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ORIGINAL ARTICLE

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Subjective image quality of digital panoramic radiographs displayed on monitor and printed on various hardcopy media

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Abstract The subjective image quality of panoramic radiographs shown on a diagnostic computer monitor were compared with professional direct thermal prints and with common inkjet prints on different paper qualities. Indirect digital panoramic radiographs were obtained from 15 patients. The images were printed with a direct thermal printer in their original format. Afterwards, these were loaded in an imaging software programme (Microsoft Photo Editor) and assessed both on computer monitor and inkjet prints on transparency, glossy, satin and regular paper. Five observers assessed subjective image quality for different regions and anatomical landmarks on a 5-point rating scale. Data were statistically analysed and inter- and intra-observer performances were calculated. Best image quality was obtained with direct thermal prints, followed in descending order by panoramic images viewed on the monitor, inkjet prints on transparencies, glossy paper, satin paper and finally regular paper. The differences were significant except for monitor images versus direct thermal prints, inkjet-transparencies and inkjet-glossy images and inkjet-satin versus inkjet-glossy images. The subjective image quality of indirect digital panoramic images is different for images shown on the computer monitor and for printed images depending on both the printer and paper type used.

Keywords Digital radiography · Dental · Printing

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Introduction

Digital radiographic imaging offers the possibility to capture radiation energy and translate it into electronic signals. The radiographic image appears on a computer monitor on which it can be interpreted, adjusted for contrast and brightness or stored using dedicated software programmes. If images have to be printed, such as for referral to a colleague or when the computer monitor is not in the immediate vicinity of the patient, printing can be performed by different devices, ranging from common inkjet to sophisticated medical printers. Furthermore, different paper qualities are available: translucent and opaque in different degrees of gloss. A number of studies have addressed diagnostic image quality of radiographs shown on computer monitor and printed radiographs. Sanderink et al. [11] investigated thermal video prints and paper laser prints for intraoral radiographs and paper laser prints for panoramic radiographs. They found that the diagnostic image quality of the intraoral radiographs for determining endodontic file length was not significantly different for monitor images and thermal print images. Laser print images, however, performed significantly worse, both for intraoral and panoramic images. Nishikawa et al. [10] compared image quality of thermal and dye sublimation prints using a number of test objects and reported a better performance of direct thermal printing for optical density, gradient value and granularity. Direct thermal printing yielded comparable results as Cathode Ray Tube (CRT) display for depiction ability and seemed therefore suitable for printing radiographic images. Guerrant et al. [4]investigated subjective image quality of digital panoramic radiographs presented on a computer monitor and as thermal prints. Although both modalities had an acceptable diagnostic image quality, images shown on the computer monitor were more often subjectively scored as being of better quality. In medical radiology, Lyttkens et al. [8] evaluated the image quality of digital chest radiographs printed with an inkjet printer (printed on mat coated paper) and a laser film printer. They found no significant difference between these printing modalities and suggested, therefore, further studies on the low-cost inkjet printing for radiological purposes.

Most studies on image viewing, however, have compared the performance of digital/digitized radiographs displayed on a computer monitor with analogue radiographs rather than with digital printed images. In a study by Ludlow and Abreu [7], analogue intraoral radiographs were digitized and shown on a desktop and laptop monitor and evaluated for caries diagnostic quality. They found a tendency towards better diagnostic performance for digital displays, although the difference was not significant. In medical radiology, high-resolution laser prints on plain paper of CT scans and radiation therapy simulation radiographs were rated acceptable for documentation in more than 90% of cases in a study by Ibbott et al. [5]. So far, no studies have been performed on the impact of paper type on the subjective image quality in oral radiography.

In the present study, a comparison was made between the subjective image quality of panoramic radiographs printed with direct thermal technology, shown on a computer monitor, and printed with an inkjet printer on regular mat paper, glossy paper, satin paper and transparencies.

