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ORIGINAL ARTICLE

A comparison of perceived diagnostic image quality in direct digital panoramic images between standard and advanced external GOP image processing

Björn Svenson[a,b], Magnus Båth[c,d], Reet Karlsson[e] and Bo Persson[e]

[a]Department of Dental Research, Postgraduate Dental Education Center, Örebro, Sweden; [b]School of Health and Medical Sciences, Örebro University, Örebro, Sweden; [c]Department of Medical Physics and Biomedical Engineering, Sahlgrenska University Hospital, Gothenburg, Sweden; [d]Department of Radiation Physics, Institute of Clinical Sciences at Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden; [e]Department of Radiology, Skaraborg Hospital Skövde, Skövde, Sweden

ABSTRACT
Objective: The objective of the present study was to study the effect of adaptive image processing (GOP processing) on the visibility of anatomical structures in direct digital panoramic images.
Material and methods: The study comprised panoramic images of 50 consecutive adult individuals aged 18–60 years. Nine dentists working with dental radiology compared the structural image quality of all standard-processed and GOP-processed panoramic images for six anatomical structures, using a six-point scale for visual grading characteristics analysis.
Results: For all anatomic structures a statistically significant difference in favour of the GOP was found.
Conclusions: The present study shows that it is possible to improve perceived diagnostic image quality of direct digital panoramic radiography using GOP technology compared to the manufacturers' standard processing. Manufacturers' image-processing programs can be further developed, as there is a possibility of improving the perceived diagnostic content of an image with external processing.

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Introduction

Direct digital technology for intraoral radiography was introduced in the late 1980s (RadioVisioGraphy®, Trophy, Vincennes, France) [1], while direct digital imaging systems for panoramic radiography were not available until the last decade [2]. Over the past three decades, there has been a significant increase in the number of panoramic units in Sweden [3]. Digital panorama technology has been developed over the past 10 years and can be obtained with either indirect digital technology or direct digital technology. The direct digital panorama technology has rapidly become the most widely used technique for panorama X-ray images in Sweden [3]. Direct digital panoramic imaging systems are widespread because of benefits such as low radiation dose, compared with conventional technology, and also advantages, such as image enhancement [4–8], for improving diagnostic quality.

In dental radiology, good diagnostic image quality is required to depict normal anatomy and pathological changes, which means that optimization of the images is required to obtain the necessary diagnostic information, but not the best image possible [9]. The quality of a panoramic image is determined not only by equipment settings and patient positioning but also by technical factors such as contrast, density and resolution. One goal of image optimization is to adjust the radiographic technique to improve image quality. To achieve this, different types of filters have been recommended [2,10].

Factors such as digital contrast enhancement and filtering may increase the diagnostic accuracy [11–13], and digital post-processing using filters turned out to significantly improve diagnostic image quality [7]. However, not all studies have shown that different types of filters had a significant effect on the image quality of a direct digital panoramic system [14,15]. It has been claimed that adjustment of image contrast and density of the post-processing technique can improve the image quality [7,16], while in other studies the opposite could be observed, that is, deterioration of accuracy through digital image enhancement of direct digital-acquired X-rays [17].

General operator processor (GOP) technology (ContextVision AB, Stockholm, Sweden) has three decades of use in medical imaging and is a versatile imaging technology – a type of advanced external image processing unique in detecting structures by examining the significance of each pixel in an image in relation to the wider context in which they appear [18]. In this way, once the structure is identified and analyzed, noise can be suppressed, and the true structure – however weak – can be emphasized and seen more clearly [18]. GOP technology can be of benefit in direct digital panoramic technique, but as far as the authors know,

CONTACT Björn Svenson bjrn.sv@icloud.com Department of Dental Research, Postgraduate Dental Education Center, P.O. Box 1126, 701 11 Örebro, Sweden

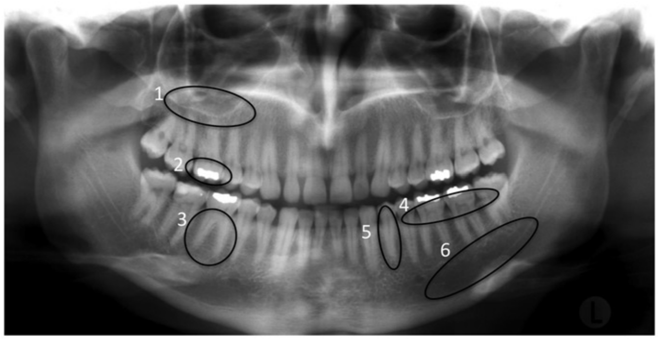

Figure 1. The six anatomical structures used in the study are displayed in the image. 1 = floor of maxillary sinus (FMS) right side; 2 = dentino-enamel junction (DEJ) of tooth 16; 3 = periodontal ligament space (PDL) of tooth 46; 4 = crista alveolaris (CRA) of the mandibular left molar area; 5 = root canal space (RCS) of tooth 34; and 6 = mandibular canal (MAC) left side [19].

there is a limited number of studies where the technique has been used [19,20].

