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ORIGINAL ARTICLE

Optimization of exposure in panoramic radiography while maintaining image quality using adaptive filtering

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ABSTRACT

Objective The purpose of the present study was to investigate the potential of using advanced external adaptive image processing for maintaining image quality while reducing exposure in dental panoramic storage phosphor plate (SPP) radiography. **Materials and methods** Thirty-seven SPP radiographs of a skull phantom were acquired using a Scanora panoramic X-ray machine with various tube load, tube voltage, SPP sensitivity and filtration settings. The radiographs were processed using General Operator Processor (GOP) technology. Fifteen dentists, all within the dental radiology field, compared the structural image quality of each radiograph with a reference image on a 5-point rating scale in a visual grading characteristics (VGC) study. The reference image was acquired with the acquisition parameters commonly used in daily operation (70 kVp, 150 mAs and sensitivity class 200) and processed using the standard process parameters supplied by the modality vendor. **Results** All GOP-processed images with similar (or higher) dose as the reference image resulted in higher image quality than the reference. All GOP-processed images with similar image quality as the reference image were acquired at a lower dose than the reference. This indicates that the external image processing improved the image quality compared with the standard processing. Regarding acquisition parameters, no strong dependency of the image quality on the radiation quality was seen and the image quality was mainly affected by the dose. **Conclusions** The present study indicates that advanced external adaptive image processing may be beneficial in panoramic radiography for increasing the image quality of SPP radiographs or for reducing the exposure while maintaining image quality.

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Introduction

Optimization of a radiological imaging system can be seen as the process of achieving sufficient diagnostic image quality while minimizing the radiation dose to the patient. X-ray exposure was reasonably easy to optimize for film-screen systems, as the degrees of freedom for the optimization of such systems was limited due to the fixed speed and latitude. Optimal exposure settings for film-screen systems have since long been determined and may still be in use, despite the introduction of digital imaging systems. However, it cannot be assumed that optimal exposure settings for film-screen systems are valid also for digital imaging techniques as the absorption properties differ. Furthermore, image processing can be used to alter the presentation of the content of digital images, leading to e.g. a weaker dependency between the radiation quality (tube voltage and filtration) and the contrast in the image. Thus, there is a potential for a more successful optimization process for digital systems in terms of achieving the necessary image quality at the lowest possible radiation dose.[1]

By reducing tube voltage,[2] tube load [3] or tube voltage *and* tube load,[4] some studies have managed to reduce radiation dose in digital panoramic radiography with a charge-coupled device (CCD) without degrading diagnostic image quality below that obtainable in a film-screen system. Regarding the magnitude of the dose, the effective dose of a number of digital panoramic units was found to vary between 4.7 μSv and 14.9 μSv.[5] For a Storage Phosphor Plate (SPP) system, an average effective dose of 8.1 μSv has been reported for panoramic examinations.[5] One may argue that the absorbed dose and, hence, the effective dose for dental examinations is very low. However, it has for example been shown in Norway that the dental x-ray examinations are the most frequent investigation of all radiological examinations in Norway.[6,7] Although the radiation dose to the single patient is low (an average effective dose of 26.2 μSv per individual has been reported), dental examinations represent 2.3% of the population dose for medical radiology examinations.[8] Furthermore, as shown by Ludlow et al.,[9] the effective dose of the panoramic technique has increased due to the revised

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tissue-weighting factors in ICRP 103.[10] The reported values above are, thus, under-estimated by today's standards. Additionally, despite the low individual dose, the cumulative effect cannot be ignored. A recent study showed that multiple exposures might be consistent with an increased risk of thyroid cancer.[11] Although the radiation dose to the thyroid gland in a panoramic examination is rather small, the anatomic position of the thyroid gland with its close connection to the mandible and its high sensitivity to radiation-induced oncogenesis [12] makes it an organ of concern in dental radiography.[13] Even if the radiation risk is low, there is still a risk of inducing parotid and thyroid tumours with dental radiology.[14–17] The need for limiting exposure to the thyroid gland in young people has been emphasized by findings following the Chernobyl accident, in which the incidence of thyroid cancer in children in the Belarus area increased from less than one case per million before the accident to 100 per million per year in certain areas.[12,18] A recently performed study showed a slightly higher risk of cancer from low radiation doses [19] and another showed that panoramic dental radiography may be cytotoxic to the buccal mucosa.[20] These findings indicate that it is important to optimize the radiation dose.[18,21]