Material and methods

Panoramic radiographs were obtained from 15 consecutive patients who consulted for different reasons. The images were taken as part of their treatment at one of the departments of the School for Dentistry, Oral Pathology and Maxillofacial Surgery of the Catholic University Leuven. The mean age of the patient sample was 31 years (range 13–54 years) and there were eight female and seven male patients. The average number of teeth present was 29 (range 26–32), with a minimum of six teeth per quadrant. All radiographs were taken with the Cranex Tome multimodal radiation unit (Soredex, Helsinki, Finland) by the same operator. Storage phosphor plates (ADCC MD, Agfa, Mortsel, Belgium) were used, which were scanned by the ADC Solo system (Agfa, Mortsel, Belgium) and stored in a Sun Ultra 10 Workstation (Sun Microsystems, Palo Alto, CA, USA) with standard image processing (Musicontrast 3, MUSICA, Agfa). Afterwards, these were printed with the Drystar 2000 printer (Agfa) *("modality A")*. The Drystar 2000 produces grey-scale images of 300 dots per inch (dpi) and 1024 shades of grey. The images are printed by means of "Direct Thermal" technology on blue transparent silver-based temperature-sensitive film (TM1B, Agfa, Mortsel, Belgium). After being converted to TIFF (Tagged Image File Format) files, the images were stored in a Pentium personal computer (Optiplex Gxi, Dell, TX, USA). They were viewed using Microsoft Photo Editor software (Microsoft, Redmond, WA, USA) on a 17-inch colour monitor (D825HT, Dell, Texas, USA) with a resolution of 1024×768 pixels and true colour (24 bit) *("modality B")*. Furthermore, they were printed with an inkjet printer (Deskjet 1120C, Hewlett-Packard, Palo Alto, CA, USA). Printing properties were set at "colour images" and "best image quality", which produces colour images of 600 dpi. The colour prints from this inkjet printer are based on the PhotoREt III (Hewlett-Packard) technology, which allows 3,500 colours per dot through a combination of 29 fine ink drops of four possible colours per dot. The Deskjet 1120C images were printed on regular matt paper (Ever Rey, Aussedat Rey, France) *("modality C1")*, glossy paper (Rey Print gloss, Aussedat Rey, France) *("modality C2")*, satin paper (R de Rey satin, Aussedat Rey, France) *("modality C3")* and transparencies (Kodak Premium Transparency Film, Eastman Kodak, Rochester, USA) *("modality C4")*.

A panel of five observers independently assessed the panoramic images. They were oral radiologists (two), final year dental students (two) and a periodontologist. General image quality, subjective image quality for possible caries, periapical pathology and periodontal marginal bone loss, visibility of the mandibular canal, condyles and anterior nasal spine had to be evaluated on a five-point scale, ranging from 1, "certainly impossible to evaluate" to 5, "certainly possible to evaluate". For caries, periodontal and periapical image quality assessment, the lower incisor and upper premolar regions were evaluated. Whenever a score of 3 or less was given, the reason for poor image quality had to be stated (unsharpness, overlap, low contrast, distortion, low density, high density). The different series of images were shown in random order. There was an interval of at least 3 days between readings of different series. Transparent images were assessed on a masked viewing box with light conditions comparable to a dental practice. Also the images shown on the monitor were viewed in normal conditions. Contrast and brightness of the monitor was standardised using a test screen (SMPTE, Society of Motion Picture and Television Engineers, NY, USA). One of the observers performed all readings twice with an interval of 4 weeks in order to assess intraobserver variability.

Non-parametric statistical analysis was performed using Statistica version 5 (StatSoft, Tulsa, USA). After dichotomising the results, logistic regression was carried out, with "observer", "region" and "monitor/hardcopy medium" as independent variables and "score" as dependent variable. Spearman rank analysis and Wilcoxon Matched Pairs analysis were carried out afterwards to analyse the effects of the different independent variables. The weighted kappa test was used to determine intraobserver variability.