Objective

The main objective of the study was to investigate whether the perceived diagnostic image quality of the direct digital dental panorama can be improved using advanced external image processing.

Materials and methods

The study was approved by the Regional Ethical Review Board in Göteborg, Sweden (Dnr 211-16). All persons involved in the study were informed of the purpose of the study both verbally and in writing. Written consent was obtained from all persons.

Design and data collection

The study is a prospective study of image quality in digital panoramic radiography. Eligible for inclusion were individuals aged 18–60 years who required a panoramic X-ray for diagnostic purposes. Fifty consecutive patients at the radiology department in Skaraborgs Hospital, Skövde, Sweden who fulfilled these criteria were asked to participate in the study. Examination of the visibility of a number of anatomical structures and projection errors was done.

X-ray equipment

All digital panoramic images were exposed by experienced radiology nurses at the radiology department of Skaraborgs Hospital, Skövde, Sweden with a Scanora multimodal direct-digital X-ray device (Scanora, Soredex, Orion Cos., Helsinki, Finland). Exposure parameters were those commonly used in panoramic surveys, depending on the patient's size, 65–75 kV, 5 or 6 mA and 15 s.

Processing

The exposed panoramic X-ray images included in the study were collected after exposure as 'raw' and processed using both the manufacturer's standard processing technology (Scanora, Soredex, Orion Cos., Helsinki, Finland) and GOP technology (ContextVision AB, Stockholm, Sweden) [18]. Each exposed panoramic radiograph thus gave rise to both a standard-processed image and secondly, a GOP-processed image. The images were stored in the Sectra PACS database (Sectra Medical Systems AB, Linköping, Sweden) for viewing. The standard-processed images were compared with the GOP-processed images with respect to a number of anatomical structures. Since the images were anonymized and without overlays, it was not possible to determine whether the image was a standard-processed image or a GOP-processed image.

Assessment of anatomical structures

Figure 1 shows the six anatomical structures used, where 1 = floor of maxillary sinus (FMS) right side, 2 = dentino-enamel junction (DEJ) of tooth 16, 3 = periodontal ligament space (PDL) of tooth 46, 4 = crista alveolaris (CRA) of the mandibular left molar area, 5 = root canal space (RCS) of tooth 34, 6 = mandibular canal (MAC) left side [19]. If the teeth to be evaluated were missing, the second molar or second premolar of the same quadrant was evaluated instead. The anatomical structures were chosen based on their image properties, which provide contrast, noise and unsharp details [19].

Observers

Nine dentists, all with experience of digital panoramic radiography and working in four different radiology departments, were asked to assess the image quality of the images. In the assessment of the standard-processed and the GOP-processed images the observers were asked to give their opinions about the visibility of the six anatomical structures, using an absolute six-point rating scale, where 1 = structures extremely difficult to visualize, 2 = structures difficult to visualize, 3 = structures relatively difficult to visualize, 4 = structures relatively easy to visualize, 5 = structures easy to visualize and 6 = structures extremely easy to visualize. The observers were given written and verbal instructions on how to perform the viewing and the evaluation of the panoramic radiographs and also how the assessment of the six structures in each image would be made. During the evaluation, the observers were allowed to adjust the window width and window level to simulate a real clinical situation [19]. Viewing of the radiographs took place in a dimmed room. The evaluations were performed on a DICOM-calibrated external monitor. The observers examined all the radiographs using ViewDEX 2.0, a Java-based DICOM-compatible software program for observer performance studies [21,22]. The images were displayed in a unique randomized order for each observer.

Table 1. Area under the visual grading characteristics (VGC) curve (AUC_{VGC}), *p* value, and confidence interval of the AUC_{VGC} for the six anatomical structures for the comparison between the GOP processed images and the standard processed images.

Anatomical structure	AUC_{VGC} (SD)	*p* Value	95% Confidence interval
FMS: floor of maxillary sinus right side	0.60 (0.02)	.000	0.55–0.64
DEJ: dentino-enamel junction of the maxillary right second molar	0.57 (0.02)	.000	0.53–0.62
PDL: periodontal ligament space of the mandibular right first molar	0.61 (0.03)	.000	0.55–0.67
CRA: crista alveolaris of the mandibular left premolar area	0.57 (0.03)	.002	0.52–0.62
RCS: root canal space of the mandibular left first premolar	0.59 (0.02)	.000	0.55–0.63
MAC: mandibular canal left side	0.62 (0.03)	.000	0.57–0.67

The analysis is based on the trapezoid VGC curve and a random-reader analysis was used. SD: Standard deviation in parentheses.