As mentioned above, digital systems enable the possibility of using image processing for enhancing the image quality. In this area, two studies have, e.g., assessed different filters for improving the image quality of panoramic radiographs.[22,23] In both studies a sharpening filter was recommended for enhancing SPP panoramic images to improve both the visualization of most of the anatomical structures and the overall quality of the image. In addition to optimizing the image processing supplied by the modality vendor, it may be beneficial to use advanced external image processing to possibly further enhance the quality of the images.[24] To our knowledge, no studies have used the general operator processor (GOP) adaptive filtering technique in panoramic radiography,[25–27] although the potential of other types of advanced image processing techniques has been demonstrated.[28,29] The purpose of the present study was, therefore, to investigate the advantages of using advanced external adaptive image processing for maintaining image quality while reducing exposure in dental panoramic SPP radiography.

Materials and methods

Radiographic equipment and technique

An Alderson Rando anthropomorphic phantom (Alderson Radiation Therapy, Los Angeles, CA) firmly fixed to the head holder of a panoramic X-ray machine (Scanora, Soredex, Orion Cos., Helsinki, Finland) was used for the exposure of panoramic radiographs (Figure 1). The radiographs were obtained with tube voltages 57, 70 and 85 kVp; and tube loads ranging from 24–480 mAs (Table 1); inherent filtration was 2.75 mm Al. Three series of panoramic radiographs were acquired, in all 37 radiographs, at the Department of Radiology, Skaraborg Hospital, using a 15×30 cm cassette with SPPs (ADCC HR MD 10 plates, Agfa-Gevaert NV, Mortsel, Belgium). The SPPs were scanned with an Agfa ADC Compact unit (Agfa-Gevaert NV) set at a speed class of 200 in the first and second series and 400 in the third series. In series 1 and 3, the inherent filtration of 2.75 mm Al was used and an extra filtration of 3 mm Al was added to the second series.

Image processing

The acquired images were extracted from the modality and processed with the external image processing software GOPView XR2 (ContextVision AB, Stockholm, Sweden). As described by Larsson et al.,[24] the input images to the external processing software should be as unaffected ('raw') as possible. The images were, therefore, extracted with neutralized image-processing parameters ('zero processed'). The external image processing was first aimed to make the images comparable to the original appearance of the clinically-used SPP image (the reference image; see below) in terms of the global contrast and grey scale appearance. This harmonization was performed in order to reduce the risk of bias due to the observers being unaccustomed to the appearance of the externally-processed images and resulted in similar panoramic field intensities for all images. In the second step, the external image processing was used to enhance contrast and edges and reduce noise in an attempt to increase the visibility of the anatomical details in the images. The software uses an adaptive filtering technique for distinguishing between noise/vague structures, strong structures, objects, etc. On the basis of this, decisions can be made for each pixel about whether (1) it and the surrounding pixels should be noise reduced, (2) it should be enhanced (if the pixel is part of a structure) or (3) contrast is already sufficient in that area (ContextVision AB. http://www.contextvision.com/modalities/digital-x-ray/gopview-xr2plus/).[30]

Image quality evaluation

During image quality evaluation, the GOP-processed images were compared with a reference image (Figure 2a). The reference image was acquired with the acquisition parameters commonly used in daily operation (70 kVp, 150 mAs and sensitivity class 200). This image was processed using the