Results

Logistic regression analysis was statistically significant. Spearman rank order correlation revealed significant differences between the modalities. Panoramic images printed with direct thermal printing (modality A) had the highest subjective image quality. These were followed by (in descending order) images shown on the monitor (modality B), inkjet images printed on transparencies (modality C4), inkjet images on glossy paper (modality C2), inkjet images on satin paper (modality C3) and inkjet images on regular mat paper (modality C1) (Fig. 1).

Wilcoxon Matched Pairs analysis showed, after Bonferroni correction for repeated testing, significant differences between modalities A and C4, C2, C3 and C1, between C4 and C1, between C2 and C1 and between C3 and C1. The difference between modality B and C1 was also statistically significant. Differences between modality B on the one hand and modality A, C4, C3 or C2 on the other hand were not statistically significant after Bonferroni correction. The difference between C3 and C2

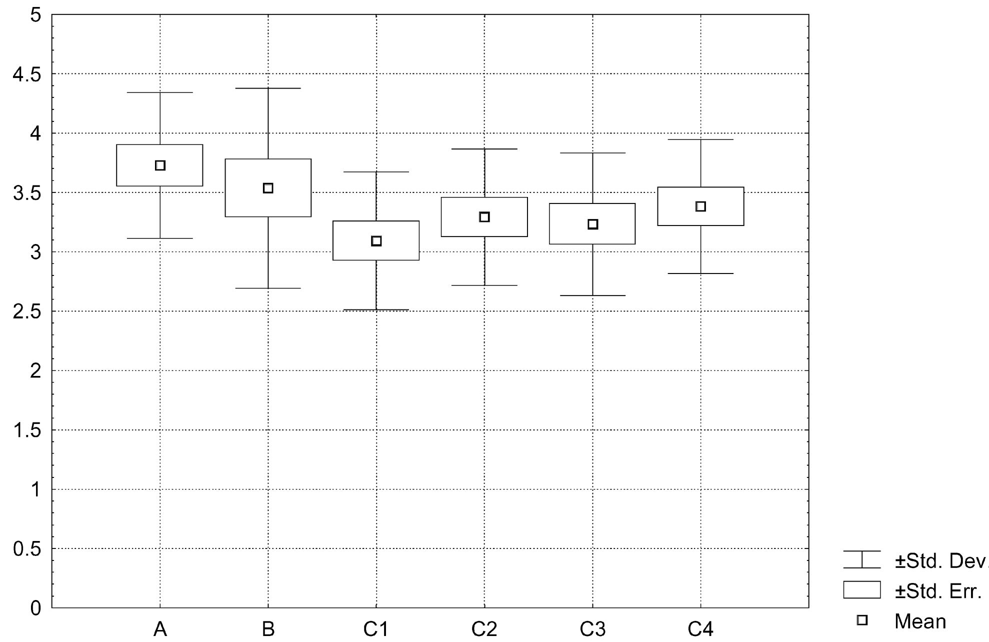

Fig. 1 The subjective image quality for the different viewing modalities is represented by the mean value for the different observers and anatomical regions. Standard error and standard deviation are represented by the *box* and *whiskers*. The scores range between 1 (certainly impossible to assess) and 5 (certainly possible to assess). *A* direct thermal printing, *B* monitor images, *C1* inkjet prints on mat paper, *C2* inkjet prints on glossy paper, *C3* inkjet prints on satin paper, *C4* inkjet prints on transparencies

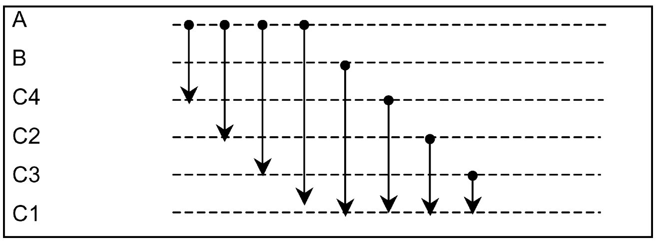

Fig. 2 A comparison of the subjective image quality for the different printing modalities and monitor images. The different modalities are ranked in descending order. Significant difference after Bonferroni correction ($p<0.003$). *A* direct thermal printing, *B* monitor images, *C1* inkjet prints on mat paper, *C2* inkjet prints on glossy paper, *C3* inkjet prints on satin paper, *C4* inkjet prints on transparencies

or C4 was also not statistically significant, nor was the difference between C4 and C2 (Fig. 2). The interobserver variability was also statistically significant. Weighted kappa for intraobserver variability was 0.83, indicating good agreement.

