% dose reduced and re-exposed radiographs of bony structures was equal or better than conventional full dose radiographs of the same area. Freshly slaughtered anterior shoulders of lambs with preserved soft-tissue mantles and natural water content served as the animal model. A comminuted fracture in the middle of the shaft was artificially produced. After taking a normal exposed reference image, dose-reduced, five underexposed images were prepared by reducing the mAs product by exactly 50% with constant anode voltage. A conventional radiograph was taken in a single plane standard position from the object, which served as the reference image. These underexposed X-rays were then optically re-exposed for a defined period of time before development. In all images different osseous structures were defined as Regions of Interest (ROI). On the basis of these ROI's, the subjective changes in image quality (information loss or gain) of images 2-6 were compared to the reference image 1 and evaluated by 16 physicians with large experience in diagnosis of orthopaedic radiographs. The evaluation of the observers scoring showed a significant decrease in subjective image quality regarding the detail recognition in all images apart from the images re-exposed for 60 sec. Comparing image 5 with the reference image, detail recognition of the ROI A was also evaluated as insignificantly improved ($p = 0.31$) even with a score of +0.06 above the level of the reference image. In conclusion, there is a possibility of reducing the collective radiation dose whilst keeping a high degree of diagnostic reliability. Film sensitization provides a technically simple and inexpensive procedure, which can be easily integrated into common film development processes and could considerably reduce patient radiation exposure as well as improve image quality and thus detail recognition.

Key words: Dose reduction, optical re-exposure, conventional radiographs, ROI analysis

INTRODUCTION

Although in the light of digital imaging the days of conventional radiographs are numbered, the complete diminish of this technique will take at least another 15 years. Especially the initial acquisition cost of this technique hinders many physicians to exchange equipment.

A procedure been previously described that has an effect on the image quality and radiation dose of conventional radiographs already at the time of acquisition (Paech *et al*., 2007). This development is using X-ray sensitization by optical re-exposure, a technique that has been known in the world of photography for a long time (Bancroft *et al*., 1931). In previous studies, it was shown that with this method of radiation reduction an improvement in the image quality in the acquisition of conventional X-rays as measured by technical methods (Signal to Noise Ratio (SNR) and Modulation Transfer Function (MTF) could be achieved (Schoknecht and Hahlbrauck, 1991). The method of optical exposure is technically simple and could be incorporated in conventional development equipment. The optical re-exposure of dose-reduced conventional X-ray imaging completely compensated the loss of information caused by underexposure as measured objectively.

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X-ray sensitisation by optical re-exposure: Although the sensitization effects of additional exposure on film has long been known, its mechanism has until not been fully understood. Some explain the sensitization effect on the elevation of electrons on higher levels and thereby creating a higher and more even distributed sensitivity level (Schoknecht and Hahlbrauck, 1991). Others have found on electron microscopy a formation of many silver clusters per grain in contrast to one grain per cluster in standard technique exposure (Tani *et al.*, 1999) and dispute the relevance of electron elevation.

In X-ray sensitisation by optical re-exposure, conventional film is re-exposed with a specific light source (opal lamp) for a defined period before development. This re-exposure leads to a homogenization of the film density by light quanta hitting the X-ray film (lower energy than X-ray quanta) and thus to an improvement of detail recognition and image quality by reducing the noise in the X-ray film (Schoknecht and Hahlbrauck, 1991).

Aim of this study was to establish if the results of optical re-exposure measured with SNR and MTF also meant that the subjective quality of 50% dose reduced and re-exposed radiographs of bony structures was equal or better than conventional full dose radiographs of the same area. The subjective improvement of image quality and detail recognition of osseous structures was assessed on the basis of a multi-observer Region of Interest (ROI) evaluation, for which an image quality score (5-step confidence scale) was developed.

MATERIALS AND METHODS

Freshly slaughtered anterior shoulders of lambs with preserved soft-tissue mantles and natural water content served as the animal model. A comminuted fracture in the middle of the shaft was artificially produced as a pathological finding.