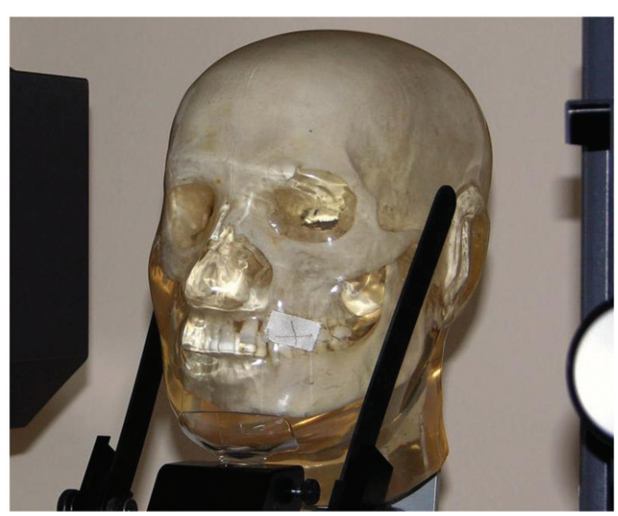


Figure 1. Phantom head placed in the Scanora X-ray unit.

standard process parameters supplied by the modality vendor, as used clinically. All 37 GOP-processed images were evaluated one by one and compared to the reference image by 15 dentists (six specialists in oral radiology and nine undergoing a specialist-training programme in oral radiology). In Figure 2b, an example of a GOP-processed image is given (the image based on the same acquisition as the reference image). All participants had good experience in panoramic radiography and were working in four different X-ray departments. All participants received written and verbal instructions on how to perform the viewing and evaluate the panoramic radiographs. The observers were asked to assess the overall image quality of each GOP-processed image on a relative 5-point rating scale ranging from 1–5 (1 = image quality much worse than reference image, 2 = image quality worse than reference image, 3 = image quality equal to reference image, 4 = image quality better than reference image, 5 = image quality much better than reference image). The observers were instructed to base their assessment of the overall image quality on the visibility of six anatomical structures as well as on the overall appearance of each image, although only a single rating was to be given for each image. The observers were pointed towards the following anatomical structures for their assessment: floor of the maxillary sinus; periodontal ligament space; dentino-enamel junction; inferior border of mandible; mandibular canal; periapical lamina dura.[3,22,31] The anatomical structures were chosen on the basis of their image characteristics providing both low- and high-contrast details.[22] During the evaluation,

Table 1. Included combinations (marked by 'x') of tube load, tube voltage and sensitivity class of SPP.

		Tube load (mAs)								
Tube voltage (kV)	Sensitivity of SPP*	24	37.5	60	96	150	240	300	380	480
57	200					x		x		x
	200+					x		x		x
	400									x
70	200			x	x	x	x		x	
	200+			x	x	x	x		x	
	400			x	x	x	x		x	
85	200	x	x	X	x	x				
	200+	x	x	X	x	x				
	400	x	x	X	x	x				

*+ = added extra filtration of 3.0 mm A.l.

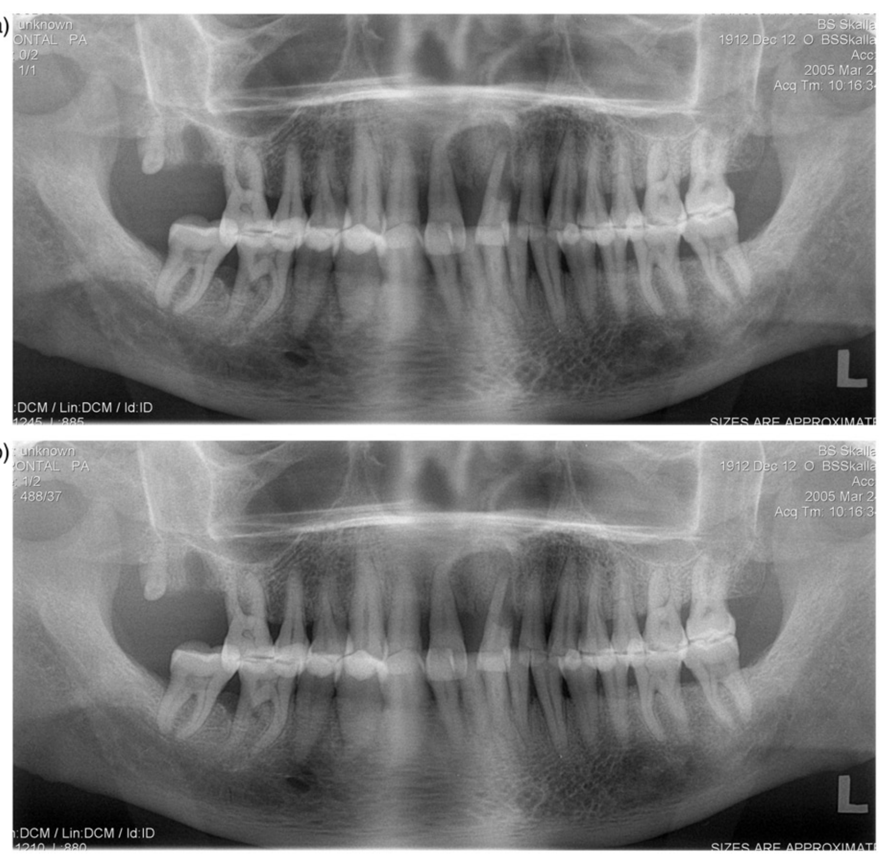
(a)
(b)