Also, for the various regions observed, subjective image quality ratings were statistically significantly different. However, imaging modalities followed the same trend for the various regions (Fig. 3). Lowest scores were given for the caries, periapical and periodontal subjective image quality in the premolar region in the upper jaw. Percentages of reasons for poor image quality (score of 3 or less) are shown in Table 1.

Discussion

From the results obtained in the current study, it was shown that modality A (direct thermal printing), a relatively expensive technique based on writing onto a heat-sensitive film, produced the best subjective image quality. Inkjet printing (modalities C1 to C4), a probably more affordable technique, yielded an overall lower subjective image quality. This difference appeared to be rather significant, as acceptable image quality was reached for the periapical premolar region of the upper jaw when modality A (direct thermal printing) was used,

Table 1 Reasons for poor image quality, expressed in % of the total number of reasons given. The total number of reasons per region is indicated by *n*

	C PM UJ	C I LJ	Pd PM UJ	Pd I LJ	Pa PM UJ	Pa I LJ	CM*	Co*	Sp
n	*111*	*106*	*117*	*55*	*104*	*67*	*50.5*	*27*	*38*
Unsharpness	22	24	26	44	46	49	35.5	15	29
Overlap	61	38	47	14	9	7	11	50	0
Low contrast	9	16	23	33	28	27	45.5	0	10.5
Distortion	0	1	1	2	0	3	0	0	0
Low density	0	12	0	2	2	0	0	0	0
High density	8	8	3	5	15	13	8	34.5	60.5

C caries, *Pd* periodontal, *Pa* periapical, *PM* premolars, *I* incisors, *UJ* maxilla, *LJ* mandible, *CM* mandibular canal, *Co* condyle, *Sp* anterior nasal spine
* average values for left and right sides