After taking a normal exposed reference image, dose-reduced, five underexposed images were prepared by reducing the mAs product by exactly 50% with constant anode voltage (Table 1). A conventional radiograph was taken in a single plane standard position from the object, which served as the reference image. The images were taken in a 12-pulse technique with a Siemens (Erlangen, Germany) rotating anode tube Optilix 150/40/102 C on a scanning table. We used the screen-film system Curix Rp1/Blue 200 (high resolution, Agfa-Gaevert, Leverkusen, Germany). A film-focus distance of 150 cm was selected. Study period was September 2005.

Thereby reproduction of the image was performed with a 52% decrease in the radiation dose.

Table 1: Imaging parameters and measurement values

Image no.	Irradiation parameters	Radiation dose (μGy)	Optical re-exposure time(s)
1	55kV, 25 mAs, 25 ms	215	0
2	55kV, 12 mAs, 12 ms	106	0
3	55kV, 12 mAs, 12 ms	106	25
4	55kV, 12 mAs, 12 ms	106	40
5	55kV, 12 mAs, 12 ms	106	60
6	55kV, 12 mAs, 12 ms	106	80

Table 2: Definition of the regions of interest

Region of Interest (ROI)	Osseous structure
ROI A	Medullary cavity and cortical bone
ROI B	Fracture zone
ROI C	Cancellous bone
ROI D	Joint cavity and articular surface

Table 3: Evaluation score of changes in image quality with regard to detail recognition

Changes in image quality	Points
Clear improvement	+2
Improvement	+1
Unchanged detail recognition	0
Worsening	-1
Clear worsening	-2

These underexposed X-rays, except for X-ray 2, were then optically re-exposed for a defined period of time before development (Table 1). Since the X-ray film used had two emulsion layers, a sensitization of both sides was required.

The re-exposure unit is based on a commercially available photograph enlarger. It has been described in detail before (Paech *et al.*, 2007). It is constructed of a stand with an opal lamp, a lens (f = 75 mm) and a red filter as well as a connected timer for controlling the length of re-exposure.

The radiation dose was measured with the calibrated dosimeter PTW Dali Gray from Dr. Pychlau's Physical Technical Works (Freiburg, Germany). A calibrated light meter from Panluxelektronik Co. (Gossen, Germany) was used for determining the lighting strength of the re-exposure unit in the film plane. It was 1 lux.

In all images different osseous structures were defined as Regions of Interest (ROI) for evaluation of the subjective changes in image quality (Table 2). These ROIs were in all images of exactly the same size and position.

On the basis of these ROI's, the subjective changes in image quality of images 2-6 compared to the reference image were investigated.

On the basis of these ROI's (Fig. 1-3), the subjective changes in image quality (information loss or gain) of images 2-6 were compared to the reference image 1 and evaluated by 16 physicians with large experience in diagnosis of orthopaedic radiographs (minimum 5 years experience). In order to record the subjective assessment, an evaluation score was developed on the basis of a current confidence scale in ROC analysis (Albeck and Borgesen, 1990; Obuchowski, 2005) represents in Table 3.

Fig. 1: Image 1 with standard X-ray exposure was used as the reference image for the evaluation of the subjective changes in image quality

Fig. 2: Image 2 is 52% dose-reduced but not re-exposed. The detail recognition appears considerably reduced

The observer was not asked to make a yes/no decision but rather to code the reliability of the decision about detail recognition on the basis of a confidence scale (image quality score). Results of the subjective changes in image quality were statistically analyzed (SPSS, 12.0, Chicago, USA). The Wilcoxon test was applied for nonparametric procedures. P values <0.05 were defined as statistically significant. The mean values and the standard deviation for all data where calculated.

The X-ray images (Image 1, 2 and 5 are illustrated in Fig. 1-3) with their regions of interest were used to determine the subjective changes in image quality.