Data processing and statistics

Description of the data processing and analysis can be found in Svenson et al. [19]. The data were evaluated using visual grading characteristics (VGC) analysis, which is a non-parametric rank-invariant statistical method for evaluating image quality [23,24]. 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 a ROC curve. The area under the VGC curve (AUC_{VGC}) ranges from 0 to 1 and is used as a measure of the difference in image quality between the two image types being compared. In the case of VGC analysis, if AUC <0.5, the reference method, in this case, standard processing is the best, and if AUC >0.5, the test method, in this case, GOP processing is the best, whereas if the AUC is not significantly different from 0.5, one cannot indicate any difference between the methods. The statistical analysis was performed using the software VGC Analyzer [25,26]. The software determines the VGC curve averaged over observers, and a bootstrapping (resampling) technique is applied to determine the asymmetric 95% confidence interval of the AUC_{VGC}. A confidence interval not covering 0.5 is interpreted as a statistically significant difference in image quality between the reference method and the test method [23,24]. The statistical analysis of the AUC_{VGC} was based on the trapezoid VGC curve, and a random-reader approach was used to allow a generalization of the results to the population of readers. A paired-data analysis was made to take the correlation between the pairs of images into account. Additionally, VGC Analyzer returns the *p* value for the null hypothesis that the two compared methods are equal (AUC_{VGC}=0.5). To investigate whether there is a difference between the two rotations of the head to the left or to the right, a mixed model was used with examiner as the random effect and image as fixed effect [27]. *p* values $<.05$ were considered statistically significant.

Results

Detectability of anatomical structures

In Table 1, the results are shown for the evaluation of the six anatomical structures for the comparison between GOP processing and standard processing. A statistically significant difference in favour of the GOP is demonstrated for all six anatomical structures. The area under the curve AUC_{VGC} varied from 0.57 to 0.62. Binormal VGC curves for the six anatomical structures are presented in Figure 2.

Discussion

Compared to intraoral X-rays, the panoramic image depicts not only the teeth but also the surrounding structures in the maxilla and the mandible, and is one of the most widely used radiological modalities in dentistry, to obtain a comprehensive survey of the maxillofacial complex [28]. Interpreting anatomical structures in the panoramic image is demanding because of the complex anatomy and the overlay of various anatomical structures, and also because of the many potential artifacts [29]. In the present study, different anatomical structures were selected to represent both simple and more difficult structures for evaluation of image quality in order to detect differences between standard- and GOP-processed images in panoramic CCD radiographs. The anatomical structures used in this study were adapted from criteria from a previous study [19].

In the present study, internal standard-processed direct digital panoramic images were compared to GOP-processed images obtained from the same direct digital panoramic device, regarding visibility of anatomical structures. All the selected structures benefited from GOP processing, as a statistically significant difference in the AUC_{VGC} between the standard- and the GOP-processed images were noted in favour of the GOP-processed images for all anatomical structures RCS, MAC, PDL, FMS, DEJ and CRA. A previous study showed that when the GOP technology was applied to panoramic digital SPP radiographs, an increased visibility of low-contrast structures was obtained compared with standard post-processed radiographs [19]. The difference between this study and the previous study on post-processed SPP radiographs is that the GOP technology was applied on the 'zero' processed CCD images, while the SPP images were post-processed.

Visibility of anatomical structures

Diagnostics in dental care often involves small objects such as the root tip or root canal to a tooth as well as minor changes such as broadening of the periodontal space or a radiopaque structure in the spongy bone indicating the mandibular canal [6]. Different anatomical structures were chosen for the evaluation of image quality in order to detect differences in visibility between the standard-processed and the GOP-processed images. The chosen structures represent anatomical details, some of which are usually easy and others more difficult to perceive in panoramic radiographs [30]. Image enhancement of the object-specific spatial frequencies can optimize the visual diagnostic evaluation [6]. In this