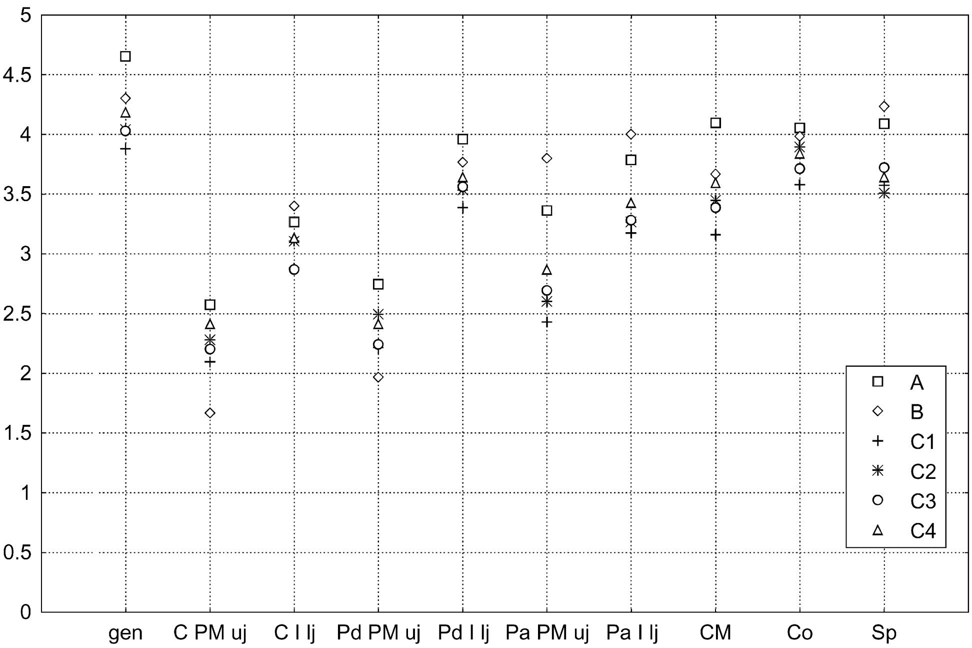

Fig. 3 Subjective image quality for monitor and different printer and paper types. For the general image quality (*gen*) and different anatomical regions, scores range between 1 (certainly impossible to assess) and 5 (certainly possible to assess). *A* direct thermal printing, *B* monitor images, *C1* inkjet prints on mat paper, *C2* inkjet prints on glossy paper, *C3* inkjet prints on satin paper, *C4* inkjet prints on transparencies, *gen* general, *C* caries, *Pd* periodontal, *Pa* periapical, *PM* premolars, *I* incisors, *uj* maxilla, *lj* mandible, *CM* mandibular canal, *Co* condyle, *Sp* anterior nasal spine. Data for CM and Co are average values for left and right sides

while modality C (inkjet printing) resulted in unacceptable subjective image quality for the same region. Within modality C, statistical differences could be observed between different paper types. C2 (glossy paper) and C4 (transparencies) appeared to yield better results than other paper types.

It might seem surprising that panoramic images shown on the computer monitor (modality B) were not scored higher than direct thermal prints. This can probably be explained by the fact that the original image format (OFL, Agfa, Belgium) was translated into TIFF and loaded in an image manipulation software not tuned to radiographic diagnosis. The reason for this transformation was to obtain images that were comparable to the ones used in dental imaging software. The original OFL image format is only used in an advanced medical software environment (MUSICA, Agfa, Belgium) and is therefore not representative for common “dental office” applications. Furthermore, the images were viewed on a regular 17-inch CRT monitor instead of on a medical diagnostic grey-scale monitor. For the inkjet prints (modalities C), the “colour images” setting was chosen because, according to a prior pilot study, this yielded a superior image quality compared with grey-scale prints. A possible explanation could be the wider variation of grey values that can be achieved by using different combinations of colours.

Although differences were observed, it should be stressed that, when looking at the average image quality for different observers and regions (Fig. 1), all viewing conditions had a score of more than 3, being “evaluation certainly or probably possible”. The high scores for general image quality might partly explain this. The lower scores for individual diagnostic tasks might—hypothetically—be explained by the virtual comparison by the observers to higher resolution intraoral radiographs. It should, therefore, be kept in mind that the main aim of panoramic radiographs is generally not to perform detailed diagnostics, but rather to present a “rough” overview of the different anatomical structures. Furthermore, certain regions (upper premolars and lower incisors) and anatomical landmarks were selected, based on a previous study [3], where these features appeared to be the most difficult regions or landmarks to evaluate. Therefore, an overall lower diagnostic profile could be expected. Especially the maxillary premolar region was scored low for caries, periapical and periodontal tasks. The reason for poor image quality in this region was reported to be unsharpness and overlap, which can be explained by the known difficulties of panoramic radiation units to image this region because of the discrepancy in jaw width between maxilla and mandible.

Scores varied significantly between observers, which is a problem that has previously been reported in other image quality assessment studies [1, 2, 6].

It is a well-known difficulty of in vivo image quality studies that a gold standard or ground truth is difficult to establish. In the present study, however, the goal was not to assess whether pathology was present (e.g. *Are caries lesions present?*), nor to assess whether specific landmarks could be diagnosed (e.g. *Where is the mandibular canal situated?*), but rather to assess different regions of the jawbone for their subjective image quality (e.g. *Is the image quality satisfactory to diagnose possible caries lesions?*). It is a method that has been used in previous studies [3, 9].

Conclusion

The subjective image quality of indirect digital panoramic images printed with direct thermal printing shown on a computer monitor or printed with an inkjet printer on different paper qualities was investigated. Monitor images and direct thermal prints performed better than inkjet prints. For inkjet prints, glossy paper and transparencies performed best, followed by regular paper and satin paper. Although differences were observed, the average subjective image quality was rated to be sufficient for all modalities.

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