Fig. 3: Image 5 was dose reduced and then optically re-exposed for 60 s

Table 4: Mean values for the subjective scoring of 16 observers compared to the reference image (image 1). Only for statistically non-significant differences p values are stated

	ROI-A	ROI-B	ROI-C	ROI-D
Mean score image 2	-1.75	-1.56	-1.81	-1.44
Mean score image 3	-1.19	-1.06	-1.19	-1.19
Mean score image 4	-0.88	-0.81	-0.81	-0.62
Mean score image 5	0.06 [ns, p = 0.32]	0.19 [ns, p = 0.11]	0.12 [ns, p = 0.18]	0 [ns, both values 0]
Mean score image 6	-1.06	-1.06	-1	-1

RESULTS

The evaluation of the observers scoring showed a significant decrease in subjective image quality regarding the detail recognition in all images apart from the images re-exposed for 60 sec (Table 4).

The subjective evaluation of the changes in image quality in ROI A is illustrated in the following Fig. 4 using the calculated mean values and standard deviations.

Comparing image 2 with the reference image, a significant worsening of detail recognition due to underexposure was found with a mean score of -1.75 (p = 0.0004).

The evaluation of image 3 already showed a non significant improvement (p = 0.07) of subjective detail recognition compared to image 2 with a score of -1.1875.

Image 4 only demonstrates a slight worsening of detail recognition in the area of the medullar cavity and cortical substance (ROI A) with -0.875 evaluation points. Compared to image 2, there is a significant improvement in image quality (p = 0.02).

Comparing image 5 with the reference image, detail recognition of the ROI A was also evaluated as insignificantly improved (p = 0.31) even with a score of

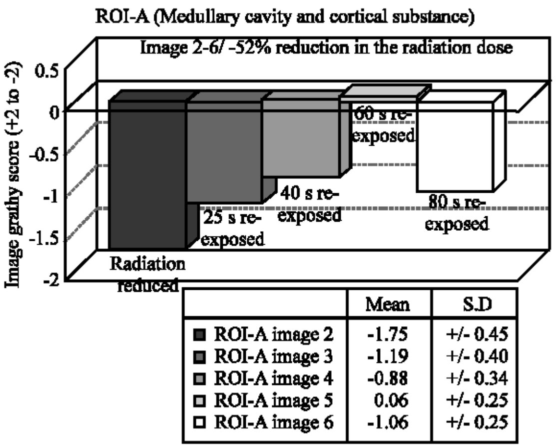

Fig. 4: The mean evaluation scores and the standard deviations for the changes in image quality in the ROI A (medullar cavity and cortical substance) of the 52% dose-reduced images 2-6. There is a dependency of the changes in image quality on optical re-exposure and its time

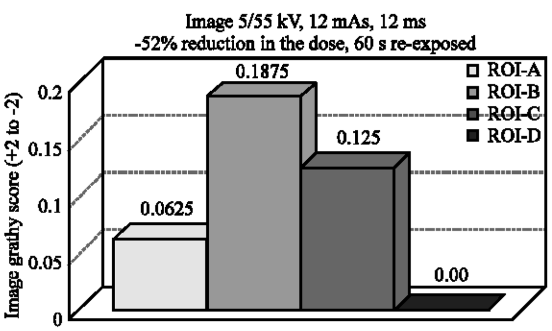

Fig. 5: The evaluation of image 5 compared to reference image 1 in the ROI A-D

+0.06 above the level of the reference image. If the mean score of image 2 is compared to image 5 then a significant improvement (p = 0.00004) from -1.75 to +0.06525 is obtained.

The comparison of image 6 with image 1 yields the score of -1.0625, which is again a significant decrease (p=0.0004) of the detail recognition.

This distribution of the mean values and standard deviations for the image scores is similarly found in the other Regions of Interest (ROI B-D). In all images only with a 60 sec re-exposure time the image quality was judged to be equal or better than the reference image. The best result of image 5 was seen in the area of the fracture zone (ROI-B) although statistically this was not judged to be better than the reference image (Fig. 5).