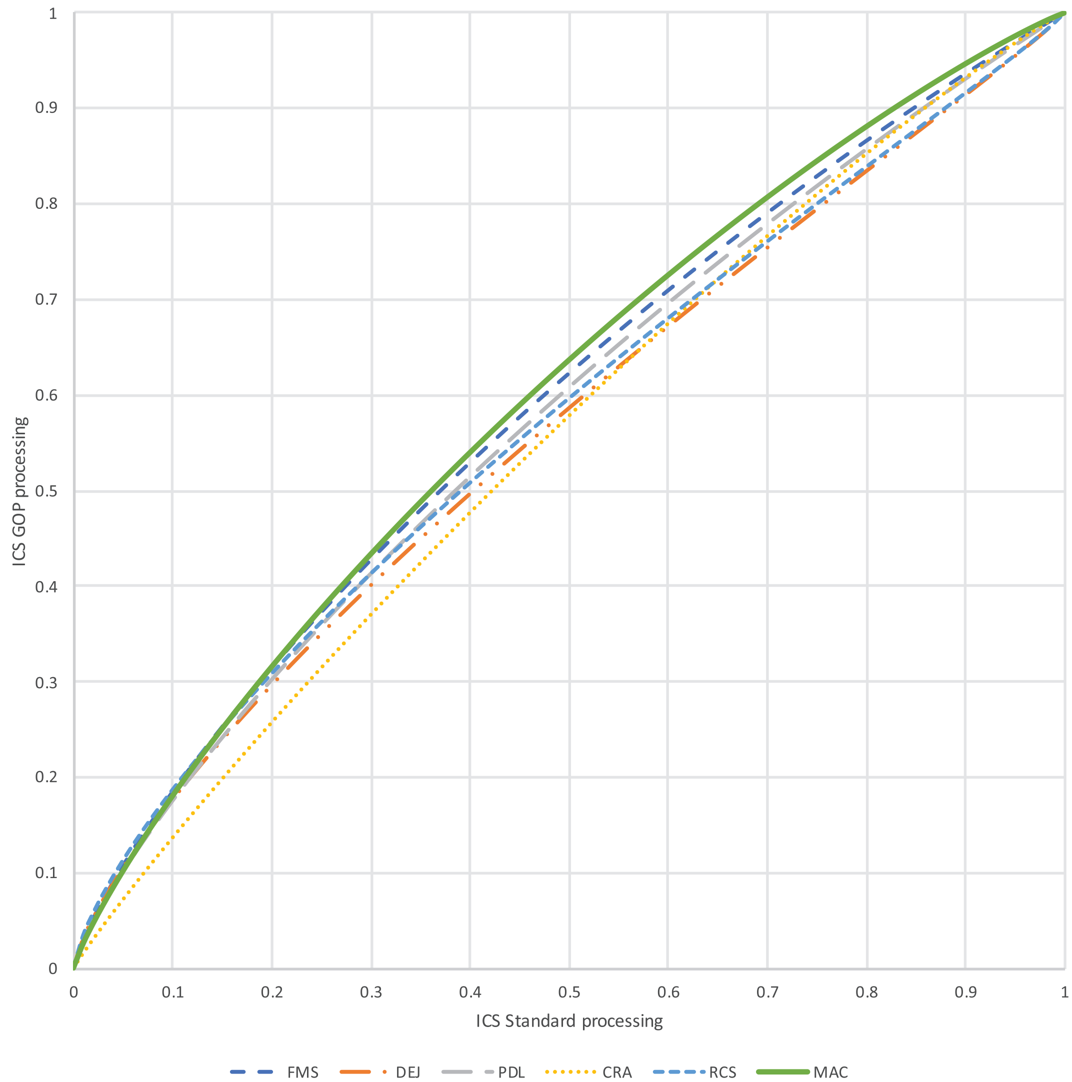

Figure 2. The binormal VGC curves are displayed for the six anatomical structures. FMS: floor of maxillary sinus right side; DEJ: dentino-enamel junction of the maxillary right first molar; PDL: periodontal ligament space of the mandibular right first molar; CRA: crista alveolaris of the mandibular left molar area; RCS: root canal space of the mandibular left first premolar; MAC: mandibular canal left side.

study, we used both high and low contrast structures to study the effect of adaptive image processing on CCD images where these were taken as raw images prior to the software's inherent processing with GOP technology. This resulted in all the structures chosen for inclusion being positively affected with better visibility due to adaptive processing, compared to the standard application process.

It should be emphasized that this study consisted of 50 panoramic images all taken on patients referred for panorama X-ray examination as part of treatment planning. The selected images were not selected to have excellent image quality, which in this study means that they were as good as other images in a clinical material affected by defects.

Image quality

In X-ray diagnostics, the goal is to optimize the radiographic examination to optimize the diagnosis of pathological changes. Optimization of an examination means that the requested diagnostic information is obtained with a radiation dose as low as diagnostically acceptable (ALADA) [31]. The dose is linked to image quality and the image quality must not be lowered so far as to compromise the diagnostic result of a radiographic procedure [9]. For the assessment of the quality of clinical radiographic images, guidelines have been established by the European Commission (EC), and diagnostic requirements against which the observer can assess an image are stated [32]; these requirements include the reproduction of anatomical structures for a normal individual.