Figure 2. The image acquired at 70kV/150 mAs/sensitivity 200 processed using the modality-specific standard processing (the reference image) (a) and externally processed (b).

the observers were allowed to adjust the window width and window level to simulate a real clinical situation. Viewing of the radiographs took place in a dimmed room. The evaluation was performed on a DICOM-calibrated external monitor (Vista Line TFT-LCD Monitor, Olorin AB, Kungsbacka, Sweden).

Dosimetry

A kerma-area product (KAP) ionization chamber (Doseguard 100, serial number 1269, RTI Electronics AB, Mölndal, Sweden) was placed after the first collimator of the panoramic X-ray machine.[32] The measurements were corrected for chamber attenuation and energy dependence. Using the calculation described by Helmrot and Alm Carlsson,[32] a conversion factor of 0.08 $mSvGy^{-1}cm^{-2}$ was applied to the KAP values to calculate effective dose for half value layer (HVL) up to 2.9 mm Al. For HVL of 3.5 mm Al, a conversion factor of 0.1 $mSvGy^{-1}cm^{-2}$ was used to calculate effective dose. The HVL values of the beam qualities used were determined using a quality assurance instrument (Mult-O-Meter 512, Unfors Instruments AB, Billdal, Sweden).

Statistics

Although numerical values were used to rate the overall image quality, they represent an ordinal scale and the ratings should be treated as ordinal data. The data were, therefore, evaluated using visual grading characteristics (VGC) analysis, which is a non-parametric rank-invariant statistical method for evaluating image quality.[33,34] In VGC analysis, ratings for two image types are used to create a VGC curve, similar to the receiver operating characteristics (ROC) analysis in which ratings for signal and no-signal images are used to create an ROC curve. The area under the VGC curve (AUC_{VGC}) ranges from 0–1 and is used as a measure of the difference in image quality between the two image types being compared. An AUC_{VGC} of 0.5 reflects similar image quality for the two image types, whereas an AUC_{VGC} above 0.5 indicates higher image quality for the assessed image type and an AUC_{VGC} under 0.5 indicates higher image quality for the reference image type. VGC analyses are based on ordinal data and, therefore, normally require absolute ratings, but, because the same image was used as a reference for the relative ratings, the given data can be treated as belonging to an ordinal scale. The standard-processed image used as reference during the evaluation of the GOP-processed images was used as reference also for the VGC analysis, meaning that the rating for this image was set to '3' for all observers. The statistical analysis was performed using the software VGC Analyzer (software developed in-house, University of Gothenburg). The software determines the VGC curve averaged over observers and a bootstrapping (re-sampling) technique is applied to determine the asymmetric 95% confidence interval of the AUC_{VGC}. A confidence interval not covering 0.5 was interpreted as a statistically significant difference in image quality between the assessed image and the reference image.[33,34] The statistical analysis of the AUC_{VGC} was based on the trapezoid VGC curve and the re-sampling was done on observers in order to take the reader variability into account in the determination of the confidence interval and for the results to be generalizable to the population of observers.