DISCUSSION

Reducing the radiation exposure of conventional X-rays to patients in order to avoid possible injury is a constant goal of modern medicine. The common limiting factor is the deterioration of image quality related to the degree of radiation reduction and the type of procedure. This also implies impairment in examination results and diagnostic reliability with markedly reduced detail recognition (Fink *et al*., 1996; Kellerer, 2002; Neofotistou *et al*., 2005; Bansal, 2006). The possibility of influencing image quality by optical re-exposure of X-ray images was investigated in 1990 at the Department of Biology of the Free University of Berlin (Schoknecht and Hahlbrauck, 1991). It was shown (with a bar dosimeter as the object) that with a highly underexposed film, in which the dosimeter could hardly be discerned, re-exposure of 20 s influenced the image quality to such an extent that the contours of the dosimeter were again clearly recognizable. In a previous study we have investigated the possibility of x-ray dose reduction in orthopaedic imaging with the use of optical re-exposures (Paech *et al*., 2007). Evaluation of the objective parameters of Modulation Transfer Function (MTF) and of the Signal-Noise Ratio (SNR) showed that the loss of detail recognition and image quality seen due to underexposure was almost completely compensated by optical X-ray sensitization and re-exposure.

The aim of this study, was to investigate the applicability of this previously unused method with consideration of the possibilities of radiation reduction and an improvement in subjective image quality of conventional X-rays in orthopedic imaging.

The study was limited to recording subjective changes in image quality of optically re-exposed, radiation-reduced X-ray images in comparison to a regularly exposed reference image created using an animal model. By evaluating ROI's, the clinical importance of this procedure was evaluated with special consideration of radiation reduction and the detail recognition of osseous structures as well as pathological findings. An image quality score (five-step confidence scale) was developed for recording the subjective changes in image quality. This is a method frequently reported in the literature for evaluating the effectiveness of imaging procedures (Harrington, 1990). The framework conditions of this study correspond to the general requirements in the literature regarding R.O.C. analysis in radiology (Albeck and Borgesen, 1990; Obuchowski, 2005). It consisted of a highly qualified observer population (n = 16) and a "test number" of 320 images (minimal recommended requirement for ROC analysis: n = 40, (Oestmann and Galanski, 1989)).

The evaluation of subjective changes in image quality showed that optical re-exposure of conventional X-ray film compensates the reduction of detail recognition caused by the decrease in the mAs product (dose reduction from 215 Gy to 106 Gy, corresponds to 52%) and the loss of information related to the length of film sensitization. The optimal re-exposure time was in all images found to be 60 s. This re-exposure time was able to completely compensate for the loss of information in the X-ray. The image quality obtained in the ROI's A, B and C was even slightly better than the image quality of the reference image (No. 1). The evaluation of subjective changes in image quality in this study also showed that there was no subjective impairment in the detail recognition of osseous lesions such as fissures and fractures or the assessment of articular surfaces despite considerable underexposure.

CONCLUSION

There is a possibility of reducing the collective radiation dose whilst keeping a high degree of diagnostic reliability.

Film sensitization provides a technically simple and inexpensive procedure, which can be easily integrated into common film development processes and could considerably reduce patient radiation exposure as well as improve image quality and thus detail recognition. Objective as well as subjective measurement showed it possible to fully compensate the reduction of radiation. It was found that the evaluation of osseous structures in conventional X-rays, which had a 52% reduction in the radiation dose and were produced using film sensitization with optimal re-exposure according to study results, showed no loss of information, i.e. complete detail recognition and image quality.

A weakness of this study is the fact that the optimal re-exposure value determined here is only valid for the screen-film combination selected, the light source applied and the object under investigation. In future studies, the variation of these parameters should investigate how X-ray sensitization is influenced and how it contributes to an increase in procedure effectiveness after determining the optimal standard conditions (e.g. optimal light source). This must be clarified by further optimization of the light source and film-foil combination as well as adjustment of the variables of different object effects. Also the possibility of application of this method in digital imaging should be evaluated.

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