Image quality can be quantified with respect to the properties contrast, sharpness and noise. *Contrast* is a result of the various attenuations of X-rays in tissue; *sharpness* is the capability to display small details and *noise* refers to the random fluctuations across the image that may affect the detection of low-contrast structures [33]. In the present study, visualization of diagnostically important structures was used as a measure of image quality and for that reason six anatomical structures – FMS, DEJ, CRA, RCS, MAC and PDL – were chosen, providing contrast, noise and unsharp details in order to detect differences between standard-processed and GOP-processed images [19]. The anatomical structures FMS, DEJ and CRA were considered as high-contrast objects, while the RCS, MAC and PDL were considered as low-contrast objects, as they consist of soft tissue surrounded by hard tissue.

However, one can discuss the choice of structures and their observability with regard to the three structures that were positively affected by GOP technology. DEJ, FMS and CRA contain high-contrast details. FMS and CRA consist of a distinctly radiopaque structure, which can be easily identified, while DEJ is the dentino-enamel junction, which appears radiopaque on radiographs and is generally regarded as a high-contrast anatomical structure [19,34]. The perception of the dentino-enamel junction can be significantly affected by the density of the surrounding shadows, and the contrast between adjacent structures can change the perceived density [35]. It has been suggested that the contrast between enamel and dentin DEJ is lower than the contrast between the root canal and dentin RCS, which has been previously considered to be harder than the former. For this reason, DEJ was considered neither a low- nor a high-contrast object, as proposed by Baksi et al. [2]. The GOP technology handles many different parts, such as edge enhancement, contrast equalization, noise and so forth.

GOP technology

GOP technology detects structures by examining the significance of each pixel in an image relative to the broader context in which it appears. Once the structure has been identified and analyzed, noise can be suppressed, and the true structure can be emphasized and seen more clearly. GOP image enhancement reduces noise and artifacts; enhances edges and lines to display more clearly defined structures; enhances image contrast, making vague structures strong and provides latitude compression so that structures in both dense and translucent areas are visible simultaneously [18]. The GOPView® XR2Plus [36] is developed as a general product for a wide variety of X-ray applications and is not specialized for panoramic images, and therefore, does not treat the periphery in any particular way. Since the technology is adaptive and adapts to the signal locally, there are no reasons why the periphery would give rise to problems that would require specialization (personal information from ContextVision AB). Sophisticated adaptive algorithms analyze every pixel to optimize the contextual enhancement. Intelligent noise suppression with simultaneous edge and contrast enhancement enables greater visibility of subtle structures. Advanced grayscale optimization gives optimal visualization of dense and soft tissue and overlapping structures [36].

Digital manipulations

In many digital imaging programs, there is often an opportunity for digital manipulation of radiographic images using enhancement tools that can increase the accuracy of the radiographic diagnosis [6,13,37]. On the other hand, the choice of the correct procedure can be time-consuming. Therefore, the use and management of an enhancement program must be easy to handle, as a large set of tools would not necessarily result in a useful application [38]. It should also be emphasized that there is a risk involved in digital manipulations of images, as the image quality may be impaired or artefacts even being produced if care is not taken. Digital manipulations of images should therefore always be performed with caution.

Limitations

The major limitation of the present study is that, it is based on subjective opinions of observers on the visibility of anatomical structures. Although this study design ('visual grading') is often used and widely interpreted as providing meaningful information about the clinical image quality, it cannot be neglected that the actual diagnostic image quality (e.g. the possibility of detecting pathology using the images) has not been investigated. In the present work, the term 'perceived diagnostic image quality' is used to emphasize that the results are based on the subjective opinions of the observers. Furthermore, although the AUC_{VGC} indicated a statistically significant increase in visibility of all structures in the GOP-processed images, the increase was relatively small. It is therefore difficult to state whether the improved visibility would affect the clinical outcome (the treatment decision). Thus, further research is needed before it can be concluded the GOP image processing improves diagnostic image quality.

Conclusion

The present study shows that it is possible to improve perceived diagnostic image quality of direct digital panoramic radiography using GOP technology compared to the manufacturers' standard processing. Manufacturers' image-processing programs can be further developed, as there is a possibility of improving the perceived diagnostic content of an image with external processing.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability

Raw data and complete patient documentation are available from the author Reet Karlsson upon request and with patient consent, but are not provided publicly due to consideration of medical confidentiality, GDPR.

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