Results

The results of the VGC analysis are presented in Figure 3, in which the AUC_{VGC} for each image is plotted as a function of effective dose. Regarding image processing, irrespective of radiation quality, all GOP-processed images with similar (or higher) dose as the reference image resulted in higher image quality than the reference. Likewise, all GOP-processed images with similar image quality as the reference image were acquired at a lower dose than the reference. This indicates that the external image processing improved the image quality compared with the standard processing. Regarding acquisition parameters, no strong dependency of the image quality on the radiation quality was seen and the image quality was mainly affected by the dose. This indicates that the external image processing managed to compensate for differences in object contrast and that there is a weaker relationship between radiation quality and image contrast in digital radiography than in film-screen radiography.

Discussion

Optimization means that the radiation dose to the patient is kept as low as reasonably achievable without compromising the diagnostic quality. The present study showed that advanced external adaptive image processing could be used to increase the image quality of panoramic SPP images and that, by adjusting the acquisition parameters, image quality could be maintained with the help of GOP technology, making it possible to obtain a diagnostic image quality on parity with that of a standard image, while reducing the effective dose. The results of the present study give support to previous studies indicating that advanced external image processing—including for example techniques for multi-scale frequency contrast enhancement and noise reduction—may be beneficial in dental radiography.[28,29]

A number of studies have shown that it is possible to achieve dose reduction in digital panoramic radiography and still retain good image quality. Gijbels et al. [5] showed that the effective dose of a number of direct digital panoramic units could range from 4.7–14.9 μSv, with exposure settings of 64–74 kV/32–128 mAs. When a panoramic SPP system with exposure settings of 70 kV/60 mAs was used, an effective dose of 8.1 μSv was achieved.[5] In the present study the effective dose for an SPP standard panoramic exposure of 70 kV/150 mAs was 6.6 μSv and the results presented in Figure 3 indicate that it should be possible to reduce this dose by at least 20–30% and still maintain image quality by improved image processing. Dula et al. [2] showed that when using a CCD system, the dose was reduced by up to 43% when panoramic radiography was performed at 60 kV/16 mA rather than the standard setting 69 kV/15 mA; they concluded that it seems possible to reduce the dose rate of X-rays without losing diagnostic quality. Dannewitz et al. [3] showed that, although the quality of

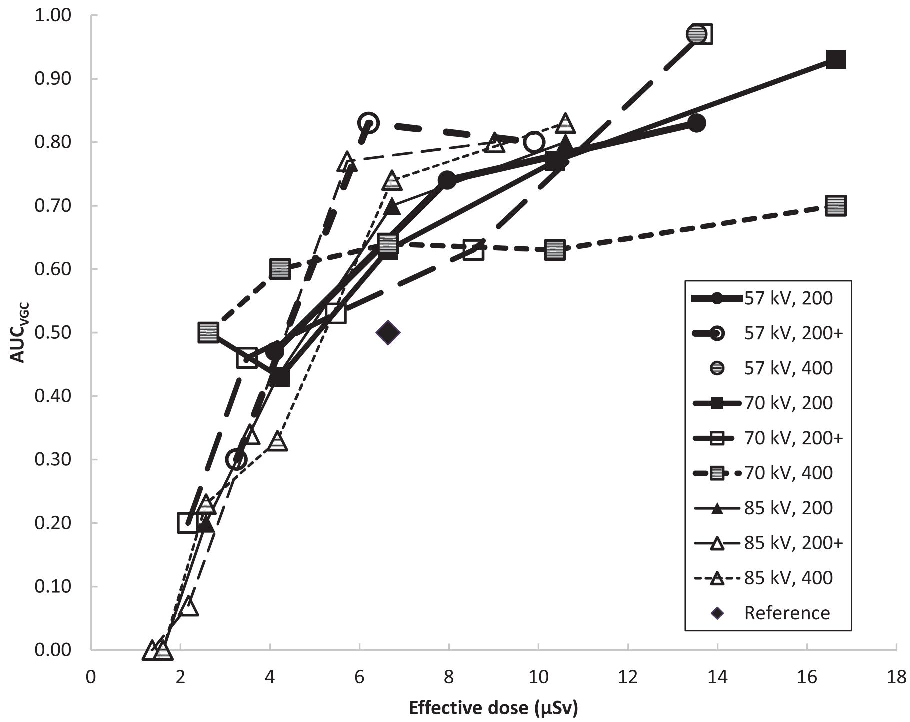


Figure 3. The AUC_{VGC} for each image plotted as a function of effective dose. Data points corresponding to images acquired with the same radiation quality and the same SPP reader setting are presented with the same type of symbol and joined by a line. The 95% CI of the AUC_{VGC} for each data point (not shown in the figure) covers ~0.3 AUC_{VGC} units.

images obtained with a CCD system at reduced mA was inferior, there was no difference in their diagnostic accuracy; these authors recommended that the tube current could be reduced by 50%. The opportunities to reduce the dose by optimization depends on the input values, but a large number of studies suggest that this type of examination is generally not optimized and that dose savings can often be made. It should be noted that all the dose values above, including those of the present study, are based on conversion factors determined before the publication of the revised tissue-weighting factors by ICRP in 2007.[10] As previously mentioned, the revision has led to an increase in the estimated effective dose in panoramic radiography. This makes the topic of the present paper of even higher relevance.

Two studies have concluded that dose reduction depends on the type of panoramic equipment used and also on the programme setting.[35] A set-up programme designed for children gave lower absorbed doses during panoramic radiography, regardless of the equipment and the receptor.[36] The Scanora panoramic unit used in the present study has two panoramic programmes: a jaw programme and a dental programme. The dental programme is recommended for children and was used in the present study because it limits the area exposed to radiation.[37] A statistically significant difference has been shown between the dental programme and the jaw programme in absorbed dose to the thyroid gland.[38]

As reported in a previous study, GOPView technology was implemented in an X-ray department in Sweden in order to harmonize digital images from different vendors.[24] It was observed that the same type of examination might show different appearances in images from different modalities and vendors. This was noted especially for panoramic images, where the quality was markedly different when sent from one PACS (Picture Archiving Communication System) to another. It could be an advantage if all images were harmonized so that a similar appearance of all panoramic radiographs from different vendors were obtained, meaning that all healthcare providers and insurers in the community area could utilize the stored images in the best way. This could be accomplished by using image-processing techniques such as the GOP technology that is performed automatically when images are sent to the workstation through a digital filter.

A limitation of the present study is that it is based on a single anthropomorphic phantom. The study, therefore, does not take into account the variation in image quality caused by anatomical differences in, e.g., tooth and bone morphology. Although the use of a standardized phantom has advantages related to the possibility of comparing results between different studies, the clinical validity of the study could be increased by instead including a large number of mandibles or large number of patients. However, as the present study investigated a large number of exposure setting combinations, it was not deemed possible or justifiable to test all these combinations on humans. An additional limitation of the study is that only one image per combination was included. Including multiple images per combination would have increased the precision of the achieved results. However, as the purpose of the study was mainly to investigate the potential of advanced external adaptive image processing for optimization of panoramic SPP images and not to focus on specific exposure setting combinations, it was judged that the use of single images per combination would be acceptable. Also, as a major source of variability in observer performance studies is often the human observers,[39,40] the use of a large number of observers—as in the present study—improves the precision of the results. A third limitation is that, in the statistical analysis, no correction for multiple tests was applied. Simply by chance, in one of every 20 tests the 95% confidence interval would indicate a significant difference, even if the null hypothesis were true. Furthermore, as the rating '3' was given to the reference image, the actual variability for this image type was neglected, in turn leading to an under-estimation of the size of the confidence interval. Combined, these two effects may have led to an increased risk of Type I errors. However, as can be seen in Figure 3, even if the results of single tests can be questioned, the general result that the GOP processing resulted in an improved image quality and that it using this technology would be possible to maintain the image quality while decreasing the dose below the clinically used dose of 6.6 μSv is clear.

In conclusion, the present study indicates that advanced external adaptive image processing may be beneficial in panoramic radiography for increasing the image quality of SPP radiographs or for reducing the dose while maintaining image quality.

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Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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